

SHRP 2 Renewal Project R07

Guide Performance Specifications

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TRANSPORTATION RESEARCH BOARD

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Contents

1	Hydraulic Cement Concrete Deck Performance Specification
22	Ground Improvement Using Vertical Support Elements Performance Specification
36	HOT Mix Asphalt Pavement Performance Specification (Design-Bid-Build)
61	HOT Mix Asphalt Pavement Performance Specification (Design-Build)
90	HOT Mix Asphalt Pavement Performance Specification with Warranty
113	Pavement Performance Specification (Design-Build-Operate-Maintain)
139	Cement Concrete Pavement Performance Specification (Design-Bid-Build)
164	Cement Concrete Pavement Performance Specification (Design-Build)
192	Cement Concrete Pavement Performance Specification with Warranty
220	Precast Concrete Pavement Performance Specification
242	Quality Management Program
260	Design and Implement Work Zone Traffic Control

HYDRAULIC CEMENT CONCRETE DECK

PERFORMANCE SPECIFICATION

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for implementation under either the design-bid-build (DBB) or design-build (DB) delivery approach.

Unless otherwise noted, the recommended performance parameters and ancillary requirements contained in this specification apply to both DBB and DB delivery, assuming roles and responsibilities will be assigned as follows:

- *Selection of the deck system by the Agency, or by Contractor if life-cycle cost (LCC) analysis is provided at bid;*
- *Mix design by the Contractor;*
- *Quality management by the Contractor;*
- *Verification testing and acceptance at the end of construction by the Agency; and*
- *Postconstruction maintenance by the Agency.*

Specification Objectives

Given the above assumptions, if a performance specification is defined as one that describes “how the finished product should perform over time” (TRC E-C137), one could argue that, absent a warranty or maintenance provision, the extent to which a Contractor could be held responsible for performance over time is limited. The goal, therefore, of this performance specification is not to monitor and evaluate Contractor performance over time (as may be the case for a performance warranty or a specified operations or maintenance period) but to

- *Focus on material properties and construction practices deemed to have the most effect on long-term performance; and*
- *Incorporate financial incentives/disincentives to promote enhanced quality or durability.*

In addition to these performance goals, this specification attempts to incorporate concepts that will promote the goals of rapid renewal (i.e., accelerate construction, minimize disruption, and achieve a long-lasting facility). To this end, prescriptive requirements have been relaxed if (1) placing such requirements under the Contractor’s control could help save time and/or minimize disruption and (2) measurement of the performance parameters at the end of construction will provide adequate assurance that the condition the prescriptive element was intended to prevent did not, and ideally, will not, occur.

Using This Guide Specification

The requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a comprehensive example that users can adapt to fit the needs of a particular project. Commentary included within the specification (as indicated with italic typeface) provides guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw upon the information provided as a basis for further modification or development of the specification.

In implementing this specification, Agencies are further encouraged to require the Contractor to develop and adhere to a comprehensive Quality Management Plan. A sample general provision addressing the roles and

responsibilities for quality management is included within the set of guide specifications developed under the SHRP 2 R07 project.

Finally, note that for a DB project, the term “Contractor” as used in this document should be interpreted as that entity given single-point responsibility for both the design and construction of the work and is thus synonymous with “Design-Builder” and “Design-Build Team.”

1 SCOPE

Construct all bridge deck systems to perform under the given loading and environmental conditions for the specified service life period.

For DB projects, the sentence above should be modified to include design as well as construction services.

Provide a Quality Management Plan (QMP) and perform all sampling, testing, and inspection necessary to control and assure the quality of the work in accordance with the QMP. The Department, acting in an oversight role, will conduct verification sampling and testing and independent assurance.

The Contractor’s preparation of a formal QMP is an integral component of this performance specification. A QMP requirement allows the Agency to eliminate prescriptive requirements in exchange for the Contractor’s development and adherence to a detailed plan of how it intends to complete the work and meet the performance requirements.

Within the limits of the Contract and applicable local, State, and Federal rules and regulations, the Contractor is encouraged to use innovative techniques and materials to meet the specified performance requirements.

Additional description may be added to this section to highlight certain project goals or performance requirements, particularly if new to the Agency or local contracting community.

2 STANDARDS AND REFERENCES

A Standards and References section applies primarily to DB projects and serves to identify the design and other procedural manuals and standards (e.g., AASHTO, FHWA, Agency) that the Contractor should follow, particularly when performing the project design work. Note that such documents may contain prescriptive requirements that could limit the Contractor’s flexibility and ability to innovate. Therefore, when referencing standards in the table below, balance the need for conformance with the Agency’s existing facilities and processes (consider, for example, tie-ins to existing facilities, environmental issues, etc.) against the opportunity for innovation.

Likewise, material standards, test methods, and similar reference documents that will likely be cited throughout a specification developed for either DBB or DB should be obtained and reviewed to ensure that they do not inadvertently impose undesired restrictions on the Contractor, in which case the specifier should identify exceptions to the standard.

2.1 Standard

Unless otherwise stipulated in this specification or as approved by the Department, design and construct the bridge deck in accordance with this performance specification and the relevant requirements of the standards listed, by order of priority, in Table 1.

If the standards conflict, adhere to the standard with the highest priority. If the standards contain any unresolved ambiguity, obtain clarification from the Department prior to proceeding with design or construction.

Use the most current version of each listed standard as of the initial publication date of the request for proposals (RFP) unless modified by addendum or change order.

Table 1: Standards for Hydraulic Cement Concrete Bridge Deck

Priority	Author or Agency	Title
1		
2		
3		
4		
5		

2.2 References

This subsection may be included if the Agency wishes to identify nonmandatory references that could assist the Contractor's efforts.

The Contractor may consult the references listed in Table 2 for supplementary guidance in designing and constructing the bridge deck system. These references have no established order of precedence and are not intended to be all-inclusive.

Table 2: References for Hydraulic Cement Concrete Decks

Author or Agency	Title

3 REQUIREMENTS

Design requirements, as identified in Section 3.1, apply to DB projects only. For DBB, specifiers may follow a more traditional AASHTO five-part format, with Materials and Construction Requirements sections immediately following the Scope/Description.

3.1 Design

Perform all bridge deck design engineering activities, including, but not be limited to, the following:

- Bridge investigation
- Structural design and analysis
- Material selection
- Mix design

The list above will vary based on how much initial design work was completed by the Agency.

The Agency may also decide to leave the deck system decision (e.g., cast-in-place concrete versus a precast system) up to the Contractor during the bidding phase, with the demonstration of adequate system life and/or life-cycle cost for the system that is designed.

All bridge engineering activities shall be directed, supervised, signed, and sealed by a Professional Engineer, licensed in the State of [-----] with a minimum of [5] years of experience in bridge engineering.

3.1.1 Bridge Investigation

Perform all structural investigations, testing, research, and analyses necessary to determine and understand the existing deck and overall superstructure and substructure conditions.

Prepare structural engineering reports documenting the assumptions, conditions, and results of the investigations and analyses, including the following:

- Structural condition of the existing super- and substructure
- Results from field investigations and laboratory testing, including a discussion of how these results affect the design of the deck system
- Design and construction parameters resulting from the structural investigation and analyses
- Condition survey results, calculations, and analyses that support design decisions

3.1.2 Design Criteria

Design the deck system in accordance with the structural information collected in accordance with Section 3.1.1, the standards identified in Section 2.1 or other approved alternatives, and the following:

Define all additional requirements that could affect the design of the deck system. For example,

- *Design service life;*
- *Traffic data;*
- *Design loading (i.e., HS-20, HS-25);*
- *Superstructure requirements (including improvement strategies);*
- *Drainage requirements;*
- *Tie-ins to existing deck, approach slabs, and roadway;*
- *Future widening (e.g., design and construction must feasibly allow for future economical expansion through addition of lanes and other elements);*
- *Different design criteria for alternative transportation modes (e.g., pedestrian, light rail);*
- *Exposure conditions; and*
- *Expected maintenance activities (e.g., deicing, plowing).*

When establishing design constraints, ensure that they do not conflict with the project's goals or other specified requirements. Ambiguities or conflicts among these design requirements and other construction or performance requirements could result in time and cost impacts for which the Agency would be liable.

3.1.3 Design Documentation

In exchange for providing the Contractor flexibility with regard to design and construction decisions, the Agency should require the Contractor to fully report out on all design assumptions and decisions.

Prepare and submit deck system design reports that include the following items, as a minimum:

- All pertinent design inputs, such as traffic volume and loading data, superstructure and substructure conditions, characteristics of the proposed construction materials, environmental conditions, and deck design life;
- Data on performance of similar bridge decks in the region (similar materials, service loadings, climate);
- Site plan showing the limits of the roadway covered by the design report;
- Discussion on site conditions that might influence the design and performance of the deck system;
- Discussion of the inputs used to arrive at design recommendations and the rationale used in selecting the recommended design strategy (where applicable, life-cycle management analysis, including the periods for reconstruction and other rehabilitation measures);
- Deck design details, including reinforcement, cover depth, deck thickness, surface texture, and typical cross section drawings;
- Comprehensive construction specifications sufficiently detailed to describe the process or end-result requirements; and
- Other considerations used in developing the deck design(s), including superstructure and substructure preparation.

3.2 Material Requirements

To prepare the Materials section, one approach would be to refer to the applicable sections in the Agency's Standard Specifications. The Standard Specifications typically contain explicit requirements restricting materials selection based on the Agency's past experience. In this manner, the Agency can be confident of receiving a product similar to what it has always received. A possible drawback to this approach is the lost opportunity associated with using alternative materials or sources that could result in superior performance or time or cost savings.

It is therefore important to carefully consider the extent to which the specification needs to prescribe basic material properties. If the end-result parameters included in the specification will not in and of themselves assure the Agency that the constructed bridge deck will meet the desired short-term and long-term performance expectations, more prescriptive materials requirements may be necessary. (Note that this strategy is in contrast to the increased latitude that should be given to the Contractor under a long-term operations and maintenance agreement, in which case the Contractor would be assuming more risk for performance over time and would thus be more inclined to investigate other materials options that, despite higher initial costs, may prove to be more economical when viewed over the duration of the Contractor's performance responsibility.)

If not already a part of the Agency's standard acceptance program, consider allowing prequalification of sources/suppliers and acceptance by certification. In keeping with the goals of rapid renewal, such provisions can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations. For example, consider allowing the Contractor to incorporate the following materials into the work by submitting manufacturer's certifications that substantiate that each shipment conforms to the specified quality requirements:

- *Cement;*
- *Fly ash and natural pozzolans;*
- *Slag;*
- *Silica fume, and*
- *Reinforcement.*

Similarly, aggregate sources may be qualified prior to construction by verifying results related to the following properties:

- *Soundness;*
- *Hardness;*
- *Polishing resistance;*
- *Freeze-thaw durability;*
- *Alkali-aggregate reactivity;*
- *Absorption; and*
- *Specific gravity.*

3.3 Construction Requirements

The Agency's confidence in its ability to predict future performance at the end of construction will control the degree to which an Agency can relax its standard construction requirements. Given today's technology and test methods, substantial departure from standard practices may be unlikely. However, should advances in technology, particularly in the area of nondestructive testing (NDT), increase the level of confidence in end-result parameters, it may be possible to eliminate certain prescriptive requirements in the interest of rapid renewal.

In exchange for providing the Contractor some flexibility with regard to mixture design and construction decisions, the Agency should require the Contractor to describe in its QMP how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, ordering, handling, placing, finishing, and curing of concrete) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

3.3.1 Mix Design

Develop and submit a mix design to the Agency for review in accordance with [Standard Specification XXX], along with documentation indicating that the proposed mix design meets the properties specified in Table 3.

Table 3: Mix Properties

Property	Test Method	Value
Compressive strength	ASTM C39	F'c + 1,200 psi or as required by ACI 318 Table 5.3.2.2
Permeability	ASTM C1202 (accelerated test)	1000 coulombs (maximum) at 28 days
Air content	ASTM C231	4% to 8%
Length Change	ASTM C157	≤ 0.04% after 28 days of air curing
Reactive Aggregates	ASTM C1567	≤ 0.10% at 16 days. If more than 0.01%, then ASTM C 1293 ≤ 0.04% at 2 years

3.3.2 Trial Placement/Installation

Trial placements provide the opportunity for the Contractor to demonstrate that its proposed materials, methods, equipment, and personnel can provide a deck that meets the specification.

Consistent with the goals of rapid renewal, trial placements are designed to expose the Contractor and the Agency to as many details of the actual construction process as possible before the actual start of deck construction, thereby providing the opportunity to revise any step in the process before the quality (and ultimate performance) of the whole deck is compromised. The trial placement is typically performed off the bridge, and traffic delays associated with removing defective product from the bridge are avoided.

The Agency may waive trial placements if the Contractor can provide sufficient evidence of recent experience with producing an acceptable deck of the type specified.

At least 1 month prior to placement, conduct a trial placement to gain experience with all aspects of this construction. The Agency may waive this requirement if the Contractor and concrete producer can show significant similar experience with the overall design, production, and placement processes.

4 QUALITY MANAGEMENT

This specification holds the Contractor responsible for performing both quality control and quality assurance in accordance with the Contractor's QMP. The Agency in turn should perform verification testing of select parameters. Although this approach may represent a departure from the traditional manner in which an Agency allocates responsibility for various quality management functions, it is consistent with the degree of risk assumed by the Contractor for performance of the work. Greater oversight by Agency personnel may add time to the project and conflict with the goals of rapid renewal.

4.1 Contractor's Responsibility for Quality Management

The requirements included in this Section 4.1 assume that the Contract includes a separate provision related to development and implementation of a QMP that defines general requirements related to the Contractor's quality management personnel and organizational structure; documentation and reporting requirements; and procedures related to nonconforming work, corrective action, and similar matters. If such requirements are not otherwise addressed in the Contract's General Conditions, a sample general provision addressing quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Note that the Agency should review the Contractor’s QMP submittal to ensure it complies with these and other Contract requirements. If the Agency disagrees with elements of the QMP, it should raise these issues with the Contractor and seek resolution. The Agency should not “approve” the Contractor’s QMP, as approval could be construed as assuming responsibility for the plan’s content.

Assume responsibility for the quality of the bridge deck, including work performed or provided by subcontractors, suppliers, and vendors.

Perform all quality management activities described in *[the Agency’s General Provision for Quality Management]*, including the additional requirements specific to bridge deck construction as defined in this Section 4.1.

4.1.1 Contractor Testing

The approach taken in this section is to establish the minimum testing requirements that the Contractor’s QMP must contain related to bridge deck construction. The intent is to provide the Contractor some latitude with respect to developing a project-specific QMP while also ensuring that the Agency’s minimum standards are met. These minimum requirements can also serve as guidance to bidders as they prepare a cost proposal for the work. The list of parameters shown in Table 4 are for illustration only and should be modified based on specific Agency or project requirements for quality management of bridge deck construction.

A possible disadvantage to this approach is that the Contractor may view these requirements not as a minimum but as all that is necessary to provide adequate quality control and quality assurance. If a best-value procurement process will be used to award the contract, the Agency should consider evaluating the proposers’ project-specific QMP, or relevant portions thereof, as part of the selection criteria.

As part of the Quality Management Plan (QMP) to be prepared, submitted, and implemented in accordance with *[the Agency’s General Provision for Quality Management]*, include, as a minimum, the sampling and testing requirements specified in Table 4, as well as all other inspections and tests the Contractor deems necessary to ensure the quality of the finished bridge deck.

If verified as described in Section 4.2.1, the Department may use the Contractor’s test results for acceptance.

Table 4: Minimum QMP Requirements for Concrete Bridge Deck

Parameter	Test Method	Frequency
A. Materials		
1. Aggregate		
a. Source verification		
b. Gradation		
c. Fine aggregate fineness		
d. Coarse aggregate shape & texture		
e. Fine aggregate shape & texture		
f. Cleanliness		
g. Moisture content		

Table 4: Minimum QMP Requirements for Concrete Bridge Deck

Parameter	Test Method	Frequency
2. Cementitious material	certification	
3. Admixtures	certification	
4. Reinforcement	certification	
<hr/>		
B. Fresh concrete		
1. Density		
2. Slump		
3. Air content		
4. Water content		
5. Placement temperature		
6. Segregation		
7. Setting time		
8. Evaporation rate		
9. Thickness		
<hr/>		
C. Hardened concrete		
1. Compressive strength		
2. Permeability		
3. Shrinkage		
4. Freeze-thaw resistance		
5. Scaling resistance		
6. Alkali-aggregate reactivity resistance		
7. Abrasion resistance		
<hr/>		
D. In-place concrete deck		
1. Cracking		
2. Thickness		
3. Cover depth		
4. Rebar location		
5. Smoothness		
6. Skid resistance		
7. Cross-slope		
8. Joint condition		

4.1.2 Production and Placement Procedures

In exchange for eliminating prescriptive requirements related to materials selection and construction methods, the Agency should require the Contractor to describe how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, ordering, handling, placing, finishing, and curing of concrete) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

Include descriptions of the following in the QMP:

1. Certified mixing plant requirements, including calibration procedures for all meters, scales, and other measuring and recording devices.
2. Laboratory location, testing equipment, and procedures for calibration.
3. General sequence of the work.
4. Concrete placement operations, including hauling, spreading, and consolidating.
5. Methods to control alignment and profile.
6. Joint installation procedures.
7. Finishing procedures.
8. Materials and methods related to curing.
9. Procedures related to cold weather placement or night work (as applicable).

The above list will vary based on how much freedom the Agency allows the Contractor with regard to the construction requirements in Section 3.3.

4.2 Department’s Quality Management Responsibilities

The Department may conduct quality inspections, audits of the Contractor’s results and records, and verification sampling and testing on any element of the work to ensure compliance with the QMP and the Contract requirements.

4.2.1 Verification Sampling and Testing

The Department will perform verification testing as described in Table 5 to validate the Contractor’s test results.

The Department will notify the Contractor before sampling so the Contractor can observe.

The Department will sample randomly at locations independent of the Contractor’s sampling and testing. In all cases, the Department will conduct the verification tests in a separate laboratory and with separate equipment from the Contractor’s tests.

Table 5: Department Verification Testing

Parameter ⁽¹⁾	Test Method ⁽¹⁾	Sampling Location	Frequency ⁽²⁾
Aggregate Gradation	Sieve Analysis - ASTM C33		
Fine Aggregate Fineness	Fineness Modulus		
Aggregate Cleanliness	ASTM C40 & ASTM C142		
Aggregate Sand Equivalent	ASTM D2419, AASHTO T176		
Aggregate Moisture Content	ASTM C70, ASTM C127, ASTM C128, ASTM C566, AASHTO T 255		
Concrete Density	ASTM C138 Weight Computation	Mix Design and Process Control Trial	
Concrete Slump	ASTM C143		at delivery
Concrete temperature	ASTM C1064	discharge	at delivery
Concrete segregation	Visual	All	during discharge
Concrete air content	ASTM C231/C173	beg. discharge	at delivery
Compressive strength	Cylinders - ASTM C39	Trial Batching	

Parameter ⁽¹⁾	Test Method ⁽¹⁾	Sampling Location	Frequency ⁽²⁾
Concrete maturity	Maturity Meter - ASTM C1074	Trial Batching	
Concrete permeability	ASTM C1202	Trial Batching	
Concrete shrinkage	ASTM C157		
Concrete water content	AASHTO T 318		
Evaporation rate	ACI 305R, Figure 2.1.5		
Curing	Visual/Material Application Monitoring	All	after finishing
Deck thickness	depth gauge/probe	all Deck	Once - end construction
Smoothness/Profile	Tolerances (in./mm)	100%	during finishing

- The parameters and test methods identified are provided for illustrative purposes only and should be modified based on Agency practices or project requirements. If an Agency has its own standard test methods for measuring these properties, specify those methods instead. For rapid renewal, the Agency should consider using NDT methods.*
- Frequency should be based on project-specific conditions and ideally should provide the ability to identify statistically valid differences between Agency and Contractor test results. A minimum Agency rate of 10% of the testing rate of the Contractor has been used as a rule of thumb.*

The Department may increase the frequency of verification testing at start-up or as necessary to validate the quality of the materials. The Department may reduce the frequency based on a history of satisfactory Contractor or material performance.

If verification tests indicate conformance with the specification, no further action is required. If verification tests indicate nonconformance with specifications, the Department and Contractor will jointly investigate the testing discrepancies. The investigation may include additional testing as well as review and observation of both the Department's and Contractor's sampling and testing procedures and equipment. Both parties will document all investigative work.

4.2.2 Independent Assurance Testing

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing activities are being performed by qualified personnel using proper procedures and properly functioning and calibrated equipment. The Department will perform IA testing using personnel other than those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor's sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

4.3 Conflict Resolution

If a dispute between some aspect of the Contractor's and the Department's testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third-party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third-party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [\[Standard Specification Section XXX\]](#).

5 ACCEPTANCE REQUIREMENTS

5.1 General

The Department will accept the bridge deck based on the Contractor's test results unless it is shown through the Department's verification testing or the conflict resolution process that the Contractor's tests are in error.

5.2 Quality Characteristics and Acceptance Limits

Acceptance requirements provide a method for determining the degree to which the deck meets the specification and for determining appropriate payment for the deck. Acceptance is based on the measurement of properties that control the quality and performance of the deck.

Various acceptance parameters are listed in Table 6 for the specifier's consideration. Target requirements, tolerances, and acceptance limits or repair requirements are suggested for each of the parameters. For example,

- *Cracks wider than 0.2 mm (0.008 in.) must be repaired.*
- *The target requirement for cover depth (CD) is the CD specified, the tolerance is CD + 1 in. (Upper Quality Limit) to CD – 0 in. (Lower Quality Limit), and the acceptance limits are 85 percent within limits (PWL) (measurements made on a 10-ft grid) for full payment.*
- *The PWL is determined using Table 7 and the instruction in Section 5.3.*
- *A Lot is measurement for 1 day or one deck span, whichever is greater; n is the number of Lots.*
- *The quality index (QI) is calculated using the Lot sample standard deviation, S_v , UQL, and LQL.*

Not all parameters shown will necessarily be appropriate or beneficial for any given project. Agencies may wish to include or exclude requirements based on the project's needs and goals, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and similar factors. Commentary provided within the table itself provides rationale for including certain parameters and, where necessary, offers additional information related to test methods and establishing targets and tolerances.

To meet the rapid renewal goal of providing long-lasting facilities, the recommendation is to emphasize parameters that relate to the durability of the in-place concrete (such as permeability, rebar cover, and cracking). Such parameters would allow the Agency to eliminate or relax prescriptive requirements related to the use of specific materials (e.g., fly ash or air entraining admixtures), proportions (e.g., minimum cement content or maximum water-to-cement—w/c—ratio), or construction operations (e.g., wet curing for a specified duration) that are often included in today's method specifications. Although such prescriptive requirements have a historical basis in producing durable concrete, they can act as a barrier to innovation.

Note that the parameters, test methods, and tolerances included in Table 6 have been identified based on state-of-the-practice testing technology, which may or may not provide rapid and repeatable results, be representative of the anticipated field conditions, or relate directly to field performance (particularly if based on laboratory testing). This specification is therefore intended to be flexible enough to accommodate advances in technology, particularly in the area of nondestructive testing (NDT), which could allow for the development of acceptance parameters that better reflect the future performance and design life of the bridge deck. As applicable, emerging NDT technologies are also discussed in the commentary included in the table.

It should also be noted that the suggested acceptance parameters represent a shift toward more end-result and in-place testing, which may blur the traditional division of risk and responsibility assumed by concrete suppliers and contractors. Meeting such requirements will likely require increased coordination and partnering between these parties.

The Department will accept the completed bridge deck in accordance with the criteria defined in Table 6.

Table 6: Acceptance Criteria

Parameter	Measurement Procedure	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Cracking	Cracks measured at 3-ft intervals on the surface of the deck in the a.m. prior to 3 hours after sunrise at a concrete age \geq 28 days	No crack wider than 0.008 in. (0.2 mm)	Repair wider cracks. Pattern: gravity fill Linear: epoxy injection
	<i>Cracks wider than 0.008 in. (0.2 mm) can allow water and chloride ions to reach the reinforcement at an earlier age than if the concrete were not cracked. Cracks wider than 0.2 mm must be repaired to reduce the risk of a reduction in service life caused by deterioration related to early age corrosion.</i>		
Cover depth	Probing fresh concrete or calibrated NDT (e.g., pacometer, GPR)	\geq specified cover depth (CD) (ACI 117 +1 in./-0 in.) Measure on 10-ft grid.	PWL 85% full payment LQL = CD UQL = CD + 1.0 in.
	<i>Cover depth over the reinforcement is another significant factor in the time to corrosion of the reinforcement. Service life can be reduced with a reduction in cover depth. Excessive cover can increase the risk of cracking in the concrete over the reinforcement. Nondestructive testing equipment that is used to measure cover depth must be calibrated to provide acceptable measurements.</i>		
Rebar location	Measure from reference surface.	\pm 0.5 in. on rebar placement Measure on 10-ft grid.	PWL 85% full payment LQL = -0.5 in. UQL = +0.5 in.
	<i>Rebar location affects the structural performance of the deck, and improperly positioned reinforcement can increase the risk of cracking and early age corrosion.</i>		
Thickness (fresh)	Probe	ACI recs. + 1/4 in./-1/8 in. Measure on 10-ft grid.	PWL 85% full payment LQL = T - 1/8 in. UQL = T + 1/4 in.
	<i>Deck thickness affects the structural performance of the deck and bridge superstructure, and the risk of increased cracking and reduced service life increases as the deck thickness decreases.</i>		

Parameter	Measurement Procedure	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Compressive Strength (Design)	Cylinders - ASTM C39 <i>(Consider accommodating referee testing from cores)</i>	Design strength min. of 5 tests per lot. At least one Sublot per day. Note: more tests may be requested (and are desirable). One test = three 4-in. × 8-in. cylinders or two 6-in. × 12-in. cylinders	PWL 85% full payment LQL = DS + 300 psi
	<i>Lab-cured compressive strength specimens provide an indication that the concrete meets the structural requirements of the bridge superstructure design and that the approved concrete mixture is being used.</i> <i>Representative cores may be taken to determine the concrete strength when the compressive strength of specimens is lower than required by the specification.</i>		
Compressive Strength (Opening to traffic)	Maturity ASTM C1074 (or field-cured specimens)	Specified Strength (min.) Minimum of 5 tests per lot. At least one Sublot per day. Specimens: One test = three 4-in. × 8-in. cylinders or two 6-in. × 12-in. cylinders	Pass or apply lane rental penalties.
	<i>Field-cured compressive strength specimens provide an indication that the concrete meets the requirements for superimposing loads and opening the deck to traffic.</i> <i>Maturity measurements may be substituted for field-cured specimens when suitable maturity curves have been developed for the concrete mixture.</i>		
Permeability (Job-site testing)	ASTM C1202 (accelerated test) Referee Testing from Cores	1500 coulombs (max) at 28 days 2000 coulombs (max) Minimum of 5 tests per lot. At least one Sublot per day. Note: more tests may be requested (and are desirable). One test = three cylinders (2-in. slice @ 4 in. × 8 in.)	PWL 85% full payment UQL = 2000 PWL < 80% penalty or apply sealer PWL < 70% penalty or apply epoxy overlay PWL < 50% reject or apply concrete overlay
	<i>Permeability specimens provide the best indication of the permeability of the concrete to penetration by chloride ions. A reduction in service life can be expected when the concrete has a higher permeability than specified.</i> <i>Given the impact of permeability on deck service life, a lower threshold value should be specified for the concrete produced for the trial placement than is required for the acceptance of the concrete placed in the deck. The lower value for the approved concrete mixture reduces the risk that concrete used in the deck has a permeability that does not meet the specification.</i>		
Air Content	ASTM C231	specified	PWL 85% full payment LQL & UQL specified
	<i>The air content of the concrete is a significant factor for the freeze–thaw durability of the concrete. Concrete with a low air content is more likely to have a reduced service life because of surface cracking and scaling.</i>		

Parameter	Measurement Procedure	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Smoothness	Profilometer-based Spec (Continuous IRI)	80 in./mi with 100-ft base length	PWL 85% full payment— see histogram from ProVAL Smoothness Assurance Module UQL = 80 in./mile
	<i>The smoothness of the deck affects the ride quality and traffic noise. While smoothness does not necessarily reduce the service life of the deck, it is a road user factor that affects the quality of the ride over the deck.</i>		
Skid resistance	ASTM E274, ASTM E524	FN40S \geq 40 Average per lane	PWL 85% full payment LQL = 40
	<i>Acceptable skid resistance is necessary to minimize the risk of skidding accidents on the deck.</i>		
Cross slope	Elevation	plans \pm 1/8 in.	PWL 85% full payment UQL = +1/8 in. LQL = -1/8 in.
	<i>Acceptable cross slope is needed for proper drainage and super elevation. Poor drainage can reduce the service life of the deck and increase the risk of wet accidents.</i>		
Joint condition	Vertical setting (depth)	plans \pm 1/8 in.	PWL 85% full payment UQL = +1/8 in. LQL = -1/8 in.
	Gap versus temperature (width)	plans \pm 1/8 in.	PWL 85% full payment UQL = +1/8 in. LQL = -1/8 in.
	Visual/Survey	proper installation	pass or replace.
Cross slope	<i>Quality joints are a major factor in the service life of the bridge beams and substructure elements. Joints must provide for movement of adjacent spans and prevent water and chlorides from reaching bridge elements under the deck.</i>		

5.3 Quality Level Analysis

- A. Unless otherwise indicated in Table 6, acceptance of material and work shall be based on the method of estimating percent within limits (PWL), where the PWL will be determined in accordance with this Section. All Sublot test result values for a Lot, as defined in Table 6, will be analyzed statistically to determine the total estimated PWL. The PWL is computed using the Lot sample average value, \bar{X} , as defined in Section 5.3.C.2, the Lot sample standard deviation, S_n , as defined in Section 5.3.C.3, for the specified number of Sublots, n , and the specification Quality Acceptance Limits, as defined in Table 6, where LQL represents the Lower Quality Limit, and UQL represents the Upper Quality Limit, as they apply to each particular acceptance parameter. From these values, the respective Quality Index (Indices), Q_L for Lower Quality Index and/or Q_U for Upper Quality Index, is (are) computed in accordance with Sections 5.3.C.4 and 5.3.C.5. Then the PWL for the Lot for the specified number of Sublots, n , is determined from Table 7.
- B. In addition, all concrete and concrete placement work shall conform to the requirements of Section 7.4. For any identified deficiencies, as defined in Section 7.4, the Contractor may either
1. Remove and replace the concrete in that particular Lot at the Contractor's expense, or

2. Accept a deduction of 50% of the contract unit price for that particular Lot of concrete.

C. PWL will be estimated as follows:

1. In accordance with this specification and the QMP, locate sampling positions, take test sample, make specimens, and test.
2. Determine the Lot sample average value, \bar{X} , by calculating the average of all Sublot test values.
3. Find the Lot sample standard deviation, S_n , by using the following formula:

$$S_n = \sqrt{\frac{\sum (x_i - \bar{X})^2}{n - 1}}$$

where

- | | | |
|-----------|---|--|
| S_n | = | standard deviation of the Sublot test values |
| x_i | = | individual Sublot test values |
| \bar{X} | = | Average of Sublot test values |
| n | = | number of Sublots |

4. Find the Lower Quality Index, Q_L , by subtracting the Lower Quality Limit, LQL, from the average value, \bar{X} , and dividing the result by S_n .

$$Q_L = \frac{\bar{X} - LQL}{S_n}$$

5. Find the Upper Quality Index, Q_U , by subtracting the Lot sample average value, \bar{X} , from the Upper Quality Limit, UQL, and dividing the result by S_n .

$$Q_U = \frac{UQL - \bar{X}}{S_n}$$

6. The percentage of material above lower tolerance limit, P_L , and the percentage of material below upper tolerance limit, P_U , will be found by entering Table 7 with Q_L and/or Q_U using the column appropriate to the total number of Sublots, n , and reading the appropriate number under the column heading "PWL."
7. For quality characteristics with only an Upper Quality Limit (e.g., permeability), PWL equals P_U . For characteristics with only a Lower Quality Limit (e.g., bond strength, compressive strength), PWL equals P_L . For concrete properties with both Upper and Lower Quality Limits (e.g., air content), first calculate the Upper Quality Index, Q_U , and the Lower Quality Index, Q_L , by using the Upper Quality Limit, UQL, and the Lower Quality Limit, LQL, respectively. The limits to be used are stipulated in Table 6. Then determine PWL using the following formula:

$$PWL = (P_U + P_L) - 100$$

8. The PWL from Table 7 that is to be used is the whole number greater than that found by using the Q_U or Q_L in the table. For example, the PWL to be used for $n = 4$ and a Q_U of 1.4200 would be 98.

Table 7: Percent within Limits (PWL)
(STANDARD DEVIATION METHOD)
Positive Values of Quality Index (QI)
(n = Number of Sublots in the Lot)

PWL	n=3	n=4	n=5	n=6	n=7	n=8
100	1.1600	1.5000	1.7900	2.0300	2.2300	2.3900
99	1.1541	1.4700	1.6714	1.8008	1.8888	1.9520
98	1.1524	1.4400	1.6016	1.6982	1.7612	1.8053
97	1.1496	1.4100	1.5427	1.6181	1.6661	1.6993
96	1.1456	1.3800	1.4897	1.5497	1.5871	1.6127
95	1.1405	1.3500	1.4407	1.4887	1.5181	1.5381
94	1.1342	1.3200	1.3946	1.4329	1.4561	1.4716
93	1.1269	1.2900	1.3508	1.3810	1.3991	1.4112
92	1.1184	1.2600	1.3088	1.3323	1.3461	1.3554
91	1.1089	1.2300	1.2683	1.2860	1.2964	1.3032
90	1.0982	1.2000	1.2290	1.2419	1.2492	1.2541
89	1.0864	1.1700	1.1909	1.1995	1.2043	1.2075
88	1.0736	1.1400	1.1537	1.1587	1.1613	1.1630
87	1.0597	1.1100	1.1173	1.1191	1.1199	1.1204
86	1.0448	1.0800	1.0817	1.0808	1.0800	1.0794
85	1.0288	1.0500	1.0467	1.0435	1.0413	1.0399
84	1.0119	1.0200	1.0124	1.0071	1.0037	1.0015
83	0.9939	0.9900	0.9785	0.9715	0.9672	0.9643
82	0.9749	0.9600	0.9452	0.9367	0.9325	0.9281
81	0.9550	0.9300	0.9123	0.9020	0.8966	0.8928
80	0.9342	0.9000	0.8799	0.8690	0.8625	0.8583
79	0.9124	0.8700	0.8478	0.8360	0.8291	0.8245
78	0.8897	0.8400	0.8160	0.8036	0.7962	0.7915
77	0.8662	0.8100	0.7846	0.7716	0.7640	0.7590
76	0.8417	0.7800	0.7535	0.7401	0.7322	0.7271
75	0.8165	0.7500	0.7226	0.7089	0.7009	0.6958
74	0.7904	0.7200	0.6921	0.6781	0.6701	0.6649
73	0.7636	0.6900	0.6617	0.6477	0.6396	0.6344
72	0.7360	0.6600	0.6316	0.6176	0.6095	0.6044
71	0.7077	0.6300	0.6016	0.5878	0.5798	0.5747
70	0.6787	0.6000	0.5719	0.5583	0.5504	0.5454
69	0.6490	0.5700	0.5423	0.5290	0.5213	0.5164
68	0.6187	0.5400	0.5129	0.4999	0.4924	0.4877
67	0.5878	0.5100	0.4836	0.4710	0.4638	0.4592
66	0.5563	0.4800	0.4545	0.4424	0.4354	0.4310
65	0.5242	0.4500	0.4255	0.4139	0.4073	0.4031
64	0.4916	0.4200	0.3967	0.3856	0.3793	0.3753
63	0.4586	0.3900	0.3679	0.3575	0.3515	0.3477
62	0.4251	0.3600	0.3392	0.3295	0.3239	0.3203
61	0.3911	0.3300	0.3107	0.3016	0.2964	0.2931
60	0.3568	0.3000	0.2822	0.2738	0.2691	0.2660
59	0.3222	0.2700	0.2537	0.2461	0.2418	0.2391
58	0.2872	0.2400	0.2254	0.2186	0.2147	0.2122
57	0.2519	0.2100	0.1971	0.1911	0.1877	0.1855
56	0.2164	0.1800	0.1688	0.1636	0.1613	0.1592
55	0.1806	0.1500	0.1408	0.1363	0.1338	0.1322
54	0.1447	0.1200	0.1125	0.1090	0.1070	0.1057

6 METHOD OF MEASUREMENT

The following clause is generally applicable to DBB projects only, as the lump-sum pricing structure found in a typical DB contract largely eliminates the use of measured quantities and unit pricing to determine progress and payment. However, the Agency may choose to measure pavement quantities for the express purpose of calculating pay factor adjustments as described in Section 7.

The Department will measure the work and/or material in accordance with the classifications shown in Table 8:

Table 8: Measurement of Work and Material

Classification	Measurement	Unit of Measure
Concrete materials ⁽¹⁾	Concrete accepted at job site	CY
Concrete placement ⁽²⁾	Concrete accepted in place	SY
Joint installation	Number joints	Unit Price (LS)
Reinforcement	Installed and accepted	pounds

Note: CY = cubic yard; SY = square yard; LS = lump sum.

1. *Cost of concrete may be determined using a default value (e.g., NCDOT).*
2. *Cost excludes cost of concrete materials.*

7 BASIS OF PAYMENT

Pay factor adjustments reward the Contractor for providing superior product and penalize the Contractor for providing product that is of somewhat less quality than specified. It is recommended that payments be based on pay adjustments determined by PWL calculations for each pay item. The PWL model encourages contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures, such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging contractors to produce a more uniform product.

Pay adjustments can be calculated using the multipliers given in Table 9. For example, if 100% of the product is within limits, the pay adjustment is 0.06 = 6%, meaning the Contractor receives a 6% bonus.

Tables 10 through 13 illustrate possible pay adjustments for different pay items. Specifiers should consider project-specific conditions and goals when selecting pay factor adjustments and weight them in accordance with the criticality of the parameter to the ultimate performance of the deck. For example, the pay adjustment for concrete materials is based a weight of 1 for compressive strength and permeability and a weight of 0.5 for air voids. The total pay adjustment is illustrated in Section 7.3, and correction for deficiencies is discussed in Section 7.4.

It is important to note that the pay factor adjustments specified in this section are tied to quantities and units prices that are not typically found in DB contracts. For the purpose of administering the quality price adjustment on a DB project, the Agency can have the Contractor submit a unit price and quantities for the specific items in question.

7.1 Pay Factor Adjustments

- A. Pay Factor adjustments for each Lot of each quality characteristic will be computed in accordance with the formulas contained in Table 9 by entering the PWL value and performing the calculation indicated for the appropriate PWL range to determine the Pay Factor.

Table 9: Adjustments to Contract Compensation

Percent Within Limits (PWL)	Pay Factor
91–100	$[0.006 (PWL-90)]$
85–90	0.0
55–84	$-0.9 + 0.01PWL$

- B. The overall Pay Factor for a given characteristic, PF_i , is determined by calculating the average of all PFs for that characteristic for every Lot in the project.

7.2 Pay Adjustment by Material/Work Classification

Based upon the quality of the deck, the Department will calculate a weighted pay adjustment for each of the material/work classifications identified in Table 8. The weights applied to each quality characteristic will be as shown in Tables 10, 11, 12, and 13.

Table 10: Pay Adjustment Criteria – Concrete Materials (PA_{cm})

Parameter	PF Designation	Weighting
Compressive Strength (design)	PF_{cs}	1
Permeability	PF_p	1
Air/Void Content	PF_{av}	0.5

$$\text{Example: } PA_{cm} = [(PF_{cs} \times 1) + (PF_p \times 1) + (PF_{av} \times 0.5)] / (1 + 1 + 0.5)$$

Table 11: Pay Adjustment Criteria – Concrete Placement (PA_{cp})

Parameter	PF Designation	Weighting
Cover depth	PF_{cd}	1
Thickness	PF_t	1
Cross slope	PF_{xs}	1
Smoothness	PF_s	1
Skid-Resistance	PF_f	1

Table 12: Pay Adjustment Criteria – Joint Installation (PA_j)

Parameter	PF Designation	Weighting
Joint condition	PF_j	1

Table 13: Pay Adjustment Criteria – Reinforcement (Pa_r)

Parameter	PF Designation	Weighting
Rebar location	PF_r	1

7.3 Total Project Adjusted Price

The Department will calculate a total project adjusted price, PA_{tot} , by summing the adjustment for each material/work class as follows:

$$PA_{tot} = (\text{CY Concrete} \times \$/\text{CY} \times PA_{cm}) + (\text{SY Concrete Placed} \times \$/\text{SY} \times PA_{cp}) + (\text{Num. Joints} \times \$/\text{Joint} \times PA_j) + (\text{Pounds rebar} \times \$/\text{lb} \times PA_r)$$

7.4 Correction of Deficiencies

Remove and replace concrete in a manner acceptable to the Department and at no cost to the Department if any of the following deficiencies exist, unless the Department elects to accept the concrete, at which time the Contractor will be compensated at 50% of the contract unit price for concrete placement specified regardless of the Pay Factors calculated in Tables 9 and 10:

1. PWL for compressive strength, permeability, or air content is below 55.
2. Compressive strength test on cylinders may indicate deficiency in the concrete when
 - a) The calculated average of any three consecutive compressive strength samples does not equal or exceed the design compressive strength.
 - b) Any individual sample's compressive strength test result is below the design compressive strength by more than 500 psi.
 - c) If either of the conditions in 7.4.2(a) or 7.4.2(b) is present, investigate the in-place compressive strength in accordance with ACI 318-99, Section 5.6.5, at no cost to the Department. If the compressive strength test results of the in-place concrete meet either, or both of the conditions in 7.4.2(a) and 7.4.2(b), consider the concrete to be deficient.

HOT MIX ASPHALT PAVEMENT

PERFORMANCE SPECIFICATION

(DESIGN-BID-BUILD)

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for implementation under a design-bid-build (DBB) delivery approach.

Users should note that this specification is part of a family of pavement specifications drafted with a specific delivery approach in mind; that is, the recommended performance parameters and material and construction requirements included in this specification are intrinsically linked to the roles and responsibilities and risk allocation deemed appropriate for a DBB project. These DBB conventions include the following:

- *Selection of the pavement type by the Agency (or by Contractor if life-cycle cost, LCC, analysis is provided at bid);*
- *Structural design by the Agency;*
- *Mix design by the Contractor (but usually per Agency guidelines or standards);*
- *Quality management by the Contractor;*
- *Verification testing and acceptance at the end of construction by the Agency; and*
- *Postconstruction maintenance by the Agency.*

Specification Objectives

Given the above assumptions, if a performance specification is defined as one that describes “how the finished product should perform over time” (TRC E-C137), one could argue that, absent a warranty provision, use of the DBB approach limits the extent to which a Contractor could be held responsible for performance over time. The goal, therefore, of this performance specification is not to monitor and evaluate Contractor performance over time (as may be the case for a performance warranty or a specified operations and maintenance period) but to

- *Focus on material properties and construction practices deemed to have the most effect on long-term performance;*
- *Use quality management and acceptance criteria that more closely correlate to performance (mechanistic structural and mix design properties); and*
- *Incorporate financial incentives/disincentives to promote enhanced quality.*

In addition to these performance goals, this specification attempts to incorporate, to the extent possible under the DBB delivery approach, concepts that will promote the goals of rapid renewal (i.e., accelerate construction, minimize disruption, and achieve a long-lasting pavement). To this end, prescriptive requirements have been relaxed if (1) placing such requirements under the Contractor’s control could help save time and/or minimize disruption and (2) measurement of the performance parameters at the end of construction will provide adequate assurance that the condition the prescriptive element was intended to prevent did not, and ideally, will not, occur.

Using This Guide Specification

The requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a comprehensive example of the possible performance requirements that could be used to promote the construction of long-lasting pavements under the DBB delivery approach. From this menu

of requirements, users should select those that best fit the needs of their particular project or program, bearing in mind that certain barriers or gaps may preclude the immediate implementation of all of the proposed parameters and test methods. For example, a performance measure may be technically valid but difficult to implement because of a need for specialized equipment or expertise, a lack of standardized test methods, absence of historical data for calibration of design or predictive models, or similar obstacles.

To help identify and address such gaps, consider each performance requirement in the context of the following questions:

- *Can a particular parameter be measured and evaluated using existing technology?*
- *In comparison with other testing techniques (or the use of method specifications), is the measurement and testing economical? Is a major capital investment required?*
- *Does the measurement technique require advanced training or a high skill level from technicians?*
- *Would a typical contractor know how to control its materials and processes to meet a particular performance standard?*
- *Is there sufficient experience or historical data to properly calibrate design or predictive models?*

Although specific answers to the above questions may vary by Agency, they generally point to three tiers of performance specifications for asphalt pavement, ranging from minimal departure from current practice to a substantial shift in practice and organizational culture that would require technological advancement and improved understanding of long-term material behavior.

- ***Tier 1** requirements do not require a substantial departure from current practice yet place more emphasis on properties known to affect the performance of asphalt pavements, including volumetric properties such as air voids, asphalt content, and voids in mineral aggregate (VMA), and as-constructed properties such as in-place density, joint compaction, and thickness.*
- ***Tier 2** requirements encourage use of more rapid and continuous nondestructive evaluation methods for acceptance purposes, such as ground-penetrating radar (GPR), which, although currently available, would require capital investment and/or further advancement to incorporate into a specification.*

As an option under Tier 2 (2B), Agencies may wish to prequalify or screen the Contractor's mix design using mechanistic, performance-based properties such as dynamic modulus, rutting resistance, and fatigue performance.

- ***Tier 3** requirements assume improved understanding of long-term material behavior as well as advances in technology, particularly in the area of nondestructive testing (NDT), which could allow for the inclusion of acceptance parameters, such as stiffness, that better reflect the future performance and design life of the pavement.*

In general, the three tiers represent a progression toward parameters and test methods that are more indicative of in-place pavement performance. When selecting the appropriate tier for a given project or program, users should balance project needs against available technology and resources, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and industry's appetite for assuming performance risk.

To denote these tiers, the numbers 1, 2, and/or 3 will appear in the right-hand margin beside a particular requirement, as applicable. If no such number appears, consider the requirement to be common to all tiers. Commentary is also included within the specification (as indicated with italic typeface) to provide additional

guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw on the information provided as a basis for further modification or development of the specification.

In implementing this specification, Agencies are further encouraged to require the Contractor to develop and adhere to a comprehensive Quality Management Plan (QMP). A sample general provision addressing the roles and responsibilities for quality management is included within the family of guide specifications developed under the SHRP 2 R07 project.

1 DESCRIPTION

Construct an HMA pavement consisting of one or more courses of asphalt mixture on a prepared foundation.

Provide a Quality Management Plan (QMP) and perform all sampling, testing, and inspection necessary to control and assure the quality of the work in accordance with the QMP. The Department, acting in an oversight role, will conduct verification sampling and testing and independent assurance.

The Contractor's preparation of a formal QMP is an integral component of this performance specification. A QMP requirement allows the Agency to reduce prescriptive requirements in exchange for the Contractor's development and adherence to a detailed plan of how it intends to complete the work and meet the performance requirements.

2 MATERIALS

To prepare the Materials section, one approach would be to refer to the applicable sections in the Agency's Standard Specifications. The Standard Specifications typically contain explicit requirements restricting materials selection based on the Agency's past experience. In this manner, the Agency can be confident of receiving a product similar to what it has always received. A possible drawback to this approach is the lost opportunity associated with using alternative materials or sources that could result in superior performance or time or cost savings.

It is therefore important to carefully consider the extent to which the specification needs to prescribe basic material properties. If the end-result parameters included in the specification will not in and of themselves assure the Agency that the constructed pavement will meet the desired short-term and long-term performance expectations, more prescriptive materials requirements may be necessary. (Note that this strategy is in contrast to the increased latitude that should be given to the Contractor under a long-term warranty or operations and maintenance agreement, in which case the Contractor would be assuming more risk for performance over time and would thus be more inclined to investigate other materials options that, despite higher initial costs, may prove to be more economical when viewed over the duration of the Contractor's performance responsibility.)

2.1 Component Materials

Evaluate material quality before and during construction in accordance with the approved QMP. Reject all non-conforming materials and replace with suitable materials.

2.1.1 Asphalt Binder

Provide asphalt binder as specified in *[Standard Specification XXX]*.

Asphalt binder properties have a great influence on low-temperature cracking, one of the major failure modes in asphalt pavement. Specifying asphalt binder with adequate low-temperature properties should reduce thermal cracking. Likewise, requiring high stiffness (G^) at high service temperatures will help reduce rutting and shoving.*

If not already a part of the Agency's standard acceptance program, consider allowing prequalification of suppliers and acceptance by certification to facilitate rapid renewal.

If the binder choice is left to the Contractor, consider requiring rutting resistance testing as described in Section 2.2.

2.1.2 Aggregate

Provide aggregate as specified in *[Standard Specification XXX]*.

Aggregate properties can greatly influence the performance of the in-place pavement, particularly with regard to safety (friction), durability (cracking), and rutting resistance. Commonly measured aggregate properties include

- *Course aggregate angularity,*
- *Fine aggregate angularity,*
- *Hardness,*
- *Soundness,*
- *Polishing resistance, and*
- *Deleterious materials.*

If not already a part of the Agency's standard acceptance program, consider allowing prequalification of aggregate sources. In keeping with the goals of rapid renewal, use of approved sources can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations.

2.2 Mix Design

Develop and submit for the Department's review a mix design that meets the requirements of *[Standard Specification XXX]*.

Alternatively, given the growing interest in mechanistic pavement design methods, an Agency may wish to consider prequalifying or screening mixtures based on the rutting and fatigue properties identified in Table 1.

Evaluating such properties at both the mix design stage and as part of verification and acceptance testing would be most applicable to high-profile/high-volume roadways, for which the cost and road user impact associated with future repairs and rehabilitation would outweigh the cost and inconvenience of doing such nontraditional testing.

Table 1: Mixture Performance Requirements

Design Parameter	Test Method	Value
Dynamic Modulus, E* ⁽¹⁾	AASHTO TP 62	
<p>1. E* is a key material input for flexible pavement structural design in the Mechanistic-Empirical Pavement Design Guide (MEPDG), and has been shown to have potential as a simple performance test for rutting and fatigue cracking. To use E* to screen mix designs, one could use the Quality Related Specification and Software described in NCHRP Report 704, in the Interactive Mix and Structure Design mode, to establish an appropriate E* value for a defined rutting failure criterion that corresponds to a project's traffic, environmental, and structural conditions. The mix can then be designed and changed as necessary to meet the desired distress criteria. (Alternatively, the structural design, particularly under a design-build project, could also be changed; but, generally, enhancing the quality of the HMA mix would be the most practical way to ensure compliance.)</p>		
Rutting Resistance ⁽²⁾	Wheel-Track Testing ⁽³⁾ <ul style="list-style-type: none"> • AASHTO TP63, Asphalt Pavement Analyzer (APA) • AASHTO T324, Hamburg • French Rut Tester 	
	AASHTO TP79, Flow Number Test using the Asphalt Mixture Performance Tester (AMPT) ⁽⁴⁾	Criteria remain under development.
<p>2. Evaluating rutting resistance will help prevent the placement of rut-susceptible mixtures, thus improving the likelihood of having a mix that performs well in the field. Better test methods, which are more indicative of performance, are needed before measurement of this parameter can become standard practice.</p> <p>3. Certain Agencies use wheel-track testing as part of the mix design process (e.g., APA used in Georgia; Hamburg used in Texas). However, wheel-track testers have limitations in scaling results to actual conditions (size, geometry). The tests will eliminate the worst offenders but do not measure any fundamental material parameter and are not necessarily indicative of performance.</p> <p>4. Flow number testing using the AMPT shows promise as being more predictive of performance than wheel-track testers. However, formal test criteria (e.g., confining stress, aging) are needed before flow number testing can be used for acceptance purposes. Several promising approaches to flow number testing have been used by researchers since the AMPT's development in NCHRP Projects 9-19 and 9-29. The FHWA's Asphalt Mixture and Construction ETG initiated a study to evaluate flow number procedures and criteria to determine which warrant further development and implementation. Dr. Haleh Azari of the AASHTO Advanced Pavement Research Laboratory (AAPRL) is working to help standardize flow number test protocols and has presented preliminary recommendations.</p>		
Fatigue Performance ⁽⁵⁾	AASHTO TP8, Beam Fatigue ⁽⁶⁾	
	Continuum Damage Based Fatigue Testing using the AMPT ⁽⁷⁾	Criteria remain under development.
<p>5. Evaluating fatigue performance is important, particularly for high-modulus mixtures, to mitigate fatigue-related problems of the in-place pavement. Fatigue testing would also provide a balance to the rutting test.</p> <p>6. Although beam fatigue testing is the method traditionally used to evaluate fatigue performance, most labs are not equipped to perform this testing (equipment is expensive). Additional drawbacks to this measurement strategy include the time needed to conduct the test and the poorly understood relationship between lab results and field performance (i.e., measured strain values).</p> <p>7. The testing protocol for the simplified viscoelastic continuum damage (S-VECD) model has been developed in the AASHTO format and is currently under review by the FHWA's Asphalt Mixtures and Construction ETG and the AASHTO Subcommittee on Materials. The AMPT-based control software for the S-VECD testing and analysis software are available from one of the two AMPT manufacturers. Results from the S-VECD testing can be obtained in two days, which</p>		

Design Parameter	Test Method	Value
<i>is much quicker than traditional beam fatigue testing.</i>		

3 CONSTRUCTION REQUIREMENTS

The Agency’s confidence in its ability to predict future performance at the end of construction will control the degree to which an Agency can relax its standard construction requirements. Given today’s technology and test methods, substantial departure from standard practices may be unlikely. However, should advances in technology (such as better forecasting models using mechanistic design methods and advancements in nondestructive testing) increase the level of confidence in end-result parameters, it may then be possible to eliminate certain prescriptive requirements in the interest of rapid renewal.

In exchange for providing the Contractor some flexibility with regard to construction decisions, the Agency should require the Contractor to describe in its QMP how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, mixing, hauling, spreading, finishing, and compaction of HMA) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

The Contractor is responsible for providing all management, professional, and technical services and labor, materials, and equipment necessary to construct the pavement.

4 QUALITY MANAGEMENT PROGRAM

This specification holds the Contractor responsible for performing tests used strictly for process control as well as tests that may be used in the Agency’s acceptance process. The Agency in turn should perform verification testing of select parameters. Although this approach may represent a departure from the traditional manner in which an Agency allocates responsibility for various quality management functions, it is consistent with the degree of risk assumed by the Contractor for performance of the work. Greater oversight by Agency personnel may add time to the project and conflict with the goals of rapid renewal.

4.1 Contractor’s Responsibility for Quality Management

The requirements included in this Section 4.1 assume the Contract includes a separate provision related to development and implementation of a QMP that defines general requirements related to the Contractor’s quality management personnel and organizational structure, documentation and reporting requirements, and procedures related to nonconforming work, corrective action, and similar matters. If such requirements are not otherwise addressed in the Contract’s General Conditions, note that a sample general provision addressing quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Note that the Agency should review the Contractor’s QMP submittal to ensure it complies with these and other Contract requirements. If the Agency disagrees with elements of the QMP, it should raise these issues with the Contractor and seek resolution. The Agency should not “approve” the Contractor’s QMP, as approval could be construed as assuming responsibility for the plan’s content.

Assume responsibility for the quality of the work, including work performed or provided by subcontractors, suppliers, and vendors.

Perform all quality management activities described in *[the Agency’s General Provision for Quality Management]*, including the additional requirements specific to HMA pavement construction as defined in this Section 4.1.

4.1.1 Contractor Testing

The approach taken in this section is to establish the minimum testing requirements that the Contractor’s QMP must contain related to asphalt pavement construction. The intent is to provide the Contractor some latitude with respect to developing a project-specific QMP while also ensuring that the Agency’s minimum standards are met. These minimum requirements can also serve as guidance to bidders as they prepare a cost proposal for the work.

A possible disadvantage to this approach is that the Contractor may view these requirements not as a minimum but as all that is necessary to provide adequate quality management. If a best-value procurement process will be used to award the Contract, the Agency should consider including the proposers’ project-specific QMP, or relevant portions thereof, as part of the selection criteria.

As part of the QMP to be prepared, submitted, and implemented in accordance with *[the Agency’s General Provision for Quality Management]*, include, as a minimum, the sampling and testing requirements specified in Table 2, as well as all other inspections and tests the Contractor deems necessary to ensure the quality of the finished pavement.

Keep the Department apprised of upcoming testing activities to allow the Department to schedule the verification and independent assurance activities described in Section 4.2. If verified as described in Section 4.2.1, the Department may use the Contractor’s test results for acceptance.

Various QMP requirements are included in Table 2 for the specifier’s consideration, not all of which will necessarily be appropriate or beneficial for a given project or program. Agencies may wish to include or exclude requirements based on the capabilities of local industry (including materials suppliers and testing firms), the project’s needs and goals, associated costs, and similar factors. Commentary included within the table itself provides rationale for including certain parameters. Test methods and frequencies are provided for illustrative purposes only and should be modified based on Agency practices or project requirements.

Table 2: Minimum QMP Requirements for Asphalt Pavement

Parameter	Test Method/Device	Frequency
A. Materials		
Aggregate ⁽¹⁾		
Course aggregate angularity (% of Fractured Faces) ⁽²⁾	ASTM D5821	
Fine aggregate angularity ⁽²⁾	AASHTO T304	
Flat and elongated particles ⁽³⁾	ASTM D4791	
Soundness ⁽⁴⁾	AASHTO T103, AASHTO T104	
Polishing Resistance ⁽⁵⁾	ASTM D3319	

Parameter	Test Method/Device	Frequency
Abrasion Resistance ⁽⁵⁾	AASHTO T96	
Sand Equivalent ⁽⁶⁾	AASHTO T176	
Clay Lumps and Friable Particles ⁽⁶⁾	AASHTO T112	
Asphalt Binder		1/binder production lot/PG grade
Additives	Certification	1 per project

1. *For higher-risk projects, the Contractor should sample and test aggregate during construction on a per lot basis. Higher risks include more severe conditions [high traffic volume, weather extremes (hot, cold, wet)], high road user impacts, public sensitivity, or longer expected service life.*
For lower-risk projects, consider allowing prequalification of aggregate sources. In keeping with the goals of rapid renewal, use of approved sources can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations.
2. *Angularity is desirable for HMA to achieve better particle-to-particle interlock for improved rutting resistance.*
3. *Flat and elongated particles can be problematic in HMA because they tend to reorient and break under compaction, resulting in decreased strength.*
4. *To minimize premature pavement distress, aggregates must be resistant to breakdown from weathering (alternate wetting/drying and freezing/thawing cycles). The freezing and thawing in water soundness test (AASHTO T103) more accurately simulates field conditions, but the test requires a longer period of time to conduct than the quicker sodium sulfate test (AASHTO T104).*
5. *Aggregates not adequately resistant to polishing and abrasion may result in premature structural failure and/or a loss of skid resistance.*
6. *The presence of soft particles, clay lumps, excess dust, and other deleterious matter can affect performance by quickly degrading, resulting in a loss of structural support and poor binder/aggregate bonding.*

B. Mixture Production

Gradation ⁽⁷⁾	AASHTO T27 & T11	1 per subplot
Laboratory Air Voids ⁽⁸⁾	AASHTO T312	1 per subplot
Asphalt Content ⁽⁹⁾	AASHTO T308	1 per subplot
Voids in Mineral Aggregate (VMA) ⁽¹⁰⁾	AASHTO R35	1 per subplot
Moisture Damage ⁽¹¹⁾	AASHTO T283	1 per lot
Dynamic Modulus, E* ⁽¹²⁾	AASHTO TP 62	1 per lot
Rutting Resistance (Flow Number) ⁽¹³⁾	AASHTO TP79	1 per lot
Fatigue ⁽¹⁴⁾	Continuum Damage	1 per lot

7. *For Contractors, gradation is an important property to control mixture production. However, as gradation is not directly indicative of performance (it indirectly controls voids), it should not be used for verification or acceptance purposes in a performance specification.*
8. *The performance of asphalt pavement is closely related to air voids (along with effective asphalt content). Excessive air void content, whether a mix design or a compaction problem, increases the likelihood of rutting and moisture damage.*
9. *Effective asphalt content (i.e., asphalt not absorbed into aggregate, as calculated based on asphalt content and aggregate bulk specific gravity) influences air voids and VMA, and is thus very closely related to performance. Asphalt content should be high enough to prevent excessive fatigue cracking, while not being so high as to increase the likelihood of bleeding and rutting.*
10. *VMA is a measure of the voids in between the mineral aggregate particles in a compacted mixture. It is determined from the bulk density of the sample, the bulk gravity of the aggregate, and the mixture's asphalt content. VMA is related to asphalt performance (although to a lesser extent than air voids and asphalt content).*

Parameter	Test Method/Device	Frequency
11. Although moisture damage is highly related to asphalt performance, the standard test method—tensile strength ratio (TSR) of soaked strength to dry strength—does not provide a straightforward relationship to performance and is fairly involved and time-consuming.		
12. Dynamic modulus, a key input in pavement structural design, will increase in importance as more Agencies adopt mechanistic design methods. Some questions remain regarding test variability and how specification limits should be set. The test is also somewhat complicated and time-consuming to perform.		
13. Research is ongoing to develop a test method and protocol that can be used to predict rutting. Use of the AMPT for flow number testing appears promising, though formal test criteria have not been validated. The FHWA's Asphalt Mixture and Construction ETG initiated a study to evaluate flow number procedures and criteria to determine which warrant further development and implementation. Dr. Haleh Azari of the AASHTO Advanced Pavement Research Laboratory (AAPRL) is working to help standardize the flow number test protocols and has presented preliminary recommendations. It may take time for industry to be receptive to performing such testing as part of their mix design and quality management responsibilities. In time, E* and flow number may supplant use of other properties, such as asphalt content and moisture damage, that only indirectly influence mechanical properties.		
14. The testing protocol for the simplified viscoelastic continuum damage (S-VECD) model has been developed in the AASHTO format and is currently under review by the FHWA's Asphalt Mixtures and Construction ETG and the AASHTO Subcommittee on Materials. The AMPT-based control software for the S-VECD testing and analysis software are available from one of the two AMPT manufacturers. Results from the S-VECD testing can be obtained in two days, which is much quicker than traditional beam fatigue testing.		

C. Installed Product

Compaction (in-place air voids) ⁽¹⁵⁾

Density gauge

Roller-Integrated Compaction Monitoring (RICM) ⁽¹⁶⁾

Ground-Penetrating Radar ⁽¹⁷⁾

Joint Compaction ⁽¹⁸⁾

Density gauge

Ground-Penetrating Radar ⁽¹⁷⁾

Smoothness/Ride Quality ⁽¹⁹⁾

Straightedge

Inertial Profiler

15. Many pavement distresses (e.g., cracking, rutting, or raveling) can be related to inadequate compaction. Compaction is therefore particularly important for DBB and DB contracts that have no postconstruction performance requirements.
16. Roller-integrated compaction monitoring (or “intelligent” compaction) is a process that includes vibratory rollers equipped with a measurement control system that can automatically record compaction parameters in response to material stiffness measured during the compaction process. The roller is equipped with a documentation system that allows for continuous recording of the roller location for corresponding stiffness-related output using global positioning systems (GPS). Although a strong correlation between RICM machine values and density has not yet been established, Contractors may find the real-time temperature and pass coverage output from the rollers to be very valuable for process control of compaction operations to accelerate construction and reduce rework. If the Contractor does provide coverage maps, consider relaxing the frequency requirements for core and density gauge testing.
17. Although still primarily used as a forensic tool, GPR could be used as an alternative or supplement to traditional core or density gauge tests if a correlation could be established between GPR-measured values of dielectric constant and density tests performed on cores.
18. Proper joint compaction is essential to ensuring the durability of joints. Requiring Contractors to test and monitor joint compaction as part of their quality management responsibilities should motivate them to pay more attention to joint compaction.
19. Ride quality (IRI) has traditionally been measured by Agency personnel for acceptance purposes; however, as

Parameter	Test Method/Device	Frequency
<i>Contractors assume more responsibility for quality management and performance, they may also find it beneficial to invest in inertial profilers. At a minimum, most Contractors will take straightedge measurements during construction to monitor smoothness.</i>		

4.1.2 Production and Placement Procedures

In exchange for eliminating prescriptive requirements related to materials selection and construction methods, the Agency should require the Contractor to describe how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the mixing, hauling, spreading, finishing, and compaction of asphalt) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

Include descriptions of the following in the QMP:

1. Certified mixing plant requirements, including calibration procedures for all meters, scales, and other measuring and recording devices, and procedures related to stockpile management, binder storage and handling, RAP processing and introduction to the plant (if applicable), and procedures related to mixing, mixture storage (if applicable), and haul unit loading.

Ensure that the Contractor has an adequate plan for checking the consistency of the produced mix and for correcting deficiencies or inconsistencies in the produced and delivered mix.

2. Laboratory location, testing equipment, procedures for calibration, and training standards for personnel (e.g., National Institute for Certification in Engineering Technologies—NICET— or local standard).
3. Paving plan, including general staging and sequencing of operations.

When reviewing the Contractor's paving plan, consider the following:

- *Is the sequence compatible with the maintenance of traffic (MOT)?*
- *Can the Contractor's equipment accommodate the proposed sequence of operations (consider size and number of equipment)?*

4. Asphalt placement operations, including hauling, spreading, finishing, and compacting.

When reviewing this portion of the Contractor's QMP, consider the following:

- *Is the proposed equipment appropriate for the project?*
 - *Is hauling equipment appropriate given the likely haul distance, haul time, and weather conditions?*
 - *Are adequate delivery vehicles available to match the production rate of the plant and the planned forward speed of the paver?*
 - *Is equipment appropriate for spreading material in front of the paver?*
- *Will the Contractor's proposed procedures minimize segregation?*
- *Will the Contractor's proposed procedures ensure ride quality?*

5. Methods to control alignment and profile.

- *Has the Contractor developed a procedure for control of the pavement profile?*
- *Has the Contractor established a procedure for checking the finished grade or profile of the intermediate layers or milled surface?*

6. Joint installation procedures.

- *Does the Contractor have a plan for constructing quality longitudinal and transverse joints?*
- *Does the plan address procedures related to end-of-day paving and joints?*

7. Procedures related to night work (as applicable).

8. Contingency plan for inclement weather.

Note that the above list will vary based on how much freedom the Agency allows the Contractor with respect to the construction requirements in Section 3.

4.2 Department’s Quality Management Responsibilities

The Department may conduct quality inspections, audits of the Contractor’s results and records, and verification sampling and testing on any element of the work to ensure compliance with the QMP and the Contract requirements.

4.2.1 Verification Sampling and Testing

Even though the Contractor may assume more responsibility for inspection and testing under a performance specification, this does not relieve the Agency of its responsibility to perform some level of independent sampling and verification testing to meet the intent of 23 CFR 637. Verification testing should be performed to validate any Contractor testing used in the Agency’s acceptance decision. The Agency may also wish to verify certain material or mixture parameters that could identify possible performance issues that would not otherwise be detected through end-result acceptance testing.

The Department will perform verification testing as described in Table 3 to validate the Contractor’s test results.

The Department will notify the Contractor before sampling so the Contractor can observe.

The Department will sample randomly at locations independent of the Contractor’s sampling and testing. In all cases, the Department will conduct the verification tests in a separate laboratory and with separate equipment from the Contractor’s tests.

Table 3: Department Verification Testing

Parameter⁽¹⁾	Test Method⁽¹⁾	Sampling Location	Frequency⁽²⁾
Materials			
Binder	Agency test		
Aggregate ⁽³⁾			
Mixture			
Asphalt Content	AASHTO T308		
Air Voids	AASHTO T312		

Parameter ⁽¹⁾	Test Method ⁽¹⁾	Sampling Location	Frequency ⁽²⁾
VMA ⁽⁴⁾	AASHTO R35		
Dynamic Modulus, E* ⁽⁵⁾	AASHTO TP 62		
Rutting (Flow Number) ⁽⁶⁾	AASHTO TP79		
Fatigue ⁽⁷⁾	S-VECD		
Installed Product			
Compaction ⁽⁸⁾	AASHTO T312	random (x,y)	
Joint Compaction ⁽⁸⁾	AASHTO T312	random (x,y)	

2B 3

1. Parameters and test methods are provided for illustrative purposes only and should be modified based on Agency practices or project requirements. If an Agency has its own standard test methods for measuring these properties, specify those methods instead.
2. Frequency should be based on project-specific conditions and ideally should provide the ability to identify statistically valid differences between Agency and Contractor test results. A minimum Agency rate of 10% of the testing rate of the Contractor has been used as a rule of thumb.
3. For higher-risk projects, Agencies should verify aggregate test results. Higher risks include more severe conditions [high traffic volume, weather extremes (hot, cold, wet)], high road user impacts, public sensitivity, or longer expected service life.
4. There is no universal understanding of VMA as a property that influences performance, and therefore several Agencies do not measure it for verification or acceptance purposes.
5. Dynamic modulus, a key input in pavement structural design, will increase in importance as more Agencies adopt mechanistic design methods. Some questions remain regarding test variability and how specification limits should be set. The test is also somewhat complicated and time-consuming to perform.
6. Research is ongoing to develop a test method and protocol that can be used to predict rutting. Flow number testing using the AMPT shows promise as being more predictive of performance than wheel-track testers. However, formal test criteria (e.g., confining stress, aging) are needed before flow number testing can be used for acceptance purposes. The FHWA's Asphalt Mixture and Construction ETG initiated a study to evaluate flow number procedures and criteria to determine which warrant further development and implementation. Dr. Haleh Azari of the AASHTO Advanced Pavement Research Laboratory (AAPRL) is working to help standardize the flow number test protocols and has presented preliminary recommendations. Use of the AMPT for flow number testing appears promising, though formal test criteria have not yet been validated. In time, E* and flow number may supplant use of other properties, such as asphalt content and moisture damage, that only indirectly influence mechanical properties.
7. The testing protocol for the simplified viscoelastic continuum damage (S-VECD) model has been developed in the AASHTO format and is currently under review by the FHWA's Asphalt Mixtures and Construction ETG and the AASHTO Subcommittee on Materials. The AMPT-based control software for the S-VECD testing and analysis software are available from one of the two AMPT manufacturers. Results from the S-VECD testing can be obtained in two days, which is much quicker than traditional beam fatigue testing.
8. Destructive core samples would provide the most accurate way to measure compaction, though they are not necessarily conducive to rapid construction/testing. If the Contractor provides RICM coverage maps for breakdown or intermediate roller operations, including surface temperature information, it may be possible to reduce the frequency of coring or to perform targeted sampling.

The Department may increase the frequency of verification testing at start-up or as necessary to validate the quality of the materials. The Department may reduce the frequency based on a history of satisfactory Contractor or material performance.

If verification tests indicate conformance with the specifications, no further action is required. If verification tests indicate nonconformance with the specifications, the Department and Contractor will jointly investigate the testing discrepancies. The investigation may include additional testing as well as

review and observation of both the Department's and Contractor's sampling and testing procedures and equipment. Both parties will document all investigative work.

When comparing Agency and Contractor test results, it is important to compare both the variances and the means. The tests most often used are the F-test (comparison of variances) and the t-test (comparison of means), which are used together.

4.2.2 Independent Assurance Testing

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing activities are being performed by qualified personnel using proper procedures and properly functioning and calibrated equipment. The Department will perform IA testing using personnel other than those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor's sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

4.3 Conflict Resolution

If a dispute between some aspect of the Contractor's and the Department's testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third-party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third-party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [\[Standard Specification Section XXX\]](#).

5 ACCEPTANCE REQUIREMENTS

Acceptance requirements provide a method for determining the degree to which the as-constructed pavement meets the specification and for determining appropriate payment. Acceptance is based on the measurement of properties that control the quality and performance of the pavement.

The quality acceptance limits presented in this section assume use of a percent within limits (PWL) approach. The PWL method encourages Contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging Contractors to produce a more uniform product.

5.1 General

The Department will accept the finished pavement based on the Contractor's test results unless it is shown through the Department's verification testing or the conflict resolution process that the Contractor's tests are in error.

5.2 Quality Characteristics and Acceptance Limits

The Department will accept the completed pavement in accordance with the criteria defined in Table 4 and properties measured and verified during construction.

Various acceptance parameters are listed in Table 4 for the specifier's consideration. Not all parameters shown will necessarily be appropriate or beneficial for any given project. Agencies may wish to include or exclude requirements based on the project's needs and goals, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and similar factors. Commentary provided within the table itself provides rationale for including certain parameters and, when applicable, offers additional information related to test methods and establishing targets and tolerances.

The quality acceptance limits presented within the table assume use of a percent within limits (PWL) approach for adjusting payment. The PWL is determined using Table 5 and the instruction in Section 5.3. A Lot is defined as the quantity (or surface area) of pavement placed in a single production day, or no more than 7,500 yd². Each Lot should be divided into no less than three and no more than eight Sublots of equal area. The quality index (QI) is calculated using the Lot sample standard deviation, S_n , and the Upper Quality Limit (UQL) and Lower Quality Limit (LQL). For additional information on establishing quality acceptance limits, refer to FHWA Publication No. FHWA-RD-02-095.

Note that the parameters, test methods, and tolerances included in Table 4 have been identified based on state-of-the-practice testing technology, which may or may not provide rapid and repeatable results, be representative of the anticipated field conditions, or relate directly to field performance (particularly if based on laboratory testing). This specification is therefore intended to be flexible enough to accommodate advances in technology, particularly in the area of nondestructive testing (NDT), which could allow for the development of acceptance parameters that better reflect the future performance and design life of the pavement. As applicable, emerging NDT technologies are also discussed in the commentary included in the table.

Table 4a: Acceptance Criteria (Materials Characteristics) ^(1,2)

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Air Voids (Laboratory Compacted)	AASHTO T312		
Asphalt Content	AASHTO T308		
Voids in Mineral Aggregate (VMA)	AASHTO R35		
<p>1. <i>Until gaps related to testing for fatigue and rutting resistance are overcome, Agencies will likely continue to use volumetric properties to evaluate quality. To provide a more comprehensive assessment of performance, it would be necessary to use or develop predictive models (e.g., Witczak equation) to relate volumetric properties to modulus and then to performance.</i></p> <p>2. <i>As an alternative to assigning pay factors to volumetric properties, Agencies could use volumetric test results as a trigger for more advanced mechanistic testing. For example, if a mix does not meet the prescribed volumetric targets, dynamic modulus testing would be required.</i></p>			

Table 4b: Acceptance Criteria (Construction Characteristics)

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Surface Distress (localized anomalies, segregation, surface irregularities) ⁽¹⁾	ASTM D6433, Pavement Condition Index (PCI) Survey or equivalent project-level visual survey ⁽²⁾	PCI > 80	The Department will evaluate deficiencies on a case-by-case basis to determine if a repair will be required.
<p>1. <i>Many specifications today require the pavement to be “free of surface defects.” Although some surface defects may not necessarily affect performance, acceptance of a marred pavement may be politically controversial. Eliminating segregation and increasing mat uniformity would decrease the risk for early pavement distress.</i></p> <p>2. <i>Visual methods generally only provide a qualitative indicator of end-of-construction quality. If NDT methods (e.g., Infrared Automated Thermal Profiling Systems or GPR) are used, it may be possible to establish a correlation to density. Refer to the SHRP 2 R06C project for an evaluation of the use of GPR and IR to detect and quantify segregation.</i></p>			
Ride Quality ⁽³⁾	AASHTO M 328, Inertial Profiler Measurement and Continuous Roughness Reporting ⁽⁴⁾ Measure pavement profile in both wheel paths simultaneously, parallel to the right edge of the lane, and in the direction of travel for each lane.	IRI ≤ 67 in./mi with 0.1 mi baselength for full payment ⁽⁵⁾ Localized Roughness: IRI ≤ 125 in./mi with 25-ft baselength	PWL 85% full payment based on continuous roughness histogram histogram from ProVAL

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p>3. <i>Studies indicate that ride quality provides an indirect measure of construction quality. It is a standard parameter for federal-aid projects; however, implementation of a ride quality requirement can present challenges:</i></p> <ul style="list-style-type: none"> <i>From an Agency’s perspective, establishing meaningful threshold values for different roadway types can be difficult.</i> <i>From industry’s perspective, if the existing roadway is rough, it may be difficult to achieve significant improvements. In such cases, the Agency may wish to adjust the standard or provide more opportunities for the Contractor to achieve smoothness (e.g., milling, multiple lifts).</i> <p>4. <i>Use of a high-speed inertial profiler to measure IRI is the standard for acceptance, though the initial cost to purchase a dedicated vehicle is high (~\$200,000). Lower-cost portable units are also commercially available but must be calibrated to the vehicle.</i></p> <p>5. <i>Threshold would vary based on roadway type. To establish a threshold for end-of-construction, look at similar projects and/or set according to expected 5-year ride and adjust downward based on new pavements. Targets may also have to be adjusted in urban areas, to account for side streets and manholes.</i></p>			
Compaction (In-place air voids/in-place density) ⁽⁶⁾	AASHTO T269/Cores ⁽⁷⁾	Maximum theoretical density /Minimum 5 tests per Lot ⁽⁸⁾	PWL 85% full payment LQL = % MTD minus UQL = % MTD plus
	ASTM D 2950/Nuclear Density Gauge ⁽⁹⁾		
	Ground-Penetrating Radar (GPR) ⁽¹⁰⁾		
	Roller-Integrated Compaction Monitoring (RICM) ⁽¹¹⁾		
<p>6. <i>Compaction is strongly related to pavement durability. The amount of air voids affects the stability and durability of the asphalt mix. When too low, rutting can occur due to plastic flow. When the voids are too high, the mix is more permeable to air and water, which can increase the rate of oxidation of the asphalt binder and ultimately result in premature cracking and/or raveling. Compaction is therefore particularly important for DBB and DB contracts that have no postconstruction performance requirements.</i></p> <p><i>If AMPT testing (e.g., E*, flow number) is being performed to address mechanical properties of the mix design, the significance and application of in-place air voids would likely change. In-place air voids would become less important for pay adjustment purposes because this parameter would no longer have to serve as a surrogate for more performance-oriented mechanistic parameters. Air voids would, however, continue to be important from a durability and aging standpoint. AMPT testing can provide important information on the mix, but compaction testing accounts for placement issues that can’t be addressed using a lab test.</i></p> <p>7. <i>Destructive core samples provide the most accurate way to measure compaction, though they are not necessarily conducive to rapid construction/testing.</i></p> <p>8. <i>If the Contractor provides RICM coverage maps for breakdown or intermediate roller operation, including surface temperature information, it may be possible to reduce the frequency of coring or to perform targeted sampling.</i></p> <p>9. <i>Though not as accurate as core tests, nuclear density gauges (as well as nonnuclear density gauges) provide a nondestructive way to measure density. Other NDT devices (e.g., GPR and RICM) do not measure density directly.</i></p> <p>10. <i>GPR measures dielectric constant, which can be correlated to density testing performed on cores (correlation coefficient ~ 0.7 to 0.8).</i></p> <p><i>GPR has primarily served as a research and forensic tool; however, as an alternative to the traditional core and density gauge tests, GPR would provide the <u>advantage</u> of</i></p>			



Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<ul style="list-style-type: none"> • <i>Near continuous measurements (approximately one measurement per 6 in.), and</i> • <i>Data collection at highway speed (resulting in minimal disruption to traffic or to the Contractor’s operations).</i> <p><i>Possible limitations associated with this technology include</i></p> <ul style="list-style-type: none"> • <i>Cost of equipment (approximately \$30,000–\$40,000),</i> • <i>Technician skill-level for data analysis and interpretation of dielectric values,</i> • <i>Processing time to analyze data (approximately 2 hours),</i> • <i>Lack of a standard test method to measure density using GPR, and</i> • <i>Need for core samples for calibration.</i> <p><i>To establish a tolerance, it would be possible to set a lower limit for density and estimate PWL based on dielectric constant.</i></p> <p>11. <i>Stiffness-related compaction data obtained from RICM technology have not shown a strong correlation to density. However, the real-time temperature and pass coverage output from the rollers can be valuable, particularly for the Contractor’s quality control operations. Further studies are needed to determine how useful machine values are for QA or acceptance purposes.</i></p>			
Joint Compaction on Longitudinal Joints ⁽¹²⁾	AASHTO T269/Cores ⁽¹³⁾	% Maximum theoretical density/Minimum 5 tests per Lot ⁽¹⁴⁾	The Department will evaluate joint deficiencies on a case-by-case basis to determine if a repair will be required.
	Ground-Penetrating Radar (GPR) ⁽¹⁵⁾		
<p>12. <i>Although not frequently included in Standard Specifications, an acceptance parameter addressing joint compaction would motivate Contractors to pay more attention to joint compaction—a key issue for ensuring the durability of joints.</i></p> <p><i>Along with compaction and smoothness, joint compaction is typically one of the most important properties of the in-place pavement to include in a payment adjustment system, particularly on high-volume roadways.</i></p> <p>13. <i>Joint density has traditionally been measured using cores. Note that nuclear density gauges may also be used to measure joint compaction, but they can be difficult to seat properly on the joint and may therefore provide questionable results.</i></p> <p>14. <i>If the Contractor provides GPR or RICM coverage maps, it may be possible to reduce the number of cores taken or to perform targeted sampling.</i></p> <p>15. <i>Refer to the advantages and disadvantages of GPR technology as identified with respect to the Compaction parameter (note 10).</i></p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Deflection/Stiffness ⁽¹⁶⁾	Falling Weight Deflectometer (FWD), ASTM D 4695 ⁽¹⁷⁾	See Note 18	
	Continuous Deflection Devices ⁽¹⁹⁾		
	Portable Seismic Pavement Analyzer (PSPA) ⁽²⁰⁾		
	GeoGauge ⁽²¹⁾		
	Roller-Integrated Compaction Monitoring (RICM) ⁽²²⁾		

16. Although not traditionally used as an acceptance parameter, stiffness measurements would provide a means to evaluate the structural adequacy of the in-place pavement. As more Agencies move toward using mechanistic design methods (which include pavement layer stiffness as a key input variable) measurement of in-place layer moduli could be used to validate design assumptions. Ultimately, if the parameter is used over time and a historical database can be developed, the information could be used to improve forecasting tools and better plan repair activities to reduce user impacts.
- Currently, measurement strategies using deflection-based technologies (e.g., FWD) are more common than stiffness-based devices (e.g., PSPA). Given the subjectivity associated with back-calculating stiffness values from deflection measurements, it is recommended that deflection (rather than stiffness) be used as the performance parameter if testing is based on FWD.
- The best application of a stiffness parameter would be on a high-profile, high-volume interstate rehabilitation project with improvements to the base or surface course or a new alignment or rehabilitation project with major repairs or structural improvements down to subgrade. Measuring stiffness would not be applicable to mill and overlay projects.
17. Compared with the alternatives, use of FWD is perhaps the closest to a “traditional” measurement strategy. It is being used within the Long-Term Pavement Performance (LTPP) program, and most agencies have access to at least one FWD device.
- However, it is important to note that FWD does not provide a direct measure of stiffness, only deflection. Deflection measurements can then be used to back calculate pavement structural layer stiffness and subgrade resilient modulus to ensure that the pavement structure at completion meets the overall strength requirements assumed during the structural design process.
- Unlike the still-experimental continuous deflection devices, FWD technology only allows discrete point measurements.
18. Given the inherent subjectivity associated with backcalculation methods (essentially a curve-fitting process), it would be difficult to implement a deflection-based stiffness parameter for acceptance/payment purposes. It would be possible to develop a target for deflection based on local conditions and pavement type if a historical database is developed and maintained.
19. Similar to FWD, continuous deflection devices, such as Rolling Wheel Deflectometers (RWD) and Traffic Speed Deflectometers (TSD), would not provide a direct measure of stiffness, only deflection.
- Such devices would provide the advantage of better spatial coverage with less impact on traffic. However, unlike FWD, these devices do not provide the full deflection basin needed to calculate multiple moduli and structural capacity. Such devices will therefore likely be better suited to network-level analysis than project-level acceptance.
- Continuous deflection devices are not yet commercially available but are under development. (The SHRP 2 R06F project is evaluating existing technologies.) Accuracy of existing devices has been found to be reasonable but not very repeatable for low-deflecting pavements.
20. PSPA measures wave velocity to calculate surface stiffness. The device can be calibrated to the specific materials being tested during the mixture design stage.
- Based on its evaluation of several NDT technologies including deflection-based (FWD, LWD), steady state vibratory (GeoGauge), dynamic cone penetration (DCP), ground-penetrating radar (GPR), nonnuclear density gauges, and intelligent compaction (IC) rollers, NCHRP Report 626, NDT Technology for Quality Assurance of HMA Pavement Construction, concluded that the PSPA device had the most accuracy and repeatability in identifying HMA pavement areas with

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p><i>anomalies.</i></p> <p><i>As also noted in NCHRP Report 626, a possible disadvantage to using this technology is the recommendation to delay testing for 1 day after HMA placement and compaction to allow the mix to cool (due to difficulty in maintaining adequate coupling between the receiver and the surface at high temperatures—the rubber pads of receivers may deteriorate or melt). Technicians also require a higher skill level to operate a PSPA than a density gauge.</i></p> <p>21. <i>A GeoGauge measures seismic input to calculate stiffness response at the surface. However, it is primarily suited to testing unbound materials and soils. The device should be calibrated to project materials and conditions to improve measurement accuracy.</i></p> <p>22. <i>Although not currently used for acceptance purposes, RICM technology is a promising technique for evaluating properties that relate more directly to performance (e.g., stiffness). The future goal for incorporating RICM technology would be to develop acceptance criteria and target values based on RICM machine values that correlate to density or other NDT modulus-based point measurements. Further studies are needed to determine the usefulness of machine values for QA or acceptance purposes.</i></p>			
Thickness ⁽²³⁾	ASTM D3549/Cores ⁽²⁴⁾	Minimum Design Thickness minus ¼ in./Minimum 3 tests per Sublot	PWL 85% full payment LQL = Design Thickness minus ¼ in. UQL = Design Thickness plus 1 in.
<div style="border: 1px dashed orange; padding: 2px;"> Ground-Penetrating Radar, ASTM D 4748 ⁽²⁵⁾ </div>			
<p>23. <i>Although measuring asphalt thickness is not standard practice for most Agencies, thickness is related to structural capacity and would provide some indication of the expected structural performance of the pavement.</i></p> <p><i>Also, to facilitate rapid renewal, thickness measurements could be used to make payment based on area (e.g., square yards instead of cubic yards or tons), eliminating the need for weight tickets and yield calculations.</i></p> <p><i>A thickness parameter would not be appropriate if the Contractor is trying to match existing conditions (variable thickness) or is dealing with rough surface conditions.</i></p> <p>24. <i>Thickness is traditionally measured using cores, despite not necessarily being conducive to rapid construction/testing.</i></p> <p>25. <i>As an alternative to destructive core sampling, GPR would provide the <u>advantage</u> of</i></p> <ul style="list-style-type: none"> • <i>Continuous measurements taken at highway speed, and</i> • <i>Reasonable accuracy and repeatability—within 10% for thickness (though not as accurate as cores).</i> <p><i>Some possible limitations associated with this technology include</i></p> <ul style="list-style-type: none"> • <i>Cost of equipment (approximately \$30,000–\$40,000 for the unit),</i> • <i>Some processing time needed to analyze data and estimate material properties (though time needed to estimate layer thickness is much less than that needed to estimate density),</i> • <i>Relatively high technician skill-level for data analysis (though less training is required to analyze GPR data for thickness than density), and</i> • <i>Cores needed to improve accuracy of data interpretation.</i> 			



Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Skid Resistance ⁽²⁶⁾	ASTM E274 ⁽²⁷⁾ ASTM E524 ASTM E501 Collect a friction number data test point every 3/10 of a lane-mile for each travel lane, at a minimum testing frequency	Evaluate 100% of pavement surface. FN40S ≥ 40 FN40R ≥ 45 / Average per lane or as per Department requirements.	PWL 85% full payment
<p>26. Skid resistance is a critical functional performance issue. However, given the political sensitivity regarding this property, it may be better to address friction by specifying material and mixture properties (e.g., polished stone testing of aggregate) than to establish a skid resistance target for end-of-construction acceptance. It may be more appropriate to implement skid resistance as a distress indicator under a postconstruction warranty or maintenance agreement.</p> <p>27. The type of test tire (smooth or ribbed) should be selected by the Department based on standard practice.</p>			

5.3 Quality Level Analysis

- A. Unless otherwise indicated in Table 4, acceptance of material and work shall be based on the method of estimating percent within limits (PWL), where the PWL will be determined in accordance with this Section. All Sublot test result values for a Lot, as defined in Table 4, will be analyzed statistically to determine the total estimated PWL. The PWL is computed using the Lot sample average value, \bar{X} , as defined in Section 5.3.C.2, the Lot sample standard deviation, S_n , as defined in Section 5.3.C.3, for the specified number of Sublots, n , and the specification Quality Acceptance Limits, as defined in Table 4, where LQL represents the Lower Quality Limit, and UQL represents the Upper Quality Limit, as they apply to each particular acceptance parameter. From these values, the respective Quality Index (Indices), Q_L for Lower Quality Index and/or Q_U for Upper Quality Index, is (are) computed in accordance with Sections 5.3.C.4 and 5.3.C.5. Then the PWL for the Lot for the specified number of Sublots, n , is determined from Table 5.
- B. In addition, all asphalt and asphalt placement work shall conform to the requirements of Section 7.4. For any identified deficiencies, as defined in Section 7.4, the Contractor may either
1. Remove and replace the asphalt pavement in that particular Lot at no additional cost to the Department, or
 2. Accept a deduction of 50% of the contract unit price for that particular Lot of asphalt.
- C. Determine the PWL as follows:
1. In accordance with this specification and the QMP, locate sampling positions, obtain test sample, make specimens, and conduct test.
 2. Determine the Lot sample average value, \bar{X} , by calculating the average of all Sublot test values.
 3. Find the Lot sample standard deviation, S_n , by using the following formula:

$$S_n = \sqrt{\frac{\sum (x_i - \bar{X})^2}{n-1}}$$

where

- S_n = standard deviation of the Sublot test values
- x_i = individual Sublot test values
- \bar{X} = average of Sublot test values
- n = number of Sublots

4. Find the Lower Quality Index, Q_L , by subtracting the Lower Quality Limit, LQL, from the average value, \bar{X} , and dividing the result by the Lot sample standard deviation, S_n .

$$Q_L = \frac{\bar{X} - LQL}{S_n}$$

5. Find the Upper Quality Index, Q_U , by subtracting the Lot sample average value, \bar{X} , from the Upper Quality Limit, UQL, and dividing the result by the Lot sample standard deviation, S_n .

$$Q_U = \frac{UQL - \bar{X}}{S_n}$$

6. Determine the percentage of material above lower tolerance limit, P_L , and the percentage of material below upper tolerance limit, P_U , by entering Table 5 with Q_L and/or Q_U using the column appropriate to the total number of Sublots, n , and reading the appropriate number under the column heading "PWL."
7. For quality characteristics with only an Upper Quality Limit, PWL equals P_U . For characteristics with only a Lower Quality Limit, PWL equals P_L . For asphalt properties with both Upper and Lower Quality Limits, first calculate the Upper Quality Index, Q_U , and the Lower Quality Index, Q_L , by using the Upper Quality Limit, UQL, and the Lower Quality Limit, LQL, respectively. The limits to be used are stipulated in Table 4. Then determine PWL using the following formula:

$$PWL = (P_U + P_L) - 100$$

8. The PWL from Table 5 that is to be used is the whole number greater than that found by using the Q_U or Q_L in the table. For example, the PWL to be used for $n = 4$ and a Q_U of 1.4200 would be 98.

Table 5: Percent within Limits (PWL)
(STANDARD DEVIATION METHOD)
Positive Values of Quality Index (QI)
(n = Number of Sublots in the Lot)

PWL	n=3	n=4	n=5	n=6	n=7	n=8
100	1.1600	1.5000	1.7900	2.0300	2.2300	2.3900
99	1.1541	1.4700	1.6714	1.8008	1.8888	1.9520
98	1.1524	1.4400	1.6016	1.6982	1.7612	1.8053
97	1.1496	1.4100	1.5427	1.6181	1.6661	1.6993
96	1.1456	1.3800	1.4897	1.5497	1.5871	1.6127
95	1.1405	1.3500	1.4407	1.4887	1.5181	1.5381
94	1.1342	1.3200	1.3946	1.4329	1.4561	1.4716
93	1.1269	1.2900	1.3508	1.3810	1.3991	1.4112
92	1.1184	1.2600	1.3088	1.3323	1.3461	1.3554
91	1.1089	1.2300	1.2683	1.2860	1.2964	1.3032
90	1.0982	1.2000	1.2290	1.2419	1.2492	1.2541
89	1.0864	1.1700	1.1909	1.1995	1.2043	1.2075
88	1.0736	1.1400	1.1537	1.1587	1.1613	1.1630
87	1.0597	1.1100	1.1173	1.1191	1.1199	1.1204
86	1.0448	1.0800	1.0817	1.0808	1.0800	1.0794
85	1.0288	1.0500	1.0467	1.0435	1.0413	1.0399
84	1.0119	1.0200	1.0124	1.0071	1.0037	1.0015
83	0.9939	0.9900	0.9785	0.9715	0.9672	0.9643
82	0.9749	0.9600	0.9452	0.9367	0.9325	0.9281
81	0.9550	0.9300	0.9123	0.9020	0.8966	0.8928
80	0.9342	0.9000	0.8799	0.8690	0.8625	0.8583
79	0.9124	0.8700	0.8478	0.8360	0.8291	0.8245
78	0.8897	0.8400	0.8160	0.8036	0.7962	0.7915
77	0.8662	0.8100	0.7846	0.7716	0.7640	0.7590
76	0.8417	0.7800	0.7535	0.7401	0.7322	0.7271
75	0.8165	0.7500	0.7226	0.7089	0.7009	0.6958
74	0.7904	0.7200	0.6921	0.6781	0.6701	0.6649
73	0.7636	0.6900	0.6617	0.6477	0.6396	0.6344
72	0.7360	0.6600	0.6316	0.6176	0.6095	0.6044
71	0.7077	0.6300	0.6016	0.5878	0.5798	0.5747
70	0.6787	0.6000	0.5719	0.5583	0.5504	0.5454
69	0.6490	0.5700	0.5423	0.5290	0.5213	0.5164
68	0.6187	0.5400	0.5129	0.4999	0.4924	0.4877
67	0.5878	0.5100	0.4836	0.4710	0.4638	0.4592
66	0.5563	0.4800	0.4545	0.4424	0.4354	0.4310
65	0.5242	0.4500	0.4255	0.4139	0.4073	0.4031
64	0.4916	0.4200	0.3967	0.3856	0.3793	0.3753
63	0.4586	0.3900	0.3679	0.3575	0.3515	0.3477
62	0.4251	0.3600	0.3392	0.3295	0.3239	0.3203
61	0.3911	0.3300	0.3107	0.3016	0.2964	0.2931
60	0.3568	0.3000	0.2822	0.2738	0.2691	0.2660
59	0.3222	0.2700	0.2537	0.2461	0.2418	0.2391
58	0.2872	0.2400	0.2254	0.2186	0.2147	0.2122
57	0.2519	0.2100	0.1971	0.1911	0.1877	0.1855
56	0.2164	0.1800	0.1688	0.1636	0.1613	0.1592
55	0.1806	0.1500	0.1408	0.1363	0.1338	0.1322
54	0.1447	0.1200	0.1125	0.1090	0.1070	0.1057

6 METHOD OF MEASUREMENT

The Department will measure the work by the ton, based on the quantity of mixture placed, completed and accepted, and verified by certified records of shipment and haul tickets. Provide a copy of the haul ticket for each load when delivered to the project site. Present certified records of shipment for the in-place quantities to the Department on a monthly basis for progress payment estimates.

Alternatively, if thickness is being measured, payment could be based on area (e.g., square yards), eliminating the need for weight tickets and yield calculations.

7 BASIS OF PAYMENT

Pay factor adjustments reward the Contractor for providing superior product and penalize the Contractor for providing product that is of lower quality than specified. This section assumes use of a percent within limits (PWL) approach to compute pay adjustments. The PWL method encourages Contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures, such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging Contractors to produce a more uniform product.

Although simple to apply, the PWL approach primarily relies on engineering judgment to establish the individual pay adjustments and weighting factors. Arguably, a more rational approach would entail the use of mathematical models to compute pay factors for a given Lot based on the effect of construction quality on the predicted performance and subsequent LCC of the as-constructed pavement.

7.1 Pay Factor Adjustments

- A. Pay Factor adjustments for each Lot of each quality characteristic will be computed in accordance with the formulas contained in Table 6 by entering the PWL value and performing the calculation indicated for the appropriate PWL range to determine the Pay Factor.

For example, if 100% of the product is within limits, the pay adjustment is $0.06 = 6\%$, meaning the Contractor receives a 6% bonus.

Table 6: Adjustments to Contract Compensation

Percent Within Limits (PWL)	Pay Factor
91–100	$[0.006 (PWL - 90)]$
85–90	0.0
55–84	$-0.9 + 0.01PWL$

- B. The overall Pay Factor for a given characteristic, PF_i , is determined by calculating the average of all PFs for that characteristic for every Lot in the project.

7.2 Pay Adjustment

Based upon the quality of the pavement, the Department will calculate a weighted pay adjustment. The weights applied to each quality characteristic will be as shown in Table 7.

Table 7 illustrates possible pay adjustments for different pay items. Specifiers should consider project-specific conditions and goals when selecting pay factor adjustments and weight them in

accordance with the criticality of the parameter to the ultimate performance of the pavement. For example, factors such as compaction, joint compaction, and smoothness are typically the most important installed properties to include in a payment system and may thus be weighted higher. Thickness could be included in a pay adjustment system if payment is based on area (e.g., square yards instead of tons). In the future, as owners and industry obtain more experience with stiffness as an acceptance parameter, this may also be incorporated into the pay adjustment system.

Agencies may wish to eliminate some factors entirely if they do not have sufficient data to support pay adjustment for those items.

Table 7: Pay Adjustment Criteria

Parameter	PF Designation	Weighting
Compaction	PF _c	1
Joint Compaction	PF _{jc}	1
Ride Quality	PF _{rq}	1
Thickness	PF _t	0.5
Skid Resistance	PF _{sr}	0.5

$$\text{Example: } PA = \frac{[(PF_c \times 1) + (PF_{jc} \times 1) + (PF_{rq} \times 1) + (PF_t \times 0.5) + (PF_{sr} \times 0.5)]}{(1+1+1+0.5+0.5)}$$

For high-risk/high-profile projects, specifiers may also wish to establish pay adjustments for key volumetric parameters of the asphalt mixture, such as asphalt content, air voids, and VMA.

Table X: Pay Adjustment Criteria – Mixture Properties

Parameter	PF Designation	Weighting
Asphalt Content	PF _{ac}	1
Air Voids	PF _{av}	1
VMA	PF _{vma}	0.5

7.3 Total Project Adjusted Price

The Department will calculate a total project Adjusted Price (AP) by multiplying the composite Pay Adjustment (PA) from Section 7.2 times the total tons of pavement in place times the unit price.

$$AP = (PA) \times (\text{Tons of Asphalt}) \times (\$/\text{Ton})$$

7.4 Correction of Deficiencies

Remove and replace or correct pavement in a manner acceptable to the Department and at no cost to the Department if any of the following deficiencies exist, unless the Department elects to accept the pavement, at which time the Contractor will be compensated at 50% of the contract unit price for asphalt placement specified regardless of the Pay Factors calculated in Tables 6 and 7:

1. PWL for density is below 55.

2. PWL for ride quality is below 55 unless the Contractor elects to level-up, overlay, mill, or use a combination thereof to correct deficiencies.
3. PWL for skid resistance is below 55 unless the Contractor elects to correct with a thin surface treatment or friction overlay as deemed acceptable to the Department.

GROUND IMPROVEMENT USING VERTICAL SUPPORT ELEMENTS

PERFORMANCE SPECIFICATION

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for ground improvement using vertical support elements (VSE).

Ground improvement VSEs are increasingly being used to solve the settlement and embankment stability issues associated with construction on marginal soils. The selection of the VSE type depends on the design loads, soil conditions, constructability of the column, available equipment and expertise, and cost.

Unless otherwise noted, the recommended performance parameters and ancillary requirements contained in this specification apply to both DBB and DB delivery, assuming roles and responsibilities will be assigned as follows:

- *Subsurface geotechnical information provided by the Agency unless bidders are directed to perform independent investigations to support their design, or a combination thereof;*
- *Selection of the ground improvement VSE technology by Contractor;*
- *Design of VSEs by the Contractor;*
- *Quality management by the Contractor;*
- *Verification and acceptance of VSEs by the Agency; and*
- *Postconstruction maintenance by the Agency.*

The goals of this performance specification are to

- *Reduce cost by allowing industry to select from a range of possible VSE technologies that will accommodate Contractor preferences and meet the required performance.*
- *Allow for new (even proprietary) technologies to be used in transportation work.*
- *Promote use and development of technologies that can be used to directly determine critical measures of performance (e.g., bearing capacity, settlement), which in the longer term will reduce risk for both the Contractor and Agency.*
- *Transfer risk to industry for design and installation of VSEs to meet the performance requirements.*

Developing performance specifications for geotechnical applications using vertical support elements (VSE) creates unique challenges because of (1) the differences in VSE technologies, materials, and installation methods, and (2) the enduring problem of carrying out system level performance assessments (i.e., full-scale settlement monitoring). As an introduction to the effort to develop this “concept” system performance specification, information and products resulting from the SHRP 2 R02 research project are also discussed as appropriate. The SHRP 2 R02 products provide an up-to-date source of information related to the various VSE technologies and specifications. Using the SHRP 2 R02 online tool (<http://geotechtools.org/>), summary tables of key performance information were prepared to identify the current state of practice with these technologies. Given the wide range of field conditions that make use of VSEs, the SHRP 2 R02 selection and guidance system shown in Appendix A (Figures 1 and 2) was used as a means to demonstrate that at the present time, it is advantageous to narrow the number of possible technologies to a smaller group before crafting a system level performance specification for a project. Two examples of narrowing the list of technologies for common geotechnical conditions—embankment support over weak wet cohesive soils versus loose saturated sands—are also shown in Appendix A (Figures 3 and 4). Appendix B (Table 3) summarizes the possible VSE technologies and system level performance criteria to improve the foundation soils (reduce settlement) for each of these geotechnical conditions.

The list of VSE technologies considered (from SHRP 2 R02 selection and guidance system) included the following:

- *Aggregate Columns,*

- *Combined Soil Stabilization with Vertical Columns,*
- *Continuous Flight Auger Piles,*
- *Deep Mixing Methods,*
- *Geotextile Encased Columns,*
- *Jet Grouting,*
- *Micropiles,*
- *Sand Compaction Piles, and*
- *Vibro-Concrete Columns.*

A few of these technologies are relatively new and do not have specifications developed for the U.S. market to date. To develop a specification, the project conditions and VSE technologies must be narrowed and be compatible. The SHRP 2 R02 selection and guidance system was used to demonstrate the process of narrowing VSEs to meet the desired project conditions. VSE technology-specific specifications are provided within the SHRP 2 R02 website. There are good examples of performance specifications, including a Florida DOT “Combined Soil Stabilization with Vertical Columns” specification and an Iowa DOT VSE performance specification. Based on a review of such specifications, the system level performance criteria common to all VSE technologies are load capacity and settlement monitoring.

1 DESCRIPTION

The work will consist of constructing vertical support elements (VSE) as specified herein and shown on the Plans, quality control testing, load testing, settlement monitoring, and coordinating with the Department. Furnish all labor, equipment, and materials necessary to plan, design, and construct ground improvements for the [*embankment, abutment, culvert, retaining wall*] structure using a vertical support element (VSE) foundation for the following ground conditions:

Insert a brief description of existing ground conditions. The ground conditions to be improved may range from weak, wet, cohesive soils to loose, saturated, granular sands.

Select a VSE solution and conduct associated testing, monitoring, sampling, and recording of the work to achieve the degree of improvement required as indicated in Section 2 and the soils investigation report and meet the performance criteria specified in Section 9 within the limits shown on the Plans.

The Department, acting in an oversight role, will conduct inspection and quality assurance sampling and testing as required.

2 REFERENCE DOCUMENTS

The Department or its authorized representative will provide the following information to the Contractor developed during the project design phase:

The list provided below is for illustrative purposes and should be modified as required based on the project requirements.

- Plans prepared by _____, dated _____.
- Foundation requirements for proposed structure (*e.g., embankment, abutment, retaining wall*).
 - Structure loads,

- Expected fill heights and borrow materials,
 - Settlement tolerances (total and differential),
 - Bearing capacity requirements,
 - Engineering properties (strength, permeability, modulus, etc.) and design input parameters, and
 - Requirements for structural reinforcement (material grade and installation procedure and time schedule for installation), including structures.
- Installation tolerances (length, diameter, inclination, and plan position).
 - Arrangement requirements such as minimum overlap of adjacent elements, minimum area replacement ratio, maximum clear space of untreated soil between adjacent buttresses or columns.

The Agency may specify minimum and maximum column diameters or minimum area replacement ratios but should allow as much latitude as possible while still satisfying the design objectives.

- Geotechnical Investigation report No.(s) _____ titled _____, dated _____.

Geotechnical information collected during the design phase is available for review by the Contractor. It is the Contractor's responsibility to review this information and determine whether this information is sufficient for the design and installation of the VSE required for the project. Any additional exploration should be performed by the Contractor at its expense and made available to the Engineer.

- Results of pre-production vertical support element test programs conducted by the Department, if any.
- Results from previous experience with VSE or special geotechnical works adjacent to the site.
- Overall construction schedule, including construction preloading or phasing schedule, if required.
- Requirements for handling/removing spoils.
- Environmental restrictions (noise, vibration, and emissions restrictions; air or water pollution constraints; known areas of subsurface contamination; presence of archeologically sensitive areas).
- Allowable displacement of adjacent structures.

3 SYSTEM LEVEL PERFORMANCE CRITERIA

Design and construct the VSE to achieve the following system level performance criteria.

Considering the current state of practice and review of the various VSE technologies, the following list summarizes performance criteria that would span multiple technologies. Use the appropriate parameters, both general and specific, for selected VSE technology.

1. Minimum average axial (allowable) bearing pressure for individual, unit cell, or group of VSE elements [__] psf.
2. Matrix soils or within VSE element standard penetration test (SPT) with allowable penetration value [____].
3. Matrix soils or within VSE element cone penetration test (CPT) with allowable end bearing pressure of [____] psf.
4. Maximum immediate and/or total settlement (and rate) of [____] inches (inches/month)
5. Maximum differential settlement of [____] inches.
6. Minimum factor of safety against slope instability of [____], liquefaction [____], or bearing capacity [____] coupled with approved design method and testing results.

4 SITE SURVEY

Careful consideration of the presence and location of all utilities and underground obstructions is required. The location of both active and abandoned buried utilities at the site can have a significant impact on the design and construction of vertical support elements. Locations of known old foundations, abandoned underground tanks, and other underground facilities and structures should also be made available to the Contractor. If available, boring logs showing the soil type, profile, and depths to firmer strata should be provided with geotechnical reports.

Review the available subsurface information, and visit the site to assess site geometry, equipment access conditions, and verify the location of existing structures and above ground utilities and facilities. Notify the Engineer of all subsurface conditions different from those shown on the plans that may require relocation of VSE or structural design modification.

5 QUALIFICATIONS

Submit documentation demonstrating experience in the design and construction of VSE.

Qualifications could consist of the following types of requirements:

- *Successful experience with VSEs for the soil conditions and project scope similar to that of the project being bid (provide reference list).*
- *A Professional Engineer licensed in the state of [__] with a minimum of five years of experience in design of VSEs to supervise the design and construction of the VSE work.*
- *A Project Manager who has been responsible for the VSE work on at least five projects. The Project Manager shall have been in full-time employment of the Contractor for at least two of those projects (provide reference list; minimum number of years/projects).*
- *A full-time Project Superintendent with at least three years of experience in VSE construction and with responsibility for a minimum of three VSE projects (provide reference list, years/projects).*
- *At least one equipment operator having a minimum of one year experience with the proposed VSE equipment and with the specific VSE construction.*
- *Provide detailed experience and/or training records of equipment operators specific to the type of ground improvement method being utilized by the Contractor for this contract.*

Submit written requests for substitution of key personnel prior to personnel changes. Demonstrate that the substitute meets the requirements listed above. Do not make substitutions until written approval is provided by the Department.

6 CONSTRUCTION SUBMITTALS AND INSTALLATION PLAN

At least 30 days prior to the start of vertical support element work, submit for review and approval the VSE Work Plan. Include the following in the VSE Work Plan:

- Design and material requirements for selected VSE,
- Working drawings,
- Proposed personnel and equipment,
- Method for locating VSE within the structure limits shown on the plans,
- Monitoring measures to prevent damage to adjacent structures,
- Installation plan,
- Method for disposal of spoils and debris,
- Sample daily production reports,
- Procedures to obtain, preserve, and transport samples of material which comprises the VSE for testing,
- Sampling and testing plan to be used to confirm constructed VSE meets design and performance requirements, and names of any subcontractors or independent laboratory used for testing, and
- Required Department inspection, and sampling and testing activities.

Assume responsibility for the quality of the VSE, including work performed or provided by subcontractors, suppliers, and vendors.

The information submitted by the Contractor on a daily basis is very important to ensure accurate tracking of production and quality. The Contractor should also submit a sample Daily Production Report to the Agency for review and approval. The content of the report will vary significantly based on the type of VSE used. The Department should review this listing carefully and request from the Contractor, prior to production, any additional information required to ensure the VSE foundation is being constructed as intended. Generating data after the fact may be impossible and/or can lead to errors or omissions.

Parameters for monitoring could include water/binder ratios, binder slurry injection pressures and quantities, mixing tool rotational speeds, mixing tool down pressures, mixing tool penetration and withdrawal rates, motor amperage or hydraulic pressure variations with depth, element location, element verticality, and other related aspects of the VSE stabilization process.

The installation plan should define the stand-by procedures to be used when obstructions are encountered. It is not always practical for the Contractor to maintain production by moving to a different section of the site and continuing deep mixing while an obstruction is being investigated. If known obstructions exist at the site, it may be necessary to differentiate between known and unknown obstructions in the specifications.

7 MATERIALS

To achieve the target performance criteria for the VSE, use materials that meet the following requirements:

- *Cement,*
- *Supplementary Cementitious Materials,*
- *Admixtures,*
- *Joint Seals and Fillers,*
- *Curing Compound and Evaporation Retarders, and*
- *Reinforcement (dowel bars, tie bars, mat reinforcement).*

The Contractor may propose alternate materials subject to Department review and approval.

8 CONSTRUCTION REQUIREMENTS

Improve subsurface soils using VSE at the locations and configurations shown on the Plans and as specified herein.

The Agency's confidence in its ability to predict future performance at the end of construction will control the degree to which an Agency can relax its standard construction requirements. It may be possible to eliminate certain prescriptive requirements in the interest of rapid renewal.

In exchange for providing the Contractor some flexibility with regard to materials and construction decisions, the Agency should require the Contractor to describe in its QMP how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its workmanship (e.g., scheduling, material handling, and installation) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

8.1 Site Preparation

Remove muck, organics, soft clay, or other unsuitable materials encountered within __ feet of the ground surface or otherwise treat to prevent problems with VSE construction. Should the VSE Contractor suspect that any soils that are excavated are contaminated by hydrocarbons, refuse, or other environmentally hazardous material, notify the Engineer immediately and proceed with work as directed.

Unsuitable or contaminated materials should generally be removed to their full depth, or to a depth of -five feet, whichever is less. The excavation is typically backfilled with appropriate soils compacted to appropriate densities.

8.2 Pre-Production Test Section

The viability of the vertical support elements can be proven either through the use of a pre-production test section or through individual element load tests. The Agency and Contractor will

need to determine which is the most appropriate for the selected VSE. The test program will be used to optimize the various parameters specific to the VSE type selected and confirm that the VSEs meet required design and performance criteria.

The Agency may waive test sections if the Contractor can provide sufficient evidence of recent experience with producing an acceptable VSE of the type proposed.

Install the test section based on the approved pre-production test section plan at the locations indicated on the Plans to verify that the proposed design, materials, equipment, and procedures can achieve the specified requirements.

8.3 Pre-Production Test Section Plan

Submit a Test Section Plan describing construction procedures, the equipment to be used to penetrate the ground and make the VSE, and all means and methods proposed for QA/QC testing.

8.4 Pre-Production Test Section Installation

Where possible, expose the test elements by excavation and measure for geometric properties. If full-depth excavation is not feasible, use drill samples or other testing method to demonstrate column size/geometry. The Contractor may propose alternative testing methods as approved by the Engineer.

Based upon review of the results of the Pre-Production Test Program, present parameters selected to achieve the specified performance and acceptance criteria for review by the Engineer. The Contractor may propose changes to the originally intended means, methods, and materials. These changes to installation procedures must be agreed to by the Department prior to production. The Contractor may be required to repeat the construction of a test section at no additional expense if selected parameters fall outside test requirements.

8.5 Installation

Install the VSE based on the results of the Pre-Production Test Program and the approved VSE work plan; using the same tooling, materials, sequence of installation, and procedures demonstrated from the test program; and conforming to the lines, grades, cross-sections, and depth indicated on the Plans.

Control the vertical alignment of the VSE during installation by measuring the alignment in two dimensions. The centerline of the elements shall not be more than [] from the indicated plan location.

Verticality of VSE elements is more important for some applications than others. Deviations from vertical can ordinarily be 1:100, unless obstructions exist or other difficult drilling conditions are present. Layout and overlap of columns should be considered for these conditions provided they are known to the Contractor. Proper set up is vital, and installation methods exist that can be employed to ensure vertical drilling within tolerance.

The depth of penetration can be controlled either by observing the length of the shaft inserted below a reference point or by subtracting the exposed length of shaft above the reference point from the total shaft length. Care should be taken to note ground surface heave that may affect reference points for measuring penetration depth. The final depth should be recorded on the Daily Production Report.

The installation of VSE columns can result in large settlement of the ground surface, depending on the method of installation of the column, particularly in loose sandy soils. If the specific type of

VSE makes use of grout or other cementitious materials, the pumping of said materials may result in fracturing of the ground and travel of the cementitious materials a considerable distance horizontally, which may lift the ground surface and structures (including buried conduits) nearby. Careful monitoring of the movements of adjacent structures and changes to such structures is necessary in order for the VSE Contractor to know when the procedures are producing ground movements and when immediate corrective action needs to be taken during VSE installation. If soil susceptible to densification is encountered, special care should be taken during VSE installation. Condition surveys are needed for the Engineer to evaluate the effect of the construction process on the serviceability of adjacent structures.

The Contractor's selection of means and methods can be heavily influenced by the handling requirements and procedures for spoils. Spoils may be handled in several different ways. Often the spoils are contained at the ground surface until they are sufficiently cured to be stockpiled and later used for engineered fill.

If operations are interrupted during the execution of a column, re-start the VSE installation appropriately from the stopping point. Provide site access to the Department for observation of the work.

By the end of the business day following each construction shift, submit a Daily Production Report in the approved format. The Contractor's field superintendent shall complete and sign the Daily Production Report at the end of every work shift. The Department will review Daily Production Reports to verify that the work plan and quality management procedures are being properly implemented.

The Department may conduct quality inspections, audits of the Contractor's results and records, and verification sampling and testing on any element of the work to ensure compliance with the VSE Work Plan.

8.6 Proof Testing

Perform proof testing of designated test VSE. Perform proof tests on [_%] of production columns at locations shown on the Plans or designated by the Engineer. Record test data and provide to the Engineer within 24 hours of test completion.

The Contractor will provide a testing plan for proof testing. The Department will provide a test loading schedule with hold times for proof tests and maximum test load (e.g.. 1.5 × Design Load).

9 PERFORMANCE ACCEPTANCE CRITERIA

Not all parameters shown will necessarily be appropriate for every VSE. Include or exclude requirements based on the VSE selected, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and similar factors.

The Department will accept the completed VSE stabilized system based on the effectiveness of the system to reduce the settlement of the embankment to acceptable levels in accordance with the criteria defined in Table 1. The basis for acceptance will be the instrumentation readings obtained from the preproduction verification and production proof load tests.

Table 1: Acceptance Criteria

Parameter	Measurement Procedure	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Bearing Capacity	Static Load Test ASTM D1194 in-p	Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footings	
Penetration depth (in.)	ASTM D1586	Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils	Minimum normalized blow count shall be ____
In-place end bearing and side friction	ASTM D3441- 05	Standard Test Method for Mechanical Cone Penetration Tests (CPT) of Soil	
Axial deflection (in.)	Static Load Test ASTM D1143	Standard Test Method for Columns Under Static Axial Compressive Load	Total creep movement of < __in. between readings and Total deflection at maximum load does not exceed 5% of column diameter or __in.
Settlement	Survey (Laser or GPS) elevation of overlying structure (bridge abutment) or earth structure (embankment or retaining wall). Establish baseline elevation at completion of construction and measure total or differential settlement during warranty term. Use additional instrumentation (i.e., inclinometers, earth pressure cells, strain gages) at critical locations	Survey to measure settlement at specified control points on an annual basis.	Total settlement (differential settlement) not to exceed __in.)
<p><i>Settlement criteria would be appropriate to continuously monitor total or differential settlement during a defined postconstruction performance period, typically several months to a year, so that adjustments can be made as necessary to avoid a major stability failure.</i></p>			

10 MEASUREMENT AND PAYMENT

The following approach is applicable to selection of VSE alternates that use different approaches to measurement. The lump-sum pricing structure is used for VSE and other major items; however, the Agency may choose to measure quantities for certain items for the express purpose of calculating pay adjustments.

The Department will measure the work in accordance with the classifications shown in Table 2:

Table 2: Measurement and Payment Summary

Item		Unit of measure
Mobilization/demobilization		Lump Sum
Pre-Production Test Section (including pre-production QA/QC Testing)		Lump Sum
Production Works VSE Elements	Production VSE works (defined by Owner)	Contingent upon type of VSE
	Add/deduct individual columns or elements	Contingent upon type of VSE
	Add/deduct overlapping column/elements for buttresses, cells, or walls	Contingent upon type of VSE
	Add/deduct mass stabilization	Contingent upon type of VSE

Any VSE settlement values not meeting the acceptance criteria in Table 1 will be cause for rejection of the VSE system. The Contractor will have the option of repairing or replacing the system, or accepting reduced payment for the rejected area at an amount acceptable to the Engineer.

Repair or replace nonconforming VSE elements in a manner acceptable to the Department and at no additional cost, unless the Department elects to accept the VSE at a reduced payment for the specified VSE.

Appendix A

GEOTECH TOOLS
GEO-CONSTRUCTION INFORMATION & TECHNOLOGY SELECTION GUIDANCE FOR GEOTECHNICAL, STRUCTURAL, & PAVEMENT ENGINEERS

SHRP2
STRATEGIC HIGHWAY RESEARCH PROGRAM
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

HOME
SHRP 2 R02 PROJECT BACKGROUND
GEOTECHNICAL DESIGN PROCESS
CATALOG OF TECHNOLOGIES
TECHNOLOGY SELECTION
GLOSSARY
ABBREVIATIONS
FREQUENTLY ASKED QUESTIONS
SUBMIT A COMMENT
SUBMIT TECHNOLOGY-SPECIFIC INFORMATION
RESOURCES
ABOUT THIS WEBSITE

Geotech Tools: Geo-construction Information & Technology Selection Guidance for Geotechnical, Structural, & Pavement Engineers was developed by a SHRP 2 project with the goal of making geotechnical solutions more accessible to public agencies in the United States. This website is a toolkit of geotechnical information to address all phases of decision making from planning to design to construction. Transportation projects can be designed to be built faster, to be less expensive, and/or to last longer with use of these tools. Anyone involved in planning, design, and construction of transportation infrastructure will benefit from the information and resources available here. The information in the system is also applicable to non-transportation works and beyond the United States. We invite your comments and feedback on any aspect of the system. A *Users' Guide to the Information and Guidance System* is available. First time users are encouraged to review the *Users' Guide*.

Geotechnical Design Process	Catalog of Technologies	Technology Selection	Glossary
Prior to technology selection, site-specific conditions and constraints must be identified. The geotechnical design process presents an overview of the considerations involved in evaluating site conditions and implementing a geoconstruction technology.	The Catalog of Technologies provides a listing of all the technologies. For each technology, the following information is available: <ul style="list-style-type: none"> • Technology Fact Sheet • Photos • Case Histories • Design Guidance • QC/QA Procedures • Cost Estimating • Specifications • Bibliography 	Technology Selection is an interactive tool to identify candidate technologies for specific geoconstruction applications using project information and constraints. Final technology selection requires project-specific engineering. Technologies can also be accessed by classification or through a catalog of specific technologies.	This website contains technical terms and industry-specific jargon. A glossary has been compiled to assist in understanding the terminology used throughout this website and in its documents.

Release 1.0

This website and its contents were developed by the SHRP 2 R02 research team. The system is currently in its first release. The applications, information resources, and referenced numerical values were current at the time of the release (November 2012). Continuous updates to the system based on technology developments and research, user comments, and submitted case histories will be made. TRB and the research team make no representation or warranty of any kind ([see disclaimers](#)).

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Last updated November 2012
RELEASE 1.0

Logged in: David White | Last login 20 Mar 2013, 05:09 PM | [update profile](#) (updated 07 Jan 2013)

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Figure 1: Introduction Web Page for SHRP 2 R02 (<http://geotechtools.org/>).

GEOTECH TOOLS
GEO-CONSTRUCTION INFORMATION & TECHNOLOGY SELECTION GUIDANCE FOR GEOTECHNICAL, STRUCTURAL, & PAVEMENT ENGINEERS

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SUBMIT TECHNOLOGY-SPECIFIC INFORMATION
RESOURCES
ABOUT THIS WEBSITE

Technologies by Classification

Geotechnical Solutions for Earthwork Construction

- [Bio-Treatment for Subgrade Stabilization](#)
- [Chemical Stabilization of Subgrades and Bases](#)
- [Excavation and Replacement](#)
- [Geocell Confinement in Pavement Systems](#)
- [Geosynthetic Reinforced Construction Platforms](#)
- [High-Energy Impact Rollers](#)
- [Intelligent Compaction](#)
- [Mechanical Stabilization of Subgrades and Bases](#)
- [Rapid Impact Compaction](#)
- [Traditional Compaction](#)

Geotechnical Solutions for Soft Ground Drainage and Consolidation

- [Electro-Osmosis](#)
- [Excavation and Replacement](#)
- [Hydraulic Fill with Geocomposite and Vacuum Consolidation](#)
- [Prefabricated Vertical Drains and Fill Preloading](#)
- [Vacuum Preloading with and without Prefabricated Vertical Drains](#)

Geotechnical Solutions for Densification of Cohesionless Soils

- [Aggregate Columns](#)
- [Blasting Densification](#)
- [Deep Dynamic Compaction](#)
- [Excavation and Replacement](#)
- [High-Energy Impact Rollers](#)
- [Intelligent Compaction](#)
- [Rapid Impact Compaction](#)
- [Sand Compaction Piles](#)
- [Vibrocompaction](#)

Geotechnical Solutions for Construction of Vertical Support Elements

- [Aggregate Columns](#)
- [Combined Soil Stabilization with Vertical Columns](#)
- [Continuous Flight Auger Piles](#)
- [Deep Mixing Methods](#)
- [Geotextile Encased Columns](#)
- [Jet Grouting](#)
- [Micropiles](#)
- [Sand Compaction Piles](#)
- [Vibro-Concrete Columns](#)

Technologies

- ▶ [Aggregate Columns](#)
- ▶ [Beneficial Reuse of Waste Materials](#)
- ▶ [Bio-Treatment for Subgrade Stabilization](#)
- ▶ [Blasting Densification](#)
- ▶ [Bulk-Infill Grouting](#)
- ▶ [Chemical Grouting/Injection Systems](#)
- ▶ [Chemical Stabilization of Subgrades and Bases](#)
- ▶ [Column-Supported Embankments](#)
- ▶ [Combined Soil Stabilization with Vertical Columns](#)
- ▶ [Compaction Grouting](#)
- ▶ [Continuous Flight Auger Piles](#)
- ▶ [Deep Dynamic Compaction](#)
- ▶ [Deep Mixing Methods](#)
- ▶ [Drilled/Grouted and Hollow Bar Soil Nailing](#)
- ▶ [Electro-Osmosis](#)
- ▶ [Excavation and Replacement](#)
- ▶ [Fiber Reinforcement in Pavement Systems](#)
- ▶ [Geocell Confinement in Pavement Systems](#)
- ▶ [Geosynthetic Reinforced Construction Platforms](#)

Figure 2: List of Current VSE Technologies from SHRP 2 R02 Project.

Project-Specific Technology Selection Results

This output provides documentation of the inputs and resulting potential technologies from the interactive selection system. The application of this system is the responsibility of the user. It is imperative that the responsible engineer understand the potential accuracy limitations of the program results, independently cross checks those results with other methods, and examines the reasonableness of the results with engineering knowledge and experience.

Please refer to the document [User's Guide to the Information and Guidance System](#) for the constraints, intended uses, and limitations of the Technology Selection portion of this website.

General Ground Characteristics

The project and site information input into the selection system is summarized below.

Selected Application: *Construction over unstable soils*
Unstable Soil Condition: *Wet and Weak, Fine Grained Soils*
Depth Below Ground Surface: *10 - 30 ft*

Project-Specific Characteristics

Purpose of Improvement: *Increase Bearing Capacity*
Additional Purpose of Improvement: *Reduce Immediate Settlement*
Project Type: *New Embankment/New Construction*
Site Characteristics: *Constrained, developed sites*
Size of Area to be Improved: *Greater than 50,000 ft² (m²)*
Project Constraints: *Existing Utilities*
Secondary Project Constraints:
Best description of the construction or implementation schedule: *Accelerated schedule*
Unstable soil condition that best describes site: *Unstable soil extends from ground surface to depth requiring improvement*
Are sufficiently thick peat layers present that will affect construction and settlement? *No*
If unstable fine grained soils are present, do the unstable soils have a shear strength less than 500 psf? *No*
Are water bearing sands present in the soil to be improved? *No*
Are any subsurface obstructions present which would cause drilling difficulty, such as cobbles, boulders, buried tree trunks, or construction debris? *No*

Potential Technologies

The potential technologies as a result of the project and site information are shown below.

Technology	Degree of Establishment*	Potential Contribution to SHRP 2 Renewal Objectives		
		Rapid Renewal*	Minimal Disruption*	Long-Lived Facilities*
▶ Aggregate Columns	4	3	1	4
▶ Combined Soil Stabilization with Vertical Columns	2	3	1	4
▶ Continuous Flight Auger Piles	4	4	1	4
▶ Sand Compaction Piles	2	4	1	3
▶ Vibro-Concrete Columns	3	4	1	4

*See the [SHRP 2 R02 Technology Ratings Summary](#) for a legend and description of rating development.

By accessing the technology selection system, the user understands, accepts responsibility for, and agrees to the following conditions and limitations:

- TRB, SHRP 2, and FHWA do not provide user assistance or support for this system.
- There are no expressed or implied warranties as outlined in the disclaimer.
- The user has read [User's Guide to the Information and Guidance System](#) and acknowledges the system's constraints and limitations.

Figure 3: Example #1. Construction Over Unstable Soils—Wet and Weak, Fine-Grained Soils.

Project-Specific Technology Selection Results

This output provides documentation of the inputs and resulting potential technologies from the interactive selection system. The application of this system is the responsibility of the user. It is imperative that the responsible engineer understand the potential accuracy limitations of the program results, independently cross checks those results with other methods, and examines the reasonableness of the results with engineering knowledge and experience.

Please refer to the document [User's Guide to the Information and Guidance System](#) for the constraints, intended uses, and limitations of the Technology Selection portion of this website.

General Ground Characteristics

The project and site information input into the selection system is summarized below.

Selected Application: *Construction over unstable soils*
Unstable Soil Condition: *Saturated, Loose Granular Soils*
Depth Below Ground Surface: *10 - 30 ft*

Project-Specific Characteristics

Purpose of Improvement: *Increase Resistance to Liquefaction*
Additional Purpose of Improvement: *Reduce Immediate Settlement*
Project Type: *Embankment Widening*
Site Characteristics: *Constrained, developed sites*
Size of Area to be Improved: *Greater than 50,000 ft² (m²)*
Project Constraints: *Existing Utilities*
Secondary Project Constraints:
Best description of the construction or implementation schedule: *No schedule or time constraints*
Unstable soil condition that best describes site: *Unstable soil extends from ground surface to depth requiring improvement*
Are sufficiently thick peat layers present that will affect construction and settlement? *No*
If unstable fine grained soils are present, do the unstable soils have a shear strength less than 500 psf? *No*
Are water bearing sands present in the soil to be improved? *Yes*
Are any subsurface obstructions present which would cause drilling difficulty, such as cobbles, boulders, buried tree trunks, or construction debris? *No*

Potential Technologies

The potential technologies as a result of the project and site information are shown below.

Technology	Degree of Establishment*	Potential Contribution to SHRP 2 Renewal Objectives		
		Rapid Renewal*	Minimal Disruption*	Long-Lived Facilities*
▶ Aggregate Columns	4	3	1	4
▶ Combined Soil Stabilization with Vertical Columns	2	3	1	4
▶ Sand Compaction Piles	2	4	1	3

*See the [SHRP 2 R02 Technology Ratings Summary](#) for a legend and description of rating development.

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Figure 4: Example #2. Construction Over Unstable Soils—Saturated, Loose Granular Soils (<http://geotechtools.org/>).

Appendix B

To develop a specification, the project conditions and VSE technologies must be narrowed and compatible. The SHRP 2 R02 selection and guidance system was used to demonstrate the process of narrowing VSE to meet the desired project conditions. Table 3 summarizes the VSE technologies, selection criteria, and suggested system level performance criteria.

Table 3: Summary of VSE analysis and suggested system level performance criteria

Attributes	Example 1: Fine-grained Soils	Example 2: Loose Granular Soils
Application	New embankment over unstable soils	
Ground Conditions	Wet and Weak, fine-grained soils 1–30 ft deep	Saturated, loose granular sands, 10–30 ft deep
Purpose	Reduce immediate settlement.	Increase liquefaction resistance and reduce immediate settlement.
Possible VSE technologies	Aggregate columns, Combine soil stabilization with vertical columns, Continuous flight auger piles, and vibro-concrete columns	Aggregate columns, Combine soil stabilization with vertical columns, and sand compaction piles
System level performance criteria to be included with specification	Minimum average axial (allowable) bearing pressure for individual, unit cell, or group of VSE elements, and/or Maximum total settlement and differential settlement via instrumentation.	Factor of safety against liquefaction, coupled with approved design method and testing results, and Achievement of minimum CPT or SPT values between VSE elements to verify soil improvement/densification.

HOT MIX ASPHALT PAVEMENT

PERFORMANCE SPECIFICATION

(DESIGN-BUILD)

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for implementation under a design-build (DB) delivery approach.

Users should note that this specification is part of a family of pavement specifications drafted with a specific delivery approach in mind; that is, the recommended performance parameters and material and construction requirements included in this specification are intrinsically linked to the roles and responsibilities and risk allocation deemed appropriate for a DB project. These DB conventions include the following:

- *Selection of the pavement type by the Agency (or by Contractor if life-cycle cost, LCC, analysis is provided at bid);*
- *Structural design by the Contractor;*
- *Mix design by the Contractor (but usually as per Agency guidelines or standards);*
- *Quality management by the Contractor (design and construction);*
- *Verification testing and acceptance at the end of construction by the Agency; and*
- *Postconstruction maintenance by the Agency.*

Specification Objectives

Absent a warranty provision, the Agency's acceptance of the work at the end of construction will release the Contractor from further responsibility for performance. The Agency's confidence in the ability of the parameters measured at the end of construction to predict future performance will therefore control the extent to which an Agency can relax its standard construction requirements in the interest of rapid renewal. The goal, therefore, of this performance specification is not to monitor and evaluate Contractor performance over time but to

- *Focus on material properties and construction practices deemed to have the most effect on long-term performance;*
- *Use quality management and acceptance criteria that more closely correlate to performance (mechanistic structural and mix design properties); and*
- *Incorporate financial incentives/disincentives to promote enhanced quality.*

In addition to these performance goals, this specification attempts to incorporate, to the extent possible under the DB delivery approach, concepts that will promote the goals of rapid renewal (i.e., accelerate construction, minimize disruption, and achieve a long-lasting pavement). To this end, prescriptive requirements have been relaxed if (1) placing such requirements under the Contractor's control could help save time and/or minimize disruption and (2) measurement of the performance parameters at the end of construction will provide adequate assurance that the condition the prescriptive element was intended to prevent did not, and ideally, will not, occur.

Using This Guide Specification

The requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a comprehensive example of the possible performance requirements that could be used to promote the construction of long-lasting pavements under the DB delivery approach. From this menu of requirements, users should select those that best fit the needs of their particular project or program, bearing in

mind that certain barriers or gaps may preclude the immediate implementation of all of the proposed parameters and test methods. For example, a performance measure may be technically valid but difficult to implement because of a need for specialized equipment or expertise, a lack of standardized test methods, absence of historical data for calibration of design or predictive models, or similar obstacles.

To help identify and address such gaps, consider each performance requirement in the context of the following questions:

- *Can a particular parameter be measured and evaluated using existing technology?*
- *In comparison with other testing techniques (or the use of method specifications), is the measurement and testing economical? Is a major capital investment required?*
- *Does the measurement technique require advanced training or a high skill level from technicians?*
- *Would a typical contractor know how to control its materials and processes to meet a particular performance standard?*
- *Is there sufficient experience or historical data to properly calibrate design or predictive models?*

Although specific answers to those questions may vary by Agency, they generally point to three tiers of performance specifications for asphalt pavement, ranging from minimal departure from current practice to a substantial shift in practice and organizational culture that would require technological advancement and improved understanding of long-term material behavior.

- **Tier 1** requirements do not require a substantial departure from current practice, yet place more emphasis on properties known to affect the performance of asphalt pavements, including volumetric properties such as air voids, asphalt content, and voids in mineral aggregate (VMA), and as-constructed properties such as in-place density, joint compaction, and thickness.
- **Tier 2** requirements encourage use of more rapid and continuous nondestructive evaluation methods for acceptance purposes, such as ground-penetrating radar (GPR), which, although currently available, would require capital investment and/or further advancement to incorporate into a specification.

As an option under Tier 2 (2B), Agencies may wish to prequalify or screen the Contractor's mix design using mechanistic, performance-based properties such as dynamic modulus, rutting resistance, and fatigue performance.

- **Tier 3** requirements assume improved understanding of long-term material behavior as well as advances in technology, particularly in the area of nondestructive testing (NDT), which could allow for the inclusion of acceptance parameters, such as stiffness, that better reflect the future performance and design life of the pavement.

In general, the three tiers represent a progression toward parameters and test methods that are more indicative of in-place pavement performance. When selecting the appropriate tier for a given project or program, users should balance project needs against available technology and resources, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and industry's appetite for assuming performance risk.

To denote these tiers, the numbers 1, 2, and/or 3 will appear in the right-hand margin beside a particular requirement, as applicable. If no such number appears, consider the requirement to be common to all tiers. Commentary is also included within the specification (as indicated with italic typeface) to provide additional guidance for extracting unnecessary requirements and for refining others based on available choices or options.

While commentary text is not intended to serve as specification requirements, users may draw on the information provided as a basis for further modification or development of the specification.

In implementing this specification, Agencies are further encouraged to require the Contractor to develop and adhere to a comprehensive Quality Management Plan (QMP). A sample general provision addressing the roles and responsibilities for quality management is included within the family of guide specifications developed under the SHRP 2 R07 project.

Finally, note that the term “Contractor” as used in this document should be interpreted as that entity given single-point responsibility for both the design and construction of the work and is thus synonymous to “Design-Builder” and “Design-Build Team.”

1 DESCRIPTION

Design and construct an HMA pavement consisting of one or more courses of asphalt mixture on a prepared foundation.

Provide a Quality Management Plan (QMP) and perform all sampling, testing, and inspection necessary to control and assure the quality of the work in accordance with the QMP. The Department, acting in an oversight role, will conduct verification sampling and testing and independent assurance.

The Contractor’s preparation of a formal QMP is an integral component of this performance specification. A QMP requirement allows the Agency to reduce prescriptive requirements in exchange for the Contractor’s development and adherence to a detailed plan of how it intends to complete the work and meet the performance requirements.

Within the limits of the Contract and applicable local, State, and Federal rules and regulations, the Contractor is encouraged to use innovative techniques and materials to meet the specified performance requirements.

Additional description may be added to this section to highlight certain project goals or performance requirements, particularly if new to the Agency or local contracting community.

2 STANDARDS AND REFERENCES

This Standards and References section serves to identify the design and other procedural manuals and standards (e.g., AASHTO, FHWA, and Agency) that the Contractor should follow, particularly when performing the project design work. Note that such documents may contain prescriptive requirements that could limit the Contractor’s flexibility and ability to innovate. Therefore, when referencing standards in Table 1, balance the need for conformance with the Agency’s existing facilities and processes [consider, for example, tie-ins to existing facilities, right-of-way (ROW) requirements, environmental issues] against the opportunity for innovation.

Likewise, materials standards, test methods, and similar reference documents cited throughout the specification should be obtained and reviewed to ensure that they do not inadvertently impose undesired restrictions on the Contractor, in which case the specifier should identify exceptions to the standard.

2.1 Standards

Unless otherwise stipulated in this specification or as approved by the Department, design and construct the pavement in accordance with this performance specification and the relevant requirements of the standards listed, by order of priority, in Table 1.

If the standards conflict, adhere to the standard with the highest priority. If the standards contain any unresolved ambiguity, obtain clarification from the Department prior to proceeding with design or construction.

Use the most current version of each listed standard as of the initial publication date of the RFP unless modified by addendum or change order.

Table 1: Standards for Pavements

Priority	Author or Agency	Title
1		
2		
3		

2.2 References

This subsection may be included if the Agency wishes to identify nonmandatory references that could assist the Contractor's efforts.

The Contractor may consult the references listed in Table 2 for supplementary guidance in designing and constructing the pavement system. These references have no established order of precedence and are not intended to be all-inclusive.

Table 2: References for Pavements

Author or Agency	Title
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3 REQUIREMENTS

3.1 Design

Perform all pavement engineering activities, including, but not limited to, the following:

List will vary based on how much initial design work was completed by the Agency.

- Pavement/geotechnical investigation
- Pavement design and analysis
- Material selection
- HMA mixture design

The Agency may also choose to allow the Contractor to select the pavement type during the bidding phase. In this case, the Agency should generally require the Contractor to follow a specified life-cycle cost (LCC) analysis procedure to demonstrate adequate pavement life and LCC for the pavement type designed. If implemented under an alternative bid provision, the Agency could use an “A+C” bid model, in which “A” represents the base bid for the selected alternative and “C” represents an LCC bid adjustment factor.

All pavement engineering activities shall be directed, supervised, signed, and sealed by a Professional Engineer, licensed in the State of [--] with a minimum of [5] years experience in pavement engineering.

3.1.1 Pavement Investigation

Perform and document all geotechnical investigations, testing, research, and analyses necessary to determine and understand the existing surface and subsurface conditions.

Prepare and submit geotechnical engineering reports documenting the assumptions, conditions, and results of the investigations and analyses, including the following:

- Geology of the project area;
- Results from field investigations and laboratory testing, including a discussion of how these results affect the design of the pavement;
- Design and construction parameters resulting from the geotechnical investigation and analyses; and
- Boring logs, laboratory results, calculations, and analyses that support design decisions.

3.1.2 Design Criteria

Table 3: Design Criteria

Design Criteria	Requirement
Structural Design Life	
Design Traffic (18-kip ESALS)	
Shoulder Type	
Drainage	Provide a free-draining pavement that will not compromise surface or subsurface drainage of existing pavement to remain in place.
Tie-ins	Minimize pavement-to-structure transition deviations.

Modify Table 3 to include all additional requirements that could affect the design of the pavement system. For example,

- *Design Reliability;*
- *Required Ride Quality (IRI);*
- *Subgrade requirements (e.g., minimum support values, improvement strategies);*
- *Future expansion (e.g., “Design and construction must feasibly allow for future economical expansion through addition of lanes and other elements.”); and*
- *Different design criteria for mainlines and ramps versus auxiliary lanes and shoulders.*

3.1.3 Design Documentation

In exchange for providing the Contractor flexibility with regard to design and construction decisions, the Agency should require the Contractor to fully document and report all design assumptions and decisions.

Prepare and submit pavement design reports that include the following items, as a minimum:

- All pertinent design inputs, such as traffic data, soils characteristics, characteristics of the proposed construction materials, environmental conditions, and pavement design life;
- Site plan showing the limits of the roadway covered by the design report;
- Discussion of site conditions that might influence the design and performance of the pavement;
- Discussion of the inputs used to arrive at design recommendations and the rationale used in selecting the recommended design strategy (where applicable, life-cycle management analysis, including the periods for resurfacing, reconstruction, and other rehabilitation measures);
- Pavement design details, including structural layer materials and thicknesses, and typical cross-section drawings;
- Comprehensive construction specifications sufficiently detailed to describe the process or end-result requirements; and
- Other considerations used in developing the pavement design(s), including subgrade preparation and stabilization procedures as applicable.

3.2 Material Requirements

To prepare the Materials section, one approach would be to refer to the applicable sections in the Agency's Standard Specifications. The Standard Specifications typically contain explicit requirements restricting materials selection based on the Agency's past experience. In this manner, the Agency can be confident of receiving a product similar to what it has always received. A possible drawback to this approach is the lost opportunity associated with using alternative materials or sources that could result in superior performance or time or cost savings.

It is therefore important to carefully consider the extent to which the specification needs to prescribe basic material properties. If the end-result parameters included in the specification will not in and of themselves assure the Agency that the constructed pavement will meet the desired short-term and long-term performance expectations, more prescriptive materials requirements may be necessary. (Note that this strategy is in contrast to the increased latitude that should be given to the Contractor under a long-term warranty or operations and maintenance agreement, in which case the Contractor would be assuming more risk for performance over time and would thus be more inclined to investigate other materials options that, despite higher initial costs, may prove to be more economical when viewed over the duration of the Contractor's performance responsibility.)

3.2.1 Component Materials

Evaluate material quality before and during construction in accordance with the approved QMP. Reject all nonconforming materials and replace with suitable materials.

- A. Asphalt Binder. Provide asphalt binder as specified in *[Standard Specification XXX]*.

Asphalt binder properties have a great influence on low-temperature cracking, one of the major failure modes in asphalt pavement. Specifying asphalt binder with adequate low-temperature properties should reduce thermal cracking. Likewise, requiring high stiffness (G) at high service temperatures will help reduce rutting and shoving.*

If not already a part of the Agency's standard acceptance program, consider allowing prequalification of suppliers and acceptance by certification to facilitate rapid renewal.

If the binder choice is left to the Contractor, consider requiring rutting resistance testing as described in Section 3.2.2.

- B. Aggregate. Provide aggregate as specified in *[Standard Specification XXX]*.

Aggregate properties can greatly influence the performance of the in-place pavement, particularly with regard to safety (friction), durability (cracking), and rutting resistance. Commonly measured aggregate properties include

- *Course aggregate angularity,*
- *Fine aggregate angularity,*
- *Hardness,*
- *Soundness,*
- *Polishing resistance, and*
- *Deleterious materials.*

If not already a part of the Agency's standard acceptance program, consider allowing prequalification of aggregate sources. In keeping with the goals of rapid renewal, use of approved sources can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations.

3.2.2 Mix Design

Develop and submit for the Department's review a mix design that meets the requirements of *[Standard Specification XXX]*.

Alternatively, given the growing interest in mechanistic pavement design methods, an Agency may wish to consider prequalifying or screening mixtures based on the rutting and fatigue properties identified in Table 4.

Evaluating such properties at both the mix design stage and as part of verification and acceptance testing would be most applicable to high-profile/high-volume roadways, for which the cost and road user impact associated with future repairs and rehabilitation would outweigh the cost and inconvenience of doing such nontraditional testing.

Table 4: Mixture Performance Requirements

Design Parameter	Test Method	Value
Dynamic Modulus, E^* ⁽¹⁾	AASHTO TP 62	
<p>1. E^* is a key material input for flexible pavement structural design in the Mechanistic-Empirical Pavement Design Guide (MEPDG), and has been shown to have potential as a simple performance test for rutting and fatigue cracking. To use E^* to screen mix designs, one could use the Quality Related Specification and Software described in NCHRP Report 704, in the Interactive Mix and Structure Design mode, to establish an appropriate E^* value for a defined rutting failure criterion that corresponds to a project’s traffic, environmental, and structural conditions. The mix can then be designed and changed as necessary to meet the desired distress criteria. (Alternatively, the structural design, particularly under a design-build project, could also be changed but, generally, enhancing the quality of the HMA mix would be the most practical way to ensure compliance.)</p>		
Rutting Resistance ⁽²⁾	Wheel-Track Testing ⁽³⁾ <ul style="list-style-type: none"> • AASHTO TP63, Asphalt Pavement Analyzer (APA) • AASHTO T324, Hamburg • French Rut Tester 	
	AASHTO TP79, Flow Number Test using the Asphalt Mixture Performance Tester (AMPT) ⁽⁴⁾	Criteria remain under development.
<p>2. Evaluating rutting resistance will help prevent the placement of rut-susceptible mixtures, thus improving the likelihood of having a mix that performs well in the field. Better test methods, which are more indicative of performance, are needed before measurement of this parameter can become standard practice.</p> <p>3. Certain Agencies use wheel-track testing as part of the mix design process (e.g., APA used in Georgia; Hamburg used in Texas). However, wheel-track testers have limitations in scaling results to actual conditions (size, geometry). The tests will eliminate the worst offenders but do not measure any fundamental material parameter and are not necessarily indicative of performance.</p> <p>4. Flow number testing using the AMPT shows promise as being more predictive of performance than wheel-track testers. However, formal test criteria (e.g., confining stress, aging) are needed before flow number testing can be used for acceptance purposes. Several promising approaches to flow number testing have been used by researchers since the AMPT’s development in NCHRP Projects 9-19 and 9-29. The FHWA Asphalt Mixture and Construction Expert Task Group (ETG) initiated a study to evaluate flow number procedures and criteria to determine which warrant further development and implementation. Dr. Haleh Azari of the AASHTO Advanced Pavement Research Laboratory (AAPRL) is working to help standardize the flow number test protocols and has presented preliminary recommendations.</p>		
Fatigue Performance ⁽⁵⁾	AASHTO TP8, Beam Fatigue ⁽⁶⁾	
	Continuum Damage Based Fatigue Testing using the AMPT ⁽⁷⁾	Criteria remain under development.
<p>5. Evaluating fatigue performance is important, particularly for high-modulus mixtures, to mitigate fatigue-related problems of the in-place pavement. Fatigue testing would also provide a balance to the rutting test.</p> <p>6. Although beam fatigue testing is the method traditionally used to evaluate fatigue performance, most labs are not equipped to perform this testing (equipment is expensive). Additional drawbacks to this measurement strategy include the time needed to conduct the test and the poorly understood relationship between lab results and field performance (i.e., measured strain values).</p> <p>7. The testing protocol for the simplified viscoelastic continuum damage (S-VECD) model has been developed in the AASHTO format and is currently under review by the FHWA’s Asphalt Mixture and Construction ETG and the AASHTO Subcommittee on Materials. The AMPT-based control software for the S-VECD testing and analysis software are available from one of the two AMPT manufacturers. Results from the S-VECD testing can be obtained in 2 days, which is</p>		

Design Parameter	Test Method	Value
<i>much quicker than traditional beam fatigue testing.</i>		

3.3 Construction Requirements

The Agency’s confidence in its ability to predict future performance at the end of construction will control the degree to which an Agency can relax its standard construction requirements. Given today’s technology and test methods, substantial departure from standard practices may be unlikely. However, should advances in technology (such as better forecasting models from mechanistic design practices and advancements in nondestructive testing) increase the level of confidence in end-result parameters, it may then be possible to eliminate certain prescriptive requirements in the interest of rapid renewal.

In exchange for providing the Contractor some flexibility with regard to construction decisions, the Agency should require the Contractor to describe in its QMP how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, mixing, hauling, spreading, finishing, and compaction of HMA) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

The Contractor is responsible for providing all management, professional, and technical services and labor, materials, and equipment necessary to construct the pavement.

Submit all changes to the design documents implemented during construction to the Department for review purposes.

4 QUALITY MANAGEMENT PROGRAM

This specification holds the Contractor responsible for performing tests used strictly for process control as well as tests that may be used in the Agency’s acceptance process. The Agency in turn should perform verification testing of select parameters. Although this approach may represent a departure from the traditional manner in which an Agency allocates responsibility for various quality management functions, it is consistent with the degree of risk assumed by the Contractor for performance of the work. Greater oversight by Agency personnel may add time to the project and conflict with the goals of rapid renewal.

4.1 Contractor’s Responsibility for Quality Management

The requirements included in this Section 4.1 assume the Contract includes a separate provision related to development and implementation of a QMP that defines general requirements related to the Contractor’s quality management personnel and organizational structure, documentation and reporting requirements, and procedures related to nonconforming work, corrective action, and similar matters. If such requirements are not otherwise addressed in the Contract’s General Conditions, note that a sample general provision addressing quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Note that the Agency should review the Contractor’s QMP submittal to ensure it complies with these and other Contract requirements. If the Agency disagrees with elements of the QMP, it should raise these issues with the Contractor and seek resolution. The Agency should not

“approve” the Contractor’s QMP, as approval could be construed as assuming responsibility for the plan’s content.

Assume responsibility for the quality of the work, including work performed or provided by subcontractors, suppliers, and vendors.

Perform all quality management activities described in *[the Agency’s General Provision for Quality Management]*, including the additional requirements specific to HMA pavement construction as defined in this Section 4.1.

4.1.1 Contractor Testing

The approach taken in this section is to establish the minimum testing requirements that the Contractor’s QMP must contain related to asphalt pavement construction. The intent is to provide the Contractor some latitude with respect to developing a project-specific QMP while also ensuring that the Agency’s minimum standards are met. These minimum requirements can also serve as guidance to bidders as they prepare a cost proposal for the work.

A possible disadvantage to this approach is that the Contractor may view these requirements not as a minimum but as all that is necessary to provide adequate quality management. If a best-value procurement process will be used to award the Contract, the Agency should consider including the proposers’ project-specific QMP, or relevant portions thereof, as part of the selection criteria.

As part of the QMP to be prepared, submitted, and implemented in accordance with *[the Agency’s General Provision for Quality Management]*, include, as a minimum, the sampling and testing requirements specified in Table 5, as well as all other inspections and tests the Contractor deems necessary to ensure the quality of the finished pavement.

Keep the Department apprised of upcoming testing activities to allow the Department to schedule the verification and independent assurance activities described in Section 4.2. If verified as described in Section 4.2.1, the Department may use the Contractor’s test results for acceptance.

Various QMP requirements are included in Table 5 for the specifier’s consideration, not all of which will necessarily be appropriate or beneficial for a given project or program. Agencies may wish to include or exclude requirements based on the capabilities of local industry (including materials suppliers and testing firms), the project’s needs and goals, associated costs, and similar factors. Commentary included within the table itself provides rationale for including certain parameters. Test methods and frequencies are provided for illustrative purposes only and should be modified based on Agency practices or project requirements.

Table 5: Minimum QMP Requirements for Asphalt Pavement

Parameter	Test Method/Device	Frequency
A. Materials		
Aggregate ⁽¹⁾		
Course aggregate angularity (% of Fractured Faces) ⁽²⁾	ASTM D5821	
Fine aggregate angularity ⁽²⁾	AASHTO T304	
Flat and elongated particles ⁽³⁾	ASTM D4791	
Soundness ⁽⁴⁾	AASHTO T103,	

Parameter	Test Method/Device	Frequency
Polishing Resistance ⁽⁵⁾	AASHTO T104	
Abrasion Resistance ⁽⁵⁾	ASTM D3319	
Sand Equivalent ⁽⁶⁾	AASHTO T96	
Clay Lumps and Friable Particles ⁽⁶⁾	AASHTO T176	
Asphalt Binder		1/binder production lot/PG grade
Additives	Certification	1 per project

1. *For higher-risk projects, the Contractor should sample and test aggregate during construction on a per Lot basis. Higher risks include more severe conditions [high traffic volume, weather extremes (hot, cold, wet)], high road user impacts, public sensitivity, or longer expected service life.*
For lower-risk projects, consider allowing prequalification of aggregate sources. In keeping with the goals of rapid renewal, use of approved sources can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations.
2. *Angularity is desirable for HMA to achieve better particle-to-particle interlock for improved rutting resistance.*
3. *Flat and elongated particles can be problematic in HMA because they tend to reorient and break under compaction, resulting in decreased strength.*
4. *To minimize premature pavement distress, aggregates must be resistant to breakdown from weathering (alternate wetting/drying and freezing/thawing cycles). The freezing and thawing in water soundness test (AASHTO T103) more accurately simulates field conditions, but the test requires a longer period of time to conduct than the quicker sodium sulfate test (AASHTO T104).*
5. *Aggregates not adequately resistant to polishing and abrasion may result in premature structural failure and/or a loss of skid resistance.*
6. *The presence of soft particles, clay lumps, excess dust, and other deleterious matter can affect performance by quickly degrading, resulting in a loss of structural support and poor binder/aggregate bonding.*

B. Mixture Production

Gradation ⁽⁷⁾	AASHTO T27 & T11	1 per Sublot
Laboratory Air Voids ⁽⁸⁾	AASHTO T312	1 per Sublot
Asphalt Content ⁽⁹⁾	AASHTO T308	1 per Sublot
Voids in Mineral Aggregate (VMA) ⁽¹⁰⁾	AASHTO R35	1 per Sublot
Moisture Damage ⁽¹¹⁾	AASHTO T283	1 per Lot
Dynamic Modulus, E* ⁽¹²⁾	AASHTO TP 62	1 per Lot
Rutting Resistance (Flow Number) ⁽¹³⁾	AASHTO TP79	1 per Lot
Fatigue ⁽¹⁴⁾	Continuum Damage	1 per Lot

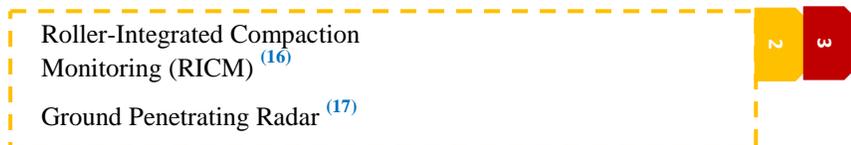
7. *For Contractors, gradation is an important property to control mixture production. However, as gradation is not directly indicative of performance (it indirectly controls voids), it should not be used for verification or acceptance purposes in a performance specification.*
8. *The performance of asphalt pavement is closely related to air voids (along with effective asphalt content). Excessive air void content, whether a mix design or a compaction problem, increases the likelihood of rutting and moisture damage.*
9. *Effective asphalt content (i.e., asphalt not absorbed into aggregate, as calculated based on asphalt content and aggregate bulk specific gravity) influences air voids and VMA and is thus very closely related to performance. Asphalt content should be high enough to prevent excessive fatigue cracking, while not being so high as to increase the likelihood of bleeding and rutting.*

Parameter	Test Method/Device	Frequency
10. VMA is a measure of the voids in between the mineral aggregate particles in a compacted mixture. It is determined from the bulk density of the sample, the bulk gravity of the aggregate, and the mixture's asphalt content. VMA is related to asphalt performance (although to a lesser extent than air voids and asphalt content).		
11. Although moisture damage is highly related to asphalt performance, the standard test method—tensile strength ratio (TSR) of soaked strength to dry strength—does not provide a straightforward relationship to performance and is fairly involved and time-consuming.		
12. Dynamic modulus, a key input in pavement structural design, will increase in importance as more Agencies adopt mechanistic design methods. Some questions remain regarding test variability and how specification limits should be set. The test is also somewhat complicated and time-consuming to perform.		
13. Research is ongoing to develop a test method and protocol that can be used to predict rutting. Flow number testing using the AMPT shows promise as being more predictive of performance than wheel-track testers. However, formal test criteria (e.g., confining stress, aging) are needed before flow number testing can be used for acceptance purposes. The FHWA Asphalt Mixture and Construction ETG initiated a study to evaluate flow number procedures and criteria to determine which warrant further development and implementation. Dr. Haleh Azari of the AASHTO Advanced Pavement Research Laboratory (AAPRL) is working to help standardize the flow number test protocols and has presented preliminary recommendations. It may take time for industry to be receptive to performing such testing as part of their mix design and quality management responsibilities. In time, E* and flow number may supplant use of other properties, such as asphalt content and moisture damage, that only indirectly influence mechanical properties.		
14. The testing protocol for the simplified viscoelastic continuum damage (S-VECD) model has been developed in the AASHTO format and is currently under review by the FHWA's Asphalt Mixture and Construction ETG and the AASHTO Subcommittee on Materials. The AMPT-based control software for the S-VECD testing and analysis software are available from one of the two AMPT manufacturers. Results from the S-VECD testing can be obtained in 2 days, which is much quicker than traditional beam fatigue testing.		

C. Installed Product

Compaction (in-place air voids) ⁽¹⁵⁾

Density Gauge



Joint Compaction ⁽¹⁸⁾

Density Gauge



Smoothness/Ride Quality ⁽¹⁹⁾

Straightedge

Inertial Profiler

15. Many pavement distresses (e.g., cracking, rutting, or raveling) can be related to inadequate compaction. Compaction is therefore particularly important for DBB and DB contracts that have no postconstruction performance requirements.
16. Roller-integrated compaction monitoring (or "intelligent" compaction) is a process that includes vibratory rollers equipped with a measurement control system that can automatically record compaction parameters in response to material stiffness measured during the compaction process. The roller is equipped with a documentation system that allows for continuous recording of the roller location for corresponding stiffness-related output using global positioning systems (GPS). Although a strong correlation between RICM machine values and density has not yet been established, Contractors may find the real-time temperature and pass coverage output from the rollers to be very valuable for process control of compaction operations to accelerate construction and reduce rework. If the Contractor does provide coverage maps, consider relaxing the frequency requirements for core and density gauge testing.
17. Although still primarily used as a forensic tool, GPR could be used as an alternative or supplement to traditional core or density gauge tests if a correlation could be established between GPR-measured values of dielectric constant and density tests performed on cores.

Parameter	Test Method/Device	Frequency
18. Proper joint compaction is essential to ensuring the durability of joints. Requiring Contractors to test and monitor joint compaction as part of their quality management responsibilities should motivate them to pay more attention to joint compaction.		
19. Ride quality (International Roughness Index—IRI) has traditionally been measured by Agency personnel for acceptance purposes; however, as Contractors assume more responsibility for quality management and performance, they may also find it beneficial to invest in inertial profilers. At a minimum, most Contractors will take straightedge measurements during construction to monitor smoothness.		

4.1.2 Production and Placement Procedures

In exchange for eliminating prescriptive requirements related to materials selection and construction methods, the Agency should require the Contractor to describe how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the mixing, hauling, spreading, finishing, and compaction of asphalt) will affect the in-place properties and performance of the work, and that the Contractor has planned the work and allocated its resources accordingly.

Include descriptions of the following in the QMP:

1. Certified mixing plant requirements, including calibration procedures for all meters, scales, and other measuring and recording devices, and procedures related to stockpile management, binder storage and handling, RAP processing and introduction to the plant (if applicable), and procedures related to mixing, mixture storage (if applicable), and haul unit loading.

Ensure that the Contractor has an adequate plan for checking the consistency of the produced mix and for correcting deficiencies or inconsistencies in the produced and delivered mix.

2. Laboratory location, testing equipment, procedures for calibration, and training standards for personnel (e.g., National Institute for Certification in Engineering Technologies—NICET— or local standard).
3. Paving plan, including general staging and sequencing of operations.

When reviewing the Contractor's paving plan, consider the following:

- *Is the sequence compatible with the maintenance of traffic (MOT)?*
- *Can the Contractor's equipment accommodate the proposed sequence of operations (consider size and number of equipment)?*

4. Asphalt placement operations, including hauling, spreading, finishing, and compacting.

When reviewing this portion of the Contractor's QMP, consider the following:

- *Is the proposed equipment appropriate for the project?*
 - *Is hauling equipment appropriate given the likely haul distance, haul time, and weather conditions?*
 - *Are adequate delivery vehicles available to match the production rate of the plant and the planned forward speed of the paver?*

- *Is equipment appropriate for spreading material in front of the paver?*
 - *Will the Contractor's proposed procedures minimize segregation?*
 - *Will the Contractor's proposed procedures ensure ride quality?*
5. Methods to control alignment and profile.
- *Has the Contractor developed a procedure for control of the pavement profile?*
 - *Has the Contractor established a procedure for checking the finished grade or profile of the intermediate layers or milled surface?*
6. Joint installation procedures.
- *Does the Contractor have a plan for constructing quality longitudinal and transverse joints?*
 - *Does the plan address procedures related to end-of-day paving and joints?*
7. Procedures related to night work (as applicable).
8. Contingency plan for inclement weather.

Note that this list will vary based on how much freedom the Agency allows the Contractor with respect to the construction requirements in Section 3.3.

4.2 Department's Quality Management Responsibilities

The Department may conduct quality inspections, audits of the Contractor's results and records, and verification sampling and testing on any element of the work to ensure compliance with the QMP and the Contract requirements.

4.2.1 Verification Sampling and Testing

Even though the Contractor may assume more responsibility for inspection and testing under a performance specification, this does not relieve the Agency of its responsibility to perform some level of independent sampling and verification testing to meet the intent of 23 CFR 637. Verification testing should be performed to validate any Contractor testing used in the Agency's acceptance decision. The Agency may also wish to verify certain material or mixture parameters that could identify possible performance issues that would not otherwise be detected through end-result acceptance testing.

The Department will perform verification testing as described in Table 6 to validate the Contractor's test results.

The Department will notify the Contractor before sampling so the Contractor can observe.

The Department will sample randomly at locations independent of the Contractor's sampling and testing. In all cases, the Department will conduct the verification tests in a separate laboratory and with separate equipment from the Contractor's tests.

Table 6: Department Verification Testing

Parameter ⁽¹⁾	Test Method ⁽¹⁾	Sampling Location	Frequency ⁽²⁾
Materials			
Binder	Agency test		
Aggregate ⁽³⁾			
Mixture			
Asphalt Content	AASHTO T308		
Air Voids	AASHTO T312		
VMA ⁽⁴⁾	AASHTO R35		
Dynamic Modulus, E* ⁽⁵⁾	AASHTO TP 62		
Rutting (Flow Number) ⁽⁶⁾	AASHTO TP79		
Fatigue ⁽⁷⁾	S-VECD		
Installed Product			
Compaction ⁽⁸⁾	AASHTO T312	random (x,y)	
Joint Compaction ⁽⁸⁾	AASHTO T312	random (x,y)	

- Parameters and test methods are provided for illustrative purposes only and should be modified based on Agency practices or project requirements. If an Agency has its own standard test methods for measuring these properties, specify those methods instead.
- Frequency should be based on project-specific conditions and ideally should provide the ability to identify statistically valid differences between Agency and Contractor test results. A minimum Agency rate of 10% of the testing rate of the Contractor has been used as a rule of thumb.
- For higher-risk projects, Agencies should verify aggregate test results. Higher risks include more severe conditions [high traffic volume, weather extremes (hot, cold, wet)], high road user impacts, public sensitivity, or longer expected service life.
- There is no universal understanding of VMA as a property that influences performance, and therefore several Agencies do not measure it for verification or acceptance purposes.
- Dynamic modulus, a key input in pavement structural design, will increase in importance as more Agencies adopt mechanistic design methods. Some questions remain regarding test variability and how specification limits should be set. The test is also somewhat complicated and time-consuming to perform.
- Flow number testing using the AMPT shows promise as being more predictive of performance than wheel-track testers. However, formal test criteria (e.g., confining stress, aging) are needed before flow number testing can be used for acceptance purposes. Several promising approaches to flow number testing have been used by researchers since the AMPT's development in NCHRP Projects 9-19 and 9-29. The FHWA's Asphalt Mixture and Construction ETG initiated a study to evaluate flow number procedures and criteria to determine which warrant further development and implementation. Dr. Haleh Azari of the AASHTO Advanced Pavement Research Laboratory (AAPRL) is working to help standardize the flow number test protocols and has presented preliminary recommendations.
- The testing protocol for the simplified viscoelastic continuum damage (S-VECD) model has been developed in the AASHTO format and is currently under review by the FHWA's Asphalt Mixture and Construction ETG and the AASHTO Subcommittee on Materials. The AMPT-based control software for the S-VECD testing and analysis software are available from one of the two AMPT manufacturers. Results from the S-VECD testing can be obtained in 2 days, which is much quicker than traditional beam fatigue testing.
- Destructive core samples provide the most accurate way to measure compaction, though they are not necessarily conducive to rapid construction/testing. If the Contractor provides RICM coverage maps for breakdown or intermediate roller operations, including surface temperature information, it may be possible to reduce the frequency of coring or to perform targeted sampling.

The Department may increase the frequency of verification testing at start-up or as necessary to validate the quality of the materials. The Department may reduce the frequency based on a history of satisfactory Contractor or material performance.

If verification tests indicate conformance with the specifications, no further action is required. If verification tests indicate nonconformance with the specifications, the Department and Contractor will jointly investigate the testing discrepancies. The investigation may include additional testing as well as review and observation of both the Department's and Contractor's sampling and testing procedures and equipment. Both parties will document all investigative work.

When comparing Agency and Contractor test results, it is important to compare both the variances and the means. The tests most often used are the F-test (comparison of variances) and the t-test (comparison of means), which are used together.

4.2.2 Independent Assurance Testing

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing activities are being performed by qualified personnel using proper procedures and properly functioning and calibrated equipment. The Department will perform IA testing using personnel other than those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor's sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

4.3 Conflict Resolution

If a dispute between some aspect of the Contractor's and the Department's testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third-party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third-party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [\[Standard Specification Section XXX\]](#).

5 ACCEPTANCE REQUIREMENTS

Acceptance requirements provide a method for determining the degree to which the as-constructed pavement meets the specification and for determining appropriate payment.

Acceptance is based on the measurement of properties that control the quality and performance of the pavement.

The quality acceptance limits presented in this section assume use of a percent within limits (PWL) approach. The PWL method encourages Contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging Contractors to produce a more uniform product.

5.1 General

The Department will accept the finished pavement based on the Contractor's test results unless it is shown through the Department's verification testing or the conflict resolution process that the Contractor's tests are in error.

5.2 Quality Characteristics and Acceptance Limits

The Department will accept the completed pavement in accordance with the criteria defined in Table 7 and properties measured and verified during construction.

Various acceptance parameters are listed in Table 7 for the specifier's consideration. Not all parameters shown will necessarily be appropriate or beneficial for any given project. Agencies may wish to include or exclude requirements based on the project's needs and goals, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and similar factors. Commentary provided within the table itself provides rationale for including certain parameters and, when applicable, offers additional information related to test methods and establishing targets and tolerances.

The quality acceptance limits presented within the table assume use of a percent within limits (PWL) approach for adjusting payment. The PWL is determined using Table 8 and the instruction in Section 5.3. A Lot is defined as the quantity (or surface area) of pavement placed in a single production day, or no more than 7,500 yd². Each Lot should be divided into no less than three and no more than eight Sublots of equal area. The quality index (QI) is calculated using the Lot sample standard deviation, S_n , and the Upper Quality Limit (UQL) and Lower Quality Limit (LQL). For additional information on establishing quality acceptance limits, refer to FHWA Publication No. FHWA-RD-02-095.

Note that the parameters, test methods, and tolerances included in Table 7 have been identified based on state-of-the-practice testing technology, which may or may not provide rapid and repeatable results, be representative of the anticipated field conditions, or relate directly to field performance (particularly if based on laboratory testing). This specification is therefore intended to be flexible enough to accommodate advances in technology, particularly in the area of nondestructive testing (NDT), which could allow for the development of acceptance parameters that better reflect the future performance and design life of the pavement. As applicable, emerging NDT technologies are also discussed in the commentary included in the table.

Table 7a: Acceptance Criteria (Materials Characteristics) ^(1,2)

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Air Voids (Laboratory Compacted)	AASHTO T312		
Asphalt Content	AASHTO T308		
Voids in Mineral Aggregate (VMA)	AASHTO R35		
<p>1. <i>Until gaps related to testing for fatigue and rutting resistance are overcome, Agencies will likely continue to use volumetric properties to evaluate quality. To provide a more comprehensive assessment of performance, it would be necessary to use or develop predictive models (e.g., Witczak equation) to relate volumetric properties to modulus and then to performance.</i></p> <p>2. <i>As an alternative to assigning pay factors to volumetric properties, Agencies could use volumetric test results as a trigger for more advanced mechanistic testing. For example, if a mix does not meet the prescribed volumetric targets, dynamic modulus testing would be required.</i></p>			

Table 7b: Acceptance Criteria (Construction Characteristics)

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Surface Distress (localized anomalies, segregation, surface irregularities) ⁽¹⁾	ASTM D6433, Pavement Condition Index (PCI) Survey or equivalent project-level visual survey ⁽²⁾	PCI > 80	The Department will evaluate deficiencies on a case-by-case basis to determine if a repair will be required.
<p>1. <i>Many specifications today require the pavement to be “free of surface defects.” Although some surface defects may not necessarily affect performance, acceptance of a marred pavement may be politically controversial. Eliminating segregation and increasing mat uniformity would decrease the risk for early pavement distress.</i></p> <p>2. <i>Visual methods generally only provide a qualitative indicator of end-of-construction quality. If NDT methods (e.g., Infrared Automated Thermal Profiling Systems or GPR) are used, it may be possible to establish a correlation to density. Refer to the SHRP 2 R06C project for an evaluation of the use of GPR and IR to detect and quantify segregation.</i></p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Ride Quality ⁽³⁾	AASHTO M 328, Inertial Profiler Measurement and Continuous Roughness Reporting ⁽⁴⁾ Measure pavement profile in both wheel paths simultaneously, parallel to the right edge of the lane, and in the direction of travel for each lane.	IRI ≤ 67 in./mi with 0.1 mi baselength for full payment ⁽⁵⁾ Localized Roughness: IRI ≤ 125 in./mi with 25-ft baselength	PWL 85% full payment based on continuous roughness histogram histogram from ProVAL
<p>3. <i>Studies indicate that ride quality provides an indirect measure of construction quality. It is a standard parameter for federal-aid projects; however, implementation of a ride quality requirement can present challenges:</i></p> <ul style="list-style-type: none"> <i>From an Agency’s perspective, establishing meaningful threshold values for different roadway types can be difficult.</i> <i>From industry’s perspective, if the existing roadway is rough, it may be difficult to achieve significant improvements. In such cases, the Agency may wish to adjust the standard or provide more opportunities for the Contractor to achieve smoothness (e.g., milling, multiple lifts).</i> <p>4. <i>Use of a high-speed inertial profiler to measure IRI is the standard for acceptance, though the initial cost to purchase a dedicated vehicle is high (~\$200,000). Lower-cost portable units are also commercially available, but must be calibrated to the vehicle.</i></p> <p>5. <i>Threshold would vary based on roadway type. To establish a threshold for end-of-construction, look at similar projects and/or set according to expected 5-year ride and adjust downward based on new pavements. Targets may also have to be adjusted in urban areas, to account for side streets and manholes.</i></p>			
Compaction (In-place air voids/in-place density) ⁽⁶⁾	AASHTO T269/Cores ⁽⁷⁾	Maximum theoretical density/	PWL 85% full payment
	ASTM D 2950/Nuclear Density Gauge ⁽⁹⁾	Minimum 5 tests per Lot ⁽⁸⁾	LQL = % MTD minus UQL = % MTD plus
	Ground-Penetrating Radar (GPR) ⁽¹⁰⁾		
	Roller-Integrated Compaction Monitoring (RICM) ⁽¹¹⁾		
<p>6. <i>Compaction is strongly related to pavement durability. The amount of air voids affects the stability and durability of the asphalt mix. When too low, rutting can occur due to plastic flow. When the voids are too high, the mix is more permeable to air and water, which can increase the rate of oxidation of the asphalt binder and ultimately result in premature cracking and/or raveling. Compaction is therefore particularly important for DBB and DB contracts that have no postconstruction performance requirements.</i></p> <p><i>If AMPT testing (e.g., E*, flow number) is being performed to address mechanical properties of the mix design, the significance and application of in-place air voids would likely change. In-place air voids would become less important for pay adjustment purposes because this parameter would no longer have to serve as a surrogate for more performance-oriented mechanistic parameters. Air voids would, however, continue to be important from a durability and aging standpoint. AMPT testing can provide important information on the mix, but compaction testing accounts for placement issues that can’t be addressed using a lab test.</i></p> <p>7. <i>Destructive core samples provide the most accurate way to measure compaction, though they are not necessarily conducive to rapid construction/testing.</i></p> <p>8. <i>If the Contractor provides RICM coverage maps for breakdown or intermediate roller operation, including surface</i></p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p><i>temperature information, it may be possible to reduce the frequency of coring or to perform targeted sampling.</i></p> <p>9. <i>Though not as accurate as core tests, nuclear density gauges (as well as nonnuclear density gauges) provide a nondestructive way to measure density. Other NDT devices (e.g., GPR and RICM) do not measure density directly.</i></p> <p>10. <i>GPR measures dielectric constant, which can be correlated to density testing performed on cores (correlation coefficient ~ 0.7 to 0.8).</i></p> <p><i>GPR has primarily served as a research and forensic tool; however, as an alternative to the traditional core and density gauge tests, GPR would provide the <u>advantage</u> of</i></p> <ul style="list-style-type: none"> • <i>Near continuous measurements (approximately one measurement per 6 in.), and</i> • <i>Data collection at highway speed (resulting in minimal disruption to traffic or to the Contractor’s operations).</i> <p><i>Possible limitations associated with this technology include</i></p> <ul style="list-style-type: none"> • <i>Cost of equipment (approximately \$30,000 –\$40,000),</i> • <i>Technician skill-level for data analysis and interpretation of dielectric values,</i> • <i>Processing time to analyze data (approximately 2 hours),</i> • <i>Lack of a standard test method to measure density using GPR, and</i> • <i>Need for core samples for calibration.</i> <p><i>To establish a tolerance, it would be possible to set a lower limit for density and estimate PWL based on dielectric constant.</i></p> <p>11. <i>Stiffness-related compaction data obtained from RICM technology have not shown a strong correlation to density. However, the real-time temperature and pass coverage output from the rollers can be valuable, particularly for the Contractor’s quality control operations. Further studies are needed to determine how useful machine values are for QA or acceptance purposes.</i></p>			
Joint Compaction on Longitudinal Joints ⁽¹²⁾	AASHTO T269/Cores ⁽¹³⁾	% Maximum theoretical density/Minimum 5 tests per Lot ⁽¹⁴⁾	The Department will evaluate joint deficiencies on a case-by-case basis to determine if a repair will be required.
	Ground-Penetrating Radar (GPR) ⁽¹⁵⁾		
<p>12. <i>Although not frequently included in Standard Specifications, an acceptance parameter addressing joint compaction would motivate Contractors to pay more attention to joint compaction—a key issue for ensuring the durability of joints.</i></p> <p><i>Along with compaction and smoothness, joint compaction is typically one of the most important properties of the in-place pavement to include in a payment adjustment system, particularly on high-volume roadways.</i></p> <p>13. <i>Joint density has traditionally been measured using cores. Note that nuclear density gauges may also be used to measure joint compaction, but they can be difficult to seat properly on the joint and may therefore provide questionable results.</i></p> <p>14. <i>If the Contractor provides GPR or RICM coverage maps, it may be possible to reduce the number of cores taken or to perform targeted sampling.</i></p> <p>15. <i>Refer to the advantages and disadvantages of GPR technology as identified with respect to the Compaction parameter (note 10).</i></p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Deflection/Stiffness ⁽¹⁶⁾	Falling Weight Deflectometer (FWD), ASTM D 4695 ⁽¹⁷⁾	See Note 18	
	Continuous Deflection Devices ⁽¹⁹⁾		
	Portable Seismic Pavement Analyzer (PSPA) ⁽²⁰⁾		
	GeoGauge ⁽²¹⁾		
	Roller-Integrated Compaction Monitoring (RICM) ⁽²²⁾		

16. Although not traditionally used as an acceptance parameter, stiffness measurements would provide a means to evaluate the structural adequacy of the in-place pavement. As more Agencies move toward using mechanistic design methods (which include pavement layer stiffness as a key input variable) measurement of in-place layer moduli could be used to validate design assumptions. Ultimately, if the parameter is used over time and a historical database can be developed, the information could be used to improve forecasting tools and better plan repair activities to reduce user impacts.

Currently, measurement strategies using deflection-based technologies (e.g., FWD) are more common than stiffness-based devices (e.g., PSPA). Given the subjectivity associated with back-calculating stiffness values from deflection measurements, it is recommended that deflection (rather than stiffness) be used as the performance parameter if testing is based on FWD.

The best application of a stiffness parameter would be on a high-profile, high-volume interstate rehabilitation project with improvements to the base or surface course or a new alignment or rehabilitation project with major repairs or structural improvements down to subgrade. Measuring stiffness would not be applicable to mill and overlay projects.

17. Compared with the alternatives, use of FWD is perhaps the closest to a “traditional” measurement strategy. It is being used within the Long-Term Pavement Performance (LTPP) program, and most agencies have access to at least one FWD device.

However, it is important to note that FWD does not provide a direct measure of stiffness, only deflection. Deflection measurements can then be used to back-calculate pavement structural layer stiffness and subgrade resilient modulus to ensure that the pavement structure at completion meets the overall strength requirements assumed during the structural design process.

Unlike the still-experimental continuous deflection devices, FWD technology only allows discrete point measurements.

18. Given the inherent subjectivity associated with back-calculation methods (essentially a curve-fitting process), it would be difficult to implement a deflection-based stiffness parameter for acceptance/payment purposes. It would be possible to develop a target for deflection based on local conditions and pavement type if a historical database is developed and maintained.

19. Similar to FWD, continuous deflection devices, such as Rolling Wheel Deflectometers (RWD) and Traffic Speed Deflectometers (TSD), would not provide a direct measure of stiffness, only deflection.

Such devices would provide the advantage of better spatial coverage with less impact on traffic. However, unlike FWD, these devices do not provide the full deflection basin needed to calculate multiple moduli and structural capacity. Such devices will therefore likely be better suited to network-level analysis than project-level acceptance.

Continuous deflection devices are not yet commercially available but are under development. (The SHRP 2 R06F project is evaluating existing technologies.) Accuracy of existing devices has been found to be reasonable but not very repeatable for low-deflecting pavements.

20. PSPA measures wave velocity to calculate surface stiffness. The device can be calibrated to the specific materials being tested during the mixture design stage.

Based on its evaluation of several NDT technologies including deflection-based (FWD, LWD), steady state vibratory (GeoGauge), dynamic cone penetrometers (DCP), ground-penetrating radar (GPR), nonnuclear density gauges, and intelligent compaction (IC) rollers, NCHRP Report 626, NDT Technology for Quality Assurance of HMA Pavement Construction, concluded that the PSPA device had the most accuracy and repeatability in identifying HMA pavement areas

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p><i>with anomalies.</i></p> <p><i>As also noted in NCHRP Report 626, a possible disadvantage to using this technology is the recommendation to delay testing for 1 day after HMA placement and compaction to allow the mix to cool (due to difficulty in maintaining adequate coupling between the receiver and the surface at high temperatures—the rubber pads of receivers may deteriorate or melt). Technicians also require a higher skill level to operate a PSPA than a density gauge.</i></p> <p>21. <i>A GeoGauge measures seismic input to calculate stiffness response at the surface. However, it is primarily suited to testing unbound materials and soils. The device should be calibrated to project materials and conditions to improve measurement accuracy.</i></p> <p>22. <i>Although not currently used for acceptance purposes, RICM technology is a promising technique for evaluating properties that relate more directly to performance (e.g. stiffness). The future goal for incorporating RICM technology would be to develop acceptance criteria and target values based on RICM machine values that correlate to density or other NDT modulus-based point measurements. Further studies are needed to determine the usefulness of machine values for QA or acceptance purposes.</i></p>			
Thickness ⁽²³⁾	ASTM D3549/Cores ⁽²⁴⁾	Minimum Design Thickness minus ¼ in./Minimum 3 tests per Sublot	PWL 85% full payment LQL = Design Thickness minus ¼ in. UQL = Design Thickness plus 1 in.
<div style="border: 1px dashed orange; padding: 2px;"> Ground-Penetrating Radar, ASTM D 4748 ⁽²⁵⁾ </div>			
<p>23. <i>Although measuring asphalt thickness is not standard practice for most Agencies, thickness is related to structural capacity and would provide some indication of the expected structural performance of the pavement.</i></p> <p><i>Also, to facilitate rapid renewal, thickness measurements could be used to make payment based on area (e.g., square yards instead of cubic yards or tons), eliminating the need for weight tickets and yield calculations.</i></p> <p><i>A thickness parameter would not be appropriate if the Contractor is trying to match existing conditions (variable thickness) or is dealing with rough surface conditions.</i></p> <p>24. <i>Thickness is traditionally measured using cores, despite not necessarily being conducive to rapid construction/testing.</i></p> <p>25. <i>As an alternative to destructive core sampling, GPR would provide the <u>advantage</u> of</i></p> <ul style="list-style-type: none"> • <i>Continuous measurements taken at highway speed, and</i> • <i>Reasonable accuracy and repeatability—within 10% for thickness (though not as accurate as cores).</i> <p><i>Some possible limitations associated with this technology include</i></p> <ul style="list-style-type: none"> • <i>Cost of equipment (approximately \$30,000–\$40,000 for the unit),</i> • <i>Some processing time needed to analyze data and estimate material properties (though time needed to estimate layer thickness is much less than that needed to estimate density),</i> • <i>Relatively high technician skill-level for data analysis (though less training is required to analyze GPR data for thickness than density), and</i> • <i>Cores needed to improve accuracy of data interpretation.</i> 			



Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Structural Capacity ⁽²⁶⁾	Falling Weight Deflectometer (FWD), ASTM D 4695 ⁽²⁷⁾	Design value/20 to 25 point measurements per project	
<p>26. For a DB project, evaluation of structural capacity could be used to determine compliance with design criteria based on a structural number or deflection criteria.</p> <p>27. FWD-based deflection measurements, along with thickness measurements, could be used to determine structural capacity. FWD provides a deflection basin, allowing calculation of multiple moduli and structural capacity. In contrast, other existing NDT devices, such as PSPA, would provide just a single modulus value. Continuous deflection-based NDT devices remain under development. They would provide a high-speed, network-level method to identify anomalies and localized areas that warrant further testing using more precise and reliable NDT point measurements such as FWD.</p>			
Skid Resistance ⁽²⁸⁾	ASTM E274 ⁽²⁹⁾ ASTM E524 ASTM E501 Collect a friction number data test point every 3/10 of a lane-mile for each travel lane, at a minimum testing frequency	Evaluate 100% of pavement surface. FN40S ≥ 40 FN40R ≥ 45 / Average per lane or as per Department requirements.	PWL 85% full payment
<p>28. Skid resistance is a critical functional performance issue. However, given the political sensitivity regarding this property, it may be better to address friction by specifying material and mixture properties (e.g., polished stone testing of aggregate) than to establish a skid resistance target for end-of-construction acceptance. It may be more appropriate to implement skid resistance as a distress indicator under a postconstruction warranty or maintenance agreement.</p> <p>29. The type of test tire (smooth or ribbed) should be selected by the Department based on standard practice.</p>			

5.3 Quality Level Analysis

For DB, payment is typically based on a lump-sum schedule of values. However, DB contracts often continue to incorporate unit-priced payment adjustments for pavements.

- A. Unless otherwise indicated in Table 7, acceptance of material and work shall be based on the method of estimating percent within limits (PWL), where the PWL will be determined in accordance with this Section. All Sublot test result values for a Lot, as defined in Table 7, will be analyzed statistically to determine the total estimated PWL. The PWL is computed using the Lot sample average value, \bar{X} , as defined in Section 5.3.C.2, the Lot sample standard deviation, S_n , as defined in Section 5.3.C.3, for the specified number of Sublots, n , and the specification Quality Acceptance Limits, as defined in Table 7, where LQL represents the Lower Quality Limit, and UQL represents the Upper Quality Limit, as they apply to each particular acceptance parameter. From these values, the respective Quality Index (Indices), Q_L for Lower Quality Index and/or Q_U for Upper Quality Index, is (are) computed in accordance with Sections 5.3.C.4 and 5.3.C.5. Then the PWL for the Lot for the specified number of Sublots, n , is determined from Table 8.
- B. In addition, all asphalt and asphalt placement work shall conform to the requirements of Section 7.4. For any identified deficiencies, as defined in Section 7.4, the Contractor may either

1. Remove and replace the asphalt pavement in that particular Lot at no additional cost to the Department, or
2. Accept a deduction of 50% of the contract unit price for that particular Lot of asphalt.

C. Determine the PWL as follows:

1. In accordance with this specification and the QMP, locate sampling positions, take test sample, make specimens, and test.
2. Determine the Lot sample average value, \bar{X} , by calculating the average of all Sublot test values.
3. Find the Lot sample standard deviation, S_n , by using the following formula:

$$S_n = \sqrt{\frac{\sum (x_i - \bar{X})^2}{n - 1}}$$

where

- S_n = standard deviation of the Sublot test values
 x_i = individual Sublot test values
 \bar{X} = average of Sublot test values
 n = number of Sublots

4. Find the Lower Quality Index, Q_L , by subtracting the Lower Quality Limit, LQL, from the average value, \bar{X} , and dividing the result by the Lot sample standard deviation, S_n .

$$Q_L = \frac{\bar{X} - LQL}{S_n}$$

5. Find the Upper Quality Index, Q_U , by subtracting the Lot sample average value, \bar{X} , from the Upper Quality Limit, UQL, and dividing the result by the Lot sample standard deviation, S_n .

$$Q_U = \frac{UQL - \bar{X}}{S_n}$$

6. Determine the percentage of material above lower tolerance limit, P_L , and the percentage of material below upper tolerance limit, P_U , by entering Table 8 with Q_L and/or Q_U using the column appropriate to the total number of Sublots, n , and reading the appropriate number under the column heading "PWL."
7. For quality characteristics with only an Upper Quality Limit, PWL equals P_U . For characteristics with only a Lower Quality Limit, PWL equals P_L . For asphalt properties with both Upper and Lower Quality Limits, first calculate the Upper Quality Index, Q_U , and the Lower Quality Index, Q_L , by using the Upper Quality Limit, UQL, and the Lower Quality

Limit, LQL, respectively. The limits to be used are stipulated in Table 7. Then determine PWL using the following formula:

$$PWL = (P_U + P_L) - 100$$

8. The PWL from Table 8 that is to be used is the whole number greater than that found by using the Q_U or Q_L in the table. For example, the PWL to be used for $n = 4$ and a Q_U of 1.4200 would be 98.

Table 8: Percent within Limits (PWL)
(STANDARD DEVIATION METHOD)
Positive Values of Quality Index (QI)
(n = Number of Sublots in the Lot)

PWL	n=3	n=4	n=5	n=6	n=7	n=8
100	1.1600	1.5000	1.7900	2.0300	2.2300	2.3900
99	1.1541	1.4700	1.6714	1.8008	1.8888	1.9520
98	1.1524	1.4400	1.6016	1.6982	1.7612	1.8053
97	1.1496	1.4100	1.5427	1.6181	1.6661	1.6993
96	1.1456	1.3800	1.4897	1.5497	1.5871	1.6127
95	1.1405	1.3500	1.4407	1.4887	1.5181	1.5381
94	1.1342	1.3200	1.3946	1.4329	1.4561	1.4716
93	1.1269	1.2900	1.3508	1.3810	1.3991	1.4112
92	1.1184	1.2600	1.3088	1.3323	1.3461	1.3554
91	1.1089	1.2300	1.2683	1.2860	1.2964	1.3032
90	1.0982	1.2000	1.2290	1.2419	1.2492	1.2541
89	1.0864	1.1700	1.1909	1.1995	1.2043	1.2075
88	1.0736	1.1400	1.1537	1.1587	1.1613	1.1630
87	1.0597	1.1100	1.1173	1.1191	1.1199	1.1204
86	1.0448	1.0800	1.0817	1.0808	1.0800	1.0794
85	1.0288	1.0500	1.0467	1.0435	1.0413	1.0399
84	1.0119	1.0200	1.0124	1.0071	1.0037	1.0015
83	0.9939	0.9900	0.9785	0.9715	0.9672	0.9643
82	0.9749	0.9600	0.9452	0.9367	0.9325	0.9281
81	0.9550	0.9300	0.9123	0.9020	0.8966	0.8928
80	0.9342	0.9000	0.8799	0.8690	0.8625	0.8583
79	0.9124	0.8700	0.8478	0.8360	0.8291	0.8245
78	0.8897	0.8400	0.8160	0.8036	0.7962	0.7915
77	0.8662	0.8100	0.7846	0.7716	0.7640	0.7590
76	0.8417	0.7800	0.7535	0.7401	0.7322	0.7271
75	0.8165	0.7500	0.7226	0.7089	0.7009	0.6958
74	0.7904	0.7200	0.6921	0.6781	0.6701	0.6649
73	0.7636	0.6900	0.6617	0.6477	0.6396	0.6344
72	0.7360	0.6600	0.6316	0.6176	0.6095	0.6044
71	0.7077	0.6300	0.6016	0.5878	0.5798	0.5747
70	0.6787	0.6000	0.5719	0.5583	0.5504	0.5454
69	0.6490	0.5700	0.5423	0.5290	0.5213	0.5164
68	0.6187	0.5400	0.5129	0.4999	0.4924	0.4877
67	0.5878	0.5100	0.4836	0.4710	0.4638	0.4592
66	0.5563	0.4800	0.4545	0.4424	0.4354	0.4310
65	0.5242	0.4500	0.4255	0.4139	0.4073	0.4031
64	0.4916	0.4200	0.3967	0.3856	0.3793	0.3753
63	0.4586	0.3900	0.3679	0.3575	0.3515	0.3477
62	0.4251	0.3600	0.3392	0.3295	0.3239	0.3203
61	0.3911	0.3300	0.3107	0.3016	0.2964	0.2931
60	0.3568	0.3000	0.2822	0.2738	0.2691	0.2660
59	0.3222	0.2700	0.2537	0.2461	0.2418	0.2391
58	0.2872	0.2400	0.2254	0.2186	0.2147	0.2122
57	0.2519	0.2100	0.1971	0.1911	0.1877	0.1855
56	0.2164	0.1800	0.1688	0.1636	0.1613	0.1592
55	0.1806	0.1500	0.1408	0.1363	0.1338	0.1322
54	0.1447	0.1200	0.1125	0.1090	0.1070	0.1057

6 METHOD OF MEASUREMENT

The lump-sum pricing structure found in a typical DB contract largely eliminates the use of measured quantities and unit pricing to determine progress and payment. However, the Agency may choose to measure pavement quantities for the express purpose of calculating pay factor adjustments as described in Section 7.

7 BASIS OF PAYMENT

DB contracts are typically lump-sum contracts in which progress payments are based on partial progress for lump-sum items in the schedule of values. However, pavements and other selected items for DB contracts continue to use unit-priced items to allow for pay factor adjustments to reward the Contractor for providing superior product and penalize the Contractor for providing product that is of lower quality than specified.

This section assumes use of a percent within limits (PWL) approach to compute pay adjustments. The PWL method encourages Contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures, such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging Contractors to produce a more uniform product.

Although simple to apply, the PWL approach primarily relies on engineering judgment to establish the individual pay adjustments and weighting factors. Arguably, a more rational approach would entail the use of mathematical models to compute pay factors for a given Lot based on the effect of construction quality on the predicted performance and subsequent LCC of the as-constructed pavement.

7.1 Pay Factor Adjustments

- A. Pay Factor adjustments for each Lot of each quality characteristic will be computed in accordance with the formulas contained in Table 9 by entering the PWL value and performing the calculation indicated for the appropriate PWL range to determine the Pay Factor.

For example, if 100% of the product is within limits, the pay adjustment is 0.06 = 6%, meaning the Contractor receives a 6% bonus.

Table 9: Adjustments to Contract Compensation

Percent Within Limits (PWL)	Pay Factor
91–100	[0.006 (PWL – 90)]
85–90	0.0
55–84	-0.9 + 0.01PWL

- B. The overall Pay Factor for a given characteristic, PF_i , is determined by calculating the average of all PFs for that characteristic for every Lot in the project.

7.2 Pay Adjustment

Based upon the quality of the pavement, the Department will calculate a weighted pay adjustment. The weights applied to each quality characteristic will be as shown in Table 10.

Table 10 illustrates possible pay adjustments for different pay items. Specifiers should consider project-specific conditions and goals when selecting pay factor adjustments and weight them in accordance with the criticality of the parameter to the ultimate performance of the pavement. For example, factors such as compaction, joint compaction, and smoothness are typically the most important installed properties to include in a payment system and may thus be weighted higher. In the future, as owners and industry obtain more experience with stiffness as an acceptance parameter, this may also be incorporated into the pay adjustment.

Agencies may wish to eliminate some factors entirely if they do not have sufficient data to support pay adjustment for those items.

Table 10: Pay Adjustment Criteria

Parameter	PF Designation	Weighting
Compaction	PF _c	1
Joint Compaction	PF _{jc}	1
Ride Quality	PF _{rq}	1
Thickness	PF _t	0.5
Skid Resistance	PF _{sr}	0.5

Example: $PA = \frac{[(PF_c \times 1) + (PF_{jc} \times 1) + (PF_{rq} \times 1) + (PF_t \times 0.5) + (PF_{sr} \times 0.5)]}{(1+1+1+0.5+0.5)}$

For high risk/high profile projects, specifiers may also wish to establish pay adjustments for key volumetric parameters of the asphalt mixture, such as asphalt content, air voids, and VMA.

Table X: Pay Adjustment Criteria – Mixture Properties

Parameter	PF Designation	Weighting
Asphalt Content	PF _{ac}	1
Air Voids	PF _{av}	1
VMA	PF _{vma}	0.5

7.3 Total Project Adjusted Price

The Department will calculate a total project Adjusted Price (AP) by multiplying the composite Pay Adjustment (PA) from Section 7.2 times the total tons of pavement in place times the unit price.

$$AP = (PA) \times (\text{Tons of Asphalt}) \times (\$/\text{Ton})$$

7.4 Correction of Deficiencies

Remove and replace or correct pavement in a manner acceptable to the Department and at no cost to the Department if any of the following deficiencies exist, unless the Department elects to accept the pavement, at which time the Contractor will be compensated at 50% of the contract unit price for asphalt placement specified regardless of the Pay Factors calculated in Tables 9 and 10:

1. PWL for compaction (density or modulus) is below 55.

2. PWL for ride quality is below 55 unless the Contractor elects to level-up, overlay, mill, or use a combination thereof to correct deficiencies.
3. PWL for skid resistance is below 55 unless the Contractor elects to correct with a thin surface treatment or friction overlay as deemed acceptable to the Department.

HOT MIX ASPHALT PAVEMENT

PERFORMANCE SPECIFICATION WITH WARRANTY

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for implementation under either a design-bid-build (DBB) or a design-build (DB) delivery approach that includes a warranty provision.

Unless otherwise noted, the recommended performance parameters and ancillary requirements contained in this specification apply to both DBB and DB delivery, assuming roles and responsibilities will be assigned as follows:

- *Selection of the pavement type by the Agency (or by Contractor if life-cycle cost, LCC, analysis is provided at bid);*
- *Structural design by the Agency (or by Contractor under DB);*
- *Mix design by the Contractor;*
- *Quality management by the Contractor;*
- *Verification testing and initial acceptance at the end of construction by the Agency;*
- *Postconstruction performance warranty provided by the Contractor;*
- *Routine maintenance by the Agency; and*
- *Final acceptance of the pavement at the end of the specified warranty period by the Agency.*

Specification Objectives

The inclusion of a warranty provision allows the Agency to expand the performance measurement strategy used under DBB and DB project delivery to include functional performance parameters that monitor and evaluate the actual performance of the pavement over time. The protection against defective work and premature failure offered by the warranty may allow the Agency to eliminate or relax some of its standard prescriptive requirements in the interest of rapid renewal.

Using This Guide Specification

The requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a detailed example that users can adapt to fit the needs of a particular project or program. Likewise, this specification is intended to be flexible enough to accommodate advances in technology that could affect the performance measurements and values during the life of the Contract.

Commentary included within the specification (as indicated with italic typeface) provides guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw upon the information provided as a basis for further modification or development of the specification.

In implementing this specification, Agencies are further encouraged to require the Contractor to develop and adhere to a comprehensive Quality Management Plan (QMP). A sample general provision addressing the roles and responsibilities for quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Finally, note that for a DB project, the term “Contractor” as used in this document should be interpreted as that entity given single-point responsibility for both the design and construction of the work and is thus synonymous with “Design-Builder” and “Design-Build Team.”

1 DESCRIPTION

[Design and] Construct an HMA pavement consisting of one or more courses of asphalt mixture on a prepared foundation.

For DB projects, the sentence above should be modified to include design as well as construction services.

Provide a Quality Management Plan (QMP) and perform all sampling, testing, and inspection necessary to control and assure the quality of the work in accordance with the QMP. The Department, acting in an oversight role, will conduct verification sampling and testing and independent assurance.

The Contractor's preparation of a formal QMP is an integral component of this performance specification. A QMP requirement allows the Agency to eliminate prescriptive requirements in exchange for the Contractor's development and adherence to a detailed plan of how it intends to complete the work and meet the performance requirements.

Warrant the finished pavement for a period of *[5–7 years]* after the date of *[Final Inspection, Substantial Completion, or opening of all lanes to unrestricted traffic]* as designated by the Department.

Maintain the pavement during the warranty period to meet the performance indicators and thresholds specified in Section 6.4. Perform all required remedial work during the warranty period and correct deficiencies identified in pavement evaluations.

Pavement evaluations should, at a minimum, include an initial and final survey with interim surveys if necessary or agreed upon.

2 STANDARDS AND REFERENCES

This Standards and References section applies primarily to DB projects and serves to identify the design and other procedural manuals and standards (e.g., AASHTO, FHWA, Agency) that the Contractor should follow, particularly when performing the project design work. Note that such documents may contain prescriptive requirements that could limit the Contractor's flexibility and ability to innovate. Therefore, when referencing standards in Table 1, balance the need for conformance with the Agency's existing facilities and processes (consider, for example, tie-ins to existing facilities, right-of-way—ROW—requirements, environmental issues) against the opportunity for innovation.

Likewise, materials standards, test methods, and similar reference documents cited throughout the specification should be obtained and reviewed to ensure that they do not inadvertently impose undesired restrictions on the Contractor, in which case the specifier should identify exceptions to the standard.

2.1 Standards

Unless otherwise stipulated in this specification or as approved by the Department, design and construct the pavement in accordance with this performance specification and the relevant requirements of the standards listed, by order of priority, in Table 1.

If the standards conflict, adhere to the standard with the highest priority. If the standards contain any unresolved ambiguity, obtain clarification from the Department prior to proceeding with design or construction.

Use the most current version of each listed standard as of the initial publication date of the RFP unless modified by addendum or change order.

Table 1: Standards for Pavements

Priority	Author or Agency	Title
1		
2		
3		

2.2 References

This subsection may be included if the Agency wishes to identify nonmandatory references that could assist the Contractor's efforts.

The Contractor may consult the references listed in Table 2 for supplementary guidance in designing and constructing the pavement system. These references have no established order of precedence and are not intended to be all-inclusive.

Table 2: References for Pavements

Author or Agency	Title
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3 REQUIREMENTS

Design requirements, as identified in Section 3.1, apply to DB projects only. For DBB, specifiers may follow a more traditional AASHTO five-part format, with Materials and Construction Requirements sections immediately following the Scope/Description.

3.1 Design

Perform all pavement engineering activities, including, but not limited to, the following:

List will vary based on how much initial design work was completed by the Agency.

- Pavement/geotechnical investigation
- Pavement design and analysis
- Material selection
- HMA mixture design

The Agency may also choose to allow the Contractor to select the pavement type during the bidding phase. In this case, the Agency should generally require the Contractor to follow a specified life-cycle cost (LCC) analysis procedure to demonstrate adequate pavement life and LCC for the pavement type designed. If implemented under an alternative bid provision, the Agency could use an "A+C" bid model, where "A" represents the base bid for the selected alternative and "C" represents an LCC bid adjustment factor.

All pavement engineering activities shall be directed, supervised, signed, and sealed by a Professional Engineer, licensed in the State of [-] with a minimum of [5] years of experience in pavement engineering.

3.1.1 Pavement Investigation

Perform and document all geotechnical investigations, testing, research, and analyses necessary to determine and understand the existing surface and subsurface conditions.

Prepare and submit geotechnical engineering reports documenting the assumptions, conditions, and results of the investigations and analyses, including the following:

- Geology of the project area;
- Results from field investigations and laboratory testing, including a discussion of how these results affect the design of the pavement;
- Design and construction parameters resulting from the geotechnical investigation and analyses; and
- Boring logs, laboratory results, calculations, and analyses that support design decisions.

3.1.2 Design Criteria

Design the pavement structure in accordance with the subsurface information collected in accordance with Section 3.1.1, the standards identified in Section 2.1 or other approved alternatives, and the criteria defined in Table 3.

Table 3: Design Criteria

Design Criteria	Requirement
Structural Design Life	
Design Traffic (18-kip ESALS)	
Shoulder Type	
Drainage	Provide a free-draining pavement that will not compromise surface or subsurface drainage of existing pavement to remain in place.
Tie-ins	Minimize pavement-to-structure transition deviations.

Modify Table 3 to include all additional requirements that could affect the design of the pavement system. For example,

- *Design Reliability;*
- *Required Ride Quality (IRI);*
- *Subgrade requirements (e.g., minimum support values, improvement strategies);*
- *Future expansion (e.g., “Design and construction must feasibly allow for future economical expansion through addition of lanes and other elements.”); and*
- *Different design criteria for mainlines and ramps versus auxiliary lanes and shoulders.*

3.1.3 Design Documentation

In exchange for providing the Contractor flexibility with regard to design and construction decisions, the Agency should require the Contractor to fully document and report all design assumptions and decisions.

Prepare pavement design reports that include the following items, as a minimum:

- All pertinent design inputs, such as traffic data, soils characteristics, characteristics of the proposed construction materials, environmental conditions, and pavement design life;
- Site plan showing the limits of the roadway covered by the design report;
- Discussion of site conditions that might influence the design and performance of the pavement;
- Discussion of the inputs used to arrive at design recommendations and the rationale used in selecting the recommended design strategy (where applicable, life-cycle management analysis, including the periods for resurfacing, reconstruction, and other rehabilitation measures);
- Pavement design details, including structural layer materials and thicknesses, and typical cross-section drawings;
- Comprehensive construction specifications sufficiently detailed to describe the process or end-result requirements; and
- Other considerations used in developing the pavement design(s), including subgrade preparation and stabilization procedures as applicable.

3.2 Material Requirements

When preparing the Materials section, carefully consider the extent to which the specification needs to prescribe basic material properties, particularly if the warranty requirements will hold the Contractor accountable for performance issues stemming from the selection and use of inferior materials.

Under the warranty requirements, the Contractor will assume risk for performance over time and should therefore be afforded more latitude to investigate materials and mix design options that could result in superior performance or time or cost savings.

3.3 Construction Requirements

The Agency's confidence in its ability to measure actual performance during the warranty period will control the degree to which an Agency can relax its standard construction requirements. In the interest of rapid renewal, consider eliminating requirements related to weather or seasonal restrictions, equipment, joints, layer thickness, etc., particularly when the warranty requirements would hold the Contractor accountable for the performance issues the prescriptive requirements were intended to prevent.

In exchange for providing the Contractor more flexibility with regard to construction decisions, the Agency should require the Contractor to describe in its QMP how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, mixing

hauling, spreading, finishing, and compaction of HMA) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

The Contractor is responsible for providing all management, professional, and technical services and labor, materials, and equipment necessary to construct the pavement.

4 QUALITY MANAGEMENT PROGRAM

This specification holds the Contractor responsible for performing tests used strictly for process control as well as tests that may be used in the Agency's acceptance decision. The Agency in turn should perform verification testing of select parameters. Although this approach may represent a departure from the traditional manner in which an Agency allocates responsibility for various quality management functions, it is consistent with the degree of risk assumed by the Contractor for performance of the work. Greater oversight by Agency personnel may add time to the project and conflict with the goals of rapid renewal.

4.1 Contractor's Responsibility for Quality Management

The requirements included in this Section 4.1 assume the Contract includes a separate provision related to development and implementation of a QMP that defines general requirements related to the Contractor's quality management personnel and organizational structure, documentation and reporting requirements, and procedures related to nonconforming work, corrective action, and similar matters. If such requirements are not otherwise addressed in the Contract's General Conditions, note that a sample general provision addressing quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Note that the Agency should review the Contractor's QMP submittal to ensure it complies with these and other Contract requirements. If the Agency disagrees with elements of the QMP, it should raise these issues with the Contractor or refer comments to the conflict resolution team as discussed in Section 6.8 (if such a team has already been established for the construction phase of the project). The Agency should not "approve" the Contractor's QMP, as approval could be construed as assuming responsibility for the plan's content.

Assume responsibility for the quality of the work, including work performed or provided by subcontractors, suppliers, and vendors.

Perform all quality management activities described in [*the Agency's General Provision for Quality Management*], including the additional requirements specific to HMA pavement construction as defined in this Section 4.1.

4.1.1 Contractor Testing

The approach taken in this section is to establish the minimum testing requirements that the Contractor's QMP must contain related to asphalt pavement construction. The intent is to provide the Contractor some latitude with respect to developing a project-specific QMP while also ensuring that the Agency's minimum standards are met. These minimum requirements can also serve as guidance to bidders as they prepare a cost proposal for the work.

A possible disadvantage to this approach is that the Contractor may view these requirements not as a minimum but as all that is necessary to provide adequate quality management. If a best-value procurement process will be used to award the contract, the Agency should consider

including the proposers' project-specific QMP, or relevant portions thereof, as part of the selection criteria.

As part of the QMP to be prepared, submitted, and implemented in accordance with *[the Agency's General Provision for Quality Management]*, include, as a minimum, the sampling and testing requirements specified in Table 4 as well as all other inspections and tests the Contractor deems necessary to ensure the quality of the finished pavement.

Keep the Department apprised of upcoming testing activities to allow the Department to schedule the verification and independent assurance activities described in Section 4.2. If verified as described in Section 4.2.1, the Department may use the Contractor's test results for acceptance.

Various QMP requirements are included in Table 4 for the specifier's consideration, not all of which will necessarily be appropriate or beneficial for a given project or program. Agencies may wish to include or exclude requirements based on the capabilities of local industry (including materials suppliers and testing firms), the project's needs and goals, associated costs, and similar factors. Commentary included within the table itself provides rationale for including certain parameters. Test methods and frequencies are provided for illustrative purposes only and should be modified based on Agency practices or project requirements.

Table 4: Minimum QMP Requirements for Asphalt Pavement

Parameter	Test Method/Device	Frequency
A. Materials		
Aggregate ⁽¹⁾		
Course Aggregate Angularity (% of Fractured Faces) ⁽²⁾	ASTM D5821	
Fine Aggregate Angularity ⁽²⁾	AASHTO T304	
Flat and Elongated Particles ⁽³⁾	ASTM D4791	
Soundness ⁽⁴⁾	AASHTO T103, AASHTO T104	
Polishing Resistance ⁽⁵⁾	ASTM D3319	
Abrasion Resistance ⁽⁵⁾	AASHTO T96	
Sand Equivalent ⁽⁶⁾	AASHTO T176	
Clay Lumps and Friable Particles ⁽⁶⁾	AASHTO T112	
Asphalt Binder		1/binder production lot/PG grade
Additives	Certification	1 per project

1. *For higher-risk projects, the Contractor should sample and test aggregate during construction on a per Lot basis. Higher risks include more severe conditions [high traffic volume, weather extremes (hot, cold, wet)], high road user impacts, public sensitivity, or longer expected service life.*

For lower-risk projects, consider allowing prequalification of aggregate sources. In keeping with the goals of rapid renewal, use of approved sources can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations.

2. *Angularity is desirable for HMA to achieve better particle-to-particle interlock and thus improve rutting resistance.*

3. *Flat and elongated particles can be problematic in HMA because they tend to reorient and break under compaction and thus may decrease strength.*

4. *To minimize premature pavement distress, aggregates must be resistant to breakdown from weathering (alternate*

Parameter	Test Method/Device	Frequency
<p>wetting/drying and freezing/thawing cycles). The freezing and thawing in water soundness test (AASHTO T103) more accurately simulates field conditions, but the test requires a longer period of time to conduct than the quicker sodium sulfate test (AASHTO T104).</p>		
<p>5. Aggregates not adequately resistant to polishing and abrasion may result in premature structural failure and/or a loss of skid resistance.</p>		
<p>6. The presence of soft particles, clay lumps, excess dust, and other deleterious matter can affect performance by quickly degrading, resulting in a loss of structural support and poor binder/aggregate bonding.</p>		
B. Mixture Production		
Gradation ⁽⁷⁾	AASHTO T27 & T11	1 per Sublot
Air Voids ⁽⁸⁾	AASHTO T312	1 per Sublot
Asphalt Content ⁽⁹⁾	AASHTO T308	1 per Sublot
Voids in Mineral Aggregate (VMA) ⁽¹⁰⁾	AASHTO R35	1 per Sublot
Moisture Damage ⁽¹¹⁾	AASHTO T283	1 per Lot
<p>7. For Contractors, gradation is an important property to control mixture production. However, as gradation is not directly indicative of performance (it indirectly controls voids), it should not be used for verification or acceptance purposes in a performance specification.</p>		
<p>8. The performance of in-place asphalt pavement is closely related to air voids (along with effective asphalt content). Excessive air void content, whether a mix design or a compaction problem, increases the likelihood of rutting and moisture damage.</p>		
<p>9. Effective asphalt content (i.e., asphalt not absorbed into aggregate, as calculated based on asphalt content and aggregate bulk specific gravity) influences air voids and VMA and is thus very closely related to performance. Asphalt content should be high enough to prevent excessive fatigue cracking, while not being so high as to increase the likelihood of rutting.</p>		
<p>10. VMA is related to asphalt performance (although to a lesser extent than air voids and asphalt content).</p>		
<p>11. Although moisture damage is highly related to asphalt performance, the standard test method—tensile strength ratio (TSR) of soaked strength to dry strength—does not provide a straightforward relationship to performance and is fairly involved and time-consuming.</p>		
C. Installed Product		
Compaction ⁽¹²⁾	Density gauge Roller-Integrated Compaction Monitoring (RICM) ⁽¹³⁾ Ground-Penetrating Radar (GPR) ⁽¹⁴⁾	
Joint Compaction ⁽¹⁵⁾	Density gauge Ground-Penetrating Radar ⁽¹⁴⁾	
Smoothness/Ride Quality ⁽¹⁶⁾	Straightedge	
<p>12. Many pavement distresses (e.g., cracking, rutting, or raveling) can be related to inadequate compaction. Compaction is therefore particularly important for DBB and DB contracts that have no postconstruction performance requirements.</p>		
<p>13. Roller-integrated compaction monitoring technology (or “intelligent” compaction) is a process that includes vibratory rollers equipped with a measurement control system that can automatically record compaction parameters in response to material stiffness measured during the compaction process. The roller is equipped with a documentation system that allows for continuous recording of the roller location for corresponding stiffness-related output using global positioning systems (GPS). Although a strong correlation between RICM machine values and density has not yet been established, Contractors may find the real-time temperature and pass coverage output from the rollers to be very valuable for process control of compaction operations to accelerate construction and reduce rework. If the Contractor does provide</p>		

Parameter	Test Method/Device	Frequency
		<i>coverage maps, consider relaxing the frequency requirements for core and density gauge testing.</i>
14.		<i>Although still primarily used as a forensic tool, GPR could be used as an alternative or supplement to traditional core or density gauge tests if a correlation could be established between GPR-measured values of dielectric constant and density tests performed on cores.</i>
15.		<i>Proper joint compaction is essential to ensuring the durability of joints. Requiring Contractors to test and monitor joint compaction as part of their quality management responsibilities should ideally motivate them to pay more attention to joint compaction.</i>
16.		<i>Ride quality (IRI) has traditionally been measured by Agency personnel for acceptance purposes; however, as Contractors assume more responsibility for quality management and performance, they may also find it beneficial to invest in inertial profilers. At a minimum, most Contractors will take straightedge measurements during construction.</i>

4.1.2 Production and Placement Procedures

In exchange for eliminating prescriptive requirements related to materials selection and construction methods, the Agency should require the Contractor to describe how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the mixing, hauling, spreading, finishing, and compaction of asphalt) will affect the in-place properties and performance of the work, and that the Contractor has planned the work and allocated its resources accordingly.

Include descriptions of the following in the QMP:

1. Certified mixing plant requirements, including calibration procedures for all meters, scales, and other measuring and recording devices, and procedures related to stockpile management, binder storage and handling, RAP processing and introduction to the plant (if applicable), and procedures related to mixing, mixture storage (if applicable), and haul unit loading.

Ensure that the Contractor has an adequate plan for checking the consistency of the produced mix and for correcting deficiencies or inconsistencies in the produced and delivered mix.

2. Laboratory location, testing equipment, procedures for calibration, and training standards for personnel (e.g., NICET or local standard).
3. Paving plan, including general staging and sequencing of operations.

When reviewing the Contractor's paving plan, consider the following:

- *Is the sequence compatible with the maintenance of traffic (MOT)?*
- *Can the Contractor's equipment accommodate the proposed sequence of operations (consider size and number of equipment)?*

4. Asphalt placement operations, including hauling, spreading, finishing, and compacting.

When reviewing this portion of the Contractor's QMP, consider the following:

- *Is the proposed equipment appropriate for the project?*

- *Is hauling equipment appropriate given the likely haul distance, haul time, and weather conditions?*
- *Are adequate delivery vehicles available to match the production rate of the plant and the planned forward speed of the paver?*
- *Is equipment appropriate for spreading material in front of the paver?*
- *Will the Contractor's proposed procedures minimize segregation?*
- *Will the Contractor's proposed procedures ensure ride quality?*

5. Methods to control alignment and profile.

- *Has the Contractor developed a procedure for control of the pavement profile?*
- *Has the Contractor established a procedure for checking the finished grade or profile of the intermediate layers or milled surface?*

6. Joint installation procedures.

- *Does the Contractor have a plan for constructing quality longitudinal and transverse joints?*
- *Does the plan address procedures related to end-of-day paving and joints?*

7. Procedures related to night work (as applicable).

8. Contingency plan for inclement weather.

Note that this list will vary based on how much freedom the Agency allows the Contractor with regard to the construction requirements in Section 3.3.

4.2 Department's Quality Management Responsibilities

The Department may conduct quality inspections, audits of the Contractor's results and records, and verification sampling and testing on any element of the work to ensure compliance with the QMP and the Contract requirements.

4.2.1 Verification Sampling and Testing

Even though the Contractor may assume more responsibility for inspection and testing under a performance specification, this does not relieve the Agency of its responsibility to perform some level of independent sampling and verification testing to meet the intent of 23 CFR 637. Verification testing should be performed to validate any Contractor testing used in the Agency's acceptance decision. The Agency may also wish to verify certain material or mixture parameters that could identify possible performance issues that would not appear before the termination of the warranty term.

The Department will perform verification testing as described in Table 5 to validate the Contractor's test results.

The Department will notify the Contractor before sampling so the Contractor can observe.

The Department will sample randomly at locations independent of the Contractor's sampling and testing. In all cases, the Department will conduct the verification tests in a separate laboratory and with separate equipment from the Contractor's tests.

Table 5: Department Verification Testing

Parameter ⁽¹⁾	Test Method ⁽¹⁾	Sampling Location	Frequency ⁽²⁾
Materials			
Binder	Agency test		
Aggregate ⁽³⁾			
Mixture			
Asphalt Content	AASHTO T308		
Air Voids	AASHTO T312		
VMA ⁽⁴⁾	AASHTO R35		
Installed Product			
Compaction ⁽⁵⁾	AASHTO T312	random (x,y)	
Joint Compaction ⁽⁵⁾	AASHTO T312	random (x,y)	

- Parameters and test methods are provided for illustrative purposes only and should be modified based on Agency practices or project requirements. If an Agency has its own standard test methods for measuring these properties, specify those methods instead.*
- Frequency should be based on project-specific conditions and ideally should provide the ability to identify statistically valid differences between Agency and Contractor test results. A minimum Agency rate of 10% of the testing rate of the Contractor has been used as a rule of thumb.*
- For higher-risk projects, Agencies should verify aggregate test results. Higher risks include more severe conditions [high traffic volume, weather extremes (hot, cold, wet)], high road user impacts, public sensitivity, or longer expected service life.*
- There is no universal understanding of VMA as a property that influences performance, and therefore several Agencies do not measure it for verification or acceptance purposes.*
- Destructive core samples provide the most accurate way to measure compaction, though they are not necessarily conducive to rapid construction/testing. If the Contractor provides RICM coverage maps for breakdown or intermediate roller operations, including surface temperature information, it may be possible to reduce the frequency of coring or to perform targeted sampling.*

The Department may increase the frequency of verification testing at start-up or as necessary to validate the quality of the materials. The Department may reduce the frequency based on a history of satisfactory Contractor or material performance.

If verification tests indicate conformance with specifications, no further action is required. If verification tests indicate nonconformance with specifications, the Department and Contractor will jointly investigate the testing discrepancies. The investigation may include additional testing as well as review and observation of both the Department's and Contractor's sampling and testing procedures and equipment. Both parties will document all investigative work.

When comparing Agency and Contractor test results, it is important to compare both the variances and the means. The tests most often used are the F-test (comparison of variances) and the t-test (comparison of means), which are used together.

4.2.2 Independent Assurance Testing

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing activities are being performed by qualified personnel using proper procedures and properly functioning and calibrated equipment. The Department will perform IA testing using personnel other than

those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor's sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

4.3 Conflict Resolution

If a dispute between some aspect of the Contractor's and the Department's testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [*Standard Specification Section XXX*].

5 ACCEPTANCE OF INITIAL CONSTRUCTION

Initial acceptance of the pavement at the end of construction is important to ensure that the basic scope of the work was completed in accordance with the plans. Note that final acceptance would not occur until after completion of the warranty term (see Section 6.7).

5.1 Initial Acceptance

Agencies should modify this section as needed to suit their specific construction closeout procedures.

The Department and the Contractor will jointly review all completed work, or a portion thereof, as determined by the Department, to evaluate conformance with the design and QMP requirements. If the work does not meet Contract requirements, perform the necessary corrections at no additional cost to the Department. Initial acceptance will occur when the Department confirms in writing that the work meets Contract requirements.

Initial acceptance will be documented by a Completion Certificate jointly executed by the Department and the Contractor. The Department will provide a copy of the Completion Certificate to the Contractor's warranty bond surety agent.

The initial acceptance or any prior inspection, acceptance, or approval by the Department will not diminish the Contractor's responsibility under the warranty. The Department may accept the work and

begin the warranty period, excluding any area requiring corrective work, to accommodate seasonal limitations or staged construction.

The Department will accept the finished pavement based on the Contractor’s test methods and results unless it is shown through the Department’s verification testing or the conflict resolution process that the Contractor’s tests are in error.

5.2 Quality Characteristics and Acceptance Limits

The Department will accept the completed pavement in accordance with the criteria defined in Table 6.

The work may be accepted based on Contractor’s testing during construction or tested separately for acceptance after construction. Various acceptance parameters are listed in Table 6 for the specifier’s consideration. If the Agency’s goal in using a warranty provision is simply to reduce oversight during construction, initial acceptance criteria may be limited to two to three key parameters such as compaction, joint compaction, and thickness. If the intention is instead to provide a long-lasting pavement, with the warranty serving as supplementary protection against premature failure, a more comprehensive list of initial acceptance parameters may be more appropriate.

Table 6: Initial Acceptance Criteria

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits	
Compaction (In-place air voids/in-place density) ⁽¹⁾	AASHTO T269/Cores ⁽²⁾	Maximum theoretical density /Minimum 5 tests per Lot	PWL = 85% full payment LQL = % MTD minus	UQL = % MTD plus
	Ground-Penetrating Radar (GPR) ⁽²⁾			
<p>1. <i>Compaction is strongly related to pavement durability. Many pavement distresses (e.g., cracking, rutting, raveling) can be related to inadequate compaction.</i></p> <p>2. <i>Destructive core samples provide the most accurate way to measure compaction, though they are not necessarily conducive to rapid construction/testing. GPR could be used as an alternative or supplement to traditional testing if a correlation could be established between GPR-measured values of dielectric constant and density tests performed on cores.</i></p>				
Joint Compaction on Longitudinal Joints ⁽³⁾	AASHTO T312/Cores ⁽⁴⁾	% Maximum theoretical density/Minimum 5 tests per Lot	The Department will evaluate joint deficiencies on a case-by-case basis to determine if a repair will be required.	
	Ground-Penetrating Radar (GPR) ⁽⁴⁾			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p>3. Although not frequently included in Standard Specifications, an acceptance parameter addressing joint compaction would motivate Contractors to pay more attention to joint compaction—a key issue for ensuring the durability of joints.</p> <p>4. Joint density has traditionally been measured using cores. If the Contractor provides GPR or RICM coverage maps, it may be possible to reduce the number of cores taken or to perform targeted sampling.</p>			
Thickness ⁽⁵⁾	ASTM D3549/Cores ⁽⁶⁾	Minimum Design Thickness minus ¼ in./Minimum 3 tests per Sublot	PWL 85% full payment LQL = Design Thickness minus ¼ in. UQL = Design Thickness plus 1 in.
	Ground-Penetrating Radar, ASTM D 4748 ⁽⁶⁾		
<p>5. Although measuring asphalt thickness is not standard practice for most Agencies, thickness is related to structural capacity and would provide some indication of the expected structural performance of the pavement.</p> <p>Also, to facilitate rapid renewal, thickness measurements could be used to make payment based on area (e.g., square yards instead of cubic yards or tons), eliminating the need for weight tickets and yield calculations.</p> <p>A thickness parameter would not be appropriate if the Contractor is trying to match existing conditions (variable thickness) or is dealing with rough surface conditions.</p> <p>6. Thickness is traditionally measured using cores, despite not necessarily being conducive to rapid construction/testing. Alternatively, thickness may be measured and accepted using nondestructive evaluation methods such as GPR. Thickness checks indicating deficient or marginal thickness (e.g., +/-½" of plan thickness) may require the Contractor to core these locations for acceptance. If the Agency requests cores and the result indicates acceptable pavement thickness, the Agency would bear the cost of coring.</p>			

5.3 Submittal of Construction Documents

Within 15 days after the date of the Completion Certificate *[or equivalent certification]*, submit to the Department a signed certification by an authorized representative of the Contractor that the materials and construction are in general conformance with the pavement design, QMP, and the Contract Documents. Include the following documentation with the certification:

1. The final HMA details and drawings for the constructed pavement.
2. A list of all construction specifications used by the Contractor and the locations where the specifications were used.
3. A list of material sources and all QMP test results with comparison to material specification limits (in hard copy and digital form) for:
 - a) mix designs and aggregates for all selected mixes
 - b) mix properties for all bituminous materials
 - c) asphalt cement and emulsions

- d) anti-stripping additive, if used, in the binder and surface courses
 - e) any other material used in the HMA including, but not limited to, fibers and mineral filler
 - f) tack coat used between HMA courses
4. All job mix formulas used with each mix design with the dates and locations where each was used.
 5. Construction test results including, but not limited to, compaction and placement requirements.

5.4 Access to Construction Documents

With 24 hours written notice, provide the Department full access at any time to all original and copies of inspection records, test results, control charts; and to testing and production facilities, as necessary to allow the Department to audit the Contractor's compliance with the requirements of the design, QMP, and Contract Documents. For purposes of this section, test results include all original supporting readings, measurements, laboratory worksheets, and calculations. When original records are not stored at the Contractor's field office, make copies of original inspection records, test results, control charts, and other QMP documents available for viewing at the Contractor's field office for the Contract within 1 Business Day of receiving a written request from the Department.

Retain and provide access to all inspection records, test results, and control charts for the duration of the warranty period. This requirement shall survive after the date of Completion Certificate.

6 WARRANTY

6.1 General

Warranty provisions are designed to minimize impacts to the Agency during the warranty period while providing an objective and measurable means to assess performance.

The Contractor shall warrant that the HMA pavement will meet the performance requirements specified in Section 6.4 for the length of the warranty period, as specified in Section 6.2.

Warranty work consists of the remedial actions needed to meet performance thresholds during the warranty period. Warranty work may include optional surveys, inspection and testing, traffic management, and elective preventive maintenance.

The Department will allow the Contractor to carry out onsite activities such as sampling, testing, inspection, traffic survey, or nonemergency repairs during the warranty period. Advise the Department in writing *[21 days]* prior to the start of each period of onsite activity. Damaging or destructive sampling, testing, or inspection shall include a repair proposal and will be subject to the Department's prior approval.

The Department will perform routine maintenance, such as snow and ice removal, application of deicing chemicals, repairs to safety appurtenances, and emergency work, if required. Submit written notification to the Department immediately upon identifying any concern regarding routine maintenance believed to affect pavement performance.

6.2 Warranty Period

The warranty shall begin on the date of *[the Completion Certificate]* and will continue for *[5 to 7]* years.

The duration of the warranty period is an important consideration. The warranty should be of sufficient duration to protect the Agency from defective work and premature failure caused by inferior materials and workmanship. Although it is possible to develop warranty provisions of sufficient duration to address long-term performance, bonding issues may preclude their practical use.

Pavement warranties are therefore generally set for a period of one-third to one-half the expected life of the pavement or treatment. An Agency should consider the pavement performance data collected through its pavement management system (PMS) to help determine the appropriate warranty period for a particular project.

6.3 Warranty Bond

Provide a *[single term or renewable with straight-line or stepped depreciation]* warranty bond in the amount of *[\$_____]* meeting *[bond rating]* before execution of the Contract. The warranty bond will commence upon completion and initial acceptance of the warranted HMA pavement and will be in effect for the warranty period(s).

The warranty bond(s) will insure the prompt completion of required pavement warranty work, including payments for all labor, equipment, and materials, and will be in effect until the end of the warranty period or when all warranty work has been completed, whichever is latest.

A warranty bond should provide adequate protection for the Agency while not overextending the Contractor's capacity to take on additional work. The bond is typically calculated as a percentage of the Contract (for example, 20%), the cost of warranty or maintenance work, or the cost of replacing the surfacing materials. If pavement work is subcontracted, the Agency may require that the subcontractor provide a warranty bond or provide a dual obligee bond to the Contractor and the Agency.

6.4 Performance Requirements During the Warranty Period

The Department will conduct an initial and final evaluation of warranted pavement using high-speed measurement methods consistent with network-level pavement management surveys. The Department will use measurement procedures in accordance with *[the Agency's pavement management system, the Agency's Pavement Surface Distress Survey Manual, or the Agency's Pavement Condition Survey program or Long-Term Pavement Performance program (LTPP) Distress Identification Guide]* or applicable test methods. The Department will also conduct interim periodic windshield surveys during the warranty period as needed.

The Department will evaluate initial warranted pavement performance by measuring *[ride quality, friction, cracking, and rutting]* in the driving lanes for the entire length of the warranty section *[auxiliary lanes and shoulders are exempt from the performance requirements]*, except that friction testing will be conducted on the driving and passing lane or middle lane for multilane facilities. The final year evaluations will be conducted on every lane in both directions throughout the length of the project for all pavement performance indicators.

For purposes of evaluation, the Department will divide the project into nominal 1-mi sections or Lots. Each section will be subdivided into 10 approximately 500-ft long segments. The Department will

evaluate ride quality using a van equipped with a laser-based inertial profiler to calculate the average IRI of two wheel paths for each segment. The Department will evaluate skid resistance using a locked wheel trailer as defined in ASTM E274 and a smooth tire as defined in ASTM E524. Skid tests will be conducted in both directions in each lane every ¼ mi *[or as defined by the Agency]*. The number of locations for skid tests will depend on the length of the project. The skid numbers will be averaged to compare with thresholds in Table 7.

The Department will evaluate rutting using a van equipped with sensors to measure the rut depth of each wheel path continuously along the length of each segment, and calculate an average rut depth of both wheel paths for each segment. The rut measurement will be made with a van using at least three to five readings across the pavement surface. These readings will be taken at the approximate right wheel path center, center of the lane, and left wheel path center. The sensors measure the relative height from the sensor to the surface and calculate the rut as the relative difference in the readings.

If during the high-speed evaluation there is visual evidence of other surface distresses (transverse or longitudinal cracking, potholes, flushing, etc.), the Department will conduct additional evaluations at any location in a lane or shoulder in accordance with *[the Agency’s pavement management system, the Agency’s Pavement Surface Distress Survey Manual, or the Agency’s Pavement Condition Survey program or Long-Term Pavement Performance program Distress Identification Guide]* to determine the extent and severity of distresses and whether these distresses exceed the threshold values and require remedial action.

If during windshield surveys any areas outside the tested lanes or sampled sections are observed to show deficiencies, the Department will conduct additional testing to determine the extent and severity of distresses based on Table 7 and whether these distresses exceed the threshold values and require remedial action.

Evaluation results will be sent to the Contractor within 20 days of the completion of the distress surveys and pavement roughness and pavement friction measurements carried out during the warranty period.

Various acceptance parameters are listed in Table 7 for the specifier’s consideration. Not all parameters shown will necessarily be appropriate for a given Agency or road network. Specifiers should substitute values that they feel are most appropriate for their highway system and technology used to monitor performance.

Table 7: Performance Indicators, Thresholds, and Guidance for Remedial Action

Performance Indicator	Threshold Levels	Guide to Remedial Action
Ride Quality—International Roughness Index (IRI)	80 in./mi (1.3 m/km) based on High-Speed Inertial Profiler/Laser Profiler ^(1, 2)	Level up, overlay, mill, or use combinations thereof to correct inadequacies.

Performance Indicator	Threshold Levels	Guide to Remedial Action
<p>1. Use of a high-speed inertial profiler to measure IRI is the standard for acceptance, though the initial cost to purchase a dedicated vehicle is high (~\$200,000). These vehicles may also be equipped with laser-based pavement profiling equipment and automated crack monitoring systems to measure roughness, rutting, pavement texture, and geometry. Lower-cost portable units for measuring IRI are also commercially available but must be calibrated to the vehicle.</p> <p>2. Thresholds for a warranty would vary based on roadway type and warranty duration. The evaluation interval or segment also will affect how the threshold is set. In the case of IRI, the shorter the segment length, the more the IRI is affected by local extremes. Thus, the historical pavement management data for 1-mi warranty sections must be adjusted to eliminate anomalies caused by bridge approaches or other pavement transitions. The threshold might also be affected by how the pavement is constructed. The more opportunities to achieve smoothness through multiple pavement layers or surface milling, the tighter the tolerance might be. If the objective of the warranty is to dramatically improve quality, then thresholds should be more stringent to achieve the warranty objective. As the duration of a warranty increases, the specified tolerances may be adjusted, though many Agencies have increased the warranty duration without adjusting the specified thresholds. Agencies have initially set thresholds that are relatively easy to achieve—to familiarize all parties with the use of warranty provisions—and increased the duration or tightened the tolerance of the warranty after gaining more experience.</p>		
Surface Friction	Skid Number must average 35 per lane with no individual value for three consecutive test sites less than 25 using a Locked Wheel Trailer (ASTM E274) and a smooth tire based on ASTM E524 or ribbed tire ^(3, 4)	Mill, apply surface treatment, or overlay to correct inadequacy.
<p>3. Select the type of test tire (smooth or ribbed) based on the Agency's standard practice.</p> <p>4. Technology is being updated to move to a continuous friction measurement in which data are based on running average per Lot.</p>		
Transverse Cracking	<p>Visually rate severity and extent of cracks (based on LTPP Distress ID Manual or equivalent). Severity based on crack width (e.g., 1 = 0.25 in. or less, 2 = 0.25 in. or greater, or a raveled crack)</p> <p>Automated Crack Monitoring Systems⁽⁵⁾</p>	<p>Rout and seal all cracks with a Department-approved sealant.</p> <p>For extensive cracking, remove and replace distressed layer(s) to a depth not to exceed the warranted pavement.</p>
<p>5. Laser-based crack measurement systems mounted on pavement management vehicles provide automated detection of cracks in addition to the evaluation of rutting, macro-texture, and potentially other road surface features. These systems use high-speed cameras, custom optics, and laser line projectors to acquire and process both 2-D images and high-resolution 3-D profiles of the road. The collected data can be analyzed with computer software. This software can detect and analyzes cracks. It also can be used to evaluate lane markings, ruts, macro-texture, drop-offs, raveling, and potholes. Cracks can then be classified as transverse, longitudinal, or alligator and the severity evaluated.</p>		
Longitudinal Cracking	<p>Visually rate severity and extent of cracks (based on LTPP Distress ID Manual or equivalent). Severity based on crack width (e.g., 1 = 0.25 in. or less, 2 = 0.25 in. or greater, or a raveled crack)</p> <p>Automated Crack Monitoring System (see note 5)</p>	<p>Rout and seal all cracks with a Department-approved sealant.</p> <p>For extensive cracking, remove and replace distressed layer(s) to a depth not to exceed the warranted pavement.</p>

Performance Indicator	Threshold Levels	Guide to Remedial Action
Rutting	High-Speed Rut Bar or Real Time Laser-based Profile System ⁽⁶⁾ 0.25 in. in depth	Mill surface with fine-toothed mill to remove ruts, overlay, or microsurface.
	High-Speed Rut Bar or Real Time Laser-based Profile System ⁽⁶⁾ 0.5 in. in depth	Remove and replace distressed layer.

6. *The existing high-speed rut bar systems use measurements based on ultrasonic sensor technology to collect pavement rutting data for pavement management system evaluations. More recently, Agencies have begun testing and implementing laser-based profiling systems for a number of pavement management applications, including continuous measurements of rut depth or the rate of rutting for flexible pavements. Laser-based profiling systems also can collect pavement geometry data for gradient (%), curvature (inches), and crossfall (%).*

Block Cracking	1% of area in a segment	Remove and replace distressed layer(s). Remove the distressed surface to a depth not to exceed the warranted pavement.
Alligator Cracking	1% of area in a segment	Remove and replace distressed layer(s). Remove the distressed surface to a depth not to exceed the warranted pavement.
Segregation or Surface Raveling	Existence	Apply a chip seal coat or partial-depth repair to the distressed areas.
Bleeding/Flushing	20% of segment length	Microsurface or remove and replace distressed surface mixture to full depth of distressed layer.
Potholes, Slippage Areas, Other Disintegrated Areas	Existence	Remove and replace distressed area(s). The removal area will be equal to 150% of the distressed area to a depth not to exceed the warranted pavement.

Performance Indicator	Threshold Levels	Guide to Remedial Action
Structural Capacity	Falling Weight Deflectometer (FWD) ⁽⁷⁾ Threshold expressed as a deflection value (e.g., inches) ⁽⁸⁾	Remove and replace distressed layers to a depth not to exceed warranted pavement.
	Rolling Wheel Deflectometer (RWD) ⁽⁹⁾	

7. *A measurement strategy using deflection-based devices, such as falling weight deflectometers (FWD), could be used as a baseline for structural capacity if a target is established for deflection at end of construction, which can be compared with deflection at final warranty acceptance. Compared with the alternatives, use of FWD is perhaps the closest to being a “traditional” measurement strategy. It is being used within the LTPP program and most agencies have access to at least one FWD device. However, it is important to note that FWD does not provide a direct measure of stiffness, only deflection. Deflection measurements can then be used to back-calculate pavement structural layer stiffness and subgrade resilient modulus to ensure that the pavement structure at completion meets the overall strength requirements assumed during the structural design process. FWD technology only allows discrete point measurements.*
8. *Given the inherent subjectivity associated with back-calculation methods (essentially a curve-fitting process), it would be difficult to implement a deflection-based stiffness parameter for acceptance/payment purposes. It would be possible to develop a target for deflection based on local conditions and pavement type if a historical database is developed and maintained.*
9. *Continuous deflection-based NDT devices, such as RWD and Traffic Speed Deflectometers (TSD), remain under development but would provide a high-speed, network-level method of assessing structural capacity or identifying anomalies that would warrant further testing using a more precise and reliable NDT point measurement such as FWD. Continuous deflection devices are not yet commercially available but are under development. (The SHRP 2 R06F project is evaluating existing technologies.) Accuracy of existing devices has been found to be reasonable but not very repeatable for low-deflecting pavements. Such devices would provide the advantage of better spatial coverage with less impact on traffic. However, unlike FWD, these devices do not provide the full deflection basin needed to calculate multiple moduli and structural capacity. Such devices will therefore likely be better suited to network-level analysis than project-level acceptance.*

6.5 Warranty Work

The Department will report the results of the pavement surveys identifying deficiencies and segments where thresholds have been exceeded within *[45 days or a reasonable length of time]* of completing the survey. The Contractor shall be responsible for remedial action for the performance indicators defined in Table 7 unless the Department determines based on Section 6.6 that the distress is caused by factors beyond the control of the Contractor.

Perform warranty work at no additional cost to the Department based on the results of pavement distress surveys. Remedial work on mainline roadway will also apply to integral shoulders, curbs, or curb and gutters. If warranty work requires corrective action to pavement markings, raised pavement markers, or adjacent lanes, shoulders, or curbs, this corrective action is included in the scope of the warranty work.

If a pavement condition survey indicates that performance thresholds are exceeded and warranty work is required, and the Contractor and Department agree with the distress survey results, submit a Remedial Work Plan and schedule, and request a permit from the Department before proceeding with warranty work. Perform remedial work *[within a defined number of days depending upon the level of severity or within the same calendar year]*. Conform to traffic control requirements *[herein or in the Standard Specifications]*.

If the pavement requires immediate remedial action for the safety of the traveling public and the Contractor has not performed the remedial work within 24 hours, the Department may perform the remedial work with other forces at the Contractor's expense. Remedial work performed by others will not alter the Contractor's obligations under the warranty.

If the Contractor does not agree with the results of the distress survey or the cost of Department-performed work, or the Department does not agree with the Contractor's proposed remedial action, the Conflict Resolution Team, as described in Section 6.8, will make a final determination within a mutually agreed upon time.

Document all warranty work according to the approved Remedial Work Plan and provide this information to the Department annually.

6.6 Exclusions

Be specific when defining exclusions. For example,

The Contractor shall not be responsible for repairing damage to the pavement resulting from causes beyond the Contractor's control as determined by the Department. This includes repair of distresses caused by

- Existing base or pavement conditions;
- Floods, tornadoes, fires, landslides, or other acts of nature;
- Chemical and fuel spills, fires, and traffic accidents, and
- Department's routine maintenance activities, or coring, milling, or other destructive procedures performed by the Department.

If, on a DB project, responsibility for evaluating and designing the pavement foundation system is assigned to the Contractor, the exclusion related to existing base conditions would not apply.

The Contractor will be relieved of the responsibility for remedial action if the estimated accumulated equivalent single axle loads (ESALs) based on a current traffic count are *[100%]* above the projected *[5-year]* accumulated ESALs. The Contractor shall not rely on the Department to conduct a traffic survey(s) during the warranty period. The Contractor will be permitted to carry out traffic surveys subject to the Department's operational requirements.

6.7 Final Warranty Acceptance

The Department will evaluate the pavement performance *[or conduct a final survey]* within *[calendar days]* of the completion of the warranty term. Perform any required remedial work based on the results of the final survey in accordance with Sections 6.5 and Table 7. The Department will issue a Final Warranty Acceptance Letter *[or an equivalent certification]* and release final payment *[retainage]* upon verification that all required performance thresholds are met and after receipt of all required QMP documentation.

6.8 Conflict Resolution

The Department will establish an on-call Conflict Resolution Team (CRT) for Warranty Work to resolve any conflicts regarding the warranty requirements. This team will be composed of one *[or two]* representatives appointed by the Contractor, one *[or two]* representatives appointed by the Department, and an independent party mutually agreed upon by the Contractor and the Department. The CRT will base decisions on a simple majority vote. The Contractor and the Department will share the expenses of the

independent party and any forensic investigations that the CRT may decide to conduct. CRT members will be knowledgeable regarding the warranty terms and conditions, and the identification and measurement of pavement distresses. The CRT will initially process any disputes involving construction and warranty work.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product for construction or the Contractor does not agree with the results of the distress survey or the cost of Department-performed work, or the Department does not agree with the Contractor-proposed remedial action, the Department will use the CRT to resolve the dispute. The CRT will provide testing. The Department may use CRT tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in *[Standard Specification Section XXX]*.

If resolution is not achieved, follow the Department’s claims procedure as specified in *[Standard Specifications Section XXX]*.

7 MEASUREMENT

The following clause is generally applicable to DBB projects only, as the lump-sum pricing structure found in a typical DB contract largely eliminates the use of measured quantities and unit pricing to determine progress and payment.

The Department will measure the work by the ton, based on the quantity of mixture placed, completed and accepted, and verified by certified records of shipment and haul tickets. Provide a copy of the haul ticket for each load when delivered to the project site. Present certified records of shipment for the quantities placed under this special provision to the Department on a monthly basis for progress payment estimates.

8 PAYMENT

Option 1: For a DBB warranty, as a unit price item for HMA during construction,

<u>Pay Item</u>	<u>Pay Unit</u>
Warranted HMA Pavement	TON

Payment is full compensation for furnishing, hauling, mixing, and placing all materials; the QMP and Job Mix Formula; Warranted HMA Pavement; the warranty bond and warranty or maintenance work; traffic control; providing required documentation; and furnishing all labor, tools, equipment, and incidentals to complete the work.

Upon completion of the placement of all asphalt, and prior to final payment, furnish the Department with all required QMP documentation and a final certification for the quantities shipped. The final certification will recapitulate the monthly submittals and show the total of all HMA incorporated into the project.

Option 2: For a DBB warranty, as a unit price for HMA pavement paid during construction and a lump-sum payment for warranty work made at Acceptance of Initial Construction,

<u>Pay Item</u>	<u>Pay Unit</u>
Warranted HMA Pavement	TON
HMA ____ Warranty	LUMP SUM

Payment for the HMA ____ Warranty will be made at Acceptance of Initial Construction. The HMA ____ Warranty lump-sum amount will be full compensation for the warranty bond, maintenance of traffic, and all costs and incidentals associated with warranty work including all materials, labor, and equipment necessary to complete all required warranty work.

Option 3:– For a DB warranty, as a lump sum for both HMA pavement and warranty work,

The Department will make partial progress payments based on the approved schedule of values. Lump-sum payments are full compensation for furnishing, hauling, mixing, and placing all materials; the QMP and Job Mix Formula; compacting mixtures; the warranty bond and warranty or maintenance work; traffic control; providing required documentation; and furnishing all labor, tools, equipment, and incidentals to complete the work.

PAVEMENT PERFORMANCE SPECIFICATION

(DESIGN-BUILD-OPERATE-MAINTAIN)

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for implementation under the design-build-operate-maintain (DBOM) delivery approach.

Users should note that this specification is part of a family of pavement specifications drafted with a specific delivery approach in mind; that is, the recommended performance parameters and design, construction, and postconstruction maintenance requirements included in this specification are intrinsically linked to the roles and responsibilities and risk allocation deemed appropriate for a DBOM project.

These DBOM conventions include

- *Selection of the pavement type and structural design by the Contractor;*
- *Quality management by the Contractor (design, construction, postconstruction maintenance);*
- *Verification testing by the Agency during construction;*
- *Postconstruction maintenance and asset management by the Contractor; and*
- *Postconstruction performance monitoring by the Agency.*

Specification Objectives

This specification has been structured to assume the Contract period is subdivided into

- *A design and construction phase, which commences on the date of Contract Award and ends on the issuance of a construction completion certificate (or similar); and.*
- *A maintenance phase, which commences on the issuance of the construction completion certificate and ends on the expiration of the Contract period, provided that the Contractor has fulfilled all of its contractual obligations by that date. (Note that this specification could also be tailored to include only maintenance-phase requirements if the project does not require an initial construction or rehabilitation effort.)*

This basic framework highlights the defining characteristic of the DBOM approach—the assignment of postconstruction maintenance responsibility and, with that, allocation of whole-life pavement performance risk, to the Contractor. This arrangement allows the Agency to shift its emphasis from the end-result and performance-related acceptance properties relied on in DBB or DB delivery to postconstruction measurement strategies that evaluate the actual performance or condition of the roadway over time.

Commensurate with the degree of risk transferred to the private sector, this specification has been drafted to provide maximum flexibility to the Contractor with respect to design, construction means and methods, and the repair and rehabilitation measures that will be required over the Contract period. At the same time, to ensure that the Contractor's motivations remain aligned with the goals of rapid renewal, the recommended measurement strategies include

- *Performance requirements defined from the road users' perspective, and*

- *Payment mechanisms that place it within the Contractor’s best interest to consider life-cycle costs (LCC) and to provide high-quality construction that will minimize the need for extensive capital investment during the maintenance phase.*

Aside from the recommended payment mechanisms and incentive/disincentive strategies, this specification does not attempt to address the financial models and funding sources (i.e., public versus private equity) that often underlie long-term DBOM contracts. Likewise, the scope of this specification is limited to the performance of the pavement itself. Ancillary items, such as guardrail, lighting, traffic, and signage, are assumed to be addressed elsewhere in the operations or maintenance agreement.

Using This Guide Specification

Note that the requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a comprehensive example that users can adapt to fit the needs of a particular project. Likewise, this specification is intended to be flexible enough to accommodate advances in technology that could affect the performance measurements and values during the life of the Contract.

Commentary included within the specification (as indicated with italic typeface) provides guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw on the information provided as a basis for further modification or development of the specification.

Finally, note that the term “Contractor” as used in this document should be interpreted as that entity given single-point responsibility for the design, construction, operation, and maintenance (and possibly financing) of the work. For a given project, other terms (e.g., Developer, Operator, Concessionaire, or Service Provider) may be more appropriate.

1 GENERAL

The intent of this performance specification is to assign to the Contractor full responsibility for the design, construction, and subsequent management, maintenance, and rehabilitation measures necessary to provide a pavement that meets the Department’s specified performance criteria.

Performance criteria have been established for the following three Contract stages:

1. End of Construction – The End-of-Construction performance measures define the condition to which the pavement must be designed and constructed for the Contractor to achieve a completion certificate signifying the end of the construction phase.
2. Maintenance Period – Maintenance phase performance measures define the condition to which the pavement must be maintained during the Maintenance Period, as defined in Section 6.6.
3. Handback – Handback performance measures define the final condition requirements of the pavement at the end of the Contract Term, as defined in Section 7.1.

Within the limits of the Contract and applicable local, State, and Federal rules and regulations, the Contractor is encouraged to use innovative techniques and materials to meet the specified performance requirements.

1.1 Scope

The Contractor is responsible for

- Design and construction of all pavement sections to meet the specified performance requirements.

If a given project entails rehabilitation of an existing pavement section (rather than construction on a new alignment), this requirement should be modified to include “rehabilitation of the existing pavement to meet the specified service level requirements.”

- All maintenance activities necessary to meet the specified standards during the Contract period.

The specification must clearly establish the extent of the required maintenance activities. For example, clarify if the Contractor is responsible for

- *Maintenance of auxiliary lanes and shoulders, or simply mainline pavement;*
- *Routine maintenance activities, such as vegetation control, litter removal, sign maintenance;*
- *Winter maintenance (i.e., prevention of ice formation; snow and ice removal); and*
- *Providing emergency response vehicles.*

The maintenance requirements included in Section 6 of this specification relate to the performance of the pavement only. It is assumed that routine maintenance of other elements of the facility (e.g., guardrail, pavement markings, traffic signals, signage), would be addressed elsewhere in the operations or maintenance agreement.

Similarly, this specification assumes that operational requirements (e.g., toll collection, issuance of permits for overweight vehicles, coordination with police and other relevant parties regarding overweight or abnormal loads, environmental compliance) would also be addressed elsewhere in the operations or maintenance agreement.

- All rehabilitation measures necessary to meet the specified standards during the Contract period and at Handback.

With regard to specifying rehabilitation requirements, the recommended approach is to allow the Contractor to assess and determine what actions are necessary to comply with the specified performance requirements. This approach will help ensure that the Contractor retains full responsibility for management of the roadway asset during the Contract term. However, if the Agency will allow only certain treatments, these should be identified in the specification.

Although contrary to the principle of paying for performance rather than for prescriptive inputs, it is also possible to require the Contractor to perform a set amount of maintenance and renewal work each year. The exact work activities required could be defined by the Agency in this specification, proposed by the Contractor in its bid, or negotiated at the time of Contract award.

A similar objective could be indirectly accomplished by structuring the payment mechanism (e.g., through an irregular payment profile) to motivate the Contractor to ramp-up services during certain years. Such approaches are generally not recommended given their potential to limit the Contractor’s flexibility and undermine the effectiveness of the risk transfer to the Contractor.

- Self-monitoring of performance and Contract compliance during the Operations and Maintenance Period.

1.2 Period of Performance

To motivate the Contractor to provide high initial construction quality and to perform preventative maintenance in a timely and efficient manner, the Contract term should be of sufficient duration to expose the Contractor to the consequences of its actions (i.e., allow the Contractor to enjoy the profits of high-quality work and to suffer losses due to poor workmanship and planning).

To achieve this objective, the duration should be such that the Contractor performs at least one major rehabilitation of the pavement. (To encourage competition between both flexible and rigid pavements, this would generally require durations of at least 30 to 40 years). If private financing is involved, the period must also be long enough to allow the Contractor to obtain its expected return on investment.

1.3 Goals

Define the ultimate goals of the specification, considering high-level user needs and the goals of rapid renewal (rapid construction, minimal disruption, and long-lasting facilities). This section could also be used to identify any Agency preferences that would not otherwise be explicitly mandated in the specification through performance requirements and the payment structure. For example, the Agency may state as one of its goals, "Minimize the extent and frequency of patching operations through the design and construction of a quality pavement and proactive rehabilitation treatment."

1.4 Definitions

Use this section as necessary to define terms that may not otherwise be included in the Standard Specifications or the Contract General Provisions.

2 STANDARDS AND REFERENCES

Standards, including design and other procedural manuals, may contain prescriptive requirements that could act to limit the Contractor's flexibility and ability to innovate. Therefore, when identifying standards, balance the need for conformance with the Agency's existing facilities and processes (consider, for example, tie-ins to existing facilities, right-of-way—ROW—requirements, environmental issues) against the opportunity to transfer full performance responsibility to the Contractor, particularly given the extent and duration of the Contractor's maintenance and operations responsibility.

2.1 Standards

Unless otherwise stipulated in this specification or as approved by the Department, design, construct, maintain, and operate the pavement in accordance with this performance specification and the relevant requirements of the standards listed, by order of priority, in Table 1.

If the standards conflict, adhere to the standard with the highest priority. If the standards contain an unresolved ambiguity, obtain clarification from the Department prior to proceeding with design or construction.

Use the most current version of each listed standard as of the initial publication date of the RFP unless modified by addendum or change order.

Table 1: Standards for Pavements

Priority	Author or Agency	Title
1		
2		
3		

2.2 References

This subsection may be included if the Agency wishes to identify nonmandatory references that could assist the Contractor's efforts.

The Contractor may consult the references listed in Table 2 for supplementary guidance in designing, constructing, and maintaining the pavement system. These references have no established order of precedence and are not intended to be all-inclusive.

Table 2: References for Pavements

Author or Agency	Title
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3 QUALITY MANAGEMENT PROGRAM

3.1 Contractor's Responsibility for Quality Management

The Contractor shall assume complete responsibility for the quality of the work, which shall extend to the work and products of subcontractors, required fabricators, suppliers, and vendors.

3.1.1 Quality Management Plan

Develop, implement, maintain, and update as necessary, a written Quality Management Plan (QMP) that addresses all stages of the Project, including

- Design,
- Construction, and
- Maintenance.

The QMP shall detail how the Contractor intends to provide quality management for all design, construction, and maintenance elements of the Project, including, but not limited to, design review; document control; change management; communication requirements; sampling, testing, and inspection; environmental monitoring and compliance; and noncompliant work corrective action plans to ensure that

the work conforms to the Contract Documents at the end of construction, during the Maintenance Phase, and at Handback.

During all stages of the Project, work on a particular component shall not begin until the QMP has been completed and prepared for that component of the work.

Make all QMP records available to the Department for inspection and review.

3.1.2 Design Phase

The QMP shall specify procedures for ensuring the quality of all design plans, specifications, reports, calculations, and other design-related documents prepared by the Contractor. All designs, drawings, specifications, and similar documents shall be stamped and signed by a Professional Engineer.

3.1.3 Construction Phase

The QMP shall ensure that the work is constructed in accordance with the design documents. Changes made to the design during construction shall be stamped and signed by a Professional Engineer from the design team. At the end of construction, a Professional Engineer from the design team shall stamp and sign the as-built construction drawings, certifying that the work was constructed in accordance with the design documents.

For all construction materials and products, the QMP shall detail the testing and acceptance program, including the following as a minimum:

1. Names and qualifications of Contractor's personnel who will be conducting the sampling and testing of materials.
2. Material property or characteristics to be measured or inspected.
3. Proposed methods of materials sampling and testing, sample size, and test frequencies.
4. List of quality control parameters and test tolerances used to control the mixture during production, including acceptable tolerances for single test and multiple tests and corrective action.
5. Procedures and requirements for documenting all material certifications, production test reports, quality control charts, equipment certifications and calibrations, and any other design or production-related records.
6. System for controlling nonconforming material, including procedures for identification, isolation, and disposition of such material.

3.1.4 Operations and Maintenance Phase

The QMP shall ensure that the pavement conforms to the required performance criteria during the Maintenance Period.

During the Maintenance Period, annually update plans detailing the monitoring, testing, maintenance, and rehabilitation activities that will be conducted during the upcoming year to ensure that all performance requirements are met. The plans shall include information on scheduling, traffic management, and communications with stakeholders. Refer to Section 6.3 for additional information on required work plans.

Consider requiring as part of the Contractor's quality management responsibilities a process for continual improvement in accordance with ISO 9001 and ISO 9004. Related activities could include identifying performance gaps, setting new performance targets, and developing improvement plans, particularly with regard to incorporating new technologies and performance measures not contemplated at the time of Contract Award.

3.2 Department's Quality Management Role

The Department will verify compliance with the specified performance criteria through inspection and verification tests, audits of the Contractor's results and records, and periodic pavement condition surveys.

4 DESIGN REQUIREMENTS

4.1 General

Perform all pavement engineering activities, including, but not be limited to, the following:

- Pavement/geotechnical investigation,
- Pavement type selection,
- New pavement design and analysis,
- Pavement monitoring and assessment,
- Pavement rehabilitation design, and
- Material selection.

All pavement engineering activities shall be directed, supervised, signed, and sealed by a Professional Engineer, licensed in the State of [-----] with a minimum of [5] years of experience in pavement engineering.

4.2 Pavement Investigation

Perform all geotechnical investigations, testing, research, and analyses necessary to determine and understand the existing surface and subsurface conditions.

Prepare geotechnical engineering reports documenting the assumptions, conditions, and results of the investigations and analyses, including the following:

- Geology of the project area;
- Results from field investigations and laboratory testing, including a discussion of how these results affect the design of the pavement;
- Design and construction parameters resulting from the geotechnical investigation and analyses; and
- Boring logs, laboratory results, calculations, and analyses that support design decisions.

4.3 Pavement Type Selection

Describe how much freedom the Contractor has with regard to pavement type selection. Consider the following questions:

- *Given the duration of the agreement, how much freedom will the Agency give the Contractor to make trade-off decisions regarding investing in design versus long-term maintenance?*
- *Does the pavement type and cross section have to be consistent for the limits of the Contract?*
- *Do shoulder and lane materials have to be the same?*
- *Do the pavement type and cross section have to be consistent for ramps and ramp shoulders?*
- *Should there be any restrictions on pavement type (e.g., flexible, rigid, composite pavement, continuously reinforced concrete pavement—CRCP)?*

The Contractor may design either flexible or rigid pavement sections. All traveled lanes and full shoulders shall be paved. The pavement type and cross section shall be consistent throughout the limits of the Project.

4.4 Pavement Design and Analysis

4.4.1 Design Criteria

Design the pavement structure in accordance with the subsurface information collected in accordance with Section 4.2 and the standards identified in Section 2.1 or other approved alternatives.

Define all additional requirements that could affect the design of the pavement system. For example,

- *Design service life;*
- *Residual life;*
- *Traffic data;*
- *Sustainability;*
- *Subgrade requirements (including improvement strategies);*
- *Environmental regulations;*
- *Drainage requirements;*
- *Tie-ins to existing roadways (e.g., do not disrupt drainage along the subgrade surface);*
- *Future expansion (e.g., design and construction must feasibly allow for future economical expansion through addition of lanes and other elements); and*
- *Different design criteria for mainlines and ramps versus auxiliary lanes and shoulders.*

4.4.2 Design Documentation

In exchange for providing the Contractor flexibility with regard to design and construction decisions, the Agency should require the Contractor to fully report on its design assumptions and decisions.

For both new construction and subsequent preservation and rehabilitation strategies, prepare pavement design reports that include the following items, as a minimum:

- All pertinent design inputs, such as traffic data, soils characteristics, characteristics of the proposed construction materials, environmental conditions, and pavement design life;
- Site plan showing the limits of the roadway covered by the design report;
- Discussion of site conditions that might influence the design and performance of the pavement;
- Discussion of the inputs used to arrive at design recommendations and the rationale used in selecting the recommended design strategy (where applicable, life-cycle management analysis, including the periods for resurfacing, reconstruction, and other rehabilitation measures);
- Pavement design details, including structural layer materials and thicknesses, and typical cross-section drawings;
- Comprehensive construction specifications sufficiently detailed to describe the process or end-result requirements;
- Other considerations used in developing the pavement design(s), including subgrade preparation and stabilization procedures as applicable; and
- For rehabilitation designs, calculated moduli, overlay needs, and existing cross sections.

5 CONSTRUCTION REQUIREMENTS

5.1 General

The Contractor is responsible for providing all management, professional, and technical services; construction quality management; and labor, materials, and equipment necessary to construct the pavement system or reconstruct or rehabilitate the existing facility to a specified service level.

Construction shall conform to the requirements of the design and the acceptance criteria specified in Section 5.3.

Submit all changes to the design documents implemented during construction to the Department for review purposes.

5.2 Traffic Management

Maintain the safe and efficient passage of traffic in the work zone in accordance with *[work zone traffic specification, if applicable]*.

5.3 Acceptance Requirements

Initial acceptance of the pavement at the end of construction is important to ensure that the basic scope of work was completed in accordance with the plans. The acceptance parameters in Table 3 provide a basis for evaluating whether the pavement meets the specified design and performance requirements at completion of construction for the required level of service. Note

that final Handback would not occur until after completion of the Maintenance Period (see Section 7).

Agencies should modify this section as needed to suit their specific construction closeout procedures.

The Department and the Contractor will jointly review all completed work, or a portion thereof, as determined by the Department, to evaluate conformance with the design, QMP requirements, and performance requirements identified in Table 3. If the work does not meet Contract requirements, perform the necessary corrections at no additional cost to the Department. Initial acceptance will occur when the Department confirms in writing that the work meets Contract requirements. Initial acceptance will be documented by a Construction Completion Certificate jointly executed by the Department and the Contractor.

Table 3: Acceptance Criteria (End of Construction)

Parameter ⁽¹⁾	Measurement Method (Test Method/device)	Target/Lot Requirements
Geometric Requirements		
Cross-Slope & Superelevation		± 0.2% of design rate
Width		≥ design width
Ride Quality	Inertial Profiler Measurement and Continuous Roughness Reporting Measure pavement profile in both wheel paths simultaneously, parallel to the right edge of the lane, and in the direction of travel for each lane.	IRI ≤ 80 in./mi with 0.1-mi baselength for full payment Localized Roughness: IRI ≤ 125 in./mi with 25-ft baselength
Skid Resistance (Friction)	ASTM E274 ASTM E524 ASTM E501 Collect a friction number (FN) data test point every 3/10 of a lane-mile for each travel lane, at a minimum testing frequency.	FN40S ≥ 40 FN40R ≥ 45 Average per lane or as per Department requirements
Surface Distress	ASTM D6433, Pavement Condition Index (PCI) Survey or equivalent project-level visual survey	PCI > 80

1. Agencies may also wish to consider having the Contractor perform falling weight deflectometer (FWD) testing to provide a baseline value of structural capacity.

Note: IRI = international roughness index.

The initial acceptance or any prior inspection, acceptance, or approval by the Department will not diminish the Contractor's responsibility for maintenance. The Department may accept the work and begin the maintenance period, excluding any area requiring corrective work, to accommodate seasonal limitations or staged construction.

5.3.1 Submittal of Construction Documents

Within 15 days after the date of the Completion Certificate *[or equivalent certification]*, submit to the Department a signed certification by an authorized representative of the Contractor that the materials and construction are in general conformance to the pavement design, QMP, and the Contract Documents. Include the following documentation with the certification:

1. The final pavement details and drawings for the *[constructed roadways, side roads, widenings, entrances, ramps, turn tapers, snowplow turnarounds, and truck pull-offs]*.
2. A list of all construction specifications used by the Contractor and the locations where the specifications were used.
3. A list of material sources and all QMP test results with comparison to material specification limits *(in hard copy and digital form)*.

5.3.2 Access to Construction Documents

Within 24 hours of written notice, provide the Department full access at any time to all original and copies of inspection records; test results; control charts; and testing and production facilities, as necessary for the Department to audit the Contractor's adherence to the requirements of the design, QMP, and Contract Documents. For purposes of this section, test results include all original supporting readings, measurements, laboratory worksheets, and calculations. When original records are not stored at the Contractor's field office, make copies of original inspection records, test results, control charts and other QMP documents available for viewing at the Contractor's field office for the Contract within 1 Business Day of receiving a written request from the Department.

Retain and provide access to all inspection records, test results, and control charts for the duration of the maintenance period. This requirement shall survive after the date of Completion Certificate.

6 MAINTENANCE REQUIREMENTS

6.1 General

The Contractor is responsible for providing all management, supervision, and professional and technical services; quality management; and labor, materials, utilities, and equipment for performing all of the duties and obligations to maintain and rehabilitate/renew the pavement during the Maintenance Period.

The performance requirements specified in Section 6.6 represent the requirements that shall be met throughout the Maintenance Period. The Contractor shall monitor roadway conditions and ensure compliance with the performance requirements throughout the Maintenance Period.

Where specific operational and performance requirements are not provided, the Contractor is expected to operate and maintain the roadway to a standard of safety, effectiveness, and operation equal to, or better than, what is currently being provided on other Department roadways of similar age and type.

The Contractor and Department understand that new methods, procedures, and products may present opportunities for improved pavement management and design during the Maintenance Period. Both

parties mutually agree to consider using new technologies and methods, provided that they are agreed to by the Contractor and the Department in writing prior to use.

6.2 Scope

The specification must clearly establish the extent of the required maintenance activities. For example, is the Contractor responsible for

- *Maintenance of auxiliary lanes and shoulders, or simply mainline pavement?*
- *Subgrade and subbase?*
- *Routine maintenance activities, such as vegetation control, litter removal, and sign maintenance?*
- *Winter maintenance?*
- *Providing emergency response vehicles?*

Maintenance work shall include all investigations, design, quality management, layout and survey, rehabilitation, documentation, and all other actions necessary to maintain the specified standards for the roadway over the Maintenance Period.

The specification must also explicitly define what “the roadway” encompasses. For example,

For the purposes of this provision, the roadway shall consist of everything within the right-of-way, whether manmade or natural, including mainline pavement, ramps, earthworks, and [XXX]. It shall also include ancillary works, such as drainage channels, berms, and erosion and sediment control measures that were constructed as part of the project but which extend outside the right-of-way. Specifically excluded are [XXX].

6.3 Work Plans

To maximize the effectiveness of the risk transfer to the Contractor, the specification should provide the Contractor maximum flexibility with regard to defining, optimizing, and performing on a timely basis the physical interventions needed in the short, medium, and long term. In other words, the specification should allow the Contractor to independently define (a) what to do, (b) where to do it, (c) how to do it, and (d) when to do it. In exchange for this flexibility, the Contractor should keep the Agency fully apprised of its pavement maintenance plans through the submittal of periodic work plans.

6.3.1 General

The Contractor is solely responsible for programming maintenance works. In developing its maintenance program, the Contractor shall strive to

- Promote whole-life, maintenance works that ensure compliance with the performance criteria;
- Optimize the level of service and investment; and
- Minimize disruption to road users.

6.3.2 Annual Plan

Within [30 days] of the Department's acceptance of the constructed work, submit a Maintenance Work Plan and Schedule that defines all preventative and routine maintenance work to be performed in a typical year, with activities logically grouped into packages that can be performed with minimal inconvenience to others and that will accommodate planned rehabilitation efforts.

Define the work packages in terms of the following items:

- Geographical boundaries [*Boundaries should be chosen so that a task can be completed within a maximum of <X> weeks.*];
- Type of task or activity [*Include activities even if the necessity or extent can only be estimated—for example, repairing erosion damage.*]; and
- Person or team who will perform the work.

Include a schedule indicating the planned start and duration of each work package. Where applicable, the plan shall include a detailed proposal related to traffic accommodation. The proposal shall indicate all planned lane closures and the planned rate of progress. The Department has the right to reject the plan if, at the sole discretion of the Department, unacceptable interference to road users or the local community will result.

Update and submit the plan to the Department by [*July 1*] of each year or as otherwise necessary.

Program routine maintenance work so as to minimize interference with rehabilitation work.

The Department's acceptance of the Maintenance Work Plan and Schedule carries no contractual significance other than to indicate that the Department would be satisfied if the Contractor carries out work in accordance with the plan. Such acceptance in no way relieves the Department of its right to direct the Contractor to vary the plan, should circumstances so require.

Circumstances that may require modifications to the plan include the following:

- The Contractor falls behind with the planned work;
- To accommodate scheduled rehabilitation work;
- To prevent or limit hazards to workers or road users;
- To prevent or limit damage to the work; and
- To accommodate ideal climatic conditions for plant growth or maintenance methods.

6.3.3 Rolling 5-Year Program

Prepare and submit, on [*month*] of each year, a work plan and schedule detailing the location and extent of all treatments proposed over the following 5 years. The program shall provide a credible indication of the work required over the following 5 years, irrespective of the Contract completion date.

6.4 Compliance Monitoring and Inspection

Critical to the success of the DBOM approach is the Contractor's responsibility for self-monitoring of pavement conditions. The information provided through the monitoring effort will allow the Contractor to define and plan all physical interventions required to ensure that the performance targets never fall below the indicated thresholds. Ideally, the Agency should not have to dictate the type and volume of road maintenance works to be carried out. Instead, the Contractor should have a vested interest in determining the best course of action to achieve the required performance levels. This strategy is expected to lead not only to significant efficiency gains but also to technological innovation.

6.4.1 General

Develop and implement a program of monitoring, inspection, and evaluations to ensure compliance with the performance requirements specified in Section 6.6. As a minimum, this program shall

- Verify the continuing safety of the facility for road users;
- Monitor performance of the facility with respect to the requirements in Section 6.6;
- Identify defects to be included for repair within the Annual Plan;
- Establish priorities for future maintenance operations and renewal work; and
- Be responsive to all reports and complaints received from road users or other third parties.

Any monitoring performed by the Department will in no way relieve the Contractor of these responsibilities.

6.4.2 Self-Audit Process

The Contractor shall establish and operate a *[monthly]* monitoring system that defines how it will assess compliance with the performance parameters specified in Section 6.6. At a minimum, this system shall identify

- The auditor *[an independent entity]*.
- The auditing process, including the measuring and assessment system, to be used.
- Selection of the audit section(s). An auditable section shall include all travel lanes of the roadway operating in one direction of approximately *[X miles]* in length. Prepare plans identifying the auditable section and submit to the Department for review and comment.
- The performance requirements, measurement procedures, threshold values at which maintenance is required, and subsequent maintenance to address noted deficiencies. As part of the Annual Plan submittal, the Contractor shall propose amendments to the measurement methods as necessary to comply with Good Industry Practice.

- Response times to mitigate hazards, permanently remedy, and permanently repair noncompliance items.

The auditing system must be fully implemented within *[X days]* of the beginning of the Maintenance Period.

6.4.3 Annual Condition Survey

Conduct an annual survey of pavement condition of *[the entire facility, including mainlines and ramps]*, performed using automated condition survey equipment to verify compliance with the criteria identified in Section 6.6.

6.4.4 Routine Observations

During the performance of roadway inspections, emergency maintenance, or at any other time the Contractor's personnel are traveling on the roadway, such personnel shall observe conditions of the roadway surface, appurtenances, and the right-of-way for the purpose of identifying deficiencies and scheduling the work required to maintain compliance with the performance requirements.

6.4.5 Department's Audit Inspections

The Department will perform physical inspections, audit the records generated from the Contractor's inspections, or both, on a random sample basis.

The Department will provide the Contractor with 24 hours' prior notice of the intent to perform an Audit Inspection, whether as a stand-alone inspection or accompanying the Contractor's inspection.

The Contractor shall provide reasonable opportunity and access to allow the Department's Audit Inspections to proceed. The Department will supply the Contractor with its monitoring and inspection results.

6.5 Documentation and Reporting

6.5.1 Inspection Records

Compile a database of rehabilitation works carried out over the entire pavement. The database shall provide a complete history of all rehabilitation activities, including the location, date, and nature of the work.

The Contractor and Department will agree on an acceptable format for maintenance records, recognizing that the parties may from time to time agree on alternative acceptable formats to account for advances and other developments in information systems.

Or,

[Maintenance records shall be compatible with the Department's statewide asset inventory and condition assessments.]

The Contractor shall retain all records in good order for the duration of the Contract in such form as to be capable of audit by the Department. Obsolete hard copies may be disposed of with the Department’s prior written approval.

6.5.2 Reports

Prepare and submit the following reports to provide project status information and to demonstrate compliance with the performance requirements.

Table 4: Reporting Requirements

Type	Required Information	Frequency
Monthly Report	<ul style="list-style-type: none"> • Work performed over the previous period • Progress on renewal activities included in the Annual Plan • Compliance with performance parameters • Updated cash flow—the actual percentage of the annual Contract value expended against each work category and the predicted cash flow for the balance of the year • Customer service reports, including identification of all inquiries and complaints received, as well as the responses provided and actions taken • Traffic management measures taken (e.g., lane closures) during the reporting period 	By [3 rd] working day of the month following
Incident Response Report (as necessary)	<ul style="list-style-type: none"> • Location and extent of all known crashes on the roadway 	Include with monthly report
Annual Report	<ul style="list-style-type: none"> • Work performed over the previous 12-month period • Progress on renewal activities • Compliance with performance parameters • Updated cashflow—the actual percentage of the annual Contract value expended against each work category and the predicted cash flow for the balance of the year 	Yearly by <insert date>
Nonconformity Report	<ul style="list-style-type: none"> • Unique reference for the nonconformity • Description of which requirement is not being met and in what way • Likely cause (what aspects of the Maintenance or Quality Management Plans are not functioning properly) 	Within [3] days of identifying a nonconformity

Table 4: Reporting Requirements

Type	Required Information	Frequency
Corrective Action Report	<ul style="list-style-type: none"> • Unique reference for the nonconformity • Description of which requirement is not being met and in what way • Identification of the primary cause of the nonconformity • Detailed corrective action plan, including planned correction date and milestones and individual(s) responsible for the plan • Method to be used to indicate successful correction of the nonconformity • Modifications to be made to the Maintenance and Quality Management Plans to prevent reoccurrence of the nonconformity 	Within [7] days of identifying a nonconformity

Upon Department request, provide written documentation or other supporting information as the Department may reasonably require to verify and audit the information contained in a report.

If the Department and Contractor do not agree on the information contained in a report, the matter will be determined in accordance with the Dispute Resolution procedure specified in *[Section 8 or Article X of the General Conditions]*.

6.6 Operational Performance Requirements

Operational performance requirements ensure that the Contractor maintains the pavement in a smooth, stable, durable, and safe condition for road users.

6.6.1 Standards

The pavement shall meet the standards specified in Table 5 during the Maintenance Period.

Failure to meet a performance requirement shall be deemed a defect. Whenever a defect is identified, either by the Contractor’s inspections, by the Department, or by any third party, the Contractor shall act to remedy and repair the defect in accordance with Section 6.6.2.

Requirements in the table will be reviewed *[annually]* by the Department and Contractor for conformance with Good Industry Practice.

Table 5: Performance Criteria (Maintenance Phase)

Performance Parameters ⁽¹⁾	Measurement Method	Target	Tolerance	Response to Defects ⁽²⁾	
				Hazard Mitigation	Permanent Repair
Geometric Requirements Cross-Slope & Superelevation Width		±1.0% of design rate ≥ design width	- -		
Smoothness (ride quality)	Inertial profiler	IRI ≤ 95 inch/mi average per 1-mi segment	+15 in./mi	24 hours	6 months
Skid Resistance (Friction) ⁽³⁾	Locked wheel trailer (ASTM E274) and a smooth tire (ASTM E524)	Average of 35 per lane with no individual value for three consecutive test sites less than 25	-	24 hours	2 months
Rutting (for flexible pavement) Segment average Localized deficiency	High-speed rut bar	0.25 in. 1.0 in.	+ 0.25 in. -	24 hours	6 months
Surface Distress	ASTM D6433, Pavement Condition Index (PCI) survey or equivalent project-level visual survey	PCI > 80	-	24 hours	1 month
Structural Capacity ⁽⁴⁾	Falling weight deflectometer (FWD)	Target may be expressed as a deflection value (e.g., in.) or as residual life (e.g., in years or remaining equivalent single axle load—ESAL—loads)	-	-	-

- The identified parameters relate to the performance of the pavement only. The Agency may wish to expand this table to address ancillary items such as pavement markings, guardrail, signage, and drainage.*
- Specification of response times can significantly influence the cost of the work. Corrective action periods should be challenging, but realistic, without entailing costs that do not provide value for the money. Therefore, when establishing the appropriate performance response times, avoid requiring excessive standby of resources by considering the time needed to (1) identify the defect, (2) determine the required corrective action, (3) schedule the necessary work, (4) mobilize the necessary forces, and (5) perform the work.*
- Failure to meet the skid resistance target should not be interpreted as a safety hazard, just that the Contractor is not in compliance with the Contract requirements.*
- FWD-based deflection measurements, along with thickness measurements, could be used to determine structural capacity. FWD provides a full deflection basin, allowing calculation of multiple moduli and structural capacity. In contrast, other existing nondestructive testing (NDT) devices, such as a Portable Seismic Pavement Analyzer (PSPA), provide just a single modulus value. Continuous deflection-based NDT devices remain under development, but would provide a high-speed, network-level method to identify anomalies and localized areas that warrant further testing using more precise and reliable NDT point measurements such as FWD.*

6.6.2 Allowable Tolerances

Maintain the roadway to conform to the allowable tolerances specified in Table 5 for individual performance requirements, subject to the following:

- If measurements indicate that the roadway no longer complies with the performance requirements but falls within the allowable tolerance(s), the Contractor will have the option of correcting the roadway such that it conforms to the performance requirements or foregoing the repairs and incurring Payment Adjustments as specified in Section 9. The option of foregoing repairs does not apply at the Handback of the roadway to the Department at the end of the Maintenance Period.
- If measurements indicate that the pavement no longer complies with the performance requirements and also exceeds any allowable tolerances, repair the roadway so that it conforms to the performance requirements.

For performance requirements that do not include an allowable tolerance, complete such work as required to achieve full compliance with the performance requirements.

In addition to the Contractor's regular inspection and measurements, the Department may undertake reviews and measurements of the roadway at any time and will advise the Contractor of noncompliance issues.

6.7 Maintenance Activities

6.7.1 General

Perform maintenance work on the facility to minimize the occurrence of defects.

Perform repair and rehabilitation services when (a) required by the approved Work Plan and (b) when a performance requirement is not met and the required level of performance cannot be achieved by means of planned maintenance.

6.7.2 Routine and Planned Maintenance

Routine maintenance of the pavement shall include, but is not be limited to, *[prompt repairs of potholes, concrete joints, drains; patching; crack sealing, etc.]*

Perform temporary repairs and patching with appropriate materials and workmanship to withstand traffic loading until a permanent repair can be made.

Rehabilitation measures, other than crack sealing and patching operations—such as fog sprays, seals, and overlays, or combinations of such measures—shall not be performed at intervals more frequent than every 5 years on any portion of the road.

Large-scale rehabilitation measures such as fog sprays, seals, and overlays, or combinations thereof, shall be performed in working sections not exceeding *[XX]* in length, with a separation between working sections of at least *[XX]*. At any time, there shall be no more than *[XX]*.

6.7.3 Unplanned Maintenance or Remedial Action

In response to an identified noncompliance issue, investigate and inspect the underlying cause or origin of the deficiency before commencing repair work. Prepare and submit for the Department's review a Remedial Action Plan recommending the most appropriate treatment to restore the asset to the required condition.

Repair all pavement surfaces to match the profile, grades, and cross-slopes of the roadway. Ensure repair areas are free of depressions or humps and there is no separation at adjacent undisturbed pavement joints.

6.7.4 Emergency Repairs

If the pavement requires immediate remedial action for the safety of the traveling public and the Contractor has not performed the remedial work within 24 hours, the Department may perform the remedial work with other forces at the Contractor's expense. Remedial work performed by others will not alter the Contractor's obligations under this agreement.

6.7.5 Maintenance and Protection of Traffic

The Agency may wish to use lane rental fees or similar techniques to motivate the Contractor to minimize traffic disruption.

Perform maintenance activities in a manner that recognizes that the safety of the public and maintenance workers, as well as the convenience of the traveling public, are of prime importance.

Traffic disruption shall be minimized such that traffic maintains a free-flow condition and an acceptable level of service.

For night work, propose lighting and safety provisions.

The number of lane closures shall be kept to an absolute minimum.

Minimize delay to road users and, to the extent that the Contractor is able to control, users of related transportation facilities.

6.7.6 Safety

The Contractor shall provide adequate protection to ensure road user and worker safety during maintenance and rehabilitation operations.

7 HANDBACK

7.1 Handback Requirements

At the end of the Contract Term, when the Department assumes responsibility for the roadway, the pavement surface, including lanes and shoulders, should be free of all evidence of structural weakness, pitting, potholes, raveling, segregation, scaling, delamination, localized roughness, and all other

deficiencies. All cracks and joints should be sealed with a sealant acceptable to the Department. The pavement surface should be free and clear of dirt, sand, and other debris.

In addition, the pavement shall meet or exceed the requirements specified in Table 6.

Table 6: Handback Requirement for Pavement Condition

Parameter	Value
Cross-Slope & Superelevation	< 0.5% deviation from design
Ride Quality	IRI < 110 in./mi
Skid Resistance (Friction)	35 SN (skid number)
Structural Capacity ⁽¹⁾	May be expressed as a modulus value (e.g., in ksi), deflection, or as residual life (e.g., in years or remaining ESAL loads)

1. *As an alternative solution for meeting structural capacity, in the final year preceding Handback, the Agency may require the Contractor to provide an overlay sufficient to handle 10 years of traffic loading.*

Upon the Contract expiration date, the pavement shall be free from all deficiencies identified during the Handback inspections.

7.2 Handback Inspections

The approach at Handback is for the Contractor and the Agency to work to jointly agree on the capital investments that the Contractor will have to perform before the expiration of the Maintenance Period. This process should involve a series of specific inspections conducted during the last 5 years prior to Handback to ensure that sufficient time and resources are allocated to performing the required remedial work.

The Contractor and Department will jointly carry out the following Handback inspections to determine what work (including major rehabilitation work as necessary) will be required to achieve the Handback requirements.

- The Initial Handback Inspection shall take place at a time, specified by the Department following consultation with the Contractor, that is at least [57] months and not more than [63] months prior to the end of the Contract Term.
- The Second Handback Inspection shall take place at a time, specified by the Department following consultation with the Contractor, that is at least [15] months and not more than [18] months prior to the end of the Contract Term.
- The Third Handback Inspection shall take place at a time, specified by the Department following consultation with the Contractor, that is not more than [1] month prior to the end of the Contract Term.

7.3 Work Plan and Schedule to Achieve Handback Requirements

Prepare a comprehensive work plan and schedule designed to ensure that the pavement will meet the Handback Requirements specified in Section 7.1 at the end of the Contract Term. Submit a plan and schedule to the Department for review and approval within

- [60] days of the Initial Handback Inspection
- [30] days of the Second Handback Inspection
- [7] days of the Third Handback Inspection

The content and format of the work plan and schedule shall be similar to that described in Section 6.3.

7.4 Holdback (Retainage)

If the Contractor fails to deliver a work plan and schedule in accordance with Section 7.3, or fails to diligently carry out the work plan in accordance with the schedule, the Department may retain from amounts thereafter becoming payable to the Contractor an amount that the Department, following consultation with the Contractor, considers to be sufficient to achieve the Handback Requirements should the Contractor fail to do so.

The Department will release the Holdback, without interest, to the Contractor as the work is performed, but not more than once monthly. If the Contractor fails to achieve the Handback Requirements by the end of the Contract Term (or, if the Term expires other than during the Construction Season, within 90 days after the next Construction Season begins), the Department may release the Contractor from its obligation to achieve the Handback Requirements and retain the remaining balance of the Holdback as liquidated damages.

The Contractor may, at any time, request the release of the remaining balance of the Holdback upon delivering to the Department an irrevocable, unconditional letter of credit in the amount of the remaining balance of the Holdback.

8 DISPUTE RESOLUTION

Include a dispute resolution provision if not otherwise included in the Contract General Conditions.

9 BASIS OF PAYMENT

9.1 Construction Phase

Payment is full compensation for all items required to design and construct the pavement as described within the Project Scope, including materials, labor, equipment, and incidentals. All costs, including engineering, construction, quality management, traffic maintenance, and documentation are considered to be included in the lump-sum price for the pavement. The Department will make partial progress payments based on the approved schedule of values to complete the required scope of work.

Under a DBOM delivery approach, payment for design and construction services may involve periodic payments during construction or could use funding mechanisms with which the Contractor (or Concessionaire under a public-private partnership agreement) will finance the costs of design and construction and be compensated through real tolls, shadow tolls, or other periodic payments during the operation and maintenance (O&M) period. These periodic payments may include a monthly capital payment for construction or major rehabilitation and a monthly O&M payment.

Given the postconstruction maintenance term, it is generally not advisable to include payment adjustments for quality at the end of construction, as payment adjustments are often included as part of an O&M payment scheme.

If timely completion of the construction phase is an issue, the Department may impose incentives or disincentives for the late completion of the construction phase of the Contract. However, the structure of the payment terms for the maintenance phase of the Contract may also be used to inherently reward or penalize the Contractor for early or late completion of the initial construction phase, without the use of an incentive/disincentive provision. By not beginning the scheduled monthly payments until after issuance of the Completion Certificate, and not adjusting the overall Contract period (construction plus maintenance) as a result of the early or late completion of the initial construction phase, the Contract would in effect impose a penalty for late completion and a corresponding bonus for early completion.

9.2 Operation and Maintenance Period

If the O&M term is fixed by the Agency, the Contractor may propose (as a factor in selection) an annual payment schedule for the entire term of the agreement. In this case, the Contractor may use whatever pavement type or design standards (within certain limits) it believes are appropriate or necessary to achieve the required performance standards. The Agency will evaluate the proposed payment schedule on a net present worth basis to determine the proposal offering the best value to the Agency. Note that if construction-phase services were financed by the Contractor but will not be compensated through toll revenue, the monthly payment may also include payment for the cost of construction and financing.

The Department will pay the Contractor a monthly payment equivalent to 1/12 of the yearly planned maintenance cost for the applicable Maintenance Period year based on the approved annual payment schedule. The Contractor will receive the monthly agreed upon payment regardless of the actual quantity of work performed and services provided. The scheduled monthly payment shall be deemed full compensation for all inspection, testing, documentation, design, maintenance, construction, and reconstruction required to fulfill the maintenance requirements.

To be entitled to the full monthly payment for maintenance services, the Contractor must ensure that the roads under Contract comply with the specified performance requirements defined in Table 5. It is possible that the Contractor will have to carry out a large amount of work to meet the required performance levels during some months and very little work during other months. However, the monthly payment remains the same as long as the required performance levels are met. The risk to the Contractor is that it may underestimate the cost or the timing of expenditures needed to maintain the pavement to the required performance for the entire maintenance period. It is also possible under this scenario that the Contractor could receive pay adjustments based on heavier than expected usage/volume, a deduction for not meeting performance service levels, or escalation/de-escalation as noted below.

The scheduled monthly payments will be fixed for the duration of the Contract period, with the exception of the following potential adjustments:

- Adjustments to compensate for heavier than expected truck traffic or traffic volume.
- Withholding of, or reduced, payment resulting from the Contractor's failure to comply with, or delay in complying with, the service level requirements of the Contract.

- Adjustment to compensate for the effects of inflation or deflation based on changes in the [XX] Cost Index.
- Approved extra work.

Payments will be calculated in accordance with the following:

$$MP = MUP_m + MAP_m - MD_m - \sum DD_m$$

where

MP = Monthly Payment;

MUP_m = A provisional monthly usage payment based on a Usage Payment (UP) for the Contract year. The UP is adjusted or indexed on an annual basis for the actual number of heavy trucks compared with projected number of trucks for the Contract year;

MAP_m = A monthly availability payment based on planned level of service considering both conformance to performance thresholds and availability of lanes;

MD_m = Monthly deductions based on failure to meet performance thresholds for a segment of the roadway; and

DD_m = A daily deduction in a given month for closing a lane or roadway segment to make repairs or mitigate events in excess of a defined grace period.

The magnitude of payment adjustments related to performance criteria depends on

- *Importance of a particular parameter to the Agency;*
- *Extent to which the safety of the public is compromised; and*
- *Incidence and persistence of the particular nonconformity (e.g., use of ratchet mechanisms).*

In some cases, the Agency may provide incentives for exceeding certain performance thresholds. Inflation or escalation may also be evaluated on an annual basis with adjustments (increases or decreases) for specific materials or other costs.

The monthly and daily deductions will be assessed based on the following tables:

Table 7 shows two approaches for calculating deductions—one method (A) based on a direct monetary deduction and the second (B) a point-based deduction system. In both cases the reductions may be ratcheted up based on not meeting specified time limits.

If during the O&M phase, performance is measured through a point-based deduction system, the Contractor must use its best efforts to meet each of the specified performance targets identified in Table 5. If in any maintenance year, the total positive points (i.e., the total points accumulated in each month for failing to achieve a target) exceed the threshold, the Contractor must provide applicable credits as determined by the Agency.

Points will be assessed and compared with total point thresholds on a monthly basis. At the end of each year, the total points accrued for that year will be aggregated. If the total points for that year equal or exceed the total point threshold relevant to that year, the Contractor must, within 60 days, calculate the credit due the Agency and fees payable for the roadway. The applicable

credit will be the amount calculated by multiplying the total points for any year by \$1,000 (indexed annually based on CPI). Negative points can be set off against positive points at the end of the year. Negative points do not carry forward to the next year.

Table 7: Application of Payment Deductions

Performance Criteria	Conditions for Payment Reductions	(A) Direct Payment Reduction (\$/lane-mile)	(B) Points
Geometric Requirements <ul style="list-style-type: none"> • Cross-Slope & Superelevation • Width 	If during operating period superelevation and cross-slope rates exceed $\pm 1\%$ of the design rates for any 1-mi evaluation section, fix in specified time period after grace period.	<ul style="list-style-type: none"> • \$2,000/week (or 20% of monthly sum for evaluation section) for first 60 days after 60-day grace period • \$6,000/week or any partial week thereafter 	10 points for every occurrence outside Target Value
Smoothness (Ride Quality)	If IRI is in excess of 10% specified threshold (110 in./mi) for any 1-mi evaluation section, fix in specified time period after grace period.	<ul style="list-style-type: none"> • \$2,000/week (or 20% of monthly sum for evaluation section) for first 60 days after 60-day grace period • \$6,000/week or any partial week thereafter 	10 points for every occurrence outside Target Value
Skid Resistance (Friction)	If areas of pavement exhibit visual appearance of polishing or flushing/bleeding, test these areas for skid resistance. If the skid number ≤ 30 , fix within the specified time period.	<ul style="list-style-type: none"> • \$2,000/week (or 20% of monthly sum for evaluation section) for first 60 days after 60-day grace period • \$6,000/week or any partial week thereafter 	10 points for every occurrence outside Target Value
Rutting (for flexible pavement) <ul style="list-style-type: none"> • Segment average • Localized deficiency 	If sections of pavement exhibit visual appearance of rutting, test sections for rutting using high-speed rut bar. If rutting is ≥ 0.5 inch for segment average, or ≥ 1.0 for localized areas, fix within the specified time period.	<ul style="list-style-type: none"> • \$2,000/week (or 20% of monthly sum for evaluation section) for first 60 days after 60-day grace period • \$6,000/week or any partial week thereafter 	10 points for every occurrence outside Target Value
Surface Distress	If areas of pavement exhibit visual appearance of surface distress based on ASTM D6433, Pavement Condition Index (PCI) survey standards, test for PCI (or an equivalent standard). If the $PCI \geq 85$, submit a remediation plan within 30 days and fix within specified time period.	<ul style="list-style-type: none"> • For remediation plan, \$1,000/week after 30 days until remediation plan is submitted • For repairs, \$2,000/week for first 60 days after 60-day grace period • \$6,000/week or any partial week thereafter 	10 points for every occurrence outside Target Value

Performance Criteria	Conditions for Payment Reductions	(A) Direct Payment Reduction (\$/lane-mile)	(B) Points
Lane Closures	<p>If a lane or multiple lanes for a section of the roadway are closed for traffic incidents, structural damage, maintenance work, weather, or other causes, daily fees will be assessed after a grace period based on a \$1,000 standard rate per section per day or portion thereof and the time required for reopening lanes. The grace periods are for the following events.</p> <ul style="list-style-type: none"> • Traffic incidents: 1-hour grace period • Structural damage: 7 days provided immediate steps are taken to warn of hazard • Weather: 2 hours after cessation of storm • Routine maintenance: 30 minutes for temporary or slow-moving work during off-peak hours 	<ul style="list-style-type: none"> • 1 times the standard rate for off-peak hours • 10 times the standard rate for peak hours 	10 points per lane per hour for every occurrence outside Target Values

CEMENT CONCRETE PAVEMENT

PERFORMANCE SPECIFICATION

(DESIGN-BID-BUILD)

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for implementation under a design-bid-build (DBB) delivery approach.

Users should note that this specification is part of a family of pavement specifications drafted with a specific delivery approach in mind; that is, the recommended performance parameters and material and construction requirements included in this specification are intrinsically linked to the roles and responsibilities and risk allocation deemed appropriate for a DBB project. These DBB conventions include the following:

- *Selection of the pavement type by the Agency (or by Contractor if life-cycle cost, LCC, analysis is provided at bid);*
- *Structural design by the Agency;*
- *Mix design by the Contractor (but usually per Agency guidelines or standards);*
- *Quality management by the Contractor;*
- *Verification testing and acceptance at the end of construction by the Agency; and*
- *Postconstruction maintenance by the Agency.*

Specification Objectives

Given those assumptions, if a performance specification is defined as one that describes “how the finished product should perform over time” (TRC E-C137), one could argue that, absent a warranty provision, use of the DBB approach limits the extent to which a Contractor could be held responsible for performance over time. The goal, therefore, of this performance specification is not to monitor and evaluate Contractor performance over time (as may be the case for a performance warranty or a specified operations and maintenance period) but to

- *Focus on material properties and construction practices deemed to have the most effect on long-term performance;*
- *Use quality management and acceptance criteria that more closely correlate to performance; and*
- *Incorporate financial incentives/disincentives to promote enhanced quality or durability.*

In addition to these performance goals, this specification attempts to incorporate, to the extent possible under the DBB delivery approach, concepts that will promote the goals of rapid renewal (i.e., accelerate construction, minimize disruption, and achieve a long-lasting pavement). To this end, prescriptive requirements have been relaxed if (1) placing such requirements under the Contractor’s control could help save time and/or minimize disruption and (2) measurement of the performance parameters at the end of construction will provide adequate assurance that the condition the prescriptive element was intended to prevent did not, and ideally, will not, occur.

Using This Guide Specification

The requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a comprehensive example of the possible performance requirements that could be used to promote the construction of long-lasting pavements under the DBB delivery approach. From this menu of requirements, users should select those that best fit the needs of their particular project or program, bearing in

mind that certain barriers or gaps may preclude the immediate implementation of all of the proposed parameters and test methods. For example, a performance measure may be technically valid but difficult to implement because of a need for specialized equipment or expertise, a lack of standardized test methods, absence of historical data for calibration of design or predictive models, or similar obstacles.

To help identify and address such gaps, consider each performance requirement in the context of the following questions:

- *Can a particular parameter be measured and evaluated using existing technology?*
- *In comparison with other testing techniques (or the use of method specifications), is the measurement and testing economical? Is a major capital investment required?*
- *Does the measurement technique require advanced training or a high skill level from technicians?*
- *Would a typical contractor know how to control its materials and processes to meet a particular performance standard?*
- *Is there sufficient experience or historical data to properly calibrate design or predictive models?*

Although specific answers to those questions may vary by Agency, they generally point to three tiers of performance specifications for concrete pavement, ranging from minimal departure from current practice to a substantial shift in practice and organizational culture that would require technological advancement and improved understanding of long-term material behavior.

- **Tier 1** requirements do not require a substantial departure from current practice, yet place more emphasis on properties known to affect durability, such as air content, and encourage the use of nondestructive testing (NDT) techniques such as maturity meters and thickness probes as a rapid renewal consideration.
- **Tier 2** requirements incorporate more performance-oriented parameters, such as permeability and air quality, for which test methods may be currently available, but which would require further advancement or refinement to provide the repeatability and accuracy needed for acceptance purposes.

To implement other Tier 2 requirements, some investment may be necessary for contractors to acquire the necessary knowledge, skills, and equipment to fulfill their obligations under a performance specification without passing on excessive risk pricing to the Agency. For example, if noise reduction is an agency goal, it would be possible to develop a functional parameter based on the noise generated from pavement-tire interaction, as measured using on-board sound intensity (OBSI). However, until industry gains more understanding about how to modify its standard means and methods to meet a certain decibel level, it may be more cost-effective to simply use a prescriptive texturing specification to accomplish the same objective.

- **Tier 3** requirements assume improved understanding of long-term material behavior as well as advances in technology, particularly in the area of NDT, which could allow for the inclusion of acceptance parameters that better reflect the future performance and design life of the pavement.

In general, the three tiers represent a progression toward parameters and test methods that are more indicative of in-place pavement performance. When selecting the appropriate tier for a given project or program, users should balance project needs against available technology and resources, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and industry's appetite for assuming performance risk.

To denote these tiers, the numbers 1, 2, and/or 3 will appear in the right-hand margin beside a particular requirement, as applicable. If no such number appears, consider the requirement to be common to all tiers. Commentary is also included within the specification (as indicated with italic typeface) to provide additional guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw on the information provided as a basis for further modification or development of the specification.

In implementing this specification, Agencies are further encouraged to require the Contractor to develop and adhere to a comprehensive Quality Management Plan (QMP). A sample general provision addressing the roles and responsibilities for quality management is included within the family of guide specifications developed under the SHRP 2 R07 project.

1 DESCRIPTION

Construct a cement concrete pavement [*consisting of normal or high early-strength (HES) cement concrete pavement, plain, reinforced or continuously reinforced concrete pavement*] on a prepared base and foundation.

Provide a Quality Management Plan (QMP) and perform all sampling, testing, and inspection necessary to control and assure the quality of the work in accordance with the QMP. The Department, acting in an oversight role, will conduct verification sampling and testing and independent assurance.

The Contractor's preparation of a formal QMP is an integral component of this performance specification. A QMP requirement allows the Agency to reduce prescriptive requirements in exchange for the Contractor's development and adherence to a detailed plan of how it intends to complete the work and meet the performance requirements.

2 MATERIALS

To prepare the Materials section, one approach would be to refer to the applicable sections in the Agency's Standard Specifications. The Standard Specifications typically contain explicit requirements restricting materials selection based on the Agency's past experience. In this manner, the Agency can be confident of receiving a product similar to what it has always received. A possible drawback to this approach is the lost opportunity associated with using alternative materials or sources that could result in superior performance or time or cost savings.

It is therefore important to carefully consider the extent to which the specification needs to prescribe basic material properties. For example,

- *Should materials conform to specific Agency, ASTM, or AASHTO standards or test methods?*
- *Should any restrictions be applied to material components [e.g., testing for reactive aggregates, coarse aggregate polished stone value (PSV), and aggregate abrasion value (AAV)], since these characteristics can have an adverse effect after grinding operations?*

If the end-result parameters included in the specification will not in and of themselves assure the Agency that the constructed pavement will meet the desired short-term and long-term performance expectations, more prescriptive materials requirements may be necessary. (Note that this strategy is in contrast to the increased latitude that should be given to the Contractor under a long-term warranty or operations and maintenance agreement, in which case the Contractor would be assuming more risk for performance over time and would thus be more inclined to investigate other materials options that, despite higher initial costs, may prove to be more economical when viewed over the duration of the Contractor's performance responsibility.)

If not already a part of the Agency's standard acceptance program, consider allowing prequalification of sources/suppliers and acceptance by certification. In keeping with the goals of rapid renewal, such provisions can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations. For example, consider allowing the Contractor to incorporate the following materials into the work by submitting manufacturer's certifications that substantiate that each shipment conforms to the specified quality requirements:

- *Cement;*
- *Supplementary Cementitious Materials;*
- *Admixtures;*
- *Joint Seals and Fillers;*
- *Curing Compound and Evaporation Retarders;*
- *Epoxy (for drilling and anchoring steel); and*
- *Reinforcement (dowel bars, tie bars, mat reinforcement).*

Similarly, aggregate sources (if Agency preapproved sources are not used) may be qualified prior to construction by verifying results related to the following properties:

- *Soundness,*
- *Hardness,*
- *Polishing resistance,*
- *Abrasion resistance,*
- *Freeze–thaw durability,*
- *Alkali–aggregate reactivity,*
- *Absorption, and*
- *Specific gravity.*

Evaluate material quality before and during construction in accordance with the approved QMP. Reject all nonconforming materials and replace with suitable materials.

3 CONSTRUCTION REQUIREMENTS

Under DBB delivery, the Agency's acceptance of the work at the end of construction will release the Contractor from further responsibility for performance. The Agency's confidence in the ability of the parameters measured at the end of construction to predict future performance will therefore control the degree to which an Agency can relax its standard construction requirements.

Today's technology and understanding of cement concrete behavior will likely not allow substantial departure from standard practices. However, should advances in technology, particularly in the area of nondestructive testing (NDT) techniques, increase the level of confidence in end-result parameters, it may be possible to eliminate certain requirements (e.g., those related to weather or seasonal restrictions, equipment, mixing, joints) in the interest of rapid renewal. In this case, the Construction Requirements section should refer to the Standard Specifications and emphasize all changes to traditional requirements, as follows.

Conform to the requirements of [*Standard Specification XXX*] and the exceptions noted below.

3.1 Mixture Design

Develop and submit for the Department’s review a cement concrete mixture design in accordance with *[Standard Specification XXX]* and *[AASHTO M 157]* along with documentation indicating that the proposed mixture design meets the criteria specified in Table 1.

If an Agency does not have batch plant certification processes in place, consider requiring National Ready Mixed Concrete Association (NRMCA) Plant Certification according to the NRMCA Certification of Ready Mixed Concrete Production Facilities Quality Control Manual.

Table 1: Mixture Properties

Design Parameter	Test Method ⁽¹⁾	Value
Compressive Strength	ASTM C39	
Flexural Strength	ASTM C78	
Freeze-Thaw Resistance	ASTM C666	
Air Content ⁽²⁾	ASTM C231 (Pressure method)	1
Air Quality ⁽²⁾	AVA Testing	2 3
Permeability ⁽³⁾	ASTM C1202 (Chloride Ion Penetration)	2
	Oxygen Permeability Index	3

- The test methods identified are provided for guidance only. If an Agency has its own standard test methods for measuring these properties, specify those methods instead.*
- Air content can be determined through conventional (volumetric or pressure) test methods; however, an issue with these methods is that samples are typically taken when delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated. Also, the pressure test provides air content but does not provide an indication of the air void system (i.e., spacing and volume). A preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) or for hardened concrete through petrographic analysis of polished thin sections taken from cores (ASTM C457). The AVA test, though not as widely accepted by industry, is a more sensitive test, and test results can be obtained in time to make adjustments in the mix during production and placement.*
- Although permeability is a critical durability indicator, some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. The chloride ion penetration test (ASTM C1202) is the most widely used for structural concrete; however, it does not directly measure concrete permeability. What it does measure is concrete resistivity, which has been shown to have a fair correlation to concrete permeability. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.*

If the Contractor is choosing its own aggregate instead of using preapproved sources, also require verification of alkali-aggregate reactivity resistance (ASTM C1260).

3.2 Equipment

Consider the extent to which the specification needs to prescribe equipment requirements (e.g., haul trucks, paver type, and mixing plant). For example, can paver requirements be eliminated if the specification includes a performance requirement related to skid resistance and/or ride quality? Consider allowing equipment that may be nonstandard (e.g., dowel bar inserters) if the Contractor can demonstrate its performance on a test strip.

3.3 Weather Limitations

Generally, it is advisable to define “cold weather” and “hot weather” conditions and limitations for material and material placement, as well as mix temperature properties for each condition.

3.4 Joints

When reviewing the Contractor’s QMP, ensure that consideration has been given to any unique situations (e.g., longitudinal joints that do not fall in the wheel paths).

3.5 Texturing

Consider allowing the Contractor to choose either a prescribed texturing technique or its own texturing technique as long as it can achieve a specified texture depth or skid resistance value.

3.6 Opening to Traffic

Consider allowing the Contractor to open the pavement to traffic after a specified concrete strength (compressive or flexural) has been achieved, rather than after a set number of days following placement. Allowing the Contractor to open the pavement to traffic earlier will facilitate rapid renewal and encourage the Contractor to develop mixture designs that will achieve the necessary performance requirements while also allowing them to open the pavement to traffic sooner.

4 QUALITY MANAGEMENT PROGRAM

This specification holds the Contractor responsible for performing tests used strictly for process control as well as tests that may be used in the Agency’s acceptance process. The Agency in turn should perform verification testing of select parameters. Although this approach may represent a departure from the traditional manner in which an Agency allocates responsibility for various quality management functions, it is consistent with the degree of risk assumed by the Contractor for performance of the work. Greater oversight by Agency personnel may add time to the project and conflict with the goals of rapid renewal.

4.1 Contractor’s Responsibility for Quality Management

The requirements included in this Section 4.1 assume the Contract includes a separate provision related to development and implementation of a QMP that defines general requirements related to the Contractor’s quality management personnel and organizational structure, documentation and reporting requirements, and procedures related to nonconforming work, corrective action, and similar matters. If such requirements are not otherwise addressed in the Contract’s General Conditions, note that a sample general provision addressing quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Note that the Agency should review the Contractor's QMP submittal to ensure it complies with these and other Contract requirements. If the Agency disagrees with elements of the QMP, it should raise these issues with the Contractor and seek resolution. The Agency should not "approve" the Contractor's QMP, as approval could be construed as assuming responsibility for the plan's content.

Assume responsibility for the quality of the work, including work performed or provided by subcontractors, suppliers, and vendors.

Perform all quality management activities described in *[the Agency's General Provision for Quality Management]*, including the additional requirements specific to cement concrete pavement construction as defined in this Section 4.1.

4.1.1 Contractor Testing

The approach taken in this section is to establish the minimum testing requirements that the Contractor's QMP must contain related to cement concrete pavement construction. The intent is to provide the Contractor some latitude with respect to developing a project-specific QMP while also ensuring that the Agency's minimum standards are met. These minimum requirements can also serve as guidance to bidders as they prepare a cost proposal for the work.

A possible disadvantage to this approach is that the Contractor may view these requirements not as a minimum but as all that is necessary to provide adequate quality management. If a best-value procurement process will be used to award the Contract, the Agency should consider including the proposers' project-specific QMP, or relevant portions thereof, as part of the selection criteria.

As part of the QMP to be prepared, submitted, and implemented in accordance with *[the Agency's General Provision for Quality Management]*, include, as a minimum, the sampling and testing requirements specified in Table 2, as well as all other inspections and tests the Contractor deems necessary to ensure the quality of the finished pavement.

Keep the Department apprised of upcoming testing activities to allow the Department to schedule the verification and independent assurance activities described in Section 4.2. If verified as described in Section 4.2.1, the Department may use the Contractor's test results for acceptance.

Various QMP requirements are included in Table 2 for the specifier's consideration, not all of which will necessarily be appropriate or beneficial for a given project or program. Agencies may wish to include or exclude requirements based on the capabilities of local industry (including materials suppliers and testing firms), the project's needs and goals, associated costs, and similar factors. Commentary included within the table itself provides rationale for including certain parameters. Test methods and frequencies are provided for illustrative purposes only and should be modified based on Agency practices or project requirements.

Table 2: Minimum QMP Requirements for Cement Concrete Pavement

Parameter	Test Method	Frequency
A. Materials		
Aggregate		
Source verification		
Gradation ⁽¹⁾	ASTM C33	
Fine aggregate fineness	ASTM C136	
Coarse aggregate shape & texture	ASTM D3398	
Fine aggregate shape & texture	ASTM D3398	
Cleanliness	ASTM C33 / ASTM C142	
Moisture content	ASTM C70 / ASTM C566	
Cementitious material	ASTM C150	
Admixtures	Certification	
Reinforcement	Certification	

1. *Gradation control improves workability, reduces shrinkage (due to less paste content), and contributes to durability. For colder climates and higher-volume roadways, for which gradation control is particularly important, consider offering the Contractor an incentive to provide a well-graded aggregate mix.*

B. Fresh Concrete

Unit Weight ⁽²⁾	ASTM C138	
Slump	ASTM C43	
Water content		
Placement temperature	ASTM C1064	
Evaporation rate	ACI 308R	
Thickness ⁽³⁾	Probe	

Air content ^(4, 5)	Pressure Method (ASTM C231)	1
Air quality ^(4, 5)	Air Void Analyzer	2 3

2. *Monitoring unit weight, a property not commonly measured today, would reveal mix design changes, thus eliminating the need for (or at least reducing the frequency of) more labor-intensive testing, such as for freeze-thaw resistance.*

3. *Measuring thickness is standard practice for (portland cement concrete) PCC pavements. To facilitate rapid renewal, the Contractor may choose to measure thickness by probing the fresh concrete to eliminate the need for coring except when verification is required. As an alternative (or supplement) to coring, NDT methods for verification may include GPR (ground-penetrating radar) with limited coring or MIT (magnetic imaging tomography) Scan T2.*

4. *The presence of closely spaced air voids is a key factor in improving the freeze-thaw resistance of concrete. In measuring air content/quality, consideration should be given to where measurements are taken, as changes in air content/quality will occur as concrete passes through the paver. Samples should be collected either behind the paver or in front of the paver with an assumed amount of air loss through the paver that is then verified through routine tests in front of and behind the paver.*

5. *Although the volumetric or pressure test is the standard method for measuring air content, it has the following limitations:*

- *Samples are typically taken when materials are delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated.*
- *A pressure test only provides information on the total volume of air; it cannot characterize the air void system (i.e.*

Parameter	Test Method	Frequency
<i>spacing and volume).</i>		
<i>The preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) (or for hardened concrete through petrographic analysis of polished thin sections). The AVA can characterize the distribution of air voids in a timely manner (within 30 minutes), allowing adjustments to be made in the concrete batching process to ensure air voids are spaced properly.</i>		

C. Hardened Concrete

Compressive Strength ⁽⁶⁾	ASTM C1074 (Maturity) ⁽⁷⁾	
Flexural Strength ⁽⁸⁾	ASTM C78	
Freeze-Thaw Resistance ⁽⁹⁾	ASTM C666	
Permeability ⁽¹⁰⁾		2
Chloride Ion Penetration	ASTM C1202	
Oxygen Permeability Index		3

- It has become standard practice to measure the compressive strength of concrete (though flexural strength would provide a more direct indication of design strength). Strength is more critical for CRCP (continuously reinforced concrete pavement) than jointed concrete. Too high a strength value could be detrimental for CRCP (i.e., an upper bound is needed).*
- Instead of testing cores or field-cured cylinders, maturity meters would provide a nondestructive way to estimate in-place concrete strength. Maturity methods are based on the concept that concrete strength is directly related to its age and temperature history, and that samples of a given mixture will attain equal strengths if they attain equal values of maturity index. Before any field measurements are taken, the strength-maturity relationship of a particular mix must be determined in the laboratory based on either compressive or flexural strength. Such maturity curves can then be used to correlate field maturity readings—taken from sensors embedded within the in situ mat about every 500 ft (or 1,000 yd² of volume)—to cylinder strength.*
- Measuring flexural strength is the preferred method for monitoring strength, as it provides a more direct comparison to design strength. However, testing can be cumbersome due to the need to fabricate and test beams for third-point loading.*
- If unit weight testing is used to monitor for mix design changes, the frequency of freeze-thaw testing may be reduced accordingly.*
- Although permeability is a critical durability indicator (particularly for cold or marine climates where salts are present in the air or the pavements), some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. The chloride ion penetration test (ASTM C1202) is the most widely used for structural concrete, though it actually measures concrete resistivity, not permeability. As an economical alternative to ASTM C1202, some Agencies have investigated the use of a surface resistivity meter to measure concrete’s resistance to chloride ion penetration. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.*

D. In-place pavement

Steel Placement		
Dowel Placement/Alignment ⁽¹¹⁾		
Smoothness ⁽¹²⁾	Straightedge	
Cross-slope		

- Dowel placement and alignment is important for proper consolidation around dowels and to avoid cracking near joints. There are currently no standard tests for dowel alignment, though one manufacturer has provided a proprietary magnetic imaging tomography (MIT) test device to measure dowel depth and alignment.*

Parameter	Test Method	Frequency
<p>12. <i>For process control, a straightedge has been the traditional method for determining pavement smoothness. A SHRP 2 research project (R06E) is developing technology for evaluating real-time smoothness behind the paver to achieve improved smoothness as part of process control during construction. For acceptance, a concrete profilograph is still the norm, but the trend is toward using inertial profilers and an IRI (international roughness index) standard.</i></p>		

4.1.2 Production and Placement Procedures

In exchange for eliminating prescriptive requirements related to materials selection and construction methods, the Agency should require the Contractor to describe how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, ordering, handling, placing, finishing, and curing of concrete) will affect the in-place properties and performance of the work, and that the Contractor has planned the work and allocated its resources accordingly.

Include descriptions of the following in the QMP:

1. Certified mixing plant requirements, including calibration procedures for all meters, scales, and other measuring and recording devices.

If an Agency does not have batch plant certification processes in place, consider requiring National Ready Mixed Concrete Association (NRMCA) Plant Certification according to the NRMCA Certification of Ready Mixed Concrete Production Facilities Quality Control Manual.

2. Laboratory location, testing equipment, procedures for calibration, and training standards for personnel (e.g., National Institute for Certification in Engineering Technologies—NICET— or local standard).

Ensure that the laboratory and equipment will be maintained for the duration of the project.

3. Paving plan, including general staging and sequencing of operations.

When reviewing the Contractor's paving plan, consider the following:

- *Is the sequence compatible with the maintenance of traffic (MOT)?*
- *Can the Contractor's equipment accommodate the proposed sequence of operations (consider size and number of equipment)?*
- *How will driveways, cross streets, and other leave-outs be handled?*

4. Steel and dowel bar placement (for CRCP).

The Contractor should describe how it will install dowel bars (baskets or inserters) and secure them during concrete placement operations.

5. Concrete placement operations, including hauling, spreading, consolidating, and texturing.

When reviewing this portion of the Contractor's QMP, consider the following:

- *Is the proposed equipment appropriate for the project?*

- *Is hauling equipment appropriate given the likely haul distance, haul time, and weather conditions?*
- *Is equipment appropriate for spreading material in front of the paver (e.g., chute, belt)?*
- *Has the Contractor included a contingency plan for equipment break downs (e.g., if paver breaks down, will they sawcut and create a joint?)*
- *Does the Contractor intend to monitor consolidation to prevent overvibration?*
- *What type of texturing will be applied? How will it be applied?*

6. Methods to control alignment and profile.

Consider allowing use of stringless paving techniques as a rapid renewal consideration.

7. Joint installation procedures.

Consider the Contractor's plans for the following:

- *Sawcutting (type of equipment, timing, use of HIPERPAV);*
- *Constructing end-of-day joints and any leave-outs; and*
- *Sealing joints (type of material and timing).*

8. Finishing procedures.

Consider the adequacy of the Contractor's plan for finishing behind the paver (e.g., type of equipment and procedures to be used). Will the auto-float be sufficient or will some hand-finishing be necessary?

9. Materials and methods related to curing, including equipment, timing, and application rate (for curing compounds).

10. Procedures related to cold weather placement and night work (as applicable).

11. Contingency plan for inclement weather.

12. Plan for early opening to traffic, if applicable.

Note that this list will vary based on how much freedom the Agency allows the Contractor with respect to the construction requirements prescribed in Section 3.

4.2 Department's Quality Management Responsibilities

The Department may conduct quality inspections, audits of the Contractor's results and records, and verification sampling and testing on any element of the work to ensure compliance with the QMP and the Contract requirements.

4.2.1 Verification Sampling and Testing

Even though the Contractor may assume more responsibility for inspection and testing under a performance specification, this does not relieve the Agency of its responsibility to perform some level of independent sampling and verification testing to meet the intent of 23 CFR 637. Verification testing should be performed to validate any Contractor testing used in the Agency's acceptance decision. The Agency may also wish to verify certain material or mixture parameters

that could identify possible performance issues that would not otherwise be detected through end-result acceptance testing.

The Department will perform verification testing as described in Table 3 to validate the Contractor’s test results.

The Department will notify the Contractor before sampling so the Contractor can observe.

The Department will sample randomly at locations independent of the Contractor’s sampling and testing. In all cases, the Department will conduct the verification tests in a separate laboratory and with separate equipment from the Contractor’s tests.

Table 3: Department Verification Testing

Parameter ⁽¹⁾	Test Method ^(1, 2)	Sampling Location ⁽²⁾	Frequency ⁽³⁾
Unit Weight	ASTM C138	At the paver	
Air content or Air quality	Pressure method (ASTM C231)	Behind the paver	1
	Hardened air (ASTM C457)	Cores from constructed pavement	
Air Quality	AVA	Behind the paver	2 3
Strength	ASTM C1074 Maturity	At the paver or field-cured specimens	
Thickness ⁽⁴⁾	Probes ASTM C174 (cores)	Probe. If deficient, take cores from constructed pavement.	
Permeability	ASTM C1202 (Chloride Ion Penetration Resistivity)	At the paver or cores from constructed pavement	2
	Oxygen Permeability Index		3

1. Durability-related parameters, including air quality, permeability, and unit weight, are the best indicators of pavement performance and would be important for verification testing. The Agency should also test for strength and thickness as part of verification testing.
2. For rapid renewal, when rapid construction is the primary objective, the Agency can verify that parameters (unit weight, air quality, strength, thickness, and permeability) meet performance requirements through nondestructive testing (e.g., taking cylinders at the paver for strength and permeability, or probing the fresh concrete behind the paver for thickness). If testing results indicate deficient or marginal results (e.g., thickness +/- 1/2" of plan thickness), the Agency should require cores for verification.
3. Frequency should be based on project-specific conditions and ideally should provide the ability to identify statistically valid differences between Agency and Contractor test results. A minimum Agency rate of 10% of the testing rate of the Contractor has been used as a rule of thumb.
4. From a long-term performance perspective, some practitioners conclude that thickness should not be an acceptance parameter, but it still should be monitored as part of the Contractor’s quality management and the Agency’s verification

Parameter ⁽¹⁾	Test Method ^(1, 2)	Sampling Location ⁽²⁾	Frequency ⁽³⁾
<i>testing to ensure that the minimum design thickness is met for structural integrity. This can be accomplished using a probe on fresh concrete and requiring repair of any Sublot not meeting the minimum requirement. For high-volume, high-profile roadways, an Agency may decide that drilled cores are necessary for acceptance.</i>			

The Department may increase the frequency of verification testing at start-up or as necessary to validate the quality of the materials. The Department may reduce the frequency based on a history of satisfactory Contractor or material performance.

If verification tests indicate conformance with the specifications, no further action is required. If verification tests indicate nonconformance with the specifications, the Department and Contractor will jointly investigate any testing discrepancies. The investigation may include additional testing as well as review and observation of both the Department’s and Contractor’s sampling and testing procedures and equipment. Both parties will document all investigative work.

When comparing Agency and Contractor test results, it is important to compare both the variances and the means. The tests most often used are the F-test (comparison of variances) and the t-test (comparison of means), which are used together.

4.2.2 Independent Assurance Testing

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing activities are being performed by qualified personnel using proper procedures and properly functioning and calibrated equipment. The Department will perform IA testing using personnel other than those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor’s sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

4.3 Conflict Resolution

If a dispute between some aspect of the Contractor’s and the Department’s testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third-party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third-party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [\[Standard Specification Section XXX\]](#).

5 ACCEPTANCE REQUIREMENTS

Acceptance requirements provide a method for determining the degree to which the as-constructed pavement meets the specification and for determining appropriate payment. Acceptance is based on the measurement of properties that control the quality and performance of the pavement.

The quality acceptance limits presented in this section assume use of a percent within limits (PWL) approach. The PWL method encourages Contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging Contractors to produce a more uniform product.

Alternatively, Agencies may prefer to adopt a more rational approach for adjusting payment that reflects the life-cycle cost (LCC) of the as-constructed pavement. Existing performance-related specification (PRS) methodology and simulation software (PaveSpec 3.0), as described in FHWA-RD-98-155, would allow users to develop a composite pay factor adjustment based on the difference between the estimated LCC of the as-designed pavement and the estimated LCC of the as-constructed pavement.

5.1 General

The Department will accept the finished pavement based on the Contractor's test methods and results unless it is shown through the Department's verification testing or the conflict resolution process that the Contractor's tests are in error.

5.2 Quality Characteristics and Acceptance Limits

The Department will accept the completed pavement in accordance with the criteria defined in Table 4 and properties measured and verified during construction.

Various acceptance parameters are listed in Table 4 for the specifier's consideration. To meet the rapid renewal goal of providing long-lasting facilities, the recommendation is to emphasize parameters that relate to the durability of the in-place concrete (such as permeability and air content). Such parameters would allow the Agency to eliminate or relax prescriptive requirements related to the use of specific materials (e.g., fly ash or air entraining admixtures), proportions (e.g., minimum cement content or maximum water-to-cement—w/c—ratio) or construction operations that are often included in today's method specifications. Although such prescriptive requirements have a historical basis in producing durable concrete, they can act as a barrier to innovation.

Not all parameters shown will necessarily be appropriate or beneficial for any given project. Agencies may wish to include or exclude requirements based on the project's needs and goals, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and similar factors.

Likewise, the choice of measurement strategy should reflect project goals and conditions. If the predominant objective is rapid construction, then measurement procedures used for acceptance should focus on rapid test methods, whether based on laboratory or field-cured specimens or, ideally, nondestructive field testing. If the predominant objective is longevity, the measurement

and test procedures for durability-related parameters may have to rely to a greater extent on in situ drilled concrete core tests.

Commentary provided within the table itself provides rationale for including certain parameters and, as necessary, offers additional information related to test methods and establishing targets and tolerances.

The quality acceptance limits presented within the table assume use of a percent within limits (PWL) approach for adjusting payment. The PWL is determined using Table 5 and the instructions in Section 5.3. A Lot is defined as the surface area (or quantity) of pavement placed in a single production day, or no more than 7,500 yd². Each Lot should be divided into no less than three and no more than eight Sublots. The quality index (QI) is calculated using the Lot sample standard deviation, S_v , and Upper Quality Limit (UQL) and Lower Quality Limit (LQL). For additional information on establishing quality acceptance limits, refer to FHWA Publication No. FHWA-RD-02-095.

Alternatively, if a PRS approach is used, target means and standard deviations should be specified. Existing PRS research (as reflected in *PaveSpec 3.0* simulation software) supports pay adjustments for the following quality characteristics: concrete strength, slab thickness, initial smoothness, entrained air content, and percent consolidation around dowel bars.

Table 4: Acceptance Criteria

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Surface Distresses ⁽¹⁾	ASTM D6433, Pavement Condition Index (PCI) Survey or equivalent project-level visual survey	PCI > 80 Evaluate 100% of pavement surface.	The Department will evaluate deficiencies on a case-by-case basis to determine if a repair will be required. ⁽²⁾
<p>1. Surface distress can be in the form of cracking, faulting, corner breaks or blow-ups, and spalling resulting from such things as excessive loading, thermal changes, moisture damage, or poor consolidation at joints. It can also occur in the form of map cracking and scaling, which can result from chemical reactivity or aggregate degradation. Surface distress is somewhat related to roughness (i.e., the more cracks and disintegration, the rougher the pavement will be) as well as structural integrity (surface distress can be a sign of impending or current structural problems).</p> <p>2. Surface distress should not be part of a payment adjustment decision, but must meet a pass/fail target for acceptance.</p>			
Thickness ⁽³⁾	ASTM C174, Cores	Minimum Design Thickness minus ¼ in. Minimum 3 tests per Sublot	PWL 85% full payment LQL = Design Thickness minus ¼ in. ⁽⁴⁾ Repair any Sublot that does not meet the LQL.
	Probing ⁽⁵⁾		
	MIT Scan T2 ⁽⁶⁾		
	GPR ⁽⁷⁾		
<p>3. From a long-term performance perspective, some practitioners conclude that thickness should not be an acceptance parameter, but it still should be monitored as part of the Contractor's quality management and the Agency's verification testing to ensure that the minimum design thickness is met for structural integrity. This can be accomplished using a probe</p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p><i>on fresh concrete and requiring repair of any Sublot not meeting the minimum requirement.</i></p> <p>4. <i>For CRCP designs, thickness may also require an upper limit for reinforcing steel design requirements (e.g., UQL = Design Thickness plus 1 in.)</i></p> <p>5. <i>Thickness is traditionally measured using cores, despite not necessarily being conducive to rapid construction/testing. For high-volume, high-profile roadways, an Agency may decide that drilled cores are necessary for acceptance. However, for low-volume roadways, consider using probing data for acceptance and excluding thickness from the payment adjustment formula.</i></p> <p>6. <i>Although used primarily for research purposes, the MIT (magnetic imaging tomography) Scan T2 provides another NDT alternative for measuring thickness. The device provides walking speed point measurements of reasonable accuracy—within 1/10 in. for 13 in. of thickness. The MIT Scan T2 requires a seated plate under the slab.</i></p> <p>7. <i>As an alternative to destructive core sampling, consider using NDT devices, such as GPR (ground-penetrating radar) with limited coring. GPR would provide the <u>advantage</u> of</i></p> <ul style="list-style-type: none"> • <i>Continuous measurements taken at highway speed, and</i> • <i>Reasonable accuracy and repeatability—within 10% for thickness (though not as accurate as cores).</i> <p><i>Some possible limitations associated with this technology include</i></p> <ul style="list-style-type: none"> • <i>Cost of equipment (approximately \$30,000–\$40,000 for the unit),</i> • <i>Some processing time needed to analyze data and estimate material properties, and</i> • <i>Relatively high technician skill-level for data analysis.</i> 			
Strength ⁽⁸⁾	ASTM C1074 (Maturity Method) ⁽⁹⁾	Minimum 5 tests (maturity readings) per Lot	PWL 85% full payment LQL = Minimum Design Strength minus 300 psi
<p>8. <i>Measuring flexural strength is the preferred method for monitoring strength, as it provides a more direct comparison to design strength. However, testing is cumbersome due to the need to fabricate and test beams for third-point loading. It has therefore become standard practice to measure the compressive strength of concrete (though flexural strength would provide a more direct indication of design strength). Strength is more critical for CRCP (continuously reinforced concrete pavement) than jointed concrete. Too high a strength value could be detrimental for CRCP (i.e., an upper bound is needed).</i></p> <p>9. <i>Instead of testing cores or field-cured cylinders, maturity meters would provide a nondestructive way to estimate in-place concrete strength. Maturity methods are based on the concept that concrete strength is directly related to its age and temperature history, and that samples of a given mixture will attain equal strengths if they attain equal values of maturity index. Before any field measurements are taken, the strength-maturity relationship of a particular mix must be determined in the laboratory based on either compressive or flexural strength. Such maturity curves can then be used to correlate field maturity readings—taken from sensors embedded within the in situ mat about every 500 ft (or 1,000 yd² of volume)—to cylinder strength.</i></p>			
Permeability ^(10, 11) (by resistivity methods)	ASTM C1202, Chloride Ion Penetration Resistivity (accelerated test)	2,000–4,000 coulombs (max) at 28 days Testing frequency per Department standard requirements (minimum two tests per day and after any mixture modifications)	PWL 85% full payment UQL = 4,000 coulombs at 28 days
	Surface Resistivity Meter	KOhm-cm	
Permeability ^(10, 11)	Oxygen Permeability Index		

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p>10. Although permeability is a critical durability indicator, particularly for cold or marine climates in which salts are present in the air or the pavements, some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. Some practitioners caution that permeability should not be incorporated into a payment adjustment system until a more rapid and repeatable test becomes standard practice.</p> <p>11. ASTM C1202 is the most widely used test for measuring permeability (though it actually measures resistivity, not permeability). Agencies have also investigated the use of a surface resistivity meter to measure concrete's resistance to chloride ion penetration as an economical and time-saving alternative to ASTM C1202. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.</p>			
Air Content ⁽¹²⁾	ASTM C231, Air Content by Pressure Method ⁽¹³⁾	Per Department standard requirements	PWL 85% full payment UQL = Target + 2 % LQL = Target - 1 %
Air Quality	Air Void Analyzer ⁽¹⁴⁾		
	ASTM C457, Hardened air from cores ⁽¹⁵⁾		
<p>12. The presence of closely spaced air voids is a key factor in improving the freeze-thaw resistance of concrete. In measuring air content/quality, consideration should be given to where measurements are taken, as changes in air content/quality will occur as concrete passes through the paver. Samples should be collected either behind the paver or in front of the paver with an assumed amount of air loss through the paver that is then verified through routine tests in front of and behind the paver.</p> <p>13. Although the volumetric or pressure test is the standard method for measuring air content, it has the following limitations:</p> <ul style="list-style-type: none"> • Samples are typically taken when materials are delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated. • A pressure test only provides information on the total volume of air; it cannot characterize the air void system (i.e., spacing and volume). <p>The preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) (or for hardened concrete through petrographic analysis of polished thin sections).</p> <p>14. If rapid construction is the primary objective, acceptance can be based on AVA testing using fresh concrete samples at the paver.</p> <p>15. If durability is the Agency's primary objective, acceptance should be based on hardened air content determined from cores removed from the constructed pavement. The Contractor may use pressure or AVA testing for monitoring air content during construction, and final acceptance will be based on hardened concrete cores using petrographic analysis of thin sections.</p>			



Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Ride Quality ⁽¹⁶⁾	AASHTO M 328, Inertial Profiler Measurement and Continuous Roughness Reporting ⁽¹⁷⁾ Measure pavement profile in both wheel paths simultaneously, parallel to the right edge of the lane, and in the direction of travel for each lane.	IRI \leq 67 in./mi with 0.1-mi baselength for full payment Localized Roughness: IRI \leq 125 in./mi with 25-ft baselength	PWL 85% full payment based on Continuous Roughness histogram from ProVAL

16. Ride quality is considered a measure of quality for the installed product and an indirect indicator of pavement performance. Continuous roughness reporting is recommended for acceptance and pay adjustments.
17. Different measurement strategies have been used depending on the application. Many Agencies use a tiered system based on road type or type of work (e.g., overlay versus reconstruction). For acceptance, a concrete profilograph is still the norm for many Agencies, but the trend is toward using an IRI (international roughness index) standard. An inertial profiler-based measurement is recommended to facilitate rapid renewal and to provide a better indication of the road user's perception of rideability. However, smoothness measurement using a profilograph may be necessary if an Agency does not have equipment and thresholds established for IRI.

Skid Resistance ⁽¹⁸⁾	ASTM E274 ASTM E524 ASTM E501 Collect a friction number (FN) data test point every 3/10 of a lane-mile for each travel lane, at a minimum testing frequency	FN40S \geq 40 FN40R \geq 45 Evaluate 100% of pavement surface. Average per lane or as per Department requirements.	PWL 85% full payment
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18. Skid resistance relates to aggregate properties (polishing resistance) and surface texture. It is a safety concern for higher-volume roadways with wet weather conditions. Some Agencies will restrict the use of softer aggregates in the mix design for certain projects or conditions to ensure adequate friction is obtained. More extensive use of diamond grinding concrete pavements has raised the importance of friction or skid resistance as a performance parameter. This parameter is most applicable as an acceptance and a functional performance requirement monitored under a warranty specification, but it may also be appropriate for nonwarranted pavement when safety (skid resistance) is a key end-result requirement for a PCC pavement.

Transverse tining is a standard and relatively inexpensive method to achieve higher-friction surfaces, particularly for wet weather conditions on high-speed concrete pavements. A disadvantage of transverse tining is that it often causes undesirable noise emissions, which has led to the use of alternative tining patterns. The requirement to meet skid resistance must also be balanced with the requirement to meet noise intensity thresholds if noise abatement is a project objective.

Skid resistance and texture depth are related but not necessarily directly correlated. Although specifying skid resistance is preferred, if an Agency does not have test procedures or acceptable threshold values for skid resistance, then texture depth, spacing, and patterning could serve as a performance measure until proper thresholds and test procedures for skid resistance are established. If the Contractor is given greater flexibility in selecting the texturing technique and aggregate properties, Skid Resistance or Texture Depth requirements will ensure that the texturing method will meet the functional requirements for safety and noise.

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Joint Deficiencies ⁽¹⁹⁾	Visual survey (includes raveling, spalling, faulting, and seal damage/integrity)	No joint deficiencies permitted	The Department will evaluate deficiencies on a case-by-case basis to determine if a repair will be required.
<p>19. Joint deficiency encompasses unacceptable spalling or raveling along the joint, as well as defective or improperly installed joint seals.</p> <p>An additional performance measure for acceptance is joint performance, as measured through load transfer efficiency (LTE) of the joint and dowel bar alignment. LTE can be measured through standard deflection testing (e.g., falling weight deflectometer, FWD), but consideration must be given to the age of the pavement, season, and time of testing. If tested at too early an age, cracks may not yet be formed at joint locations. If tested in warmer seasons or time of day, LTE may be artificially high and not representative of the true average LTE.</p>			
Load Transfer Efficiency (LTE) ⁽²⁰⁾	Deflection Testing (e.g., FWD)	Evaluate 5% of the joints in each Lot per Department random sampling protocols. LTE ≥ 90%	PWL 85% full payment LQL = 80% LTE
<p>20. If evaluating LTE, consideration must be given to the age of the pavement, season, and time of testing. If pavement is tested at too early an age, cracks may not yet be formed at joint locations. If tested in warmer seasons or time of day, LTE may be artificially high and not representative of the true average LTE.</p>			
Dowel Bar Alignment ⁽²¹⁾	GPR or MIT Scan	Evaluate 5% of the joints in each Lot per Department random sampling protocols.	PWL 85% full payment
<p>21. Measuring dowel bar alignment is still an evolving practice. Ground-penetrating radar (GPR) and magnetic tomography technology (MIT Scan) are the only devices known to provide reasonable measurement precision. But these technologies also have some shortcomings, such as difficulty with measuring dowel bar locations if the dowel basket ties have not been cut. An alternative is to measure joint functionality by monitoring joint width at various times of day and various seasons, which will indicate whether a joint is “locked up” or functioning normally.</p> <p>Agencies may also wish to consider a requirement for dowel bar alignment at transverse joints.</p>			
Steel Location ⁽²²⁾	GPR or MIT Scan Measured from reference surface	± 0.5 in. on vertical rebar/tie-bar placement ± 1 in. on horizontal tie-bar placement	PWL 85% full payment
<p>22. Currently, there are no established test methods for measuring steel location postconstruction. GPR and MIT Scan techniques are available but currently do not provide the necessary precision.</p>			
Tire-Pavement Noise ⁽²³⁾	On-Board Sound Intensity (OBSI) measurement with a Standard Reference Test Tire, AASHTO TP 76 ⁽²⁴⁾	Maximum A-weighted tire-pavement noise level of 100 dB at 50 mph ⁽²⁵⁾ Evaluate 100% of pavement surface.	PWL 85% full payment
<p>23. Noise caused by tire-pavement interaction is a performance parameter addressing noise impacts to highway abutters. If a noise performance parameter is included, industry must be allowed to be more innovative with respect to surface texturing or pavement design. Alternative tining or other drag texturing methods and diamond grinding can meet skid resistance with reduced noise intensity. Similarly, alternative pavement designs using thin open-graded (pervious) concrete wearing surfaces or exposed aggregate surfaces have been shown to reduce noise compared with other pavement types.</p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p>24. <i>On-Board Sound Intensity (OBSI) measures tire-pavement noise at the source using microphones in a sound intensity probe configuration mounted to the outside of a vehicle near the tire-pavement interface. The directional characteristic of the probe makes it better suited for measuring a specific noise source, while attenuating sounds from other sources in other directions (such as engine or exhaust noise), and correlates well with sound measured at the roadside. The OBSI method was first standardized by AASHTO in 2008 and has undergone annual updates as provisional standard TP 76, "Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method."</i></p> <p>25. <i>At present, there are no established thresholds for tire-pavement noise. The values shown above should be modified according to the Agency's standard practice.</i></p>			

5.3 Quality Level Analysis

- A. Unless otherwise indicated in Table 4, acceptance of material and work shall be based on the method of estimating percent within limits (PWL), where the PWL will be determined in accordance with this Section. All Sublot test result values for a Lot, as defined in Table 4, will be analyzed statistically to determine the total estimated PWL. The PWL is computed using the Lot sample average value, \bar{X} , as defined in Section 5.3.C.2, the Lot sample standard deviation, S_n , as defined in Section 5.3.C.3, for the specified number of Sublots, n , and the specification Quality Acceptance Limits, as defined in Table 4, where LQL represents the Lower Quality Limit, and UQL represents the Upper Quality Limit, as they apply to each particular acceptance parameter. From these values, the respective Quality Index (Indices), Q_L for Lower Quality Index and/or Q_U for Upper Quality Index, is (are) computed in accordance with Sections 5.3.C.4 and 5.3.C.5. Then the PWL for the Lot for the specified number of Sublots, n , is determined from Table 5.
- B. In addition, all concrete and concrete placement work shall conform to the requirements of Section 7.4. For any identified deficiencies, as defined in Section 7.4, the Contractor may either
1. Remove and replace the concrete in that particular Lot at no additional cost to the Department, or
 2. Accept a deduction of 50% of the contract unit price for that particular Lot of concrete.
- C. Determine the PWL as follows:
1. In accordance with this specification and the QMP, locate sampling positions, obtain test sample, make specimens, and conduct test.
 2. Determine the Lot sample average value, \bar{X} , by calculating the average of all Sublot test values.
 3. Find the Lot sample standard deviation, S_n , by using the following formula:

$$S_n = \sqrt{\frac{\sum (x_i - \bar{X})^2}{n - 1}}$$

where

- S_n = standard deviation of the Sublot test values
- x_i = individual Sublot test values
- \bar{X} = average of Sublot test values
- n = number of Sublots

4. Find the Lower Quality Index, Q_L , by subtracting the Lower Quality Limit, LQL, from the average value, \bar{X} , and dividing the result by the Lot sample standard deviation, S_n .

$$Q_L = \frac{\bar{X} - LQL}{S_n}$$

5. Find the Upper Quality Index, Q_U , by subtracting the Lot sample average value, \bar{X} , from the Upper Quality Limit, UQL, and dividing the result by the Lot sample standard deviation, S_n .

$$Q_U = \frac{UQL - \bar{X}}{S_n}$$

6. Determine the percentage of material above lower tolerance limit, P_L , and the percentage of material below upper tolerance limit, P_U , by entering Table 5 with Q_L and/or Q_U using the column appropriate to the total number of Sublots, n , and reading the appropriate number under the column heading "PWL."
7. For quality characteristics with only an Upper Quality Limit (e.g., permeability), PWL equals P_U . For characteristics with only a Lower Quality Limit (e.g., thickness), PWL equals P_L . For concrete properties with both Upper and Lower Quality Limits (e.g., air content), first calculate the Upper Quality Index, Q_U , and the Lower Quality Index, Q_L , by using the Upper Quality Limit, UQL, and the Lower Quality Limit, LQL, respectively. The limits to be used are stipulated in Table 4. Then determine PWL using the following formula:

$$PWL = (P_U + P_L) - 100$$

8. The PWL from Table 5 that is to be used is the whole number greater than that found by using the Q_U or Q_L in the table. For example, the PWL to be used for $n = 4$ and a Q_U of 1.4200 would be 98.

Table 5: Percent within Limits (PWL)
(STANDARD DEVIATION METHOD)
Positive Values of Quality Index (QI)
(n = Number of Sublots in the Lot)

PWL	n=3	n=4	n=5	n=6	n=7	n=8
100	1.1600	1.5000	1.7900	2.0300	2.2300	2.3900
99	1.1541	1.4700	1.6714	1.8008	1.8888	1.9520
98	1.1524	1.4400	1.6016	1.6982	1.7612	1.8053
97	1.1496	1.4100	1.5427	1.6181	1.6661	1.6993
96	1.1456	1.3800	1.4897	1.5497	1.5871	1.6127
95	1.1405	1.3500	1.4407	1.4887	1.5181	1.5381
94	1.1342	1.3200	1.3946	1.4329	1.4561	1.4716
93	1.1269	1.2900	1.3508	1.3810	1.3991	1.4112
92	1.1184	1.2600	1.3088	1.3323	1.3461	1.3554
91	1.1089	1.2300	1.2683	1.2860	1.2964	1.3032
90	1.0982	1.2000	1.2290	1.2419	1.2492	1.2541
89	1.0864	1.1700	1.1909	1.1995	1.2043	1.2075
88	1.0736	1.1400	1.1537	1.1587	1.1613	1.1630
87	1.0597	1.1100	1.1173	1.1191	1.1199	1.1204
86	1.0448	1.0800	1.0817	1.0808	1.0800	1.0794
85	1.0288	1.0500	1.0467	1.0435	1.0413	1.0399
84	1.0119	1.0200	1.0124	1.0071	1.0037	1.0015
83	0.9939	0.9900	0.9785	0.9715	0.9672	0.9643
82	0.9749	0.9600	0.9452	0.9367	0.9325	0.9281
81	0.9550	0.9300	0.9123	0.9020	0.8966	0.8928
80	0.9342	0.9000	0.8799	0.8690	0.8625	0.8583
79	0.9124	0.8700	0.8478	0.8360	0.8291	0.8245
78	0.8897	0.8400	0.8160	0.8036	0.7962	0.7915
77	0.8662	0.8100	0.7846	0.7716	0.7640	0.7590
76	0.8417	0.7800	0.7535	0.7401	0.7322	0.7271
75	0.8165	0.7500	0.7226	0.7089	0.7009	0.6958
74	0.7904	0.7200	0.6921	0.6781	0.6701	0.6649
73	0.7636	0.6900	0.6617	0.6477	0.6396	0.6344
72	0.7360	0.6600	0.6316	0.6176	0.6095	0.6044
71	0.7077	0.6300	0.6016	0.5878	0.5798	0.5747
70	0.6787	0.6000	0.5719	0.5583	0.5504	0.5454
69	0.6490	0.5700	0.5423	0.5290	0.5213	0.5164
68	0.6187	0.5400	0.5129	0.4999	0.4924	0.4877
67	0.5878	0.5100	0.4836	0.4710	0.4638	0.4592
66	0.5563	0.4800	0.4545	0.4424	0.4354	0.4310
65	0.5242	0.4500	0.4255	0.4139	0.4073	0.4031
64	0.4916	0.4200	0.3967	0.3856	0.3793	0.3753
63	0.4586	0.3900	0.3679	0.3575	0.3515	0.3477
62	0.4251	0.3600	0.3392	0.3295	0.3239	0.3203
61	0.3911	0.3300	0.3107	0.3016	0.2964	0.2931
60	0.3568	0.3000	0.2822	0.2738	0.2691	0.2660
59	0.3222	0.2700	0.2537	0.2461	0.2418	0.2391
58	0.2872	0.2400	0.2254	0.2186	0.2147	0.2122
57	0.2519	0.2100	0.1971	0.1911	0.1877	0.1855
56	0.2164	0.1800	0.1688	0.1636	0.1613	0.1592
55	0.1806	0.1500	0.1408	0.1363	0.1338	0.1322
54	0.1447	0.1200	0.1125	0.1090	0.1070	0.1057

6 METHOD OF MEASUREMENT

To facilitate rapid renewal, it is recommended that measurement be based on square yards completed in place, including any reinforcement, dowel bars, and joint forming/sealing.

The Department will measure the work by the number of square yards completed and accepted in place. The width equals the pavement width shown on the typical cross section of the plans plus additional as the Department directs in writing. The Department will field measure length along the center line of the pavement.

7 BASIS OF PAYMENT

Pay factor adjustments reward the Contractor for providing superior product and penalize the Contractor for providing product that is of lower quality than specified. This section assumes use of a percent within limits (PWL) approach to compute pay adjustments. The PWL method encourages Contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging Contractors to produce a more uniform product.

Although simple to apply, the PWL approach primarily relies on engineering judgment to establish the individual pay adjustments and weighting factors. Arguably, a more rational approach would entail the use of mathematical models to compute pay factors for a given Lot based on the effect of construction quality on the predicted performance and subsequent LCC of the as-constructed pavement. The existing PRS methodology and simulation software (PaveSpec 3.0), as described in FHWA-RD-98-155, can directly consider the following quality characteristics in the computation of pay factors: concrete strength, slab thickness, initial smoothness, entrained air content, and percent consolidation around dowel bars. Moving forward, it is anticipated that updates to PaveSpec will incorporate additional quality characteristics and distress models that align with mechanistic design methods.

7.1 Pay Factor Adjustments

- A. Pay Factor adjustments for each Lot of each quality characteristic will be computed in accordance with the formulas contained in Table 6 by entering the PWL value and performing the calculation indicated for the appropriate PWL range.

For example, if 100% of the product is within limits, the pay adjustment is 0.06 = 6%, meaning the Contractor receives a 6% bonus.

Table 6: Adjustments to Contract Compensation

Percent Within Limits (PWL)	Pay Factor
91–100	[0.006 (PWL – 90)]
85–90	0.0
55–84	-0.9 + 0.01PWL

- B. The overall Pay Factor for a given characteristic, PF_i , is determined by calculating the average of all PFs for that characteristic for every Lot in the project.

7.2 Pay Adjustment

Based upon the quality of the pavement, the Department will calculate a weighted pay adjustment. The weights applied to each quality characteristic will be as shown in Table 7.

Table 7 illustrates possible pay adjustments for different pay items. Specifiers should consider project-specific conditions and goals when selecting pay factor adjustments and weight them in accordance with the criticality of the parameter to the ultimate performance of the pavement. For example, durability factors such as permeability and air content may be weighted heavier than strength and thickness. Agencies may wish to eliminate some factors entirely if they do not have sufficient data to support pay adjustment for those items.

Table 7: Pay Adjustment Criteria

Parameter	PF Designation	Weighting
Compressive Strength	PF _{cs} *	0.5
Permeability	PF _p	1
Air Content	PF _a	1
Thickness	PF _t *	0.5
Ride Quality	PF _{rq}	1
Skid Resistance	PF _{sr}	0.5
Load Transfer Efficiency	PF _{lte}	0.5
Dowel Bar Alignment	PF _{da}	1
Steel Location	PF _{sl}	1
Tire-Pavement Noise	PF _n	1

*PF = 0.0 for PWL > 84

Example of a composite pay adjustment, PA:

$$= \frac{[(PF_{cs} \times 0.5) + (PF_p \times 1) + (PF_a \times 1) + (PF_t \times 0.5) + (PF_{rq} \times 1) + (PF_{sr} \times 0.5) + (PF_{lte} \times 0.5) + (PF_{da} \times 1) + (PF_{sl} \times 1) + (PF_n \times 1)]}{(0.5 + 1 + 1 + 0.5 + 1 + 0.5 + 0.5 + 1 + 1 + 1)}$$

7.3 Total Project Adjusted Price

The Department will calculate a total project Adjusted Price (AP) by multiplying the composite Pay Adjustment (PA) from Section 7.2 times the total area of pavement in place, in square yards (SY), times the unit price.

$$AP = (PA) \times (SY \text{ Concrete}) \times (\$/SY)$$

7.4 Correction of Deficiencies

Remove and replace or correct pavement in a manner acceptable to the Department and at no cost to the Department if any of the following deficiencies exist, unless the Department elects to accept the concrete, at which time the Contractor will be compensated at 50% of the contract unit price for concrete placement specified regardless of the Pay Factors calculated in Tables 6 and 7:

1. PWL for compressive strength, permeability, or air content is below 55.

2. PWL for ride quality is below 55 unless the Contractor elects to grind pavement to within specification.
3. PWL for skid resistance is below 55 unless the Contractor elects to correct with grinding, shotblasting, or a thin friction overlay as deemed acceptable to the Department.
4. If the calculated average of two consecutive thickness probe tests indicates deficient thickness greater than 10%.
5. PWL for tire-pavement noise is below 55 unless the Contractor elects to correct with grinding or with a thin friction overlay as deemed acceptable to the Department.
6. PWL for load transfer efficiency is below 55 unless the Contractor elects to correct load transfer with a dowel bar retrofit deemed acceptable to the Department.
7. PWL for dowel bar alignment or steel location is below 55.

CEMENT CONCRETE PAVEMENT

PERFORMANCE SPECIFICATION

(DESIGN-BUILD)

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for implementation under a design-build (DB) delivery approach.

Users should note that this specification is part of a family of pavement specifications drafted with a specific delivery approach in mind; that is, the recommended performance parameters and design and construction requirements included in this specification are intrinsically linked to the roles and responsibilities and risk allocation deemed appropriate for a DB project. These DB conventions include the following:

- *Selection of the pavement type by the Agency (or by Contractor if life-cycle cost, LCC, analysis is provided at bid);*
- *Structural design by the Contractor;*
- *Mix design by the Contractor (but usually as per Agency guidelines or standards);*
- *Quality management by the Contractor (design and construction);*
- *Verification testing and acceptance at the end of construction by the Agency; and*
- *Postconstruction maintenance by the Agency.*

Specification Objectives

Absent a warranty provision, the Agency's acceptance of the work at the end of construction will release the Contractor from further responsibility for performance. The Agency's confidence in the ability of the parameters measured at the end of construction to predict future performance will therefore control the extent to which an Agency can relax its standard construction requirements in the interest of rapid renewal. The goal, therefore, of this performance specification is not to monitor and evaluate Contractor performance over time but to

- *Focus on material properties and construction practices deemed to have the most effect on long-term performance;*
- *Use quality management and acceptance criteria that more closely correlate to performance; and*
- *Incorporate financial incentives/disincentives to promote enhanced quality or durability.*

In addition to these performance goals, this specification attempts to incorporate, to the extent possible under the DB delivery approach, concepts that will promote the goals of rapid renewal (i.e., accelerate construction, minimize disruption, and achieve a long-lasting pavement). To this end, prescriptive requirements have been relaxed if (1) placing such requirements under the Contractor's control could help save time and/or minimize disruption, and (2) measurement of the performance parameters at the end of construction will provide adequate assurance that the condition the prescriptive element was intended to prevent did not, and ideally, will not, occur.

Using This Guide Specification

The requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a comprehensive example of the possible performance requirements that could be used to promote the construction of long-lasting pavements under the DB delivery approach. From this menu of requirements, users should select those that best fit the needs of their particular project or program, bearing in mind that certain barriers or gaps may preclude the immediate implementation of all of the proposed parameters

and test methods. For example, a performance measure may be technically valid but difficult to implement because of a need for specialized equipment or expertise, a lack of standardized test methods, absence of historical data for calibration of design or predictive models, or similar obstacles.

To help identify and address such gaps, consider each performance requirement in the context of the following questions:

- Can a particular parameter be measured and evaluated using existing technology?
- In comparison with other testing techniques (or the use of method specifications), is the measurement and testing economical? Is a major capital investment required?
- Does the measurement technique require advanced training or a high skill level from technicians?
- Would a typical contractor know how to control its materials and processes to meet a particular performance standard?
- Is there sufficient experience or historical data to properly calibrate design or predictive models?

Although specific answers to those questions may vary by Agency, they generally point to three tiers of performance specifications for concrete pavement, ranging from minimal departure from current practice to a substantial shift in practice and organizational culture that would require technological advancement and improved understanding of long-term material behavior.

- **Tier 1** requirements do not require a substantial departure from current practice, yet place more emphasis on properties known to affect durability, such as air content, and encourage the use of nondestructive testing (NDT) techniques, such as maturity meters and thickness probes, as a rapid renewal consideration.
- **Tier 2** requirements incorporate more performance-oriented parameters, such as permeability and air quality, for which test methods may be currently available but which would require further advancement or refinement to provide the repeatability and accuracy needed for acceptance purposes.

To implement other Tier 2 requirements, some investment may be necessary for contractors to acquire the necessary knowledge, skills, and equipment to fulfill their obligations under a performance specification without passing on excessive risk pricing to the Agency. For example, if noise reduction is an agency goal, it would be possible to develop a functional parameter based on the noise generated from pavement-tire interaction, as measured using on-board sound intensity (OBSI). However, until industry gains more understanding about how to modify its standard means and methods to meet a certain decibel level, it may be more cost-effective to simply use a prescriptive texturing specification to accomplish the same objective.

- **Tier 3** requirements assume improved understanding of long-term material behavior as well as advances in technology, particularly in the area of NDT, which could allow for the inclusion of acceptance parameters that better reflect the future performance and design life of the pavement.

In general, the three tiers represent a progression toward parameters and test methods that are more indicative of in-place pavement performance. When selecting the appropriate tier for a given project or program, users should balance project needs against available technology and resources, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and industry's appetite for assuming performance risk.

To denote these tiers, the numbers 1, 2, and/or 3 will appear in the right-hand margin beside a particular requirement, as applicable. If no such number appears, consider the requirement to be common to all tiers.

Commentary is also included within the specification (as indicated with italic typeface) to provide additional guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw upon the information provided as a basis for further modification or development of the specification.

In implementing this specification, Agencies are further encouraged to require the Contractor to develop and adhere to a comprehensive Quality Management Plan (QMP). A sample general provision addressing the roles and responsibilities for quality management is included within the family of guide specifications developed under the SHRP 2 R07 project.

Finally, note that the term “Contractor” as used in this document should be interpreted as that entity given single-point responsibility for both the design and construction of the work and is thus synonymous to “Design-Builder” and “Design-Build Team.”

1 DESCRIPTION

Design and construct all pavement sections to perform under the given loading and environmental conditions for the specified service life period.

Provide a Quality Management Plan (QMP) and perform all sampling, testing, and inspection necessary to control and assure the quality of the work in accordance with the QMP. The Department, acting in an oversight role, will conduct verification sampling and testing and independent assurance.

The Contractor’s preparation of a formal QMP is an integral component of this performance specification. A QMP requirement allows the Agency to reduce prescriptive requirements in exchange for the Contractor’s development and adherence to a detailed plan of how it intends to complete the work and meet the performance requirements.

Within the limits of the Contract and applicable local, State, and Federal rules and regulations, the Contractor is encouraged to use innovative techniques and materials to meet the specified performance requirements.

Additional description may be added to this section to highlight certain project goals or performance requirements, particularly if new to the Agency or local contracting community.

2 STANDARDS AND REFERENCES

This Standards and References section serves to identify the design and other procedural manuals and standards (e.g., AASHTO, FHWA, Agency) that the Contractor should follow, particularly when performing the project design work. Note that such documents may contain prescriptive requirements that could limit the Contractor’s flexibility and ability to innovate. Therefore, when referencing standards in Table 1, balance the need for conformance with the Agency’s existing facilities and processes (consider, for example, tie-ins to existing facilities, right-of-way, ROW, requirements, environmental issues) against the opportunity for innovation.

Likewise, materials standards, test methods, and similar reference documents cited throughout the specification should be obtained and reviewed to ensure that they do not inadvertently impose undesired restrictions on the Contractor, in which case the specifier should identify exceptions to the standard.

2.1 Standards

Unless otherwise stipulated in this specification or as approved by the Department, design and construct the pavement in accordance with this performance specification and the relevant requirements of the standards listed, by order of priority, in Table 1.

If the standards conflict, adhere to the standard with the highest priority. If the standards contain any unresolved ambiguity, obtain clarification from the Department prior to proceeding with design or construction.

Use the most current version of each listed standard as of the initial publication date of the RFP unless modified by addendum or change order.

Table 1: Standards for Pavements

Priority	Author or Agency	Title
1		
2		
3		

2.2 References

This subsection may be included if the Agency wishes to identify nonmandatory references that could assist the Contractor's efforts.

The Contractor may consult the references listed in Table 2 for supplementary guidance in designing and constructing the pavement system. These references have no established order of precedence and are not intended to be all-inclusive.

Table 2: References for Pavements

Author or Agency	Title
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3 REQUIREMENTS

3.1 Design

Perform all pavement engineering activities, including, but not limited to, the following:

List will vary based on how much initial design work was completed by the Agency.

- Pavement/geotechnical investigation
- Pavement design and analysis
- Material selection
- Cement concrete mixture design

The Agency may also choose to allow the Contractor to select the pavement type during the bidding phase. In this case, the Agency should generally require the Contractor to follow a specified life-cycle cost (LCC) analysis procedure to demonstrate adequate pavement life and LCC for the pavement type designed. If implemented under an alternate bid provision, the Agency could use an "A+C" bid model, in which "A" represents the base bid for the selected alternate and "C" represents an LCC bid adjustment factor.

All pavement engineering activities shall be directed, supervised, signed, and sealed by a Professional Engineer, licensed in the State of [-] with a minimum of [5] years of experience in pavement engineering.

3.1.1 Pavement Investigation

Perform and document all geotechnical investigations, testing, research, and analyses necessary to determine and understand the existing surface and subsurface conditions.

Prepare and submit geotechnical engineering reports documenting the assumptions, conditions, and results of the investigations and analyses, including the following:

- Geology of the project area;
- Results from field investigations and laboratory testing, including a discussion of how these results affect the design of the pavement;
- Design and construction parameters resulting from the geotechnical investigation and analyses; and
- Boring logs, laboratory results, calculations, and analyses that support design decisions.

3.1.2 Design Criteria

Design the pavement structure in accordance with the subsurface information collected as specified in Section 3.1.1, the standards identified in Section 2.1 or other approved alternatives, and the criteria defined in Table 3.

Table 3: Design Criteria

Design Criteria	Requirement
Design Life	
Design Traffic (18-kip ESALS)	
Shoulder Type	<i>(e.g., tied concrete shoulders, widened lanes, asphalt or granular shoulders)</i>
Drainage	Provide a free-draining pavement that will not compromise surface or subsurface drainage of existing pavement to remain in place.
Tie-ins	Minimize pavement-to-structure transition deviations.
Joints	Longitudinal pavement joints must be on lane lines or within 1 ft of the centerline of the lane.

Modify Table 3 to include all additional requirements that could affect the design of the pavement system. For example,

- *Design Reliability;*
- *PCC Modulus of Rupture and Elastic Modulus;*
- *Required Ride Quality (international roughness index, IRI/profilograph index, PrI);*
- *Pavement Type—such as continuously reinforced concrete pavement (CRCP), roller-compacted concrete pavement (RCCP), or jointed plain concrete pavement (JPCP);*
- *Load Transfer Coefficient;*
- *Subgrade requirements [e.g., minimum support values (minimum strain rate, MSR), improvement strategies];*
- *Future expansion (e.g., “Design and construction must feasibly allow for future economical expansion through addition of lanes and other elements.”); and*
- *Different design criteria for mainlines and ramps versus auxiliary lanes and shoulders.*

3.1.3 Design Documentation

In exchange for providing the Contractor flexibility with regard to design and construction decisions, the Agency should require the Contractor to fully document and report all design assumptions and decisions.

Prepare and submit pavement design reports that include the following items, as a minimum:

- All pertinent design inputs, such as traffic data, soils characteristics, characteristics of the proposed construction materials, environmental conditions, and pavement design life;
- Site plan showing the limits of the roadway covered by the design report;
- Discussion of site conditions that might influence the design and performance of the pavement;
- Discussion of the inputs used to arrive at design recommendations and the rationale used in selecting the recommended design strategy (where applicable, life-cycle management analysis, including the periods for resurfacing, reconstruction, and other rehabilitation measures);
- Pavement design details, including structural layer materials and thicknesses, and typical cross-section drawings;
- Comprehensive construction specifications sufficiently detailed to describe the process or end result requirements; and
- Other considerations used in developing the pavement design(s), including subgrade preparation and stabilization procedures as applicable.

3.2 Material Requirements

To prepare the Materials section, one approach would be to refer to the applicable sections in the Agency’s Standard Specifications. The Standard Specifications typically contain explicit requirements restricting materials selection based on the Agency’s past experience. In this manner, the Agency can be confident of receiving a product similar to what it has always received. A possible drawback to this approach is the lost opportunity associated with using alternative materials or sources that could result in superior performance or time or cost savings.

It is therefore important to carefully consider the extent to which the specification needs to prescribe basic material properties. For example,

- *Should materials conform to specific Agency, ASTM, or AASHTO standards or test methods?*
- *Should any restrictions be applied to material components [e.g., testing for reactive aggregates, coarse aggregate polished stone value (PSV), and aggregate abrasion value (AAV)], that could cause adverse effects?*

If the end-result parameters included in the specification will not in and of themselves assure the Agency that the constructed pavement will meet the desired short-term and long-term performance expectations, more prescriptive materials requirements may be necessary. (Note that this strategy is in contrast to the increased latitude that should be given to the Contractor under a long-term warranty or operations and maintenance agreement, in which case the Contractor would be assuming more risk for performance over time and would thus be more inclined to investigate other materials options that, despite higher initial costs, may prove to be more economical when viewed over the duration of the Contractor's performance responsibility.)

If not already a part of the Agency's standard acceptance program, consider allowing prequalification of sources/suppliers and acceptance by certification. In keeping with the goals of rapid renewal, such provisions can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations. For example, consider allowing the Contractor to incorporate the following materials into the work by submitting manufacturer's certifications that substantiate that each shipment conforms to the specified quality requirements:

- *Cement;*
- *Supplementary Cementitious Materials;*
- *Admixtures;*
- *Joint Seals and Fillers;*
- *Curing Compound and Evaporation Retarders;*
- *Epoxy (for drilling and anchoring steel); and*
- *Reinforcement (dowel bars, tie bars, mat reinforcement).*

Similarly, aggregate sources (if Agency preapproved sources are not used) may be qualified prior to construction by verifying results related to the following properties:

- *Soundness,*
- *Hardness,*
- *Polishing resistance,*
- *Abrasion resistance,*
- *Freeze-thaw durability,*
- *Alkali-aggregate reactivity,*
- *Absorption, and*
- *Specific gravity.*

Evaluate material quality before and during construction in accordance with the approved QMP. Reject all nonconforming materials and replace with suitable materials.

3.3 Construction Requirements

The Agency's confidence in its ability to predict future performance at the end of construction will control the degree to which an Agency can relax its standard construction requirements. Given today's technology and test methods, substantial departure from standard practices may be

unlikely. However, should advances in technology (such as better forecasting models from mechanistic design practices and advancements in nondestructive testing) increase the level of confidence in end-result parameters, it may then be possible to eliminate certain prescriptive requirements in the interest of rapid renewal.

In exchange for providing the Contractor some flexibility with regard to mixture design and construction decisions, the Agency should require the Contractor to describe in its QMP how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, ordering, handling, placing, finishing, and curing of concrete) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

3.3.1 General

The Contractor is responsible for providing all management, professional, and technical services; and labor, materials, and equipment necessary to construct the pavement.

Submit any changes to the design documents implemented during construction to the Department for review purposes.

3.3.2 Mixture Design

Develop and submit for the Department’s review a cement concrete mixture design in accordance with *[Standard Specification XXX]* and *[AASHTO M 157]* along with documentation indicating that the proposed mixture design meets the criteria specified in Table 4.

If an Agency does not have batch plant certification processes in place, consider requiring National Ready Mixed Concrete Association (NRMCA) Plant Certification according to the NRMCA Certification of Ready Mixed Concrete Production Facilities Quality Control Manual.

Table 4: Mixture Properties

Design Parameter	Test Method ⁽¹⁾	Value
Compressive Strength	ASTM C39	
Flexural Strength	ASTM C78	
Freeze-Thaw Resistance	ASTM C666	
Air Content ⁽²⁾	ASTM C231 (Pressure method)	1
Air Quality ⁽²⁾	AVA Testing	2 3
Permeability ⁽³⁾	ASTM C1202 (Chloride Ion Penetration)	2
	Oxygen Permeability Index	3

Design Parameter	Test Method ⁽¹⁾	Value
Coefficient of Thermal Expansion ⁽⁴⁾	AASHTO TP60	

1. *The test methods identified are provided for guidance only. If an Agency has its own standard test methods for measuring these properties, specify those methods instead.*
2. *Air content can be determined through conventional (volumetric or pressure) test methods; however, an issue with these methods is that samples are typically taken when delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated. Also, the pressure test provides air content but does not provide an indication of the air void system (i.e., spacing and volume). A preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) or for hardened concrete through petrographic analysis of polished thin sections taken from cores (ASTM C457). The AVA test, though not as widely accepted by industry, is a more sensitive test, and test results can be obtained in time to make adjustments in the mix during production and placement.*
3. *Although permeability is a critical durability indicator, some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. The chloride ion penetration test (ASTM C1202) is the most widely used for structural concrete; however, it does not directly measure concrete permeability. What it does measure is concrete resistivity, which has been shown to have a fair correlation to concrete permeability. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.*
4. *Coefficient of thermal expansion (CTE) testing can be used to validate the mix design with design assumptions for the site-specific environmental conditions.*

If the Contractor is choosing its own aggregate instead of using preapproved sources, also require verification of alkali-aggregate reactivity resistance (ASTM C1260).

4 QUALITY MANAGEMENT PROGRAM

This specification holds the Contractor responsible for performing tests used strictly for process control as well as tests that may be used in the Agency’s acceptance process. The Agency in turn should perform verification testing of select parameters. Although this approach may represent a departure from the traditional manner in which an Agency allocates responsibility for various quality management functions, it is consistent with the degree of risk assumed by the Contractor for performance of the work. Greater oversight by Agency personnel may add time to the project and conflict with the goals of rapid renewal.

4.1 Contractor’s Responsibility for Quality Management

The requirements included in this Section 4.1 assume the Contract includes a separate provision related to development and implementation of a QMP that defines general requirements related to the Contractor’s quality management personnel and organizational structure, documentation and reporting requirements, and procedures related to nonconforming work, corrective action, and similar matters. If such requirements are not otherwise addressed in the Contract’s General Conditions, note that a sample general provision addressing quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Note that the Agency should review the Contractor’s QMP submittal to ensure it complies with these and other Contract requirements. If the Agency disagrees with elements of the QMP, it should raise these issues with the Contractor and seek resolution. The Agency should not “approve” the Contractor’s QMP, as approval could be construed as assuming responsibility for the plan’s content.

Assume responsibility for the quality of the work, including work performed or provided by subcontractors, suppliers, and vendors.

Perform all quality management activities described in *[the Agency’s General Provision for Quality Management]*, including the additional requirements specific to cement concrete pavement construction as defined in this Section 4.1.

4.1.1 Contractor Testing

The approach taken in this section is to establish the minimum testing requirements that the Contractor’s QMP must contain related to cement concrete pavement construction. The intent is to provide the Contractor some latitude with respect to developing a project-specific QMP while also ensuring that the Agency’s minimum standards are met. These minimum requirements can also serve as guidance to bidders as they prepare a cost proposal for the work.

A possible disadvantage to this approach is that the Contractor may view these requirements not as a minimum but as all that is necessary to provide adequate quality management. If a best-value procurement process will be used to award the Contract, the Agency should consider evaluating the proposers’ project-specific QMP, or relevant portions thereof, as part of the selection criteria.

As part of the QMP to be prepared, submitted, and implemented in accordance with *[the Agency’s General Provision for Quality Management]*, include, as a minimum, the sampling and testing requirements specified in Table 5, as well as all other inspections and tests the Contractor deems necessary to ensure the quality of the finished pavement.

Keep the Department apprised of upcoming testing activities to allow the Department to schedule the verification and independent assurance activities described in Section 4.2. If verified as described in Section 4.2.1, the Department may use the Contractor’s test results for acceptance.

Various QMP requirements are included in Table 5 for the specifier’s consideration, not all of which will necessarily be appropriate or beneficial for a given project or program. Agencies may wish to include or exclude requirements based on the capabilities of local industry (including materials suppliers and testing firms), the project’s needs and goals, associated costs, and similar factors. Commentary included within the table itself provides rationale for including certain parameters. Test methods and frequencies are provided for illustrative purposes only and should be modified based on Agency practices or project requirements.

Table 5: Minimum QMP Requirements for Cement Concrete Pavement

Parameter	Test Method	Frequency
A. Materials		
Aggregate		
Source verification		
Gradation ⁽¹⁾	ASTM C33	
Fine aggregate fineness	ASTM C136	
Coarse aggregate shape & texture	ASTM D3398	
Fine aggregate shape & texture	ASTM D3398	
Cleanliness	ASTM C33 / ASTM C142	
Moisture content	ASTM C70 / ASTM C566	
Cementitious material	ASTM C150	

Parameter	Test Method	Frequency
Admixtures	Certification	
Reinforcement	Certification	

1. *Gradation control improves workability, reduces shrinkage (due to less paste content), and contributes to durability. For colder climates and higher-volume roadways, for which gradation control is particularly important, consider offering the Contractor an incentive to provide a well-graded aggregate mix.*

B. Fresh Concrete

Unit Weight ⁽²⁾	ASTM C138	
Slump	ASTM C43	
Water content		
Placement temperature	ASTM C1064	
Evaporation rate	ACI 308R	
Thickness ⁽³⁾	Probe	
Air content ^(4, 5)	Pressure Method (ASTM C231)	1
Air quality ^(4, 5)	Air Void Analyzer	2 3

2. *Monitoring unit weight, a property not commonly measured today, would reveal mix design changes, thus eliminating the need for (or at least reducing the frequency of) more labor-intensive testing, such as for freeze-thaw resistance.*
3. *Measuring thickness is standard practice for portland cement concrete (PCC) pavements. To facilitate rapid renewal, the Contractor may choose to measure thickness by probing the fresh concrete to eliminate the need for coring except when verification is required. As an alternative (or supplement) to coring, NDT methods for verification may include GPR (ground-penetrating radar) with limited coring, or MIT (magnetic imaging tomography) Scan T2.*
4. *The presence of closely spaced air voids is a key factor in improving the freeze-thaw resistance of concrete. In measuring air content/quality, consideration should be given to where measurements are taken, as changes in air content/quality will occur as concrete passes through the paver. Samples should be collected either behind the paver or in front of the paver with an assumed amount of air loss through the paver that is then verified through routine tests in front of and behind the paver.*
5. *Although the volumetric or pressure test is the standard method for measuring air content, it has the following limitations:*
 - *Samples are typically taken when materials are delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated.*
 - *A pressure test only provides information on the total volume of air; it cannot characterize the air void system (i.e. spacing and volume).*

The preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) (or for hardened concrete through petrographic analysis of polished thin sections). The AVA can characterize the distribution of air voids in a timely manner (within 30 minutes), allowing adjustments to be made in the concrete batching process to ensure air voids are spaced properly.

C. Hardened Concrete

Compressive Strength ⁽⁶⁾	ASTM C1074 (Maturity) ⁽⁷⁾	
Flexural Strength ⁽⁸⁾	ASTM C78	
Freeze-Thaw Resistance ⁽⁹⁾	ASTM C666	
Permeability ⁽¹⁰⁾		2

Parameter	Test Method	Frequency
Chloride Ion Penetration	ASTM C1202	
Oxygen Permeability Index		
Coefficient of Thermal Expansion ⁽¹¹⁾	AASHTO TP60	

3

6. *It has become standard practice to measure the compressive strength of concrete (though flexural strength would provide a more direct indication of design strength). Strength is more critical for CRCP than jointed concrete. Too high a strength value could be detrimental for CRCP (i.e., an upper bound is needed).*
7. *Instead of testing cores or field-cured cylinders, maturity meters would provide a nondestructive way to estimate in-place concrete strength. Maturity methods are based on the concept that concrete strength is directly related to its age and temperature history, and that samples of a given mixture will attain equal strengths if they attain equal values of maturity index. Before any field measurements are taken, the strength-maturity relationship of a particular mix must be determined in the laboratory based on either compressive or flexural strength. Such maturity curves can then be used to correlate field maturity readings—taken from sensors embedded within the in situ mat about every 500 ft (or 1,000 yd² of volume)—to cylinder strength.*
8. *Measuring flexural strength is the preferred method for monitoring strength, as it provides a more direct comparison to design strength. However, testing can be cumbersome due to the need to fabricate and test beams for third-point loading.*
9. *If unit weight testing is used to monitor for mix design changes, the frequency of freeze-thaw testing may be reduced accordingly.*
10. *Although permeability is a critical durability indicator (particularly for cold or marine climates where salts are present in the air or the pavements), some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. The chloride ion penetration test (ASTM C1202) is the most widely used for structural concrete, though it actually measures concrete resistivity, not permeability. As an economical alternative to ASTM C1202, some Agencies have investigated the use of a surface resistivity meter to measure concrete's resistance to chloride ion penetration. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.*
11. *Agencies may also wish to require testing for coefficient of thermal expansion (CTE), as this is a key input for mechanistic-empirical pavement design.*

D. In-place pavement

Steel Placement

Dowel Placement/Alignment ⁽¹²⁾

Smoothness ⁽¹³⁾

Straightedge

Cross-slope

12. *Dowel placement and alignment is important for proper consolidation around dowels and to avoid cracking near joints. There are currently no standard tests for dowel alignment, though one manufacturer has provided a proprietary magnetic imaging tomography (MIT) test device to measure dowel depth and alignment.*
13. *For process control, a straightedge has been the traditional method for determining pavement smoothness. A SHRP 2 research project (R06E) is developing technology for evaluating real-time smoothness behind the paver to achieve improved smoothness as part of process control during construction. For acceptance, a concrete profilograph is still the norm, but the trend is toward using inertial profilers and an IRI standard.*

4.1.2 Production and Placement Procedures

In exchange for eliminating prescriptive requirements related to materials selection and construction methods, the Agency should require the Contractor to describe how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, ordering, handling, placing, finishing, and curing of concrete) will affect the in-place properties and performance of the work, and that the Contractor has planned the work and allocated its resources accordingly.

Include descriptions of the following in the QMP:

1. Certified mixing plant requirements, including calibration procedures for all meters, scales, and other measuring and recording devices.

If an Agency does not have batch plant certification processes in place, consider requiring National Ready Mixed Concrete Association (NRMCA) Plant Certification according to the NRMCA Certification of Ready Mixed Concrete Production Facilities Quality Control Manual.

2. Laboratory location, testing equipment, procedures for calibration, and training standards for personnel (e.g., National Institute for Certification in Engineering Technologies—NICET— or local standard).

Ensure that the laboratory and equipment will be maintained for the duration of the project.

3. Paving plan, including general staging and sequencing of operations.

When reviewing the Contractor's paving plan, consider the following:

- *Is the sequence compatible with the maintenance of traffic (MOT)?*
- *Can the Contractor's equipment accommodate the proposed sequence of operations (consider size and number of equipment)?*
- *How will driveways, cross streets, and other leave-outs be handled?*

4. Steel and dowel bar placement (for CRCP).

The Contractor should describe how it will install dowel bars (baskets or inserters) and secure them during concrete placement operations.

5. Concrete placement operations, including hauling, spreading, consolidating, and texturing.

When reviewing this portion of the Contractor's QMP, consider the following:

- *Is the proposed equipment appropriate for the project?*
 - *Is hauling equipment appropriate given the likely haul distance, haul time, and weather conditions?*
 - *Is equipment appropriate for spreading material in front of the paver (e.g., chute, belt)?*
- *Has the Contractor included a contingency plan for equipment break downs (e.g., if paver breaks down, will they sawcut and create a joint)?*
- *Does the Contractor intend to monitor consolidation to prevent overvibration?*
- *What type of texturing will be applied? How will it be applied?*

6. Methods to control alignment and profile.

Consider allowing use of stringless paving techniques as a rapid renewal consideration.

7. Joint installation procedures.

Consider the Contractor's plans for the following:

- *Sawcutting (type of equipment, timing, use of HIPERPAV);*
- *Constructing end-of-day joints and any leave-outs; and*
- *Sealing joints (type of material and timing).*

8. Finishing procedures.

Consider the adequacy of the Contractor's plan for finishing behind the paver (e.g., type of equipment and procedures to be used). Will the auto-float be sufficient or will some hand-finishing be necessary?

9. Materials and methods related to curing, including equipment, timing, and application rate (for curing compounds).

10. Procedures related to cold weather placement and night work (as applicable).

11. Contingency plan for inclement weather.

12. Plan for early opening to traffic, if applicable.

This list will vary based on how much freedom the Agency allows the Contractor with regard to the construction requirements in Section 3.3.

4.2 Department's Quality Management Responsibilities

The Department may conduct quality inspections, audits of the Contractor's results and records, and verification sampling and testing on any element of the work to ensure compliance with the QMP and the Contract requirements.

4.2.1 Verification Sampling and Testing

Even though the Contractor may assume more responsibility for inspection and testing under a performance specification, this does not relieve the Agency of its responsibility to perform some level of independent sampling and verification testing to meet the intent of 23 CFR 637. Verification testing should be performed to validate any Contractor testing used in the Agency's acceptance decision. The Agency may also wish to verify certain material or mixture parameters that could identify possible performance issues that would not otherwise be detected through end-result acceptance testing.

On fast-paced DB projects, the Agency may wish to consider dedicating staff and/or augmenting staff resources with outside consultants to keep pace with Contractor testing.

The Department will perform verification testing as described in Table 6 to validate the Contractor's test results.

The Department will notify the Contractor before sampling so the Contractor can observe.

The Department will sample randomly at locations independent of the Contractor’s sampling and testing. In all cases, the Department will conduct the verification tests in a separate laboratory and with separate equipment from the Contractor’s tests.

Table 6: Department Verification Testing

Parameter ⁽¹⁾	Test Method ^(1, 2)	Sampling Location ⁽²⁾	Frequency ⁽³⁾
Unit Weight	ASTM C138	At the paver	
Air content or Air quality	Pressure method (ASTM C231)	Behind the paver	1
	Hardened air (ASTM C457)	Cores from constructed pavement	
Air Quality	AVA	Behind the paver	2 3
Strength	ASTM C1074 Maturity	At the paver or field-cured specimens	
Thickness ⁽⁴⁾	Probes ASTM C174 (cores)	Probe. If deficient, take cores from constructed pavement.	
Permeability	ASTM C1202 (Chloride Ion Penetration Resistivity)	At the paver or cores from constructed pavement	2
Oxygen Permeability Index			3

1. Durability-related parameters, including air quality, permeability, and unit weight, are the best indicators of pavement performance and would be important for verification testing. The Agency should also test for strength and thickness as part of verification testing.
2. For rapid renewal, when rapid construction is the primary objective, the Agency can verify that parameters (unit weight, air quality, strength, thickness, and permeability) meet performance requirements through nondestructive testing (e.g., taking cylinders at the paver for strength and permeability, or probing the fresh concrete behind the paver for thickness). If testing results indicate deficient or marginal results (e.g., thickness +/- 1/2 in. of plan thickness), the Agency should require cores for verification.
3. Frequency should be based on project-specific conditions and ideally should provide the ability to identify statistically valid differences between Agency and Contractor test results. A minimum Agency rate of 10% of the testing rate of the Contractor has been used as a rule of thumb.
4. From a long-term performance perspective, some practitioners conclude that thickness should not be an acceptance parameter, but it still should be monitored as part of the Contractor’s quality management and the Agency’s verification testing to ensure that the minimum design thickness is met for structural integrity. This can be accomplished using a probe on fresh concrete and requiring repair of any Sublot not meeting the minimum requirement. For high-volume, high-profile roadways, an Agency may decide that drilled cores are necessary for acceptance.

The Department may increase the frequency of verification testing at start-up or as necessary to validate the quality of the materials. The Department may reduce the frequency based on a history of satisfactory Contractor or material performance.

If verification tests indicate conformance with the specifications, no further action is required. If verification tests indicate nonconformance with the specifications, the Department and Contractor will jointly investigate any testing discrepancies. The investigation may include additional testing as well as review and observation of both the Department's and Contractor's sampling and testing procedures and equipment. Both parties will document all investigative work.

When comparing Agency and Contractor test results, it is important to compare both the variances and the means. The tests most often used are the F-test (comparison of variances) and the t-test (comparison of means), which are used together.

4.2.2 Independent Assurance Testing

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing activities are being performed by qualified personnel using proper procedures and properly functioning and calibrated equipment. The Department will perform IA testing using personnel other than those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor's sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

4.3 Conflict Resolution

If a dispute between some aspect of the Contractor's and the Department's testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third-party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third-party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [\[Standard Specification Section XXX\]](#).

5 ACCEPTANCE REQUIREMENTS

Acceptance requirements provide a method for determining the degree to which the as-constructed pavement meets the specification and for determining appropriate payment. Acceptance is based on the measurement of properties that control the quality and performance of the pavement.

The quality acceptance limits presented in this section assume use of a percent within limits (PWL) approach. The PWL method encourages Contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging Contractors to produce a more uniform product.

Alternatively, Agencies may prefer to adopt a more rational approach for adjusting payment that reflects the life-cycle cost (LCC) of the as-constructed pavement. Existing performance-related specification (PRS) methodology and simulation software (PaveSpec 3.0), as described in FHWA-RD-98-155, would allow users to develop a composite pay factor adjustment based on the difference between the estimated LCC of the as-designed pavement and the estimated LCC of the as-constructed pavement.

5.1 General

The Department will accept the finished pavement based on the Contractor's test results unless it is shown through the Department's verification testing or the conflict resolution process that the Contractor's tests are in error.

5.2 Quality Characteristics and Acceptance Limits

The Department will accept the completed pavement in accordance with the criteria defined in Table 7 and properties measured and verified during construction.

Various acceptance parameters are listed in Table 7 for the specifier's consideration. To meet the rapid renewal goal of providing long-lasting facilities, the recommendation is to emphasize parameters that relate to the durability of the in-place concrete (such as permeability and air content). Such parameters would allow the Agency to eliminate or relax prescriptive requirements related to the use of specific materials (e.g., fly ash or air entraining admixtures), proportions (e.g., minimum cement content or maximum water-to-cement—w/c—ratio) or construction operations that are often included in today's method specifications. Although such prescriptive requirements have a historical basis in producing durable concrete, they can act as a barrier to innovation.

Not all parameters shown will necessarily be appropriate or beneficial for any given project. Agencies may wish to include or exclude requirements based on the project's needs and goals, the capabilities of local industry (including materials suppliers and testing firms), associated costs, and similar factors.

Likewise, the choice of measurement strategy should reflect project goals and conditions. If the predominant objective is rapid construction, then measurement procedures used for acceptance should focus on rapid test methods, whether based on laboratory or field-cured specimens or, ideally, nondestructive field testing. If the predominant objective is longevity, the measurement and test procedures for durability-related parameters may have to rely to a greater extent on in situ drilled concrete core tests.

Commentary provided within the table itself provides rationale for including certain parameters and, as necessary, offers additional information related to test methods and establishing targets and tolerances.

The quality acceptance limits presented within the table assume use of a percent within limits (PWL) approach for adjusting payment. The PWL is determined using Table 8 and the instruction

in Section 5.3. A Lot is defined as the surface area (or quantity) of pavement placed in a single production day, or no more than 7,500 yd². Each Lot should be divided into no less than three and no more than eight Sublots. The quality index (QI) is calculated using the Lot sample standard deviation, S_n , and Upper Quality Limit (UQL) and Lower Quality Limit (LQL). For additional information on establishing quality acceptance limits, refer to FHWA Publication No. FHWA-RD-02-095.

Alternatively, if a PRS approach is used, target means and standard deviations should be specified. Existing PRS research (as reflected in *PaveSpec 3.0* simulation software) supports pay adjustments for the following quality characteristics: concrete strength, slab thickness, initial smoothness, entrained air content, and percent consolidation around dowel bars.

Table 7: Acceptance Criteria

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Surface Distresses ⁽¹⁾	ASTM D6433, Pavement Condition Index (PCI) Survey or equivalent project-level visual survey	PCI > 80 Evaluate 100% of pavement surface.	The Department will evaluate deficiencies on a case-by-case basis to determine if a repair will be required. ⁽²⁾
<p>1. Surface distress can be in the form of cracking, faulting, corner breaks or blow-ups, and spalling resulting from such things as excessive loading, thermal changes, moisture damage, or poor consolidation at joints. It can also occur in the form of map cracking and scaling, which can result from chemical reactivity or aggregate degradation. Surface distress is somewhat related to roughness (i.e., the more cracks and disintegration, the rougher the pavement will be) as well as structural integrity (surface distress can be a sign of impending or current structural problems).</p> <p>2. Surface distress should not be part of a payment adjustment decision, but must meet a pass/fail target for acceptance.</p>			
Thickness ⁽³⁾	ASTM C174, Cores	Minimum Design Thickness minus ¼ in. Minimum 3 tests per Sublot	PWL 85% full payment LQL = Design Thickness minus ¼ in. ⁽⁴⁾ Repair any Sublot that does not meet the LQL.
	Probing ⁽⁵⁾		
	MIT Scan T2 ⁽⁶⁾		
	GPR ⁽⁷⁾		
<p>3. From a long-term performance perspective, some practitioners conclude that thickness should not be an acceptance parameter, but it still should be monitored as part of the Contractor’s quality management and the Agency’s verification testing to ensure that the minimum design thickness is met for structural integrity. This can be accomplished using a probe on fresh concrete and requiring repair of any Sublot not meeting the minimum requirement.</p> <p>4. For CRCP designs, thickness may also require an upper limit for reinforcing steel design requirements (e.g., UQL = Design Thickness plus 1 in.)</p> <p>5. Thickness is traditionally measured using cores, despite not necessarily being conducive to rapid construction/testing. For high-volume, high-profile roadways, an Agency may decide that drilled cores are necessary for acceptance. However, for low-volume roadways, consider using probing data for acceptance and excluding thickness from the payment adjustment formula.</p> <p>6. Although used primarily for research purposes, the MIT (magnetic imaging tomography) Scan T2 provides another NDT</p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
<p><i>alternative for measuring thickness. The device provides walking-speed point measurements of reasonable accuracy—within 1/10 in. for 13 in. of thickness. The MIT Scan T2 requires a seated plate under the slab.</i></p> <p>7. <i>As an alternative to destructive core sampling, consider using NDT devices, such as GPR (ground-penetrating radar) with limited coring. GPR would provide the <u>advantage of</u></i></p> <ul style="list-style-type: none"> <i>Continuous measurements taken at highway speed, and</i> <i>Reasonable accuracy and repeatability—within 10% for thickness (though not as accurate as cores).</i> <p><i>Some possible limitations associated with this technology include</i></p> <ul style="list-style-type: none"> <i>Cost of equipment (approximately \$30,000–\$40,000 for the unit),</i> <i>Some processing time needed to analyze data and estimate material properties, and</i> <i>Relatively high technician skill level for data analysis.</i> 			
Strength ⁽⁸⁾	ASTM C1074 (Maturity Method) ⁽⁹⁾	Minimum 5 tests (maturity readings) per Lot	PWL 85% full payment LQL = Minimum Design Strength minus 300 psi
<p>8. <i>Measuring flexural strength is the preferred method for monitoring strength, as it provides a more direct comparison to design strength. However, testing is cumbersome due to the need to fabricate and test beams for third-point loading. It has therefore become standard practice to measure the compressive strength of concrete (though flexural strength would provide a more direct indication of design strength). Strength is more critical for CRCP than jointed concrete. Too high a strength value could be detrimental for CRCP (i.e., an upper bound is needed).</i></p> <p>9. <i>Instead of testing cores or field-cured cylinders, maturity meters would provide a nondestructive way to estimate in-place concrete strength. Maturity methods are based on the concept that concrete strength is directly related to its age and temperature history, and that samples of a given mixture will attain equal strengths if they attain equal values of maturity index. Before any field measurements are taken, the strength-maturity relationship of a particular mix must be determined in the laboratory based on either compressive or flexural strength. Such maturity curves can then be used to correlate field maturity readings—taken from sensors embedded within the in situ mat about every 500 ft (or 1,000 yd² of volume)—to cylinder strength.</i></p>			
Permeability ^(10, 11) (by resistivity methods)	ASTM C1202, Chloride Ion Penetration Resistivity (accelerated test)	2,000–4,000 coulombs (max) at 28 days Testing frequency per Department standard requirements (minimum two tests per day and after any mixture modifications)	PWL 85% full payment UQL = 4,000 coulombs at 28 days
	Surface Resistivity Meter	KOhm-cm	
Permeability ^(10, 11)	Oxygen Permeability Index		
<p>10. <i>Although permeability is a critical durability indicator, particularly for cold or marine climates in which salts are present in the air or the pavements, some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. Some practitioners caution that permeability should not be incorporated into a payment adjustment system until a more rapid and repeatable test becomes standard practice.</i></p> <p>11. <i>ASTM C1202 is the most widely used test for measuring permeability (though it actually measures resistivity, not permeability). Agencies have also investigated the use of a surface resistivity meter to measure concrete's resistance to chloride ion penetration as an economical and time-saving alternative to ASTM C1202. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.</i></p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Air Content ⁽¹²⁾	ASTM C231, Air Content by Pressure Method ⁽¹³⁾	Per Department standard requirements	PWL 85% full payment UQL = Target + 2 % LQL = Target – 1 %
Air Quality	Air Void Analyzer ⁽¹⁴⁾		
	ASTM C457, Hardened air from cores ⁽¹⁵⁾		
<p>12. The presence of closely spaced air voids is a key factor in improving the freeze-thaw resistance of concrete. In measuring air content/quality, consideration should be given to where measurements are taken, as changes in air content/quality will occur as concrete passes through the paver. Samples should be collected either behind the paver or in front of the paver with an assumed amount of air loss through the paver that is then verified through routine tests in front of and behind the paver.</p> <p>13. Although the volumetric or pressure test is the standard method for measuring air content, it has the following limitations:</p> <ul style="list-style-type: none"> • Samples are typically taken when materials are delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated. • A pressure test only provides information on the total volume of air; it cannot characterize the air void system (i.e., spacing and volume). <p>The preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) (or for hardened concrete through petrographic analysis of polished thin sections).</p> <p>14. If rapid construction is the primary objective, acceptance can be based on AVA testing using fresh concrete samples at the paver.</p> <p>15. If durability is the Agency's primary objective, acceptance should be based on hardened air content determined from cores removed from the constructed pavement. The Contractor may use pressure or AVA testing for monitoring air content during construction, and final acceptance will be based on hardened concrete cores using petrographic analysis of thin sections.</p>			
Ride Quality ⁽¹⁶⁾	AASHTO M 328, Inertial Profiler Measurement and Continuous Roughness Reporting ⁽¹⁷⁾ Measure pavement profile in both wheel paths simultaneously, parallel to the right edge of the lane, and in the direction of travel for each lane.	IRI ≤ 67 in./mi with 0.1-mi baselength for full payment Localized Roughness: IRI ≤ 125 in./mi with 25-ft baselength	PWL 85% full payment based on Continuous Roughness histogram from ProVAL
<p>16. Ride quality is considered a measure of quality for the installed product and an indirect indicator of pavement performance. Continuous roughness reporting is recommended for acceptance and pay adjustments.</p> <p>17. Different measurement strategies have been used depending on the application. Many Agencies use a tiered system based on road type or type of work (e.g., overlay versus reconstruction). For acceptance, a concrete profilograph is still the norm for many Agencies, but the trend is toward using an IRI (International Roughness Index) standard. An inertial profiler-based measurement is recommended to facilitate rapid renewal and to provide a better indication of the road user's perception of rideability. However, smoothness measurement using a profilograph may be necessary if an Agency does not have equipment and thresholds established for IRI.</p>			

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Skid Resistance ⁽¹⁸⁾	ASTM E274 ASTM E524 ASTM E501 Collect a friction number (FN) data test point every 3/10 of a lane-mile for each travel lane, at a minimum testing frequency	FN40S \geq 40 FN40R \geq 45 Evaluate 100% of pavement surface. Average per lane or as per Department requirements	PWL 85% full payment

18. Skid resistance relates to aggregate properties (polishing resistance) and surface texture. It is a safety concern for higher-volume roadways with wet weather conditions. Some Agencies will restrict the use of softer aggregates in the mix design for certain projects or conditions to ensure adequate friction is obtained. More extensive use of diamond grinding concrete pavements has raised the importance of friction or skid resistance as a performance parameter. This parameter is most applicable as an acceptance and a functional performance requirement monitored under a warranty specification, but may also be appropriate for nonwarranted pavement when safety (skid resistance) is a key end-result requirement for a PCC pavement.

Transverse tining is a standard and relatively inexpensive method to achieve higher-friction surfaces, particularly for wet weather conditions on high-speed concrete pavements. A disadvantage of transverse tining is that it often causes undesirable noise emissions, which has led to the use of alternative tining patterns. The requirement to meet skid resistance must also be balanced with the requirement to meet noise intensity thresholds if noise abatement is a project objective.

Skid resistance and texture depth are related but not necessarily directly correlated. Although specifying skid resistance is preferred, if an Agency does not have test procedures or acceptable threshold values for skid resistance, then texture depth, spacing, and patterning could serve as a performance measure until proper thresholds and test procedures for skid resistance are established. If the Contractor is given greater flexibility in selecting the texturing technique and aggregate properties, Skid Resistance or Texture Depth requirements will ensure that the texturing method will meet the functional requirements for safety and noise.

Joint Deficiencies ⁽¹⁹⁾	Visual survey (includes raveling, spalling, faulting, and seal damage/integrity)	No joint deficiencies permitted	The Department will evaluate deficiencies on a case-by-case basis to determine if a repair will be required.
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19. Joint deficiency encompasses unacceptable spalling or raveling along the joint, as well as defective or improperly installed joint seals.

An additional performance measure for acceptance is joint performance, as measured through load transfer efficiency (LTE) of the joint and dowel bar alignment. LTE can be measured through standard deflection testing (e.g., falling weight deflectometer, FWD), but consideration must be given to the age of the pavement, season, and time of testing. If tested at too early an age, cracks may not yet be formed at joint locations. If tested in warmer seasons or time of day, LTE may be artificially high and not representative of the true average LTE.

Load Transfer Efficiency (LTE) ⁽²⁰⁾	Deflection Testing (e.g., FWD)	Evaluate 5% of the joints in each Lot per Department random sampling protocols. LTE \geq 90%	PWL 85% full payment LQL = 80% LTE
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20. If evaluating LTE, consideration must be given to the age of the pavement, season, and time of testing. If tested at too early an age, cracks may not yet be formed at joint locations. If tested in warmer seasons or time of day, LTE may be artificially high and not representative of the true average LTE.

Parameter	Measurement Procedure (Test Method/Device)	Target/Lot Requirements	Tolerance/Quality Acceptance Limits
Dowel Bar Alignment ⁽²¹⁾	GPR or MIT Scan	Evaluate 5% of the joints in each Lot per Department random sampling protocols.	PWL 85% full payment
<p>21. <i>Measuring dowel bar alignment is still an evolving practice. Ground-penetrating radar (GPR) and magnetic tomography technology (MIT Scan) are the only devices known to provide reasonable measurement precision. But these technologies also have some shortcomings, such as difficulty with measuring dowel bar locations if the dowel basket ties have not been cut. An alternative is to measure joint functionality by monitoring joint width at various times of day and various seasons, which will indicate whether a joint is “locked up” or functioning normally.</i></p> <p><i>Agencies may also wish to consider a requirement for dowel bar alignment at transverse joints.</i></p>			
Steel Location ⁽²²⁾	GPR or MIT Scan Measured from reference surface	± 0.5 in. on vertical rebar/tie-bar placement ± 1 in. on horizontal tie-bar placement	PWL 85% full payment
<p>22. <i>Currently, there are no established test methods for measuring steel location postconstruction. GPR and MIT Scan techniques are available but currently do not provide the necessary precision.</i></p>			
Tire-Pavement Noise ⁽²³⁾	On-Board Sound Intensity (OBSI) measurement with a Standard Reference Test Tire, AASHTO TP 76 ⁽²⁴⁾	Maximum A-weighted tire-pavement noise level of 100 dB at 50 mph ⁽²⁵⁾ Evaluate 100% of pavement surface.	PWL 85% full payment
<p>23. <i>Noise caused by tire-pavement interaction is a performance parameter addressing noise impacts to highway abutters. If a noise performance parameter is included, industry must be allowed to be more innovative with respect to surface texturing or pavement design. Alternative tining or other drag texturing methods and diamond grinding can meet skid resistance with reduced noise intensity. Similarly, alternative pavement designs using thin open-graded (pervious) concrete wearing surfaces or exposed aggregate surfaces have been shown to reduce noise compared with other pavement types.</i></p> <p>24. <i>On-board sound intensity (OBSI) measures tire-pavement noise at the source using microphones in a sound intensity probe configuration mounted to the outside of a vehicle near the tire-pavement interface. The directional characteristic of the probe makes it better suited for measuring a specific noise source, while attenuating sounds from other sources in other directions (such as engine or exhaust noise), and correlates well with sound measured at the roadside. The OBSI method was first standardized by the AASHTO in 2008 and has undergone annual updates as provisional standard TP 76, “Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method.”</i></p> <p>25. <i>At present, there are no established thresholds for tire-pavement noise. The values shown above should be modified according to the Agency’s standard practice.</i></p>			

5.3 Quality Level Analysis

For DB, payment is typically based on lump-sum values. However, current DB contracts continue to incorporate unit-priced payment adjustments for pavements.

- A. Unless otherwise indicated in Table 7, acceptance of material and work shall be based on the method of estimating percent within limits (PWL), where the PWL will be determined in accordance with this Section. All Sublot test result values for a Lot, as defined in Table 7, will be analyzed statistically to determine the total estimated PWL. The PWL is computed using the Lot sample average value, \bar{X} , as defined in Section 5.3.C.2, the Lot sample standard deviation, S_n , as

defined in Section 5.3.C.3, for the specified number of Sublots, n , and the specification Quality Acceptance Limits, as defined in Table 7, where LQL represents the Lower Quality Limit, and UQL represents the Upper Quality Limit, as they apply to each particular acceptance parameter. From these values, the respective Quality Index (Indices), Q_L for Lower Quality Index and/or Q_U for Upper Quality Index, is (are) computed in accordance with Sections 5.3.C.4 and 5.3.C.5. Then the PWL for the Lot for the specified number of Sublots, n , is determined from Table 8.

B. In addition, all concrete and concrete placement work shall conform to the requirements of Section 7.4. For any identified deficiencies, as defined in Section 7.4, the Contractor may either

1. Remove and replace the concrete in that particular Lot at no additional cost to the Department, or
2. Accept a deduction of 50% of the contract unit price for that particular Lot of concrete.

C. Determine the PWL as follows:

1. In accordance with this specification and the QMP, locate sampling positions, obtain test sample, make specimens, and conduct test.
2. Determine the Lot sample average value, \bar{X} , by calculating the average of all Sublot test values.
3. Find the Lot sample standard deviation, S_n , by using the following formula:

$$S_n = \sqrt{\frac{\sum (x_i - \bar{X})^2}{n - 1}}$$

where

- S_n = standard deviation of the Sublot test values
- x_i = individual Sublot test values
- \bar{X} = average of Sublot test values
- n = number of Sublots

4. Find the Lower Quality Index, Q_L , by subtracting the Lower Quality Limit, LQL, from the average value, \bar{X} , and dividing the result by the Lot sample standard deviation, S_n .

$$Q_L = \frac{\bar{X} - LQL}{S_n}$$

5. Find the Upper Quality Index, Q_U , by subtracting the Lot sample average value, \bar{X} , from the Upper Quality Limit, UQL, and dividing the result by the Lot sample standard deviation, S_n .

$$Q_U = \frac{UQL - \bar{X}}{S_n}$$

6. Determine the percentage of material above lower tolerance limit, P_L , and the percentage of material below upper tolerance limit, P_U , by entering Table 8 with Q_L and/or Q_U using the column appropriate to the total number of Sublots, n , and reading the appropriate number under the column heading “PWL.”
7. For quality characteristics with only an Upper Quality Limit (e.g., permeability), PWL equals P_U . For characteristics with only a Lower Quality Limit (e.g., LTE), PWL equals P_L . For concrete properties with both Upper and Lower Quality Limits (e.g., air content), first calculate the Upper Quality Index, Q_U , and the Lower Quality Index, Q_L , by using the Upper Quality Limit, UQL, and the Lower Quality Limit, LQL, respectively. The limits to be used are stipulated in Table 7. Then determine PWL using the following formula:

$$PWL = (P_U + P_L) - 100$$

8. The PWL from Table 8 that is to be used is the whole number greater than that found by using the Q_U or Q_L in the table. For example, the PWL to be used for $n = 4$ and a Q_U of 1.4200 would be 98.

Table 8: Percent within Limits (PWL)
(STANDARD DEVIATION METHOD)
Positive Values of Quality Index (QI)
(n = Number of Sublots in the Lot)

PWL	n=3	n=4	n=5	n=6	n=7	n=8
100	1.1600	1.5000	1.7900	2.0300	2.2300	2.3900
99	1.1541	1.4700	1.6714	1.8008	1.8888	1.9520
98	1.1524	1.4400	1.6016	1.6982	1.7612	1.8053
97	1.1496	1.4100	1.5427	1.6181	1.6661	1.6993
96	1.1456	1.3800	1.4897	1.5497	1.5871	1.6127
95	1.1405	1.3500	1.4407	1.4887	1.5181	1.5381
94	1.1342	1.3200	1.3946	1.4329	1.4561	1.4716
93	1.1269	1.2900	1.3508	1.3810	1.3991	1.4112
92	1.1184	1.2600	1.3088	1.3323	1.3461	1.3554
91	1.1089	1.2300	1.2683	1.2860	1.2964	1.3032
90	1.0982	1.2000	1.2290	1.2419	1.2492	1.2541
89	1.0864	1.1700	1.1909	1.1995	1.2043	1.2075
88	1.0736	1.1400	1.1537	1.1587	1.1613	1.1630
87	1.0597	1.1100	1.1173	1.1191	1.1199	1.1204
86	1.0448	1.0800	1.0817	1.0808	1.0800	1.0794
85	1.0288	1.0500	1.0467	1.0435	1.0413	1.0399
84	1.0119	1.0200	1.0124	1.0071	1.0037	1.0015
83	0.9939	0.9900	0.9785	0.9715	0.9672	0.9643
82	0.9749	0.9600	0.9452	0.9367	0.9325	0.9281
81	0.9550	0.9300	0.9123	0.9020	0.8966	0.8928
80	0.9342	0.9000	0.8799	0.8690	0.8625	0.8583
79	0.9124	0.8700	0.8478	0.8360	0.8291	0.8245
78	0.8897	0.8400	0.8160	0.8036	0.7962	0.7915
77	0.8662	0.8100	0.7846	0.7716	0.7640	0.7590
76	0.8417	0.7800	0.7535	0.7401	0.7322	0.7271
75	0.8165	0.7500	0.7226	0.7089	0.7009	0.6958
74	0.7904	0.7200	0.6921	0.6781	0.6701	0.6649
73	0.7636	0.6900	0.6617	0.6477	0.6396	0.6344
72	0.7360	0.6600	0.6316	0.6176	0.6095	0.6044
71	0.7077	0.6300	0.6016	0.5878	0.5798	0.5747
70	0.6787	0.6000	0.5719	0.5583	0.5504	0.5454
69	0.6490	0.5700	0.5423	0.5290	0.5213	0.5164
68	0.6187	0.5400	0.5129	0.4999	0.4924	0.4877
67	0.5878	0.5100	0.4836	0.4710	0.4638	0.4592
66	0.5563	0.4800	0.4545	0.4424	0.4354	0.4310
65	0.5242	0.4500	0.4255	0.4139	0.4073	0.4031
64	0.4916	0.4200	0.3967	0.3856	0.3793	0.3753
63	0.4586	0.3900	0.3679	0.3575	0.3515	0.3477
62	0.4251	0.3600	0.3392	0.3295	0.3239	0.3203
61	0.3911	0.3300	0.3107	0.3016	0.2964	0.2931
60	0.3568	0.3000	0.2822	0.2738	0.2691	0.2660
59	0.3222	0.2700	0.2537	0.2461	0.2418	0.2391
58	0.2872	0.2400	0.2254	0.2186	0.2147	0.2122
57	0.2519	0.2100	0.1971	0.1911	0.1877	0.1855
56	0.2164	0.1800	0.1688	0.1636	0.1613	0.1592
55	0.1806	0.1500	0.1408	0.1363	0.1338	0.1322
54	0.1447	0.1200	0.1125	0.1090	0.1070	0.1057

6 METHOD OF MEASUREMENT

The lump-sum pricing structure found in a typical DB contract largely eliminates the use of measured quantities and unit pricing to determine progress and payment. However, the Agency may choose to measure pavement quantities for the express purpose of calculating pay factor adjustments as described in Section 7.

7 BASIS OF PAYMENT

DB contracts are typically lump-sum contracts in which progress payments are based on partial progress for lump-sum items in the schedule of values. However, pavements and other selected items for DB contracts continue to use unit-priced items to allow for pay factor adjustments to reward the Contractor for providing superior product and penalize the Contractor for providing product that is of lower quality than specified.

This section assumes use of a percent within limits (PWL) approach to compute pay adjustments. The PWL method encourages Contractors to produce consistent quality work, with monetary rewards and penalties tied to a statistically valid measure of quality. Unlike other quality measures such as computing an average from material samples, PWL captures both the mean and standard deviation in one measure, encouraging Contractors to produce a more uniform product.

Although simple to apply, the PWL approach primarily relies on engineering judgment to establish the individual pay adjustments and weighting factors. Arguably, a more rational approach would entail the use of mathematical models to compute pay factors for a given Lot based on the effect of construction quality on the predicted performance and subsequent LCC of the as-constructed pavement. The existing PRS methodology and simulation software (PaveSpec 3.0), as described in FHWA-RD-98-155, can directly consider the following quality characteristics in the computation of pay factors: concrete strength, slab thickness, initial smoothness, entrained air content, and percent consolidation around dowel bars. Moving forward, it is anticipated that updates to PaveSpec will incorporate additional quality characteristics and distress models that align with mechanistic design methods.

7.1 Pay Factor Adjustments

- A. Pay Factor adjustments for each Lot of each quality characteristic will be computed in accordance with the formulas contained in Table 9 by entering the PWL value and performing the calculation indicated for the appropriate PWL range.

For example, if 100% of the product is within limits, the pay adjustment is 0.06 = 6%, meaning the Contractor receives a 6% bonus.

Table 9: Adjustments to Contract Compensation

Percent Within Limits (PWL)	Pay Factor
91–100	[0.006 (PWL – 90)]
85–90	0.0
55–84	–0.9 + 0.01PWL

- B. The overall Pay Factor for a given characteristic, PF_i , is determined by calculating the average of all PFs for that characteristic for every Lot in the project.

7.2 Pay Adjustment

Based upon the quality of the pavement, the Department will calculate a weighted pay adjustment. The weights applied to each quality characteristic will be as shown in Table 10.

Table 10 illustrates possible pay adjustments for different pay items. Specifiers should consider project-specific conditions and goals when selecting pay factor adjustments and weight them in accordance with the criticality of the parameter to the ultimate performance of the pavement. For example, durability factors such as permeability and air content may be weighted heavier than strength and thickness. Agencies may wish to eliminate some factors entirely if they do not have sufficient data to support pay adjustment for those items.

Table 10: Pay Adjustment Criteria

Parameter	PF Designation	Weighting
Compressive Strength	PF _{cs} *	0.5
Permeability	PF _p	1
Air Content	PF _a	1
Thickness	PF _t *	0.5
Ride Quality	PF _{rq}	1
Skid Resistance	PF _{sr}	0.5
Load Transfer Efficiency	PF _{lte}	0.5
Dowel Bar Alignment	PF _{da}	1
Steel Location	PF _{sl}	1
Tire-Pavement Noise	PF _n	1

*PF = 0.0 for PWL > 84

Example of a composite pay adjustment, PA:

$$= \frac{[(PF_{cs} \times 0.5) + (PF_p \times 1) + (PF_a \times 1) + (PF_t \times 0.5) + (PF_{rq} \times 1) + (PF_{sr} \times 0.5) + (PF_{lte} \times 0.5) + (PF_{da} \times 1) + (PF_{sl} \times 1) + (PF_n \times 1)]}{(0.5 + 1 + 1 + 0.5 + 1 + 0.5 + 0.5 + 1 + 1 + 1)}$$

7.3 Total Project Adjusted Price

The Department will calculate a total project Adjusted Price (AP) by multiplying the composite Pay Adjustment (PA) from Section 7.2 times the total area of pavement in place, in square yards (SY), times the unit price.

$$AP = (PA) \times (SY \text{ Concrete}) \times (\$/SY)$$

7.4 Correction of Deficiencies

Remove and replace or correct pavement in a manner acceptable to the Department and at no cost to the Department if any of the following deficiencies exist, unless the Department elects to accept the concrete, at which time the Contractor will be compensated at 50% of the contract unit price for concrete placement specified regardless of the Pay Factors calculated in Tables 9 and 10:

1. PWL for compressive strength, permeability, or air content is below 55.
2. PWL for ride quality is below 55 unless the Contractor elects to grind pavement to within specification.

3. PWL for skid resistance is below 55 unless the Contractor elects to correct with grinding, shotblasting, or a thin friction overlay as deemed acceptable to the Department.
4. PWL for tire-pavement noise is below 55 unless the Contractor elects to correct with grinding or with a thin friction overlay as deemed acceptable to the Department.
5. If the calculated average of two consecutive thickness probe tests indicates deficient thickness greater than 10%.
6. PWL for load transfer efficiency is below 55 unless the Contractor elects to correct load transfer with a dowel bar retrofit deemed acceptable to the Department.
7. PWL for dowel bar alignment or steel location is below 55.

CEMENT CONCRETE PAVEMENT

PERFORMANCE SPECIFICATION WITH WARRANTY

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance warranty provision for implementation under either a design-bid-build (DBB) or a design-build (DB) delivery approach.

Unless otherwise noted, the recommended performance parameters and ancillary requirements contained in this specification apply to both DBB and DB delivery, assuming roles and responsibilities will be assigned as follows:

- *Selection of the pavement type by the Agency (or by Contractor if life-cycle cost, LCC, analysis is provided at bid);*
- *Structural design by the Agency (or by Contractor under DB);*
- *Mix design by the Contractor;*
- *Quality management by the Contractor;*
- *Verification testing and initial acceptance at the end of construction by the Agency;*
- *Postconstruction performance warranty provided by the Contractor;*
- *Routine maintenance by the Agency; and*
- *Final acceptance of the pavement at the end of the specified warranty period by the Agency.*

Specification Objectives

The inclusion of a warranty provision allows the Agency to expand the performance measurement strategy used under DBB and DB project delivery to include functional performance parameters that monitor and evaluate the actual performance of the pavement over time. The protection against defective work and premature failure offered by the warranty may allow the Agency to eliminate or relax some of its standard prescriptive requirements in the interest of rapid renewal.

Using This Guide Specification

The requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a detailed example that users can adapt to fit the needs of a particular project or program. Likewise, this specification is intended to be flexible enough to accommodate advances in technology that could affect the performance measurements and values during the life of the Contract.

Commentary included within the specification (as indicated with italic typeface) provides guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw upon the information provided as a basis for further modification or development of the specification.

In implementing this specification, Agencies are further encouraged to require the Contractor to develop and adhere to a comprehensive Quality Management Plan (QMP). A sample general provision addressing the roles and responsibilities for quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Finally, note that for a DB project, the term “Contractor” as used in this document should be interpreted as that entity given single-point responsibility for both the design and construction of the work and is thus synonymous to “Design-Builder” and “Design-Build Team.”

1 DESCRIPTION

[Design and] Construct a cement concrete pavement *[consisting of normal or high early-strength (HES) cement concrete pavement, plain, reinforced or continuously reinforced concrete pavement]* on a prepared base and foundation.

For DB projects, the sentence above should be modified to include design as well as construction services.

Provide a Quality Management Plan (QMP) and perform all sampling, testing, and inspection necessary to control and assure the quality of the work in accordance with the QMP. The Department, acting in an oversight role, will conduct verification sampling and testing and independent assurance.

The Contractor's preparation of a formal QMP is an integral component of this performance specification. A QMP requirement allows the Agency to eliminate prescriptive requirements in exchange for the Contractor's development and adherence to a detailed plan of how it intends to complete the work and meet the performance requirements.

Warrant the finished pavement for a period of *[10 years]* after the date of *[Final Inspection, Substantial Completion, or opening of all lanes to unrestricted traffic]* as designated by the Department.

Maintain the pavement during the warranty period to meet the performance indicators and thresholds specified in Section 6.4. Perform all required remedial work during the warranty period and correct deficiencies identified in pavement evaluations.

Pavement evaluations should, at a minimum, include an initial and final survey with interim surveys if necessary or agreed upon.

2 STANDARDS AND REFERENCES

This Standards and References section applies primarily to DB projects and serves to identify the design and other procedural manuals and standards (e.g., AASHTO, FHWA, Agency) that the Contractor should follow, particularly when performing the project design work. Note that such documents may contain prescriptive requirements that could limit the Contractor's flexibility and ability to innovate. Therefore, when referencing standards in Table 1, balance the need for conformance with the Agency's existing facilities and processes (consider, for example, tie-ins to existing facilities, right-of-way—ROW—requirements, environmental issues) against the opportunity for innovation.

Likewise, materials standards, test methods, and similar reference documents cited throughout the specification should be obtained and reviewed to ensure that they do not inadvertently impose undesired restrictions on the Contractor, in which case the specifier should identify exceptions to the standard.

2.1 Standards

Unless otherwise stipulated in this specification or as approved by the Department, design and construct the pavement in accordance with this performance specification and the relevant requirements of the standards listed, by order of priority, in Table 1.

If the standards conflict, adhere to the standard with the highest priority. If the standards contain any unresolved ambiguity, obtain clarification from the Department prior to proceeding with design or construction.

Use the most current version of each listed standard as of the initial publication date of the RFP unless modified by addendum or change order.

Table 1: Standards for Pavements

Priority	Author or Agency	Title
1		
2		
3		

2.2 References

This subsection may be included if the Agency wishes to identify nonmandatory references that could assist the Contractor's efforts.

The Contractor may consult the references listed in Table 2 for supplementary guidance in designing and constructing the pavement system. These references have no established order of precedence and are not intended to be all-inclusive.

Table 2: References for Pavements

Author or Agency	Title

3 REQUIREMENTS

Design requirements, as identified in Section 3.1, apply to DB projects only. For DBB, specifiers may follow a more traditional AASHTO five-part format, with Materials and Construction Requirements sections immediately following the Scope/Description.

3.1 Design

Perform all pavement engineering activities, including, but not limited to, the following:

List will vary based on how much initial design work was completed by the Agency.

- Pavement/geotechnical investigation
- Pavement design and analysis
- Material selection
- Cement concrete mix design

The Agency may also choose to allow the Contractor to select the pavement type during the bidding phase. In this case, the Agency should generally require the Contractor to follow a

specified LCC analysis procedure to demonstrate adequate pavement life and LCC for the pavement type designed. If implemented under an alternative bid provision, the Agency could use an "A+C" bid model, in which "A" represents the base bid for the selected alternate and "C" represents an LCC bid adjustment factor.

All pavement engineering activities shall be directed, supervised, signed, and sealed by a Professional Engineer, licensed in the State of [-] with a minimum of [5] years of experience in pavement engineering.

3.1.1 Pavement Investigation

Perform and document all geotechnical investigations, testing, research, and analyses necessary to determine and understand the existing surface and subsurface conditions.

Prepare and submit geotechnical engineering reports documenting the assumptions, conditions, and results of the investigations and analyses, including the following:

- Geology of the project area;
- Results from field investigations and laboratory testing, including a discussion of how these results affect the design of the pavement;
- Design and construction parameters resulting from the geotechnical investigation and analyses; and
- Boring logs, laboratory results, calculations, and analyses that support design decisions.

3.1.2 Design Criteria

Design the pavement structure in accordance with the subsurface information collected in accordance with Section 3.1.1, the standards identified in Section 2.1 or other approved alternatives, and the criteria defined in Table 3.

Table 3: Design Criteria

Design Criteria	Requirement
Design Life	
Design Traffic (18-kip ESALS)	
Shoulder Type	<i>(e.g., tied concrete shoulders, widened lanes, asphalt or granular shoulders)</i>
Drainage	Provide a free-draining pavement that will not compromise surface or subsurface drainage of existing pavement to remain in place.
Tie-ins	Minimize pavement-to-structure transition deviations.
Joints	Longitudinal pavement joints must be on lane lines or within 1 ft of the centerline of the lane.

Modify Table 3 to include all additional requirements that could affect the design of the pavement system. For example,

- *Design Reliability;*
- *PCC Modulus of Rupture and Elastic Modulus;*
- *Required Ride Quality (international roughness index, IRI/Profilograph Index, PrI);*
- *Pavement Type—such as continuously reinforced concrete pavement (CRCP), roller-compacted concrete pavement (RCCP), or jointed plain concrete pavement (JPCP);*
- *Load Transfer Coefficient;*
- *Subgrade requirements [e.g., minimum support values (minimum strain rate, MSR), improvement strategies];*
- *Future expansion (e.g., “Design and construction must feasibly allow for future economical expansion through addition of lanes and other elements.”); and*
- *Different design criteria for mainlines and ramps versus auxiliary lanes and shoulders.*

3.1.3 Design Documentation

In exchange for providing the Contractor flexibility with regard to design and construction decisions, the Agency should require the Contractor to fully document and report all design assumptions and decisions.

Prepare and submit pavement design reports that include the following items, as a minimum:

- All pertinent design inputs, such as traffic data, soils characteristics, characteristics of the proposed construction materials, environmental conditions, and pavement design life;
- Site plan showing the limits of the roadway covered by the design report;
- Discussion of site conditions that might influence the design and performance of the pavement;
- Discussion of the inputs used to arrive at design recommendations and the rationale used in selecting the recommended design strategy (where applicable, life-cycle management analysis, including the periods for resurfacing, reconstruction, and other rehabilitation measures);
- Pavement design details, including structural layer materials and thicknesses, and typical cross-section drawings;
- Comprehensive construction specifications sufficiently detailed to describe the process or end-result requirements; and
- Other considerations used in developing the pavement design(s), including subgrade preparation and stabilization procedures as applicable.

3.2 Material Requirements

When preparing the Materials section, carefully consider the extent to which the specification needs to prescribe basic material properties, particularly if the warranty requirements will hold the Contractor accountable for performance issues stemming from the selection and use of inferior materials.

Under the warranty requirements, the Contractor will assume risk for performance over time and should therefore be afforded more latitude to investigate materials options that could result in superior performance or time or cost savings.

If not already a part of the Agency's standard acceptance program, consider allowing prequalification of sources/suppliers and acceptance by certification. In keeping with the goals of rapid renewal, such provisions can help streamline construction by reducing the need for testing that could otherwise delay or disrupt operations. For example, consider allowing the Contractor to incorporate the following materials into the work by submitting manufacturer's certifications that substantiate that each shipment conforms to the specified quality requirements:

- *Cement;*
- *Supplementary Cementitious Materials;*
- *Admixtures;*
- *Joint Seals and Fillers;*
- *Curing Compound and Evaporation Retarders;*
- *Epoxy (for drilling and anchoring steel); and*
- *Reinforcement (dowel bars, tie bars, mat reinforcement).*

Similarly, aggregate sources (if Agency preapproved sources are not used) may be qualified prior to construction by verifying results related to the following properties:

- *Soundness,*
- *Hardness,*
- *Polishing resistance,*
- *Abrasion resistance,*
- *Freeze-thaw durability,*
- *Alkali-aggregate reactivity,*
- *Absorption, and*
- *Specific gravity.*

Evaluate material quality before and during construction in accordance with the approved QMP. Reject all nonconforming materials and replace with suitable materials.

3.3 Construction Requirements

The Agency's confidence in its ability to measure actual performance during the warranty period will control the degree to which an Agency can relax its standard construction requirements. In the interest of rapid renewal, consider eliminating requirements related to weather or seasonal restrictions, equipment, joints, temperature, curing, etc., particularly when the warranty requirements would hold the Contractor accountable for the performance issues the prescriptive requirements were intended to prevent.

In exchange for providing the Contractor more flexibility with regard to mixture design and construction decisions, the Agency should require the Contractor to describe in its QMP how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, ordering, handling, placing, finishing, and curing of concrete) will affect the in-place properties and performance of the work and that the Contractor has planned the work and allocated its resources accordingly.

3.3.1 General

The Contractor is responsible for providing all management, professional, and technical services; and labor, materials, and equipment necessary to construct the pavement.

3.3.2 Mix Design

Develop and submit for the Department’s review a cement concrete mixture design in accordance with *[Standard Specification XXX]* and *[AASHTO M 157]* along with documentation indicating that the proposed mixture design meets the criteria specified in Table 4.

If an Agency does not have batch plant certification processes in place, consider requiring National Ready Mixed Concrete Association (NRMCA) Plant Certification according to the NRMCA Certification of Ready Mixed Concrete Production Facilities Quality Control Manual.

Table 4: Mixture Properties

Design Parameter	Test Method ⁽¹⁾	Value
Compressive Strength	ASTM C39	
Flexural Strength	ASTM C78	
Freeze-Thaw Resistance	ASTM C666	
Air Quality ⁽²⁾	AVA Testing	
Permeability ⁽³⁾	ASTM C1202 (Chloride Ion Penetration)	
	Oxygen Permeability Index	
Coefficient of Thermal Expansion ⁽⁴⁾	AASHTO TP60	

- 1. The test methods identified are provided for guidance only. If an Agency has its own standard test methods for measuring these properties, specify those methods instead.*
- 2. Air content can be determined through conventional (volumetric or pressure) test methods; however, an issue with these methods is that samples are typically taken when delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated. Also, the pressure test provides air content but does not provide an indication of the air void system (i.e., spacing and volume). A preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) or for hardened concrete through petrographic analysis of polished thin sections taken from cores (ASTM C457). The AVA test, though not as widely accepted by industry, is a more sensitive test, and test results can be obtained in time to make adjustments in the mix during production and placement.*
- 3. Although permeability is a critical durability indicator, some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. The chloride ion penetration test (ASTM C1202) is the most widely used for structural concrete; however, it does not directly measure concrete permeability. What it does measure is concrete resistivity, which has been shown to have a fair correlation to concrete permeability. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.*
- 4. Coefficient of thermal expansion (CTE) testing can be used to validate the mix design with design assumptions for the site-specific environmental conditions.*

If the Contractor is choosing its own aggregate instead of using preapproved sources, also require verification of alkali-aggregate reactivity resistance (ASTM C1260).

4 QUALITY MANAGEMENT PROGRAM

This specification holds the Contractor responsible for performing tests used strictly for process control as well as tests that may be used in the Agency's acceptance decision. The Agency in turn should perform verification testing of select parameters. Although this approach may represent a departure from the traditional manner in which an Agency allocates responsibility for various quality management functions, it is consistent with the degree of risk assumed by the Contractor for performance of the work. Greater oversight by Agency personnel may add time to the project and conflict with the goals of rapid renewal.

4.1 Contractor's Responsibility for Quality Management

The requirements included in this Section 4.1 assume the Contract includes a separate provision related to development and implementation of a QMP that defines general requirements related to the Contractor's quality management personnel and organizational structure, documentation and reporting requirements, and procedures related to nonconforming work, corrective action, and similar matters. If such requirements are not otherwise addressed in the Contract's General Conditions, note that a sample general provision addressing quality management is included among the guide specifications developed under the SHRP 2 R07 project.

Note that the Agency should review the Contractor's QMP submittal to ensure it complies with these and other Contract requirements. If the Agency disagrees with elements of the QMP, it should raise these issues with the Contractor or refer comments to the conflict resolution team as discussed in Section 6.8 (if such a team has already been established for the construction phase of the project). The Agency should not "approve" the Contractor's QMP, as approval could be construed as assuming responsibility for the plan's content.

Assume responsibility for the quality of the work, including work performed or provided by subcontractors, suppliers, and vendors.

Perform all quality management activities described in *[the Agency's General Provision for Quality Management]*, including the additional requirements specific to cement concrete pavement construction as defined in this Section 4.1.

4.1.1 Contractor Testing

The approach taken in this section is to establish the minimum testing requirements that the Contractor's QMP must contain related to cement concrete pavement construction. The intent is to provide the Contractor some latitude with respect to developing a project-specific QMP while also ensuring that the Agency's minimum standards are met. These minimum requirements can also serve as guidance to bidders as they prepare a cost proposal for the work.

A possible disadvantage to this approach is that the Contractor may view these requirements not as a minimum but as all that is necessary to provide adequate quality management. If a best-value procurement process will be used to award the contract, the Agency should consider evaluating the proposers' project-specific QMP, or relevant portions thereof, as part of the selection criteria.

As part of the QMP to be prepared, submitted, and implemented in accordance with *[the Agency's General Provision for Quality Management]*, include, as a minimum, the sampling and testing requirements specified in Table 5, as well as all other inspections and tests the Contractor deems necessary to ensure the quality of the finished pavement.

Keep the Department apprised of upcoming testing activities to allow the Department to schedule the verification and independent assurance activities described in Section **Error! Reference source not found.** If verified as described in Section 4.2.1, the Department may use the Contractor’s test results for acceptance.

Various QMP requirements are included in Table 5 for the specifier’s consideration, not all of which will necessarily be appropriate or beneficial for a given project or program. Agencies may wish to include or exclude requirements based on the capabilities of local industry (including materials suppliers and testing firms), the project’s needs and goals, associated costs, and similar factors. Commentary included within the table itself provides rationale for including certain parameters. Test methods and frequencies are provided for illustrative purposes only and should be modified based on Agency practices or project requirements.

Table 5: Minimum QMP Requirements for Cement Concrete Pavement

Parameter	Test Method	Frequency
A. Materials		
Aggregate		
Source verification		
Gradation ⁽¹⁾	ASTM C33	
Fine aggregate fineness	ASTM C136	
Coarse aggregate shape & texture	ASTM D3398	
Fine aggregate shape & texture	ASTM D3398	
Cleanliness	ASTM C33 / ASTM C142	
Moisture content	ASTM C70 / ASTM C566	
Cementitious material	ASTM C150	
Admixtures	Certification	
Reinforcement	Certification	
<p>1. <i>Gradation control improves workability, reduces shrinkage (due to less paste content), and contributes to durability. For colder climates and higher-volume roadways, for which gradation control is particularly important, consider offering the Contractor an incentive to provide a well-graded aggregate mix.</i></p>		
B. Fresh Concrete		
Unit Weight ⁽²⁾	ASTM C138	
Slump	ASTM C43	
Water content		
Placement temperature	ASTM C1064	
Evaporation rate	ACI 308R	
Thickness ⁽³⁾	Probe	
Air content/quality ^(4, 5)	Air Void Analyzer	
<p>2. <i>Monitoring unit weight, a property not commonly measured today, would reveal mix design changes, thus eliminating the need for (or at least reducing the frequency of) more labor-intensive testing, such as for freeze-thaw resistance.</i></p> <p>3. <i>Measuring thickness is standard practice for portland cement concrete (PCC) pavements. To facilitate rapid renewal, the Contractor may choose to measure thickness by probing the fresh concrete to eliminate the need for coring except when verification is required. As an alternative (or supplement) to coring, nondestructive testing (NDT) methods for verification may include GPR (ground-penetrating radar) with limited coring, or MIT (magnetic imaging tomography) Scan T2.</i></p> <p>4. <i>The presence of closely spaced air voids is a key factor in improving the freeze-thaw resistance of concrete. In measuring</i></p>		

Parameter	Test Method	Frequency
<i>air content/quality, consideration should be given to where measurements are taken, as changes in air content/quality will occur as concrete passes through the paver. Samples should be collected either behind the paver or in front of the paver with an assumed amount of air loss through the paver that is then verified through routine tests in front of and behind the paver.</i>		
5.	<i>Although the volumetric or pressure test is the standard method for measuring air content, it has the following limitations:</i>	
	<ul style="list-style-type: none"> <i>Samples are typically taken when materials are delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated.</i> <i>A pressure test only provides information on the total volume of air; it cannot characterize the air void system (i.e., spacing and volume).</i> 	
<i>The preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) (or for hardened concrete through petrographic analysis of polished thin sections). The AVA can characterize the distribution of air voids in a timely manner (within 30 minutes), allowing adjustments to be made in the concrete batching process to ensure air voids are spaced properly.</i>		

C. Hardened Concrete

Compressive Strength ⁽⁶⁾	ASTM C1074 (Maturity) ⁽⁷⁾	
Flexural Strength ⁽⁸⁾	ASTM C78	
Freeze-Thaw Resistance ⁽⁹⁾	ASTM C666	
Permeability ⁽¹⁰⁾		
Chloride Ion Penetration	ASTM C1202	
Oxygen Permeability Index		
Coefficient of Thermal Expansion ⁽¹¹⁾	AASHTO TP60	

- It has become standard practice to measure the compressive strength of concrete (though flexural strength would provide a more direct indication of design strength). Strength is more critical for CRCP than jointed concrete. Too high a strength value could be detrimental for CRCP (i.e., an upper bound is needed).*
- Instead of testing cores or field-cured cylinders, maturity meters would provide a nondestructive way to estimate in-place concrete strength. Maturity methods are based on the concept that concrete strength is directly related to its age and temperature history, and that samples of a given mixture will attain equal strengths if they attain equal values of maturity index. Before any field measurements are taken, the strength-maturity relationship of a particular mix must be determined in the laboratory based on either compressive or flexural strength. Such maturity curves can then be used to correlate field maturity readings—taken from sensors embedded within the in situ mat about every 500 ft (or 1,000 yd² of volume)—to cylinder strength.*
- Measuring flexural strength is the preferred method for monitoring strength, as it provides a more direct comparison to design strength. However, testing can be cumbersome due to the need to fabricate and test beams for third-point loading.*
- If unit weight testing is used to monitor for mix design changes, the frequency of freeze-thaw testing may be reduced accordingly.*
- Although permeability is a critical durability indicator (particularly for cold or marine climates where salts are present in the air or the pavements), some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. The chloride ion penetration test (ASTM C1202) is the most widely used for structural concrete, though it actually measures concrete resistivity, not permeability. As an economical alternative to ASTM C1202, some Agencies have investigated the use of a surface resistivity meter to measure concrete's resistance to chloride ion penetration. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.*
- Agencies may also wish to require testing for coefficient of thermal expansion (CTE), as this is a key input for mechanistic-empirical pavement design.*

Parameter	Test Method	Frequency
D. In-place pavement		
Steel Placement		
Dowel Placement/Alignment ⁽¹²⁾		
Smoothness ⁽¹³⁾	Straightedge	
Cross-slope		
<p>12. <i>Dowel placement and alignment is important for proper consolidation around dowels and to avoid cracking near joints. There are currently no standard tests for dowel alignment, though one manufacturer has provided a proprietary magnetic imaging tomography (MIT) test device to measure dowel depth and alignment.</i></p> <p>13. <i>For process control, a straightedge has been the traditional method for determining pavement smoothness. A SHRP 2 research project (R06E) is developing technology for evaluating real-time smoothness behind the paver to achieve improved smoothness as part of process control during construction. For acceptance, a concrete profilograph is still the norm, but the trend is toward using inertial profilers and an IRI standard.</i></p>		

4.1.2 Production and Placement Procedures

In exchange for eliminating prescriptive requirements related to materials selection and construction methods, the Agency should require the Contractor to describe how it intends to perform the work and meet the performance requirements. A well-developed plan should help assure the Agency that the Contractor understands how its own actions (e.g., in the scheduling, ordering, handling, placing, finishing, and curing of concrete) will affect the in-place properties and performance of the work, and that the Contractor has planned the work and allocated its resources accordingly.

Include descriptions of the following in the QMP:

1. Certified mixing plant requirements, including calibration procedures for all meters, scales, and other measuring and recording devices.

If an Agency does not have batch plant certification processes in place, consider requiring National Ready Mixed Concrete Association (NRMCA) Plant Certification according to the NRMCA Certification of Ready Mixed Concrete Production Facilities Quality Control Manual.

2. Laboratory location, testing equipment, procedures for calibration, and training standards for personnel (e.g., National Institute for Certification in Engineering Technologies—NICET— or local standard).

Ensure that the laboratory and equipment will be maintained for the duration of the project.

3. Paving plan, including general staging and sequencing of operations.

When reviewing the Contractor's paving plan, consider the following:

- *Is the sequence compatible with the maintenance of traffic (MOT)?*
- *Can the Contractor's equipment accommodate the proposed sequence of operations (consider size and number of equipment)?*
- *How will driveways, cross streets, and other leave-outs be handled?*

4. Steel and dowel bar placement (for CRCP).

The Contractor should describe how it will install dowel bars (baskets or inserters) and secure them during concrete placement operations.

5. Concrete placement operations, including hauling, spreading, consolidating, and texturing.

When reviewing this portion of the Contractor's QMP, consider the following:

- *Is the proposed equipment appropriate for the project?*
 - *Is hauling equipment appropriate given the likely haul distance, haul time, and weather conditions?*
 - *Is equipment appropriate for spreading material in front of the paver (e.g., chute, belt)?*
- *Has the Contractor included a contingency plan for equipment break downs (e.g., if paver breaks down, will they sawcut and create a joint)?*
- *Does the Contractor intend to monitor consolidation to prevent overvibration?*
- *What type of texturing will be applied? How will it be applied?*

6. Methods to control alignment and profile.

Consider allowing use of stringless paving techniques as a rapid renewal consideration.

7. Joint installation procedures.

Consider the Contractor's plans for the following:

- *Sawcutting (type of equipment, timing, use of HIPERPAV);*
- *Constructing end-of-day joints and any leave-outs; and*
- *Sealing joints (type of material and timing).*

8. Finishing procedures.

Consider the adequacy of the Contractor's plan for finishing behind the paver (e.g., type of equipment and procedures to be used). Will the auto-float be sufficient or will some hand-finishing be necessary?

9. Materials and methods related to curing, including equipment, timing, and application rate (for curing compounds).

10. Procedures related to cold weather placement and night work (as applicable).

11. Contingency plan for inclement weather.

12. Plan for early opening to traffic, if applicable.

This list will vary based on how much freedom the Agency allows the Contractor with regard to the construction requirements in Section 3.3.

4.2 Department's Quality Management Responsibilities

The Department may conduct quality inspections, audits of the Contractor's results and records, and verification sampling and testing on any element of the work to ensure compliance with the QMP and the Contract requirements.

4.2.1 Verification Sampling and Testing

Even though the Contractor may assume more responsibility for inspection and testing under a performance specification, this does not relieve the Agency of its responsibility to perform some level of independent sampling and verification testing to meet the intent of 23 CFR 637. Verification testing should be performed to validate any Contractor testing used in the Agency's acceptance decision. The Agency may also wish to verify certain material or mixture parameters that could identify possible performance issues that would not appear before the termination of the warranty term.

The Department will perform verification testing as described in Table 6 to validate the Contractor's test results.

The Department will notify the Contractor before sampling so the Contractor can observe.

The Department will sample randomly at locations independent of the Contractor's sampling and testing. In all cases, the Department will conduct the verification tests in a separate laboratory and with separate equipment from the Contractor's tests.

Table 6: Department Verification Testing

Parameter ⁽¹⁾	Test Method ^(1, 2)	Sampling Location ⁽²⁾	Frequency ⁽³⁾
Unit Weight	ASTM C138	At the paver	
Air Quality	Hardened air content from cores (ASTM C457)	Cores	
	AVA testing	Behind paver	
Strength	ASTM C1074 Maturity	At the paver or field-cured specimens	
Thickness ⁽⁴⁾	Probes ASTM C174 (cores)	Probe. If deficient, take cores from constructed pavement.	
Permeability	ASTM C1202	At the paver or cores from constructed pavement	

- 1. Durability-related parameters, including air quality, permeability, and unit weight, are the best indicators of pavement performance and would be important for verification testing. The Agency should also test for strength and thickness as part of verification testing.*
- 2. For rapid renewal, when rapid construction is the primary objective, the Agency can verify that parameters (unit weight, air quality, strength, thickness, and permeability) meet performance requirements through nondestructive testing (e.g., taking cylinders at the paver for strength and permeability, or probing the fresh concrete behind the paver for thickness). If testing results indicate deficient or marginal results (e.g., thickness +/- 1/2" of plan thickness), the Agency should require cores for verification.*
- 3. Frequency should be based on project-specific conditions and ideally should provide the ability to identify statistically valid differences between Agency and Contractor test results. A minimum Agency rate of 10% of the testing rate of the Contractor has been used as a rule of thumb.*
- 4. From a long-term performance perspective, some practitioners conclude that thickness should not be an acceptance parameter, but it still should be monitored as part of the Contractor's quality control and the Agency's verification testing to ensure that the minimum design thickness is met for structural integrity. This can be accomplished using a probe on fresh concrete and requiring repair of any Sublot not meeting the minimum requirement. For high-volume, high-profile*

Parameter ⁽¹⁾	Test Method ^(1, 2)	Sampling Location ⁽²⁾	Frequency ⁽³⁾
<i>roadways, an Agency may decide that drilled cores are necessary for acceptance.</i>			

The Department may increase the frequency of verification testing at start-up or as necessary to validate the quality of the materials. The Department may reduce the frequency based on a history of satisfactory Contractor or material performance.

If verification tests indicate conformance with specifications, no further action is required. If verification tests indicate nonconformance with specifications, the Department and Contractor will jointly investigate any testing discrepancies. The investigation may include additional testing as well as review and observation of both the Department's and Contractor's sampling and testing procedures and equipment. Both parties will document all investigative work.

When comparing Agency and Contractor test results, it is important to compare both the variances and the means. The tests most often used are the F-test (comparison of variances) and the t-test (comparison of means), which are used together.

4.2.2 Independent Assurance Testing

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing activities are being performed by qualified personnel using proper procedures and properly functioning and calibrated equipment. The Department will perform IA testing using personnel other than those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor's sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

4.3 Conflict Resolution

If a dispute between some aspect of the Contractor's and the Department's testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third-party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third-party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in *[Standard Specification Section XXX]*.

5 ACCEPTANCE OF INITIAL CONSTRUCTION

Initial acceptance of the pavement at the end of construction is important to ensure that the basic scope of the work was completed in accordance with the plans. Note that final acceptance will not occur until after completion of the warranty term (see Section 6.7).

5.1 Initial Acceptance

Agencies should modify this section as needed to suit their specific construction closeout procedures.

The Department and the Contractor will jointly review all completed work, or a portion thereof, as determined by the Department, to evaluate conformance with the design and QMP requirements. If the work does not meet Contract requirements, perform the necessary corrections, at no additional cost to the Department. Initial acceptance will occur when the Department confirms in writing that the work meets Contract requirements.

Initial acceptance will be documented by a Completion Certification jointly executed by the Department and the Contractor. The Department will provide a copy of the Completion Certificate to the Contractor's warranty bond surety agent.

The initial acceptance or any prior inspection, acceptance or approval by the Department will not diminish the Contractor's responsibility under the warranty. The Department may accept the work and begin the warranty period, excluding any area requiring corrective work, to accommodate seasonal limitations or staged construction.

The Department will accept the finished pavement based on the Contractor's test methods and results unless it is shown through the Department's verification testing or the conflict resolution process that the Contractor's tests are in error.

5.2 Quality Characteristics and Acceptance Limits

The Department will accept the completed pavement in accordance with the criteria defined in Table 7.

The work may be accepted based on Contractor's testing during construction, or tested separately for acceptance after construction. Various acceptance parameters are listed in Table 7 for the specifier's consideration. If the Agency's goal in using a warranty provision is simply to reduce oversight during construction, initial acceptance criteria may be limited to three or four key parameters such as thickness, strength, air content, permeability, and ride quality. If the intention is instead to provide a long-lasting pavement, with the warranty serving as supplementary protection against premature failure, a more comprehensive list of initial acceptance parameters may be more appropriate.

Table 7: Initial Acceptance Criteria

Parameter	Measurement Procedure (Test Method/Device)	Frequency/Lot Requirements	Acceptance Limits
Thickness	ASTM C174, Cores ⁽¹⁾	Minimum Design Thickness minus ¼ in. Minimum 3 tests per Sublot	Minimum Design Thickness minus ¼ in. ⁽²⁾ Repair any Sublot that does not meet the LQL.
	Probing ⁽¹⁾		
	MIT Scan T2 ⁽³⁾		
<p>1. Thickness is traditionally measured using cores, despite not necessarily being conducive to rapid construction/testing. For high-volume, high-profile roadways, an Agency may decide that drilled cores are necessary for acceptance. However, for low-volume roadways, consider using probing data for acceptance and requiring repair of any Sublot not meeting the minimum requirement. Thickness may be measured and accepted by performing depth checks of the plastic pavement prior to placement of curing compound. Thickness checks indicating deficient or marginal thickness (e.g., +/-½ in. less than plan thickness) may require the Contractor to core these locations for acceptance, particularly if the pavement has been diamond ground for surface correction. If the Agency requests cores as a result of grinding and the result indicates acceptable pavement thickness, the Agency will bear the cost of coring.</p> <p>2. For CRCP designs, thickness may also require an upper limit for reinforcing steel design requirements (e.g., UQL = Design Thickness plus 1 in.).</p> <p>3. Although used primarily for research purposes, the MIT (magnetic imaging tomography) Scan T2 provides another NDT alternative for measuring thickness. The device provides walking-speed point measurements of reasonable accuracy—within 1/10 in. for 13 in. of thickness. The MIT Scan T2 requires a seated plate under the slab.</p>			
Strength ⁽⁴⁾	ASTM C1074 (Maturity Method) ⁽⁵⁾	Minimum 5 tests (maturity readings) per Lot	Minimum Design Strength minus 300 psi
<p>4. Measuring flexural strength is the preferred method for monitoring strength, as it provides a more direct comparison to design strength. However, testing is cumbersome due to the need to fabricate and test beams for third-point loading. It has therefore become standard practice to measure the compressive strength of concrete. Strength is more critical for CRCP than jointed concrete, as too high a strength value could be detrimental for CRCP (i.e., an upper bound is needed).</p> <p>5. Instead of testing cores or field-cured cylinders, maturity meters would provide a nondestructive way to estimate in-place concrete strength. Maturity methods are based on the concept that concrete strength is directly related to its age and temperature history, and that samples of a given mixture will attain equal strengths if they attain equal values of maturity index. Before any field measurements are taken, the strength-maturity relationship of a particular mix must be determined in the laboratory based on either compressive or flexural strength. Such maturity curves can then be used to correlate field maturity readings taken from sensors embedded within the in situ mat about every 500 ft (or 1,000 yd² of volume) to cylinder strength.</p>			
Permeability ⁽⁶⁾	ASTM C1202, Chloride Ion Penetration Resistivity (accelerated test) ⁽⁷⁾	Testing frequency per Department standard requirements (minimum two tests per day and after any mixture modifications)	2,000-4,000 coulombs (max) at 28 days
	Surface Resistivity Meter		KOhm-centimeter
	Oxygen Permeability Index		

Parameter	Measurement Procedure (Test Method/Device)	Frequency/Lot Requirements	Acceptance Limits
<p>6. Although permeability is a critical durability indicator, particularly for cold or marine climates in which salts are present in the air or the pavements, some questions remain regarding the accuracy and repeatability of the test methods currently available for evaluating this parameter. Some practitioners caution that permeability should not be incorporated into a payment adjustment system until a more rapid and repeatable test becomes standard practice.</p> <p>7. ASTM C1202 is the most widely used test for measuring permeability (though it actually measures resistivity, not permeability). Agencies have also investigated the use of a surface resistivity meter to measure concrete's resistance to chloride ion penetration as an economical and time-saving alternative to ASTM C1202. Other alternatives, such as the oxygen permeability index, may provide a better indication of true permeability and should be considered once standard test procedures have been established.</p>			
Air Content/Air Quality ^(8, 9)	Air Void Analyzer ⁽¹⁰⁾		
	ASTM C457, Hardened air content from cores ⁽¹¹⁾		
<p>8. The presence of closely spaced air voids is a key factor in improving the freeze-thaw resistance of concrete. In measuring air content/quality, consideration should be given to where measurements are taken, as changes in air content/quality will occur as concrete passes through the paver. Samples should be collected either behind the paver or in front of the paver with an assumed amount of air loss through the paver that is then verified through routine tests in front of and behind the paver.</p> <p>9. Although the volumetric or pressure test is the standard method for measuring air content, it has the following limitations:</p> <ul style="list-style-type: none"> • Samples are typically taken when materials are delivered to the site, which is not representative of concrete coming off the paver where concrete has been vibrated. • A pressure test only provides information on the total volume of air; it cannot characterize the air void system (i.e., spacing and volume). <p>The preferred test is for Air Quality, which considers air bubble size and spacing. This can be accomplished for fresh concrete using the air void analyzer (AVA) (or for hardened concrete through petrographic analysis of polished thin sections).</p> <p>10. If rapid construction is the primary objective, acceptance can be based on AVA testing using fresh concrete samples at the paver.</p> <p>11. If durability is the Agency's primary objective, acceptance should be based on hardened air content determined from cores removed from the constructed pavement. The Contractor may use pressure or AVA testing for monitoring air content during construction, and final acceptance will be based on hardened concrete cores using petrographic analysis of thin sections.</p>			

Parameter	Measurement Procedure (Test Method/Device)	Frequency/Lot Requirements	Acceptance Limits
Ride Quality ⁽¹²⁾	AASHTO M 328, Inertial Profiler Measurement and Continuous Roughness Reporting ⁽¹³⁾ Measure pavement profile in both wheel paths simultaneously, parallel to the right edge of the lane, and in the direction of travel for each lane.	Continuous	IRI ≤ 67 inch/mi with 0.1-mi baselength for full payment Localized Roughness: IRI ≤ 125 inch/mi with 25-ft baselength
<p>12. Ride quality is considered a measure of quality for the installed product and an indirect indicator of pavement performance. Continuous roughness reporting is recommended for acceptance and pay adjustments.</p> <p>13. Different measurement strategies have been used depending on the application. Many Agencies use a tiered system based on road type or type of work (e.g., overlay versus reconstruction). For Quality Assurance, a concrete profilograph is still the norm for acceptance of PCC pavement for many Agencies, but the trend is toward using an IRI (International Roughness Index) standard. An inertial profiler-based measurement is recommended to facilitate rapid renewal and to provide a better indication of the road user's perception of rideability. However, smoothness measurement using a profilograph may be necessary if an Agency does not have equipment and thresholds established for IRI.</p>			
Skid Resistance ⁽¹⁴⁾	ASTM E274 Skid Trailer ASTM E524 ASTM E501 Collect a friction number (FN) data test point every 3/10 of a lane-mile for each travel lane, at a minimum testing frequency	Evaluate 100% of pavement surface. ⁽¹⁵⁾ Average per lane or as per Department requirements.	FN40S ≥ 40 FN40R ≥ 45
<p>14. Skid resistance relates to aggregate properties (polishing resistance) and surface texture. It is a safety concern for higher-volume roadways with wet weather conditions. Some Agencies will restrict the use of softer aggregates in the mix design for certain projects or conditions to ensure adequate friction is obtained. More extensive use of diamond grinding concrete pavements has raised the importance of friction or skid resistance as a performance parameter.</p> <p>Transverse tining is a standard and relatively inexpensive method to achieve higher-friction surfaces, particularly for wet weather conditions on high-speed concrete pavements. A disadvantage of transverse tining is that it often causes undesirable noise emissions, which has led to the use of alternative tining patterns. The requirement to meet skid resistance must also be balanced with the requirement to meet noise intensity thresholds if noise abatement is a project objective.</p> <p>Skid resistance and texture depth are related but not necessarily directly correlated. Although specifying skid resistance is preferred, if an Agency does not have test procedures or acceptable threshold values for skid resistance, then texture depth, spacing, and patterning could serve as a performance measure until proper thresholds and test procedures for skid resistance are established. If the Contractor is given greater flexibility in selecting the texturing technique and aggregate properties, Skid Resistance or Texture Depth requirements will ensure that the texturing method will meet the functional requirements for safety and noise.</p> <p>15. Technology is being updated to move to a continuous friction measurement when data is based on running average per Lot.</p>			

Parameter	Measurement Procedure (Test Method/Device)	Frequency/Lot Requirements	Acceptance Limits
Joint Deficiencies ⁽¹⁶⁾	Visual survey (includes raveling, spalling, faulting, and seal damage/integrity)	No joint deficiencies permitted	The Department will evaluate deficiencies on a case-by-case basis to determine if a repair will be required.
<p>16. <i>Joint deficiency encompasses unacceptable spalling or raveling along the joint, as well as defective or improperly installed joint seals.</i></p> <p><i>An additional performance measure for acceptance is joint performance, as measured through load transfer efficiency (LTE) of the joint and dowel bar alignment. LTE can be measured through standard deflection testing (e.g., falling weight deflectometer, FWD), but consideration must be given to the age of the pavement, season, and time of testing. If tested at too early an age, cracks may not yet be formed at joint locations. If tested in warmer seasons or time of day, LTE may be artificially high and not representative of the true average LTE.</i></p>			
Load Transfer Efficiency (LTE) ⁽¹⁷⁾	Deflection Testing (e.g., FWD)	Evaluate 5% of the joints in each Lot per Department random sampling protocols. LTE ≥ 90%	PWL 85% full payment LQL = 80% LTE
<p>17. <i>If evaluating LTE, consideration must be given to the age of the pavement, season, and time of testing. If tested at too early an age, cracks may not yet be formed at joint locations. If tested in warmer seasons or time of day, LTE may be artificially high and not representative of the true average LTE.</i></p>			
Tire-Pavement Noise ⁽¹⁸⁾	On-Board Sound Intensity (OBSI) measurement with a Standard Reference Test Tire, AASHTO TP 76 ⁽¹⁹⁾	Maximum A-weighted tire-pavement noise level of 100 dB at 50 mph ⁽²⁰⁾ Evaluate 100% of pavement surface.	PWL 85% full payment
<p>18. <i>Noise caused by tire-pavement interaction is a performance parameter addressing noise impacts to highway abutters. If a noise performance parameter is included, industry must be allowed to be more innovative with respect to surface texturing or pavement design. Alternative tining or other drag texturing methods and diamond grinding can meet skid resistance with reduced noise intensity. Similarly, alternative pavement designs using thin open-graded (pervious) concrete wearing surfaces or exposed aggregate surfaces have been shown to reduce noise compared with other pavement types.</i></p> <p>19. <i>On-Board Sound Intensity (OBSI) measures tire-pavement noise at the source using microphones in a sound intensity probe configuration mounted to the outside of a vehicle near the tire-pavement interface. The directional characteristic of the probe makes it better suited for measuring a specific noise source, while attenuating sounds from other sources in other directions (such as engine or exhaust noise), and correlates well with sound measured at the roadside. The OBSI method was first standardized by the AASHTO in 2008 and has undergone annual updates as provisional standard TP 76, "Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method."</i></p> <p>20. <i>At present, there are no established thresholds for tire-pavement noise. The values shown above should be modified according to the Agency's standard practice.</i></p>			

5.3 Submittal of Construction Documents

Within 15 days after the date of the Completion Certificate *[or equivalent certification]*, submit to the Department a signed certification by an authorized representative of the Contractor that the materials and construction are in general conformance with the pavement design, QMP, and the Contract Documents. Include the following documentation with the certification:

- The final details and as-built drawings for the constructed pavement.

- A list of all the construction specifications used by the Contractor and the locations where the specifications were used.
- A list of material sources and all QMP test results with comparison to material specification limits (in hard copy and digital form).
- All job mix formulas used with each mix design with the dates and locations where each one was used.
- Construction test results including but not limited to placement requirements.

5.4 Access to Construction Documents

With 24 hours written notice, provide the Department full access at any time to all original and copies of inspection records, test results, and control charts; and to testing and production facilities, as necessary to allow the Department to audit the Contractor's compliance with the requirements of the design, QMP, and Contract Documents. For purposes of this section, test results include all original supporting readings, measurements, laboratory worksheets, and calculations. When original records are not stored at the Contractor's field office, make copies of original inspection records, test results, control charts and other QMP documents available for viewing at the Contractor's field office for the Contract within 1 Business Day of receiving a written request from the Department.

Retain and provide access to all inspection records, test results, and control charts for the duration of the warranty period. This requirement shall survive after the date of Completion Certificate.

6 WARRANTY

6.1 General

Warranty provisions are designed to minimize impacts to the Agency during the warranty period while providing an objective and measurable means to assess performance.

The Contractor shall warrant that the cement concrete pavement will meet the performance requirements specified in Section 6.4 for the length of the warranty period, as specified in Section 6.2.

Warranty work consists of the remedial actions needed to meet performance thresholds during the warranty period. Warranty work may include optional surveys, inspection and testing, traffic management, and elective preventative maintenance.

The Department will allow the Contractor to carry out on-site activities such as sampling, testing, inspection, traffic survey, or non-emergency repairs during the warranty period. Advise the Department in writing *[21 days]* prior to the start of each period of on-site activity. Damaging or destructive sampling, testing, or inspection shall include a repair proposal and will be subject to the Department's prior approval.

The Department will perform routine maintenance, such as snow and ice removal, application of de-icing chemicals, repairs to safety appurtenances, and emergency work, if required. Submit written notification to the Department immediately upon identifying any concern regarding routine maintenance believed to affect pavement performance.

6.2 Warranty Period

The warranty shall begin on the date of *[the Completion Certificate]* and will continue for *[5 to 10]* years.

The duration of the warranty period is an important consideration. The warranty should be of sufficient duration to protect the Agency from defective work and premature failure caused by inferior materials and workmanship. Although it is possible to develop warranty provisions of sufficient duration to address long-term performance, bonding issues may preclude their practical use.

Pavement warranties are therefore generally set for a period of one-third to one-half the expected life of the pavement or treatment. An Agency should consider the pavement performance data collected through its pavement management system (PMS) to help determine the appropriate warranty period for a particular project.

6.3 Warranty Bond

Provide a *[single term or renewable with straight-line or stepped depreciation]* warranty bond in the amount of *[\$_____]* meeting *[bond rating]* before execution of the Contract. The warranty bond will commence upon completion and initial acceptance of the warranted pavement and will be in effect for the warranty period(s).

The warranty bond(s) will insure the prompt completion of required pavement warranty work, including payments for all labor, equipment, and materials, and will be in effect until the end of the warranty period or when all warranty work has been completed, whichever is latest.

A warranty bond should provide adequate protection for the Agency while not overextending the Contractor's capacity to take on additional work. The bond is typically calculated as a percentage of the Contract (for example, 20%), the cost of warranty or maintenance work, or the cost of replacing the surfacing materials. If pavement work is subcontracted, the Agency may require that the subcontractor provide a warranty bond or provide a dual obligee bond to the Contractor and the Agency.

6.4 Performance Requirements During the Warranty Period

The Department will conduct an initial and final evaluation of warranted pavement using high-speed measurement methods consistent with network-level pavement management surveys. The Department will use measurement procedures in accordance with *[the Agency's pavement management system, the Agency's Pavement Surface Distress Survey Manual, or the Agency's Pavement Condition Survey Program or Long-Term Pavement Performance Program Distress Identification Guide]* or applicable test methods. The Department will also conduct interim periodic windshield surveys during the warranty period as needed.

The Department will evaluate initial pavement warranty performance by measuring *[ride quality, friction, and surface distresses]* in the driving lanes for the entire length of the warranty section *[auxiliary lanes and shoulders are exempt from the performance requirements]*, except that friction testing will be conducted on the driving and passing lane or middle lane for multi-lane facilities. The final year evaluations will be conducted on every lane in both directions throughout the length of the project for all pavement performance indicators.

For purposes of evaluation, the Department will divide the project into nominal 1-mi sections or Lots. Each section of driving lanes will be subdivided into 10 approximately 500-ft long segments. The

Department will evaluate ride quality using a van equipped with a laser-based inertial profiler *[For rapid renewal, IRI measurements using a high-speed inertial profiler are preferred over profilograph index (PrI) using a profilometer]* to calculate the average IRI of two wheel paths for each segment. The Department will evaluate skid resistance using a locked wheel trailer as defined in ASTM E274 and a ribbed tire as defined in ASTM E524. Skid tests will be conducted in both directions in each lane every ¼ mi *[or as defined by the Agency]*. The number of locations for skid tests will depend on the length of the project. The skid numbers will be averaged to compare with thresholds in Table 8.

If during the high-speed evaluation there is visual evidence of other surface distresses (cracking, spalling, popouts, etc.), the Department will conduct additional evaluations at any location in a lane or shoulder in accordance with *[the Agency’s pavement management system, the Agency’s Pavement Surface Distress Survey Manual, or the Agency’s Pavement Condition Survey Program or Long-Term Pavement Performance Program Distress Identification Guide]* to determine the extent and severity of distresses and whether these distresses exceed the threshold values and require remedial action.

If during windshield surveys any areas outside the tested lanes or sampled sections are observed to show deficiencies, the Department will conduct additional testing to determine the extent and severity of distresses based on Table 8 and whether these distresses exceed the threshold values and require remedial action.

Evaluation results will be sent to the Contractor within 20 days of the completion of the distress surveys, and pavement roughness and pavement friction measurements carried out during the warranty period.

Table 8 is a sample that may be used as a basis for the actual table to be prepared for the specification. Modifications and additions may be needed to address the specific needs of a given Agency or road network.

With the exception of Ride Quality and Skid Resistance, the threshold levels provided in the table were based on the Long-Term Pavement Performance Program (LTPP) Distress Identification Guide for jointed cement concrete pavements. Individual Agencies should substitute values that they feel are most appropriate for their highway system and technology used to monitor performance. Likewise, Agency-established ride quality and skid resistance values should be used for these particular performance indicators.

Table 8: Performance Indicators, Thresholds, and Guidance for Remedial Action

Performance Indicator	Threshold Levels	Guide to Remedial Action
Transverse Cracking ⁽¹⁾	<p>Visually rate severity and extent of cracks <i>(based on LTPP Distress ID Manual or equivalent)</i>. Low Severity: Crack width <0.1 in. (3 mm), no spalling, and no measureable faulting</p> <p>Low Extent: No more than 4 slabs per lane-mile</p> <p>Automated Crack Monitoring Systems <i>(thresholds based on geometry, incidence, and severity)</i></p>	<p>Treat in accordance with Department’s treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Repair crack (stitching or retrofit load transfer) if low severity or replace slab if it exceeds low severity.</p>

Performance Indicator	Threshold Levels	Guide to Remedial Action
<p>1. <i>Laser-based crack measurement systems (based on digital imaging technology) combined with surface profile systems mounted on pavement management vehicles provide automated detection of cracks in addition to the evaluation of macro-texture, and potentially other road surface distress features. These systems use high-speed cameras, custom optics, and laser line projectors to acquire and process both 2D images and high-resolution 3D profiles of the road. The collected data can be analyzed with computer software. This software can detect and analyzes cracks. It also can be used to evaluate lane markings, macro-texture, drop-offs, slab curling, and blow-ups. Cracks can be classified as transverse, longitudinal, map, or "D," and the severity evaluated.</i></p>		
<p>Longitudinal Cracking</p>	<p>Visually rate severity and extent of cracks (based on LTPP Distress ID Manual or equivalent). Low Severity: Crack width <0.1 in. (3 mm), no spalling, and no measureable faulting</p> <p>Low Extent: No more than 4 slabs per lane-mile</p> <p>Automated Crack Monitoring Systems (<i>thresholds based on geometry, incidence, and severity</i>)</p>	<p>Treat in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Repair crack (stitching or retrofit load transfer) if low severity or replace slab if it exceeds low severity.</p>
<p>Durability ("D") Cracking</p>	<p>None allowed</p>	<p>Replace affected slab.</p>
<p>Corner Breaks</p>	<p>Low Severity: Crack is not spalled for more than 10% of the length of the crack; no measurable faulting; corner piece is not broken into two or more pieces</p> <p>Low Extent: No more than 2 slabs per lane-mile</p>	<p>Treat in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Replace slab if it exceeds low severity.</p>
<p>Joint Seal Damage (Transverse and Longitudinal)</p>	<p>Low Severity: Damage to the joint seal which includes extrusion, hardening, adhesive/bonding failure, cohesive/splitting failure, or complete loss of sealant</p> <p>Low Extent: Less than 10% of the joint length per lane-mile</p>	<p>Treat in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Remove existing sealant and reseal joint over affected length.</p>

Performance Indicator	Threshold Levels	Guide to Remedial Action
Joint Spalling (Transverse and Longitudinal)	<p>Low Severity: <3 in. (75 mm) wide, measured to the face of the longitudinal joint with loss of material, or spalls with no loss of material and no patching</p> <p>Low Extent: Longitudinal: Less than 5% of the joint length per lane-mile Transverse: Less than 25% of a joint</p>	<p>Treat in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Repair spalls with epoxy or cement mortar if low severity; repair joint to full depth if it exceeds low severity.</p>
Faulting of Transverse Joints and Cracks	None allowed	<p>Treat in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Diamond grind to remove fault or replace slab full depth.</p>
Scaling	Low Extent: <1% of surface area per lane-mile	<p>Treat in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Diamond grind to remove scaling if low extent exceeded.</p>
Map Cracking	None allowed	<p>Treat in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Replace slab full depth.</p>
Popouts	<p>Small pieces of pavement broken loose from the surface, less than 1 in. (25 mm) in diameter.</p> <p>Low Extent: 3 or less per square yard.</p>	<p>Treat in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Replace slab full depth if low extent exceeded.</p>
Surface Cracking	Low Extent: <1% of surface area per lane-mile	<p>Seal in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i></p> <p>or</p> <p>Replace affected slabs full depth if low extent exceeded.</p>
Blow-ups	Not allowed	Replace affected slab(s) full depth.
Patch Deterioration	Low Severity: Patch has low severity distress of any type and no measurable faulting or settlement.	Replace patch full depth if low severity is exceeded.

Performance Indicator	Threshold Levels	Guide to Remedial Action
Ride Quality (Profilograph or Inertial Profiler testing) ⁽²⁾	80–100 in./mi (IRI) ⁽³⁾ or [XX] in./mi (PrI) Based on average IRI or PrI for a given year as determined by the Department for each year of the warranty.	Diamond grind or remove and replace slabs full depth to achieve ride quality requirements.

- A concrete profilograph is still the norm for acceptance of PCC pavement for many Agencies, but the trend is toward using an IRI (International Roughness Index) standard for acceptance and for warranty monitoring. An inertial profiler-based measurement is recommended for warranty evaluations to facilitate rapid testing and to provide a better indication of the road user's perception of rideability. However, smoothness measurement using a profilograph may be necessary if an Agency does not have test methods and standard requirements established for IRI.*
- The evaluation interval or segment also will affect how the threshold is set. In the case of IRI, the shorter the segment length, the more the IRI is affected by local extremes. Thus, the historical pavement management data for 1-mi warranty sections must be adjusted to eliminate anomalies caused by bridge approaches or other pavement transitions. The threshold might also be affected by how the pavement is constructed. The more opportunities to achieve smoothness through multiple pavement layers or surface milling, the tighter the tolerance might be. If the objective of the warranty is to dramatically improve performance, then thresholds should be more stringent to achieve the warranty objective. As the duration of a warranty increases, the specified tolerances may be adjusted, though many Agencies have increased the warranty duration without adjusting the specified thresholds. Agencies have initially set thresholds that are relatively easy to achieve to familiarize all parties with the use of warranty provisions, then increased the duration or tightened the tolerance of the warranty after gaining more experience.*

Skid Resistance	Skid Number tested in accordance with <i>[Agency's Test Method XX for locked wheel skid trailer with ribbed tire]</i> must average <i>[FN40 = 45]</i> or greater in each lane with no individual value for three consecutive test sites less than <i>[FN40 = 30]</i> . ^(4, 5)	Diamond grind or skid abrade surface to achieve skid resistance requirements in accordance with Department's treatment matrix for pavement distresses. <i>[Publication XXX]</i>
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- The type of test tire (smooth or ribbed) should be selected by the Department based on standard practice.*
- Technology is being updated to move to a continuous friction measurement in which data is based on running average per Lot. Also laser-based surface profile systems are being used to analyze pavement macro-texture and texture depth, which has an effect on friction and other properties such as noise and rolling resistance.*

6.5 Warranty Work

The Department will report the results of the pavement surveys identifying deficiencies and segments where thresholds have been exceeded within *[45 days or a reasonable length of time]* of completing the survey. The Contractor shall be responsible for remedial action for the performance indicators defined in Table 8 unless the Department determines based on Section 6.6 that the distress is caused by factors beyond the control of the Contractor.

Perform warranty work at no additional cost to the Department based on the results of pavement distress surveys. Remedial work on mainline roadway will also apply to integral shoulders, curbs, or curb and gutters. If warranty work requires corrective action to pavement markings, raised pavement markers, or adjacent lanes, shoulders, or curbs, this corrective action is included in the scope of the warranty work.

If a pavement condition survey indicates that performance thresholds are exceeded and warranty work is required, and the Contractor and Department agree with the distress survey results, submit a Remedial Work Plan and schedule, and request a permit from the Department before proceeding with warranty work. Perform remedial work *[within a defined number of days depending on the level of severity or within the same calendar year]*. Conform to traffic control requirements *[herein or in the Standard Specifications]*.

If the pavement requires immediate remedial action for the safety of the traveling public and the Contractor has not performed the remedial work within 24 hours, the Department may perform the remedial work with other forces at the Contractor's expense. Remedial work performed by others will not alter the Contractor's obligations under the warranty.

If the Contractor does not agree with the results of the distress survey or the cost of Department performed work, or the Department does not agree with the Contractor proposed remedial action, the Conflict Resolution Team, as described in Section 6.8, will make a final determination within a mutually agreed upon time.

Document all warranty work according to the approved Remedial Work Plan and provide this information to the Department annually.

6.6 Exclusions

Be specific when defining exclusions. For example,

The Contractor shall not be responsible for repairing damage to the pavement resulting from causes beyond the Contractor's control as determined by the Department. This includes repair of distresses caused by

- Existing base or pavement conditions;
- Floods, tornadoes, fires, landslides, or other acts of nature;
- Chemical and fuel spills, fires, and traffic accidents; and
- Department's routine maintenance activities, or coring, milling, or other destructive procedures performed by the Department.

If, on a DB project, responsibility for evaluating and designing the pavement foundation system is assigned to the Contractor, the exclusion related to existing base conditions would not apply.

The Contractor will be relieved of the responsibility for remedial action if the estimated accumulated equivalent single axle loads (ESALs) based on a current traffic count are *[100%]* above the projected *[10th year]* accumulated ESALs. The Contractor shall not rely on the Department to conduct a traffic survey(s) during the warranty period. The Contractor will be permitted to carry out traffic surveys subject to the Department's operational requirements.

6.7 Final Warranty Acceptance

The Department will evaluate the pavement performance *[or conduct a final survey]* within *[calendar days]* of the completion of the warranty term. Perform any required remedial work based on the results of the final survey in accordance with Sections 6.5 and Table 8. The Department will issue a Final Warranty Acceptance Letter *[or an equivalent certification]* and release final payment *[retainage]* upon verification that all required performance thresholds are met and after receipt of all required QMP documentation.

6.8 Conflict Resolution

The Department will establish an on-call Conflict Resolution Team (CRT) for Warranty Work to resolve any conflicts regarding the warranty requirements. This team will be composed of one (*or two*) representative(s) appointed by the Contractor, one (*or two*) representative(s) appointed by the Department, and an independent party mutually agreed upon by the Contractor and the Department. The CRT will base decisions on a simple majority vote. The Contractor and the Department will share the expenses of the independent party and any forensic investigations that the CRT may decide to conduct. CRT members will be knowledgeable regarding the warranty terms and conditions, and the identification and measurement of pavement distresses. The CRT will initially process any disputes involving construction and warranty work.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product for construction or the Contractor does not agree with the results of the distress survey or the cost of Department-performed work, or the Department does not agree with the Contractor-proposed remedial action, the Department will use the CRT to resolve the dispute. The CRT will provide testing. The Department may use CRT tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [*Standard Specification Section XXX*].

If resolution is not achieved, follow the Department's claims procedure as specified in [*Standard Specifications Section XXX*].

7 MEASUREMENT

To facilitate rapid renewal, it is recommended that measurement be based on square yards completed in place, including any reinforcement, dowel bars, and joint forming/sealing.

Note for DB projects, the lump-sum pricing structure may eliminate the use of measured quantities and unit pricing to determine progress and payment.

The Department will measure the work by the number of square yards completed and accepted in place. The width equals the pavement width shown on the typical cross section of the plans plus additional as the Department directs in writing. The Department will field measure length along the center line of the pavement.

8 PAYMENT

Option 1: For a DBB warranty, as a unit price item for PCC pavement paid during construction,

<u>Pay Item</u>	<u>Pay Unit</u>
Warranted PCC Pavement	SQUARE YARD

Payment is full compensation for the warranted PCC pavement, including all reinforcement, dowel bars, and joint forming/sealing; the QMP and PCC mix design; the warranty bond and warranty or maintenance work; traffic control; providing required documentation; and furnishing all labor, tools, equipment, and incidentals to complete the work.

Upon completion of the placement of all PCC pavement, and prior to final payment, furnish the Department with all required QMP documentation and a final certification for the quantities shipped. The

final certification will recapitulate the monthly submittals and show the total of all PCC incorporated into the project.

Option 2: For a DBB warranty as a unit price for PCC pavement paid during construction and lump-sum payment for warranty work made at Acceptance of Initial Construction,

<u>Pay Item</u>	<u>Pay Unit</u>
Warranted PCC Pavement	SQUARE YARD
PCC ____ Warranty	LUMP SUM

Payment for the PCC ____ Warranty will be made at Acceptance of Initial Construction. The PCC _____ Warranty lump-sum amount will be full compensation for the warranty bond, maintenance of traffic, and all costs and incidentals associated with warranty work including all materials, labor, and equipment necessary to complete all required warranty work.

Option 3: For a DB warranty as a lump sum for both PCC pavement and warranty work,

<u>Pay Item</u>	<u>Pay Unit</u>
Warranted PCC Pavement	LUMP SUM

The Department will make partial progress payments based on an approved schedule of values. Payment will be full compensation for the QMP and PCC Mix Design; Warranted PCC pavement, the warranty bond, and warranty or maintenance work; traffic control; providing required documentation; and furnishing all labor, tools, equipment, and incidentals to complete the work.

PRECAST CONCRETE PAVEMENT

PERFORMANCE SPECIFICATION

Overview

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for modular concrete pavement under the design-bid-build (DBB) delivery approach. This guide specification could also be adapted for use under other contracting mechanisms, such as design-build, design-bid-build with short-term warranty, and design-build-operate-maintain. Much of the specification content was developed under the SHRP 2 R05 project, which specifically focused on development of modular pavement guidance and specifications for rapid renewal.

Modular pavement technology is a relatively new method of pavement construction. However, with the implementation of modular pavement technology in dozens of states and for hundreds of lane-miles of pavement, it is now recognized as a mature and no longer experimental technology. Precast concrete pavement (PCP per Project R05 terminology) is the predominant type of modular pavement construction used in the United States and throughout the world, and will therefore be the focus of this specification. (Note, however, that this template could also be adapted to other modular systems addressed by the R05 project, such as rollable asphalt.)

There are essentially two types of systems and two types of applications for precast concrete pavement technology, as described further in the R05 project. Jointed PCP systems or JPrCP use precast concrete panels that essentially replicate conventional cast-in-place concrete pavement. These systems generally utilize reinforced precast concrete panels similar in size to a typical cast-in-place jointed concrete pavement slab (e.g., one lane wide and 12 ft to 16 ft between joints), and utilize dowelled joints to provide load transfer between individual panels.

The other predominant type of precast concrete pavement system is precast prestressed concrete pavement or PPCP. PPCP utilizes prestressed precast panels that are typically pretensioned in one or both directions during fabrication and posttensioned in one or both directions after being installed on site. PPCP provides the advantage of being able to use precast panels that are thinner than those which would be used for conventional concrete pavement, thus reducing concrete usage and permitting in-kind replacement of existing pavement (i.e., using precast panels with the same thickness as the existing pavement even if a thicker concrete slab would be necessary for the design conditions). PPCP adds a level of complexity to precast concrete pavement construction since prestressing is incorporated. This requires additional specifications for prestressing and associated components.

The two types of applications for PCP are “intermittent” and “continuous” construction. Intermittent construction generally entails the replacement or reconstruction of isolated areas or individual slabs of a concrete pavement. This is typically done in a pavement repair or maintenance scenario. Continuous construction typically involves the construction of new or reconstruction of existing pavement over a longer section of a roadway. Continuous construction is typically used within a new construction or full reconstruction scenario. However, certain rehabilitation projects may include reconstruction of longer sections of pavement, utilizing a continuous PCP application.

Many of the functional performance properties for conventional concrete pavement also apply to precast concrete pavement construction. There is no reason, for example, why a precast concrete pavement cannot be held to the same level of ride quality as a cast-in-place concrete pavement. However, the agency must recognize the need to allow the contractor to perform additional steps, such as diamond grinding, to achieve these requirements.

Precast concrete pavement is typically more costly than cast-in-place pavement. However, it presents a solution for rapid renewal that can be deployed during short lane closures, minimizing the disruption to the traveling public. As such, the additional costs can generally be justified through reduced user delay costs. PCP technology is also

intended as a low-maintenance long-lasting solution for pavement construction, and therefore, life-cycle costs should be considered when justifying higher initial cost.

Specification Objectives

One of the primary objectives of this specification is to increase the comfort level with precast concrete pavement technology by providing agencies with specification requirements that have been determined to be most critical for the successful use of PCP.

It must be recognized that PCP is essentially a pavement-structure hybrid. While the finished product is a concrete slab on grade (i.e., a pavement), the constituents of this pavement (precast concrete panels) are products more commonly used for bridges and geotechnical structures. As such, typical concrete pavement specifications cannot be simply applied to precast concrete pavement, as there are additional considerations (e.g., for the concrete and reinforcement) that must be taken into account. Likewise typical precast concrete specifications cannot be simply applied, since the finished product is a pavement which is subjected to different conditions than most structural elements (e.g., bridge deck or retaining wall panels). This specification provides guidance as to which Agency standard specifications are applicable to PCP, which should only be used with modifications, and which finished-product requirements should be included to help ensure the desired long-term performance of the PCP.

A key component of this specification, described in greater detail in the R05 effort, is the System Approval and Trial Installation process. A number of proprietary PCP systems are currently available and have been demonstrated as proven for PCP construction. These systems typically utilize patent-protected components and details for fabrication and installation of the precast panels. While such systems should not be precluded from use, Agencies are typically unable to specify a sole-source proprietary product for use on a project, unless no other comparable alternatives are available. Similar to a preapproved products list that an Agency may create for a particular product to be used during construction, the System Approval and Trial Installation process provides a method for vetting and approving the use of PCP systems, whether proprietary or not. This will allow a Contractor to submit virtually any PCP system for use as long as it meets the requirements from the System Approval and Trial Installation process.

Using This Guide Specification

The requirements and values contained within this guide specification are not intended to be definite or absolute. Rather, they are meant to provide a detailed example that users can adapt to fit the needs of a particular project. Commentary is included within the specification (as indicated with italic typeface) to provide additional guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw upon the information provided as a basis for further modification or development of the specification.

1 GENERAL

This specification details the requirements for materials and fabrication and installation processes for precast concrete pavement (PCP) systems to be used for continuous or intermittent new construction or reconstruction of existing asphalt and concrete pavements.

1.1 Description

Fabricate and install a PCP system at the locations shown on the contract drawings. The PCP system shall be the [Agency name]'s generic system [Include Reference Detail] or an alternate system preapproved by the [Agency Name].

The work shall include, but is not necessarily limited to, the following:

1. Sawcutting and removing existing pavement [*reconstruction projects only*]
2. Existing or new base preparation
3. Installation of approved bedding material (if necessary)
4. Fine grading of the base/bedding (if necessary)
5. Installation of load transfer device at transverse joints
6. Installation of tie bars along the longitudinal joints (as required)
7. Placement of precast panels
8. Posttensioning [*PPCP systems only*]
9. Grouting of posttensioning tendons [*PPCP systems only*]
10. Panel undersealing
11. Backfilling of load transfer device and tie bar slots, blockouts and ports (as required)
12. Grinding
13. Joint sawing (if applicable) and joint sealing.

Assume full responsibility for the materials and processes that produce the end products specified in this specification. Ensure that the processes for fabricating and installing the precast panels are valid and meet the requirements of this specification.

Perform all inspection, sampling, and testing necessary to control the quality of the precast panels produced at the fabrication plant and of the finished precast concrete pavement. End product acceptance is the responsibility of the Department and will be based on acceptance testing of the following:

1. Fabricated Precast Panels
 - a. Concrete requirements
 - b. Panel dimensional tolerances
 - c. Panel embedment tolerances
2. Installed Precast Panels
 - a. Vertical elevation difference at transverse joints
 - b. Deflection testing
 - c. Damaged or defective concrete
 - d. Ride quality of the finished surface

1.2 Definitions

Use this section as necessary to define terms that may not otherwise be included in the Standard Specifications or General Conditions.

For the purpose of this specification, the following definitions will apply:

1. *PCP* – Precast Concrete Pavement (generic/all systems)
2. *PPCP* – Precast Prestressed Concrete Pavement systems
3. *JPrCP* – Jointed Precast Concrete Pavement systems
4. *Panels* – Individual precast concrete elements used for producing the finished, in-place pavement
5. *Slabs* – Generally, a section of posttensioned pavement consisting of a number of individual panels
6. *PCI* – Precast Prestressed Concrete Institute
7. *NPCA* – National Precast Concrete Association

2 MATERIALS

Material requirements should not deviate from standard specifications for concrete pavement and precast concrete. However, materials for PCP must carefully mesh the requirements for both precast concrete and concrete pavement. Materials not commonly used for concrete pavement may be necessary for precast concrete. Cements that will allow faster strength development, for example, may be necessary to maintain the production requirements for a precast concrete fabrication plant. Likewise, material requirements common to concrete pavement but not precast concrete, may need to be incorporated to help ensure the long-term performance of the PCP. Requirements for aggregate durability (to prevent D-cracking or alkali-silica reactivity) or requirements for cement sulfate-attack resistance, for example, that may not normally be required for precast concrete elements, may need to be included.

Additional materials specific to PCP which should be considered include materials for lifting anchors for the precast panels; materials for backfilling dowel slots, lifting anchors; materials for underslab grouting; materials for prestressing steel, posttensioning hardware, and grout; and materials for joints, in particular wider expansion joints for PPCP systems.

Use materials conforming to the following Standard Specifications:

- Cement [*Standard Specification XXX*]
- Aggregate [*Standard Specification XXX*]
- Supplementary Cementitious Materials [*Standard Specification XXX*]
- Admixtures [*Standard Specification XXX*]
- Joint Seals and Fillers [*Standard Specification XXX*]
- Water [*Standard Specification XXX*]
- Curing Compound and Evaporation Retarders (if used at the fabrication plant) [*Standard Specification XXX*]
- Epoxy (for drilling and anchoring dowel and tie bars into existing pavement; for joints between PPCP panels) [*Standard Specification XXX*]
- Reinforcement (dowel bars, tie bars, mat reinforcement) [*Standard Specification XXX*]
- Lifting Devices (for lifting and handling of precast panels) [*Standard Specification XXX*]
- Prestressing Steel (for pretensioning and posttensioning) [*Standard Specification XXX*]
- Posttensioning Hardware (ducts, anchors, gaskets, couplers) [*Standard Specification XXX*]
- Grout Material (for backfilling dowel and tie bar slots, filling lifting anchor recesses, undersealing, and posttensioning grouting) [*Standard Specification XXX*]

The following concrete properties are recommended for precast concrete pavement panels, per the R05 project specifications:

- *Design concrete flexural strength: 650 psi;*
- *Minimum concrete compressive strength at time of panel form stripping: 2,500 psi;*

- *Minimum concrete compressive strength at time of panel shipment to the project site: 4,000 psi;*
- *Minimum concrete compressive strength at 28 days: 4,500 psi (minimum);*
- *Concrete air content: based on Agency practice;*
- *Concrete durability requirements: based on Agency practice;*
- *Concrete aggregate quality and gradation requirements: based on Agency practice;*
- *Cementitious materials requirements: based on Agency practice; and*
- *Concrete admixture requirements: based on Agency practice.*

The following material requirements are recommended for grout backfill materials for dowel and tie bar slots, lifting anchor recesses, and any blockouts, per the R05 project specifications:

- *Compressive Strength, Opening to Traffic: 2,500 psi (min);*
- *Compressive Strength, 28-day: 4,000 psi (min);*
- *Expansion: 0.40% (max.);*
- *Contraction: 0.05% (max);*
- *Freeze-Thaw Loss (25 cycles at 10% NaCl): 1.0% (max);*
- *Bond Strength (to dry PCC at 28 days): 300 psi (min);*
- *Initial Set Time: 15 minutes (min);*
- *Chloride Content: 0.05% (max); and*
- *Sulfate Content: 5.0% (max).*

The following material requirements are recommended for polyurethane undersealing materials used in lieu of grout, per the R05 project specifications:

- *Compressive Strength (ASTM D1621): 60 psi (min), 130 psi (max);*
- *Flexural Strength (ASTM D790): 80 psi (min), 180 psi (max);*
- *Shear Strength (ASTM C273): 60 psi (min), 130 psi (max); and*
- *Recommended Density (in situ): 4 lb/ft³ (min), 6 lb/ft³ (max).*

3 CONSTRUCTION REQUIREMENTS

Under design-bid-build delivery, the Department's acceptance of the work at the end of construction will release the Contractor from further responsibility for performance. The Department's confidence in the ability of the parameters measured at the end of construction to predict future performance will therefore control the degree to which a Department can relax its standard construction requirements. This section provides guidance on specifying key components of PCP construction in a manner that will provide the Agency some assurance of the performance of the PCP.

The two primary components of construction for PCP are panel fabrication and installation on site. The specification should include requirements for the precast panels before they are shipped from the fabrication plant to the project site. However, acceptance of the precast panels at the fabrication plant does not constitute acceptance of the finished product, nor a guarantee that the panels can be properly assembled in the field to achieve the requirements for the finished pavement.

As discussed previously, the System Approval and Trial Installation process, presented in Appendix A to this specification, are critical for ensuring that the Department can accept a contractor-selected PCP system.

3.1 Approved Precast Pavement Systems

The following PCP systems are approved for use by the Department:

1. [Agency]'s generic PCP system [Include Reference Details]
2. [List of other Approved Systems]

The Department will base final approval for the system on fabricator shop drawings specifically developed for the project.

Approval for use of PCP systems not on the list will be contingent upon the Contractor obtaining approval for use of the system prior to submitting the bid. The system approval is based on standard (generic) shop drawings for the PCP system. The Department will base final approval for these systems on fabricator shop drawings specifically developed for the project.

3.2 Panel Layout and Shop Drawings

Provide project-specific panel layout drawings and shop drawings from the panel fabricator. The fabricator shop drawings to manufacture the project precast concrete panels shall be based on the approved standard (generic) drawings for the PCP system proposed for use. Include the PCP system approval details on the fabricator standard drawings and the fabricator shop drawings.

3.3 Preconstruction Submittals

Submit preconstruction submittals to the Engineer before the prepaving meeting. Submittals include, but are not limited to, the following:

1. Panel Fabrication Submittals
 - a. Concrete plant certification (from [Agency], PCI, or NPCA)
 - b. Concrete testing laboratory certification (per ASTM C 1077)
 - c. Concrete testing personnel certification (per ASTM C 1077)
 - d. Reinforcing steel certification
 - e. Prestressing steel certification (PPCP systems only)
 - f. Post-tensioning duct certification (PPCP systems only)
 - g. Lifting anchor certification
 - h. Dowel bar and tie bar certification
 - i. Cement mill certificates
 - j. Supplementary cementing material mill certificates
 - k. Aggregate certification
 - l. Admixture certification
 - m. Water certification
 - n. For each concrete mixture to be used:
 - i. Maximum aggregate size and target air content
 - ii. Concrete mixture proportions
 - iii. Concrete compressive strength data
2. Panel Installation Submittals
 - a. Expansion board certification

- b. Joint seal certification
- c. Slab-base friction-reducing material certification, if applicable
- d. Dowel and tie bar slot backfill material certification, if applicable
- e. Blockout backfill material or grout certification
- f. Lifting anchor patching material or grout certification
- g. Posttensioning duct grout certification (PPCP systems only)
- h. Transverse keyway joint epoxy certification, if applicable
- i. Transverse keyway joint duct coupler certification, if applicable
- j. Posttensioning anchorage hardware certification
- k. Expansion joint sealant and/or system certification, if applicable
- l. On-site equipment list
- m. Existing pavement removal plan
- n. Maintenance of traffic (MOT) plan
- o. Contractor quality control/acceptance testing program.
- p. Emergency management plan
- q. Inclement weather plan
- r. Contingency plan for opening to traffic prior to completion of panel installation

3.4 Contractor Process Control Testing Submittals

Submit process control testing results to the Engineer in writing within 24 hours of completion of the tests. These submittals include the following process control tests:

1. Panel Fabrication Submittals
 - a. Concrete air content
 - b. Concrete compressive strength at time of form stripping
 - c. Concrete compressive strength at time of panel shipment to the project site
 - d. Concrete compressive strength at the specified age (e.g., 28 days)
 - e. Pretensioning tendon elongation, if applicable
 - f. Embedment (reinforcement, dowels, anchors, etc.) tolerances
 - g. Panel dimensional tolerances
2. Panel Installation Submittals
 - a. Posttensioning tendon elongations
 - b. Undersealing grout compressive strength at the specified age, as per AASHTO T-106
 - c. Posttensioning duct grout compressive strength at the specified age
 - d. Transverse keyway joint patching or grout material compressive strength at the specified age, if appropriate
 - e. Dowel and tie bar slot backfill material compressive strength at the specified age
 - f. Blockout and lifting anchor patching material compressive strength at the specified age, if appropriate
 - g. Vertical elevation difference at transverse joint corners before and after grinding, if applicable
 - h. Dowel bar alignment [*Only if Department requires dowel bar alignment testing for new jointed concrete pavements*]

3.5 Panel Fabrication

Fabricate panels for an approved PCP system at a PCI, NPCA, or [Agency name] certified plant.

Fabricate the panels in accordance with the approved fabricator shop drawings. Install all reinforcement, dowel and tie bars, and prestressing steel (if appropriate), posttensioning hardware [e.g., anchors, ducts, couplers, if appropriate], and other embedments [e.g., lifting inserts, grout ports] in the amounts and at locations designated in the fabricator shop drawings.

Produce concrete in accordance with the requirements of ASTM C94 [or Agency Standard Specifications]. Concrete supplied for the panels shall be certified by the [Agency name] or in accordance with the requirements of National Ready Mix Concrete Association’s QC3 checklist.

Ensure that the concrete mixture used for panel fabrication conforms to the concrete mixture submitted to the Department. If the cementitious content, aggregate source, aggregate gradation, or water to cementitious materials ratio changes, resubmit the mixture design for approval before using the new mixture for panel fabrication.

Place concrete and consolidate, as necessary, to ensure that the concrete quality is uniform throughout the panel and the concrete aggregates do not segregate.

Cure, strip from forms, store, and ship precast panels in accordance with [Agency Standard Specifications for precast concrete elements].

Additional requirements may be added for surface texture based on standard Agency practice. Note that most precast concrete pavements will be diamond ground for ride quality, which may remove any texture applied at the fabrication plant. Some form of texturing should be required during fabrication to ensure adequate texture and skid resistance for the panels before diamond grinding. Broom or turf-drag textures are commonly used, but tining may also be required, depending on Agency standards.

Additional requirements may also be added for curing, considering that most precast elements are steam cured, which is not typical for pavements.

The following two tables provide the dimensional tolerances for PCP and JPrCP precast concrete panels, respectively, as recommended from the R05 project:

Table A: Precast Panel Dimensional and Embedment Tolerances for PPCP Systems

Measurement	Tolerance
Length and width	+/- 1/4 in.
Nominal thickness	+/- 1/8 in.
Squareness (difference in measurement from corner to corner across top surface, measured diagonally)	+/- 1/8 in.
Horizontal alignment (on release of pretensioning stress)-deviation from straightness of mating edge of panels	+/- 1/8 in.
Vertical alignment-camber (on release of pretensioning stress, if appropriate)	+/- 1/8 in.
Deviation of ends (horizontal skew)	+/- 1/8 in.
Deviation of ends (vertical batter)	+/- 1/8 in.
Keyway dimensional tolerance	+/- 1/16 in.
Position of strands (if appropriate)	+/- 1/8 in. vertical* +/- 1/4 in. horizontal
Position of posttensioning ducts at mating edges (if appropriate)	+/- 1/8 in. vertical* +/- 1/8 in. horizontal
Straightness of posttensioning ducts (if appropriate)	+/- 1/4 in. vertical*

Measurement	Tolerance
	+/- 1/4 in. horizontal
Vertical dowel alignment (parallel to bottom of panel)	+/- 1/8 in.
Horizontal dowel alignment (normal to expansion joint)	+/- 1/8 in.
Dowel location (deviation from shop drawings)	+/- 1/4 in. vertical* +/- 1/4 in. horizontal
Dowel embedment (in either side of expansion joint)	+/- 1.0 in.
Position of lifting anchors	+/- 3.0 in.
Position of non-prestressing reinforcement	+/- 1/4 in.
Straightness of expansion joints	+/- 1/8 in.
Initial width of expansion joints	+/- 1/8 in.
Dimensions of blockouts/pockets	+/- 1/8 in.

* Measured from bottom of panel.

Table B: Precast Panel Dimensional and Embedment Tolerances for JPrCP Systems

Panel Feature	Tolerance
Length or width	+/- ¼ in.
Thickness	+/- ¼ in.
Squareness of corner - plan view	+/- ¼ in. over 12 in.
Squareness of the sides - section view	+/- ¼ in. over the thickness
Local smoothness of any surface	¼ in. over 10 ft in any direction
Vertical location of reinforcement	+/- ½ in.
Vertical location of pretensioning strand	+/- ¼ in.
Blockout dimensions (if applicable)	+/- ¼ in.
Location of lifting inserts	+/- ½ in.

3.6 Panel Installation

Prepare the base, including placement of any friction-reducing materials, and install the panels in accordance with the approved panel layout and the PCP system's standard installation instructions (as approved through the Department's PCP System Approval and Trial Installation process). Install all dowel bars, tie bars, posttensioning tendons (if appropriate) in accordance with the PCP system's standard installation instructions.

Stress posttensioning tendons, if used, in accordance with [Agency standard specifications for posttensioned concrete], and in the sequence outlined in the PCP system installation instructions.

Backfill dowel and tie bar slots, blockouts, and lifting anchor recesses with the approved backfill material and in accordance with the PCP system installation guidelines.

Perform pavement undersealing in accordance with [Agency standard specifications for pavement undersealing] and the PCP system installation guidelines.

Grout posttensioning tendons in accordance with [Agency standard specifications for posttensioning tendon grouting], the PCP system installation guidelines, and the Post-Tensioning Institute (PTI) Specification for Grouting of Post-Tensioned Structures. PCP system-specific guidelines approved for use by the Department may supersede the Department's standard specifications and the PTI specification.

Perform all joint sealing according to [Agency standard specifications for posttensioning tendon grouting] and the PCP system installation guidelines.

The R05 guide specifications for precast concrete pavement provide additional detail on the various steps involved in PCP construction. However, this level of prescription should not be necessary if a PCP system has been approved for use and demonstrated during a Trial Installation.

4 CONTRACTOR QUALITY CONTROL

4.1 General

Provide and maintain a Quality Management Program for both the panel fabrication and panel installation processes, defined as all activities and documentation of the following:

- Mix design (panel fabrication)
- Process control and inspection (panel fabrication and installation)
- Sampling, testing, measurement, and corrective work (panel fabrication and installation)

Perform the inspections and tests required to substantiate conformance with the contract documents and the accepted quality control plan. Document quality control inspections and tests and make them available to the Department for review.

Precast concrete fabrication plants typically have very robust Quality Control (QC) programs in place for monitoring the fabrication of the precast elements. Depending on the type of products normally produced at a given plant, additional requirements may be necessary for producing pavement panels.

Quality Control during installation primarily encompasses items such as properly backfilling dowel and tie bar slots, installation and stressing of posttensioning tendons, grouting of posttensioning tendons, and undersealing the pavement. Protecting the precast panels from damage during shipment and installation is also a key aspect of Quality Control, but that is difficult to measure and quantify and should therefore be subject to rigorous inspection.

4.2 Quality Management Program

At least [14] days prior to the start of fabrication of precast panels, submit a written Quality Management Program (QMP) to the Department for review and approval. The QMP shall define how the Contractor will develop a mix design; conduct process control inspections, both at the fabrication plant and during installation; perform sampling and testing, both at the fabrication plant and during installation; and make process adjustments in a manner that will ensure that the materials provided and the completed work conform to the contract requirements. Do not change the QMP without the Department's review. Update the QMP with changes as they become effective.

Include the following as a minimum in the QMP:

1. Names and qualifications of contractor's personnel who will be conducting the sampling and testing of materials at the fabrication plant and during panel installation.
2. Preliminary mix design information including anticipated producers, manufacturers, and sources of mix materials, and the name, title, and phone number of the person responsible for developing the mix design
3. Materials proposed for use in the cement concrete including specific properties of each and certification that all products used meet the quality requirements established in the QMP.

4. Certified batch plant and truck mixed concrete requirements or volumetric mixed concrete requirements including calibration results of all meters, scales, and other measuring and recording devices.
5. Location of the laboratory, laboratory equipment, and procedures for calibration, at the fabrication plant and installation site.
6. Proposed methods of materials sampling and testing, sample size, and test frequencies.
7. List of quality control parameters and test tolerances used to control the mixture during production, including acceptable tolerances for single test and multiple tests and corrective action.
8. Quality control charts maintained at the laboratory to monitor specified quality control parameters.
9. Method used to monitor temperature, slump, unit weight, and air content to assure uniformity at the fabrication plant, and specified test frequency to achieve target values for the designated class of concrete.
10. Procedures and requirements for documenting all material certifications, production test reports, quality control charts, equipment certifications and calibrations, and any other design or production-related records.
11. System for controlling nonconforming material, including procedures for identification, isolation, and disposition of such material.

4.3 Personnel Requirements

1. All sampling personnel shall have the following qualifications:

- a.

Consider Precast/Prestressed Concrete Institute (PCI), American Concrete Institute (ACI), National Ready Mixed Concrete Association (NRMCA), or U.S. Department of Transportation (DOT)-specific certification.

2. All testing, data analysis, and data posting personnel shall have the following qualifications:

- a.

Consider PCI, ACI, NRMCA, or DOT-specific certification.

4.4 Testing Laboratory Requirements

Perform testing at a Department-qualified laboratory for tests conducted at the fabrication plant, and tests conducted on materials used during panel installation.

4.5 Equipment

Furnish the necessary equipment and supplies for performing quality control testing. The Department may inspect the measuring and testing devices to confirm both calibration and condition. Maintain a calibration record at the laboratory.

4.6 Documentation

Documentation for testing completed at the fabrication plant will include standard concrete material testing (unit weight, strength, air content, and permeability) as well as any additional testing required for prestressing, such as strand elongations.

Documentation for testing completed during installation will include that required for testing of grout and backfill materials, as well as any additional testing required for posttensioning, such as strand elongations.

4.6.1 Control Charts

Maintain control charts when required by the test reporting procedures. Ensure that all tests are recorded and become part of the project records. Plot required test results on the control charts. Include random, nonrandom, and Engineer-requested testing, but only include the Contractor’s randomly selected QC test results in running averages. The Contractor may plot other contractor-performed process control or informational tests on the control charts, but do not include them in running averages.

Post control charts in an Engineer-approved location and update daily. Ensure that the control charts include the project number, the test number, each test element, the applicable warning and control limits, the Contractor’s individual test results, the running average of the last 4 data points, and the Engineer’s verification and independent assurance test data points. Use the control charts as part of a process control system for identifying potential problems and assignable causes.

4.6.2 Records

Document all observations, inspection records, mixture adjustments, and test results daily.

4.7 Required Sampling and Testing

Use the test methods identified in Tables 1 and 2 or other methods the Engineer approves, to perform the following tests at a frequency greater than or equal to that indicated:

Table 1: Minimum Quality Control Requirements for Panel Fabrication

Requirement	Test Method	Frequency
Unit Weight	ASTM C138	<i>[Per Agency standard practice for precast concrete elements.]</i>
Air Content or Air Quality	Pressure (ASTM C231) or Air Void Analyzer (ASTM C457)	<i>[Per Agency standard practice for precast concrete elements.]</i>
Compressive Strength	ASTM C39	<i>[Per Agency standard practice for precast concrete elements.]</i>
Permeability	ASTM C1202	<i>[Per Agency standard practice for precast concrete elements.]</i>
Strand Elongation (<i>prestressed panels only</i>)	Measurement	<i>[Per Agency standard practice for precast concrete elements.]</i>

Table 2: Minimum Quality Control Requirements for Panel Installation

Requirement	Test Method	Frequency
Base Compaction	Light Weight Deflectometer	<i>[Determined based on area of</i>

Requirement	Test Method	Frequency
	(ASTM E2583)	<i>PCP to be installed]</i>
Backfill Material Compressive Strength	ASTM C942	
Grout Compressive Strength <i>(underslab and posttensioning grout)</i>	ASTM C942	
Posttensioning Strand Elongation <i>(PPCP systems only)</i>	Measurement	Every strand
Permeability	ASTM C1202	

Test methods listed in Tables 1 and 2 are intended as guidance only. If a Department has its own standard test methods for measuring these properties, particularly at a precast fabrication plant, those should be specified instead.

The test for Base Compaction using the Light Weight Deflectometer (LWD) was a technique recommended by the SHRP 2 R05 team. The LWD is a portable and compact nondestructive test (NDT) device that permits checking base compaction in confined spaces, such as those typically encountered in a reconstruction or rehabilitation project using precast concrete pavement.

A number of additional tests can be specified for the posttensioning grout and grouting operations. Most posttensioning grouts are prepackaged and, if mixed according to the manufacturer's specifications, will meet industry-adopted requirements.

Perform and document all other inspections and tests necessary to ensure the quality of the finished pavement.

The Department may periodically observe Contractor sampling and testing. Make test results available to the Department for review.

4.8 Corrective Action

Take prompt action to correct conditions that have resulted in, or could result in, materials and products not conforming to the requirements of the specification. Make corrections to the QMP and submit to the Engineer.

An entire precast panel may be rejected as defective material at the fabrication plant if the constituent concrete does not meet the requirements or if the dimensional or embedment tolerances are not achieved. Panels may also be rejected at the installation site if they are substantially damaged due to shipment or handling issues. Acceptance at the fabrication plant does not constitute acceptance for the finished pavement.

4.9 Department’s Quality Management Responsibilities

The Department may conduct quality inspections, audits of the Contractor’s results and records, and verification sampling and testing on any element of the work to ensure compliance with the QMP and the Contract requirements.

4.9.1 Verification Sampling and Testing

Even though the Contractor may assume more responsibility for inspection and testing under a performance specification, this does not relieve the Agency of its responsibility to perform some level of independent sampling and verification testing to meet the intent of 23 CFR 637. Verification testing should be performed to validate any Contractor testing used in the Agency’s acceptance decision. The Agency may also wish to verify certain material or mixture parameters that could identify possible performance issues that would not otherwise be detected through end-result acceptance testing.

Most Agency-certified precast fabrication plants will have processes in place for Department verification of plant test results. The Agency may wish to use similar procedures for precast concrete pavement panel fabrication. Likewise, standard procedures may be available for verification of test results related to posttensioning. Tables 3 and 4 provide some additional verification testing that may be required for PCP construction.

Department verification testing personnel will have the same certification level requirements specified for Contractor testing personnel for each test being verified.

The Department will notify the Contractor before sampling so the Contractor can observe.

The Department will sample randomly at locations independent of the Contractor’s quality control work. In all cases, the Department will conduct the verification tests in a separate laboratory and with separate equipment from the Contractor’s quality control tests.

The Department will perform verification testing as specified in Tables 3 and 4.

Table 3: Department Verification Testing for Panel Fabrication

Requirement	Test Method	Sampling Location	Frequency
Unit Weight	ASTM C138	<i>[Per Agency standard practice for precast concrete elements.]</i>	<i>[Per Agency standard practice for precast concrete elements.]</i>
Air Content or Air Quality	Pressure (ASTM C231) or Air Void Analyzer (ASTM C457)	<i>[Per Agency standard practice for precast concrete elements.]</i>	<i>[Per Agency standard practice for precast concrete elements.]</i>
Compressive Strength	ASTM C1074 (Maturity Method)	<i>[Per Agency standard practice for precast concrete elements.]</i>	<i>[Per Agency standard practice for precast concrete elements.]</i>
Permeability	ASTM C1202	<i>[Per Agency standard practice for precast concrete elements.]</i>	<i>[Per Agency standard practice for precast concrete elements.]</i>

Requirement	Test Method	Sampling Location	Frequency
		<i>practice for precast concrete elements.]</i>	<i>standard practice for precast concrete elements.]</i>

Table 4: Department Verification Testing for Panel Installation

Requirement	Test Method	Frequency
Base Compaction	Light Weight Deflectometer (ASTM E2583)	
Backfill Material Compressive Strength	ASTM C942	
Grout Compressive Strength (underslab and posttensioning grout)	ASTM C942	
Permeability	ASTM C1202	

Test methods listed in Tables 3 and 4 are intended as guidance only. If a Department has its own standard test methods for measuring these properties, those should be specified instead.

If verification tests indicate conformance with specifications, no further action is required. If verification tests indicate nonconformance with specifications, the Engineer and Contractor will jointly investigate any testing discrepancies. The investigation may include additional testing as well as review and observation of both the Department’s and Contractor’s sampling and testing procedures and equipment. Both parties will document all investigative work.

4.9.2 Independent Assurance Testing

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing activities are being performed by qualified personnel using proper procedures and properly functioning and calibrated equipment. The Department will perform IA testing using personnel other than those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor’s sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

4.9.3 Conflict Resolution

If a dispute between some aspect of the Contractor’s and the Department’s testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third-party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third-party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [*Standard Specification Section XXX*].

5 ACCEPTANCE REQUIREMENTS

Acceptance requirements are provided for the finished pavement. In addition, acceptance of the precast panels at the fabrication plant will help ensure the precast panels, as produced, meet the requirements set forth in these specifications. Concrete properties and dimensional tolerances will be checked throughout the fabrication process. The finished product will also be inspected for damaged or defective concrete prior to acceptance at the fabrication plant. Without acceptance at the fabrication plant, defective precast panels could potentially be shipped and installed and accepted as part of the finished pavement as long as the finished pavement requirements have been achieved. Panels could also be damaged during shipment and handling. Defective panels could potentially affect the longevity of the finished pavement and therefore should not be allowed.

Acceptance requirements provide a method for determining the degree to which the pavement meets the specification and for determining appropriate payment for the pavement. Acceptance is based on the measurement of properties that control the quality and performance of the pavement.

Various acceptance parameters are listed in Table 5 for the specifier's consideration. Of these, key acceptance parameters defined by the R05 team include

- *Damaged or Defective Concrete (at the fabrication plant);*
- *Vertical Elevation Difference at Joints (in place);*
- *Deflection Testing/Joint Load Transfer (in place);*
- *Surface Distress (in place); and*
- *Ride Quality (in place).*

Additional in-place acceptance parameters such as skid resistance, dowel bar alignment, joint deficiencies, steel location (for steel installed in the field, not at the fabrication plant), and tire pavement noise may also be considered as more advanced acceptance parameters; but their inclusion will generally require that an Agency already have standard acceptance requirements in place.

If additional acceptance parameters are included, the Agency may wish to consider a percent within limits (PWL) approach for adjusting payment, similar to that presented for conventional concrete pavement construction under a DBB contracting mechanism.

The Department will accept the pavement based on the parameters specified in Table 5.

Table 5: Acceptance Criteria Quality Characteristics

Parameter	Measurement Procedure	Measurement Requirements	Tolerance/Acceptance Limits
Damaged or Defective Concrete (at the fabrication plant)	Visual inspection of precast panels for distresses or defective concrete at the fabrication plant (includes honeycombed concrete, cracking, spalling, scaling, popouts, surface texture, and marred surface)	Evaluate 100% of precast panels at the fabrication plant. No damaged or defective concrete is permitted.	Any precast panels with distresses or defective concrete will be evaluated on a case-by-case basis by the Department to determine if a repair will be permitted or if the panel will be rejected.
<i>Distresses in PCP pavements most commonly occur during installation of the panels due to issues with handling and installation. Additional distresses, such as cracking, may occur during construction due to issues with panel support and construction equipment loads. Both the finished surface and the edges of PCP panels should be inspected for damage and distress.</i>			
Vertical Elevation Difference at Transverse Joints	Georgia Faultmeter	Evaluate 100% of joints between precast panels.	Maximum vertical elevation difference: 0.25 in. <i>Excessive vertical elevation difference will be evaluated on a case-by-case basis by the Department to determine if it can practically be removed with diamond grinding.</i>
<i>While diamond grinding is commonly used to correct vertical elevation differences between panels, excessive vertical elevation differences or an excessive number over a section of pavement may be indicative of bigger issues with base compaction or installation of the panels.</i>			
Load Transfer Efficiency/Relative Deflection	Deflection Testing (FWD [ASTM D4694], RWD, RDD, etc.)	Evaluate 10% of the joints of JPrCP pavements using random sampling protocols and 100% of the expansion joints for PPCP.	Relative Deflection (9,000 lb test load): JPrCP \leq 0.002 in. PPCP \leq 0.0025 in.
<i>Measuring load transfer across a joint is critical for determining whether the load transfer mechanisms (dowels or keyways) are functioning properly. The SHRP 2 R05 effort revealed that measuring load transfer efficiency (LTE) can provide highly variable results, depending on the stiffness of the underlying base. The R05 team therefore recommended an evaluation of relative deflection across a joint rather than LTE. Deflection can be tested using the Falling Weight Deflectometer (FWD), Rolling Wheel Deflectometer (RWD), Rolling Dynamic Deflectometer (RDD), or similar devices.</i>			
Surface Distress	Project-level visual survey (includes cracking, spalling, scaling, popouts, surface texture, and marred surface).	Evaluate 100% of pavement surface. No surface distress is permitted.	Any distresses will be evaluated on a case-by-case basis by the Department to determine if a repair will be required.
<i>Distresses in PCP pavements most commonly occur during installation of the panels due to issues with handling and installation. Additional distresses, such as cracking, may occur during construction due to issues with panel support and construction equipment loads. Both the finished surface and the edges of PCP panels should be inspected for damage and distress.</i>			

Parameter	Measurement Procedure	Measurement Requirements	Tolerance/Acceptance Limits
Ride Quality	Inertial Profiler Measurement and Continuous Roughness Reporting	Evaluate 100% of pavement surface after any final correction (diamond grinding).	HRI \leq 67 in./mi with 0.1-mi baselength for full payment Localized Roughness: HRI \leq 125 in./mi with 25-ft baselength
<p><i>Note: HRI = Half-Car Roughness Index.</i></p> <p><i>Diamond grinding is virtually always required for achieving ride quality requirements. Therefore, the Department should permit correction (diamond grinding) without penalty before evaluating for acceptance. The Department may wish to relax ride quality requirements for PCP, but it should be possible for most Agency ride quality requirements to be achieved with diamond grinding.</i></p>			
Dowel Bar Alignment	NDT (GPR or MIT Scan)	Evaluate 5% of the joints for JPrCP and 100% of the expansion joints for PPCP.	
<p><i>Measuring dowel bar alignment is still an evolving practice. Ground-penetrating radar (GPR) and magnetic imaging tomography (MIT) scan are the only devices known to be able to measure with reasonable precision, but the technology has some shortcomings, such as difficulty with measuring dowel bar locations if the dowel basket ties have not been cut. An alternative is to measure joint functionality by monitoring joint width at various times of day and various seasons, which will indicate whether a joint is locked up or functioning normally.</i></p>			
Steel Location	NDT (GPR or MIT Scan) Measured from reference surface	Evaluate 5% of any tie bar locations.	\pm 0.5-in. on vertical tie bar placement \pm 1-in. on horizontal tie bar placement
<p><i>Measuring steel location is primarily for checking the locations of tie bars used to tie PCP panels to existing pavement or adjacent PCP. Steel location in the PCP panels should be addressed with precast fabrication plant inspections. Currently there are no established test methods for measuring steel location postconstruction. GPR and MIT techniques are available but do not provide the necessary precision.</i></p>			
Skid Resistance	ASTM E274 ASTM E524 ASTM E501	Evaluate 100% of pavement surface. Average per lane or as per Department requirements.	FN40S \geq 40 FN40R \geq 45
<p><i>Note: FN = Friction Number; S = Smooth; R = Ribbed.</i></p> <p><i>The type of test tire (smooth or ribbed) should be selected by the Department based on standard practice.</i></p>			
Tire-Pavement Noise	On-Board Sound Intensity (OBSI) measurement with a Standard Reference Test Tire (SRTT) AASHTO TP 76-11	Evaluate 100% of pavement surface.	Maximum A-weighted tire-pavement noise level of 100 dB at 50 mph
<p><i>At present there are no established thresholds for tire-pavement noise. These values should be modified according to Department standard practice.</i></p>			

Parameter	Measurement Procedure	Measurement Requirements	Tolerance/Acceptance Limits
Joint Deficiencies	Visual survey (includes raveling, spalling, faulting, and seal damage/integrity)	Evaluate 100% of pavement joints.	No joint deficiencies permitted. <i>Any joint deficiencies will be evaluated on a case-by-case basis by the Department to determine if a repair will be required.</i>
<i>Joint deficiency encompasses unacceptable spalling of joints (commonly due to mishandling of panels), as well as defective or improperly installed joint seals for both JPrCP and PPCP.</i>			

Test methods listed in Table 5 are intended as guidance only. If a Department has its own standard test methods for measuring these properties, those should be specified instead.

6 METHOD OF MEASUREMENT

To facilitate rapid renewal, it is recommended that measurement be based on square yards completed in place, including any reinforcement, dowel bars, posttensioning, undersealing, and joint sealing.

The Department will measure the work by the number of square yards completed and accepted in place.

7 PAYMENT

The unit price bid shall include the cost of all engineering, design, fabrication, quality control, labor, material, and equipment necessary to satisfactorily perform the work described in this specification, including technical assistance from the PCP system designer, as necessary.

Many of the items commonly specified for pay adjustment for conventional concrete pavement (thickness, strength, air content) will be addressed with acceptance or rejection of the precast panels at the fabrication plant. However, items such as ride quality may form a basis for incentive or reduced pavement, as with conventional concrete pavement, as they will help encourage more attention to detail in the installation of the precast panels. The Agency may also wish to consider requiring a 1-year materials and workmanship warranty for cracking and surface and joint distress.

Because there is generally a lag between when precast panels are produced and when they are installed and accepted, Agencies may wish to consider providing advanced payment for "materials on hand." The partial payment for such materials, however, should not relieve the Contractor of responsibility for adequate handling, storage, and protection of the panels prior to their installation and final acceptance

Appendix A - PCP System Approval and Trial Installation

As discussed in the specification, the System Approval and Trial Installation processes are essential for an Agency wishing to permit contractor-selected PCP systems on a particular project. The following section describes what should be considered in System Approval and Trial Installation and is based on the System Approval guidelines developed by the AASHTO Technology Implementation Group (TIG) for Precast Concrete Paving Slabs.

1. Requirements for System Approval

The system approval process consists of two phases:

- Submittal and review of Fabricator Standard Drawings and Standard Installation Instructions.
- Construction and evaluation of a Trial Installation.

Each of these phases is described below.

1.1 Submittal of Fabricator Standard Drawings and Standard Installation Instructions

A. Fabricator Standard Drawings

The manufacturer shall provide the Fabricator's Standard Drawings (developed or approved by the system designer) to *[Department Name]*. These drawings shall include the following details:

- Transverse joint type, locations, and spacing, and the mechanism used to transfer loads across transverse joints after slabs are placed.
- Longitudinal joint type, locations, and spacing, and the mechanism used to tie adjacent slabs together (if appropriate).
- Pretensioned Systems: Pretensioning materials, tensioning/detensioning procedures and sequence.
- Posttensioned Systems: Posttensioning hardware and material details; installation and tensioning sequencing; and tendon grouting materials and procedures.
- Lifting insert type, location, positions, and grout capping method.
- Grout port type, location, positioning, and capping method.
- Tolerance, texturing, curing, sampling, and testing requirements listed in the Fabrication and Construction Specification for Precast Concrete Pavement Slab Systems.

B. Installation Instructions

The manufacturer shall provide Standard Installation Instructions (developed or approved by the system designer) to *[Department Name]* a minimum of 7 days prior to the Trial Installation. After the completion of the Trial Installation, the instructions shall be evaluated by the Agency and revised by the manufacturer as required prior to final approval.

These instructions will include the need for any special equipment and will address the following:

1. Subbase Preparation (if appropriate)

Include complete instructions for required subbase preparation procedures.

2. Pre-overlay Preparation (if appropriate)

Include complete instructions for preparing the existing pavement surface (either asphalt or concrete) to receive a precast concrete pavement overlay.

3. Slab Installation

Include complete instructions for lifting, moving, protecting, lowering, and adjusting the positions of the slabs.

4. Posttensioning (if appropriate)

Include complete instructions for posttensioning and describe any special requirements for posttensioning sequencing.

5. Bed and Level Slabs

Include complete instructions for ensuring that the slabs are fully supported by underlying layers at the correct line, grade, and cross-slope while meeting contract smoothness requirements. Slabs may be placed by one of the following means:

- Grade-supported: Placed on a precisely graded bedding layer and stabilized in place using cementitious grout to fill any small, isolated voids between the slabs and bedding layer.
- Grout- or Urethane Polymer-Supported: Placed or held near final position and anchored/supported in place using cementitious grout (grout-supported), urethane polymer foam (urethane polymer-supported) or another accepted material.
- Placed by other methods approved by the Department.

For grade-supported slabs, include all pertinent bedding and leveling instructions, including

- Bedding material composition and gradation.
- Method used to place the bedding material.
- Stabilizing grout mix design and anticipated strength gain. [Note: Stabilizing grout must develop a minimum compressive strength of 4 MPa (600 psi) within 24 hours.]
- Method used to place stabilizing grout beneath the slab.
- Method(s) used to ensure complete support after placement, as described for the Trial Installation.

For grout- or urethane polymer-supported slabs, include all pertinent support and leveling instructions, including

- Material properties, composition, mix design (if appropriate), and required strength gain of any slab-supporting material. [Note: Cementitious support grouts must develop a minimum compressive strength of 4 MPa (600 psi) before opening to construction or service traffic. Urethane polymer materials must be fully cured before opening to construction or service traffic.]
- Method used to place the slab-supporting material (i.e., urethane polymer or cementitious grout) beneath the slab.
- Equipment and experience required to successfully install the slab-supporting material.
- Method(s) used to ensure complete slab contact with the slab-supporting material after placement, as described for the Trial Installation.

6. Encasing Pavement Hardware and Filling Blockouts

Include instructions for completely encasing load transfer devices and longitudinal joint ties, as well as for filling grout ports, lifting insert holes and blockouts (for posttensioned systems). Include all pertinent information, including

- Material properties, composition, mix design, and required strength gain of any encasement and/or grout fill materials that are not named in the Standard Specifications or Special Provisions.
- Revised instructions for those materials for which the manufacturer's instructions are not to be followed exactly.
- Methods used to place encasement and/or grout fill materials.
- Method(s) used to ensure complete hardware encasement, as described for the Trial Installation.

After the standard drawings and installation instructions have been approved, any subsequent changes must be submitted to and approved by the Department to maintain product status on the Approved List. The Department reserves the right to require additional trial installations if the changes are deemed significant.

1.2 Trial Installation

Arrange for a trial installation, at no cost to the Department, at a facility agreeable to the Department, such that Department personnel, particularly those directly involved with the approval process and those involved with any projects, will be present during the installation. Place a *minimum* of four (4) slabs in a manner that simulates the construction of at least two travel lanes of pavement over a minimum length of 24 ft. Provide a drill rig, with operator, capable of retrieving 6-in. diameter cores from any portion of the slab, and a technician capable of fabricating test specimens in accordance with [*Standard Specification XXX*]. As a minimum, the following will be evaluated:

1. Stabilizing Grout Properties and Completeness of Placement (for grade-supported applications)

Fabricate and test 24 cube specimens meeting the requirements of [*Standard Specification XXX for Pavement Undersealing Material*] and demonstrate completeness of placement. Completeness of placement must be demonstrated by retrieving and inspecting at least three cores (6-in. diameter) from random locations within the trial installation area.

2. Supporting Material Properties and Completeness of Placement (for grout- and urethane polymer-supported systems)

For grout-supported systems, fabricate and test 24 cube specimens according to the requirements of [*Standard Specification XXX for Concrete Repair Material*]. For urethane polymer-supported systems, the urethane polymer material must be preapproved and used according to the manufacturer's recommendations; no further testing of the material is required. Completeness of placement of either material must be demonstrated by retrieving and inspecting at least three cores (6-in. diameter) from random locations within the trial installation area.

3. Encasement, Grout Fill, and Capping Material Properties and Completeness of Placement

If a material identified in the Fabrication and Construction Specifications (under Material Requirements) as Encasement Material for Pavement Hardware is used in accordance with the manufacturer's written instructions, no further material testing is required. If a different material is used or if a material is not used in accordance with the manufacturer's instructions, fabricate a sufficient number of test specimens of appropriate sizes to determine the properties identified in [*Department Standard Specification for Concrete Repair Material*]. Demonstrate completeness of placement through encasement areas by drilling, retrieving, and inspecting at least two cores (6-in. diameter) from randomly selected hardware encasement locations (e.g., through dowel bars).

4. Panel Fit and Duct Alignment

For posttensioned systems utilizing keyed joints between panels, ensure proper contact between the vertical faces of adjacent panels and proper fit of mating keyways, and ensure uniform joint width between adjacent panels. For posttensioned systems utilizing double-grooved joints, ensure duct continuity by using duct gaskets or splices. Ensure that posttensioning tendons can be inserted through the panels by feeding a tendon, of the same size as that to be used for final posttensioning, through each posttensioning duct in the assembled panels.

5. Dimensions and Tolerance

Slabs must conform to the Fabricator Standard Drawings and be capable of being placed to meet the specified joint width and vertical deviation tolerances.

6. Instruction Completeness

Manufacturer's instructions must accurately reflect the processes used in the trial installation.

7. Load Transfer Efficiency (LTE)

The Department reserves the right to conduct falling weight deflectometer (FWD) tests to determine the LTE at the joints. Inadequate load transfer [i.e., $LTE \leq 80\%$ when differential deflection ($d_{\text{loaded}} - d_{\text{unloaded}}$) exceeds (0.005 in.) for a load of 9,000 lb applied in the wheel path] may be cause for rejection.

2. Basis for Approval

Approval will be based upon successful demonstration that the proposed system meets the requirements set forth above based upon (a) submitted documents and (b) field testing performed by the Department and the Contractor at the Trial Installation. Field testing shall include the items listed above (e.g., FWD, cores). Partial approval may be granted contingent upon successful completion of field testing at the Trial Installation. Approved systems will be placed on the Department's Approved Products List [*Designation for Precast Concrete Pavement*]. Rejection may be based upon unsuccessful past performance.

QUALITY MANAGEMENT PROGRAM

Managing quality has traditionally been the responsibility of the Agency. However, performance specifications, particularly when implemented as part of an alternative project delivery system, provide the opportunity to assign quality management responsibilities to the entity best suited to carry them out in a satisfactory manner. This assignment of quality management responsibilities should be consistent with the degree of risk assumed by the Contractor for the performance of the work. Too much oversight by Agency forces could shift significant risk back to the Agency, while too little could compromise safety and performance. Given the importance of the quality management program to the outcome of the project, the Contract Documents should clarify the role of all parties to the Contract (including third-party inspection or construction engineering and inspection, CEI, firms) in ensuring the project's goals are met.

The following guide specification highlights the essential elements of a General Provision for Quality Management and supplements the material-specific testing and inspection requirements otherwise contained in the technical provisions. Commentary included within the specification (as indicated with italic typeface) provides guidance for extracting unnecessary requirements and for refining others based on available choices or options. While commentary text is not intended to serve as specification requirements, users may draw upon the information provided as a basis for further modification or development of the specification.

Unless otherwise noted, the specified requirements apply to both design-bid-build (DBB) and design-build (DB) delivery. For a DB project, the term "Contractor" as used in this document should be interpreted as that entity given single-point responsibility for both the design and construction of the work and is thus synonymous to "Design-Builder" and "Design-Build Team."

1 GENERAL

The Contractor shall develop, implement, and manage a Quality Management Program that ensures the completed project conforms to the quality and performance requirements specified in the Contract Documents.

The Quality Management Program shall be implemented at all levels of the Contractor's and its subcontractors' organizations for *[both design and]* construction services.

The Department, acting in an oversight role, will conduct independent assurance and verification testing and inspection.

1.1 Cooperation

The Contractor and the Department shall work cooperatively within their respective responsibilities to produce and document a high quality project that meets or exceeds the quality and performance requirements of the Contract Documents.

The Contractor shall assist the Department's efforts to obtain information regarding the nature, quantity, quality, and performance of any part of the work. Such assistance shall extend to providing Department personnel reasonable access to project records and the project site.

To foster a collaborative development process for a DB project, the Agency may wish to consider co-locating its key personnel with those of the Contractor. Colocation is intended to facilitate regular interaction and the free exchange of information between the parties. Under such conditions, however, Agency personnel must take care to avoid controlling or directing the

Contractor's work in a manner inconsistent with the Contract Documents and the degree of design and construction risk to be assumed by the Contractor.

1.2 Role of the Contractor

The Contractor shall have the full and complete responsibility for the quality and performance of the work, including the work and products of consultants, subcontractors, fabricators, suppliers, and vendors.

The Contractor shall develop, submit for review, implement, and adjust if necessary, a Quality Management Plan (QMP) for the work as specified in Section 2.

1.3 Role of the Department

The Department will review the QMP for conformance with the minimum requirements established in the Contract Documents. The Department's review and acceptance of the QMP shall not relieve the Contractor of its full and complete responsibility for the quality, performance, and workmanship of the completed project.

The Department will oversee the work to determine in general if the work, when completed, will be in accordance with the Contract Documents. The Department will not make exhaustive or continuous on-site inspections as to the quality, performance, or quantity of the work. However, the Department may perform periodic quality inspections, audits, and sampling and testing on any element of the work to ensure compliance with the QMP and the Contract Documents. The Department will act in a timely manner so as not to delay or interfere with the Contractor's prosecution of the work.

The Department's determination shall be final on all matters related to the quality and acceptability of materials and workmanship and conformance with performance requirements.

2 QUALITY MANAGEMENT PLAN (QMP)

2.1 General Requirements

The example language that follows assumes that any related performance specifications will provide the Contractor significant flexibility with regard to [design and] construction decisions, in exchange for the Contractor preparing and adhering to a detailed Quality Management Plan (QMP). This plan should contain the necessary detail and project-specific information to assure the Agency that (1) the Contractor understands how its own actions will affect the in-place properties and performance of the work and (2) the Contractor has planned the work and allocated its resources accordingly.

Specifiers should tailor quality management assignments to fit the needs of a particular project or program. This example places quality management responsibility for both design and construction on the Contractor (with the Agency performing oversight through verification testing). Other approaches, in which the Agency retains a more traditional quality management role, are also possible.

Note that a DBB project would exclude requirements related to Design Quality Assurance (QA) and Quality Control (QC), as the Agency would retain such design-related responsibilities.

The Contractor shall develop and implement a written QMP that details how the Contractor intends to perform the following tasks:

- A. Design Quality Control (Design QC) to check the Design Documents for the following:
1. accuracy of math and engineering computations,
 2. technical accuracy,
 3. conformance to Contract Document requirements,
 4. proper form and content,
 5. coordination between design disciplines, and
 6. coordination of the sequence of construction.
- B. Design Quality Assurance (Design QA) to substantiate that
1. quality control checks and reviews required by the QMP are being performed,
 2. the design approach is appropriate,
 3. correct analyses are being applied,
 4. the design is constructible, and
 5. the design solution is practical, cost-effective, and fit for the purpose and function specified in the Contract Documents.
- C. Construction Quality Control (Construction QC), including
1. establishment of horizontal and vertical controls on site,
 2. technical review of shop drawings,
 3. technical review of material submittals,
 4. routine inspection, sampling, and testing needed to ensure that the final installed work meets the requirements of the Contract Documents, and
 5. verification of pay quantities.
- D. Construction Quality Assurance (Construction QA) to include inspection quality assurance and testing quality assurance.

2.2 QMP Submittal

Prior to the start of the work, the Contractor shall submit the QMP to the Department for review. The Department will accept, reject, or comment on the QMP within *[10 days]* of its submission. If the QMP is not acceptable to the Department within *[60 days]* of its initial submittal, the Contractor shall stop work, unless the parties otherwise agree in writing.

If the Contractor was selected through a best-value procurement process, which required a narrative discussion or an outline/plan of the Contractor's proposed quality management program as part of the technical (nonprice) selection criteria, the Contractor shall identify any changes in its plan, including those affecting personnel assignments, made since the proposal submission.

Instead of preparing a single QMP, the Contractor may choose to prepare a Design QMP and a Construction QMP. In this case, the Contractor shall ensure that each plan clearly identifies and establishes the organizational and technical interfaces needed to coordinate the work covered by the respective Design and Construction QMPs. Each plan shall be acceptable to the Department within [30 days] after the work covered under a particular plan begins or the work addressed therein shall be stopped.

2.3 Quality Management Team

The QMP shall detail the role of the Contractor, the Designer, the Design and Construction Quality Managers, and other members of the Contractor's team, including all consultants, subcontractors, suppliers, and vendors at all tiers having a significant quality role.

The QMP shall describe how members of the Contractor's quality management organization will operate independently from design and production staff.

2.3.1 Organizational Chart

The QMP shall include an organizational chart of all quality management personnel, indicating lines of reporting and how these personnel integrate with other management, design, and construction functions and personnel. The organizational chart shall identify all quality management staff by name, function, firm, and location, and shall indicate the total staff required to implement all elements of the QMP, including inspection and testing for each item of work. The organizational chart shall indicate which personnel are employees of the Contractor and which are provided by an outside organization.

2.3.2 QMP Administrator

The Contractor shall designate one of its Key Personnel to be the QMP Administrator, who shall be responsible for overseeing the overall quality program and for preparing, implementing, and updating the QMP.

The QMP Administrator shall not report to the Contractor's Project Manager, but shall instead report directly to an officer of the Contractor's organization not directly responsible for design or construction.

The QMP Administrator shall have full authority to institute any and all actions necessary for the successful implementation of the QMP, including stopping work upon detection of a deficiency or nonconformance in materials, workmanship, documentation, or other operational procedures.

As the primary point of contact to the Department for all issues relating to the Contractor's QMP, the QMP Administrator shall be present and available for consultation with the Department's Representative and other personnel throughout the duration of the project. The QMP Administrator shall attend the regular progress meetings and such other meetings as the Department's Representative may request, including individual meetings between the QMP Administrator and Department staff.

The Design and Construction Quality Managers and their respective staffs, as defined in paragraphs 3.2 and 4.2, respectively, shall report directly to the QMP Administrator.

2.4 Design Quality Management

Include this section for DB projects only.

The QMP shall specify procedures for ensuring the quality of all design plans, specifications, reports, calculations, and other design and construction documents prepared by the Contractor. These procedures shall be consistent with the design control requirements described in Section 3.

As a minimum, the QMP shall address the following with respect to design quality management:

1. Names, qualifications, duties, and authority of each person assigned to a design quality management role (as a minimum, the QMP shall address the personnel that will fill the roles identified in Section 3.2);
2. Independence of the Quality Management Team from the design production team;
3. Procedures for preparing and checking all drawings, specifications, calculations, reports, and other design submittals;
4. Procedure for verification and control of computer programs used in design;
5. Level, frequency, and methods of design review, including the methods for independent review of the interim and final drawings, specifications, and other design submittals to ensure compliance with the Contract Documents;
6. Procedures for coordinating work performed by different persons to ensure that conflicts, omissions, or misalignments do not occur between design discipline drawings and specifications;
7. Project elements requiring special attention or emphasis, including applicable standards of quality or practice to be met, level of completeness, and/or extent of detailing required; and
8. Process to propose, receive, track, respond to, and distribute valid design changes.

2.5 Construction Quality Management

The QMP shall describe the specific procedures the Contractor will follow to ensure that the work conforms to the Contract Documents.

As a minimum, the QMP shall address the following with respect to construction quality management:

1. The organizational structure and reporting requirements demonstrating that the firms or individuals assigned to a construction quality management role have sufficient independence to allow their primary concern to be quality, as opposed to schedule and budget (as a minimum, the QMP shall address the personnel or firms that will fill the roles identified in Section 4.2);
2. A program for inspection of all work, including examinations, measurement, and testing;
3. A materials sampling, testing, and analysis plan, including locations, frequencies, and techniques to demonstrate that materials that will be incorporated into the work comply with the Contract Documents;
4. Total list of all tests to be performed, and the respective test methods and copies of forms to be used for recording inspection results, performance, or test data;
5. Procedures for inspecting, sampling, and testing the work, including the work performed by subcontractors, fabricators, suppliers, and other vendors;
6. Documentation procedures for preparing and maintaining quality records, including audit inspection reports, design review records, material certifications, production test reports, quality control charts, equipment certifications and calibrations, vendor evaluation reports,

and any other design or production-related records. *Such records should provide the Agency with an auditable record of the Contractor's quality management activities.*

7. Procedures for conducting and documenting off-site inspections;
8. Procedures to ensure that all activities affecting the quality of the work are accomplished under suitably controlled conditions, using appropriate equipment, and with assurance that all prerequisites to the proper accomplishment of a given task have been satisfied;
9. Methods and procedures for instructing quality management personnel, construction supervisors, and foremen on the QMP and its requirements;
10. Any necessary coordination of construction quality management tasks with the Contractor's *Project Management and Safety Plans*;
11. All Witness Points and Hold Points requested by either the Contractor or the Department;
12. Field procedures related to stockpile management, and material transport, delivery, and storage;
13. Procedures for inspecting, testing, and calibrating equipment;
14. Procedures for handling nonconforming work; and
15. Procedures for corrective/preventive actions.

2.6 QMP Updates and Revisions

2.6.1 QMP Maintenance

- A. Once the QMP has been accepted, the Contractor shall submit all proposed changes to the QMP and quality program staffing to the Department for written acceptance prior to their implementation.
- B. The Contractor shall regularly maintain and update the QMP to reflect current conditions and to contain current versions of the following information:
 1. Organizational chart identifying all quality management personnel, their roles, authority, and chain of command;
 2. Description of the roles and responsibilities of all quality management personnel; and
 3. Identification of inspection and testing firms and laboratories, including information on each firm's capability to provide the specific services required to assure the quality of the work, certifications held, and equipment calibration records.
- C. On an annual basis (within 12 months of receipt of the last Department review), the Contractor shall submit either an updated QMP for Department review or a narrative statement, signed by the Contractor's QMP Administrator, that no updates or revisions have been made to the approved QMP during that 12-month period, and that the current processes and procedures are functioning as intended.

2.6.2 QMP Revisions

- A. The Contractor shall revise the QMP if its quality management organization identifies a systematic nonconformance in the work performed or in the manner in which the work is inspected, sampled, or tested, or after the Department advises the Contractor of such a problem.
- B. A revised version of the QMP, with the revisions highlighted, shall be submitted to the Department for review within *[30 days]* of the identification of the need for the revision.

3 DESIGN CONTROL

Include this Section 3 for DB projects only.

3.1 General

The Contractor shall have full and complete responsibility for providing plans and specifications suitable for delivering the finished construction work in accordance with the Contract Documents. The Department's review and acceptance of design documents shall not relieve the Contractor of this responsibility.

The Contractor shall not begin construction work until the Readiness-for-Construction Plans and Specifications and Working Plans covering such work have been reviewed and approved by the Department. The Contractor shall not amend or alter such plans and specifications, including making field changes, without the concurrence of the Design Manager, completion of the necessary Design Review processes, and acceptance by the Department.

The procedures for checking the design of permanent components of the project also apply to the design of major temporary components and construction sequences of the work that affect the permanent components.

3.2 Contractor's Design Organization

The Contractor shall appoint licensed architects, engineers, and other licensed design professionals to perform the design services required by the Contract Documents.

3.2.1 Design Manager

The Contractor shall appoint a Design Manager to manage all work performed by the Contractor's design staff. The Design Manager shall be assigned to the Project Office for the duration of the design phase and shall be present as required thereafter to manage design support during construction, design changes, and completion of As-Built Plans.

The Design Manager's duties shall include, as a minimum, oversight, assessment, and evaluation of the following:

1. Design reports;
2. Site investigations and reports;
3. Analytical approach;

4. Drawings and specifications for conformance with the Contract Documents and professional standards of practice, and for compliance with codes, permits, and regulations;
5. Constructability reviews;
6. Field design changes; and
7. As-built plans for conformity with final design and Contract Documents.

For complex projects, the Agency and Contractor may consider grouping project elements into discrete Work Packages that can be designed, reviewed, and constructed as self-contained units, in which case the Design Manager shall also be responsible for ensuring the coordination of the different Work Packages. This Work Package approach could be used to facilitate the fast-tracking of certain project elements before the design of the entire project is complete.

The Design Manager shall submit all design documents related to permanent and major temporary components to the Design Quality Manager for review and acceptance.

3.2.2 Engineer-of-Record

The Contractor shall designate an Engineer-of-Record, licensed in the State of [XXX], to sign and seal design reports, design and working plans, and specifications for the project (*or for each Work Package, if applicable*).

3.2.3 Design Quality Manager

The Contractor shall appoint a Design Quality Manager to oversee the quality management of all design work performed by the Contractor. The Design Quality Manager shall report to the QMP Administrator and shall be assigned to the Project Office as required throughout the design process and shall be present as required thereafter to provide quality management related to design changes and the completion of As-Built Plans.

The Design Quality Manager shall independently review and accept design documents received from the Design Manager prior to requesting review from the Department. The Design Quality Manager shall conduct design reviews in accordance with the QMP, and shall certify to the Contractor and to the Department that the design complies with the Contract Documents.

3.2.4 Design Checkers

The Contractor shall assign experienced, senior design professionals to act as Design Checkers of all design work. These professionals shall be registered professional engineers or architects in the design discipline and type of work being checked and shall have an equal or higher level of qualification and experience than the architects, engineers, and other design professionals performing the design.

Design checkers shall not be directly involved with the design item, segment, or phase being checked. If design checkers are not available within the design firm conducting the design work, the Contractor shall arrange for an independent firm, other than the design firm or subsidiaries of the design firm, to conduct quality checks. The independent firm shall follow the design quality management procedures outlined in the Contractor's approved QMP.

Design checkers shall fully document the results of the design checks, including responses to comments and resulting changes to the design documents.

3.3 Design Review Plan and Schedule

As part of its Quality Management Program, the Contractor shall prepare and submit, within 30 days of receiving Notice to Proceed, a written Design Review Plan (“Plan”) for review and comment by the Department. The Plan shall describe the level of design that the Contractor will accomplish for each of the planned stages of design development (i.e., baseline, interim, readiness-for-construction, as-built) and shall provide a description and checklist identifying the design product that will be reviewed.

It is recognized and anticipated that the Design Review process and the frequency, duration, and intensity of Design Reviews may vary with the complexity of the work in question. The duration of Design Reviews will be discussed and mutually agreed upon by the Department and the Contractor during a Design Workshop conducted within 45 days of Notice to Proceed and verified and modified by mutual agreement during the course of the project.

The Contractor is responsible for scheduling and conducting Design Reviews to meet the design and construction needs of the Project Schedule. The Contractor shall incorporate the Design Reviews into its Project Schedule and report progress in the monthly updates. The Contractor shall give written notice to the Department at least 1 week prior to any Design Review in which the Department is to participate.

3.4 Design Reviews by Department

The Contractor’s role as Engineer-of-Record and the internal design reviews conducted by the Contractor’s Design Quality Manager in accordance with the QMP do not diminish the Agency’s oversight responsibility. It is therefore recommended that the Agency still participate in some more formal reviews to ensure the Contractor’s design complies with the technical criteria and performance requirements outlined in the Contract Documents.

The following section assumes the Agency will conduct reviews at three stages of the design process: Baseline, Interim, and Readiness for Construction. An Agency may wish to increase or decrease the number of design reviews it will conduct based on the project conditions (e.g., level of preliminary design by the Agency, schedule constraints).

To avoid compromising the transfer of design risk to the Contractor, Agency personnel should refrain from directing, completing, or otherwise actively interfering with any aspect of the Contractor’s engineering and design efforts. Agency reviews should be limited to verifying conformance with the Contract Documents. The Agency should not assume the responsibility (and liability) for performing detailed design checks.

If the Contractor will be assuming postconstruction responsibility through either a long-term performance warranty or a maintenance/operation agreement, requirements related to the Agency’s formal participation in such reviews, particularly with regard to required Agency approvals, may be relaxed. In such cases, the Agency should require the Design Quality Manager to prepare and submit a written Design Review report within 5 days of each Design Review, identifying nonconformance issues, other comments generated as a result of the review, and all actions taken or to be taken as a result of the review. The exact content and format of these reports should be mutually agreed on and addressed in the QMP.

The Department will participate in the Design Reviews identified below and will provide written comments or direction on the Contractor’s design submittals based on the approved Design Review Plan and as agreed upon at the Design Workshop. The Contractor’s Design Quality Manager, Engineer-of-Record, and any specialists having significant input into the design or review shall be present. The Department may also invite other stakeholders to attend.

Department participation in design reviews shall not relieve the Contractor of the responsibility for the satisfactory completion of the work. Likewise, Department review and comment on design documents shall not be construed as transferring design liability from the Contractor to the Department.

All Design Reviews shall include a comment and Nonconformance Report resolution process, whereby unresolved comments and nonconforming work are discussed and a corrective action plan and schedule for resolution is developed.

3.4.1 Baseline Design Review

Baseline Design Review shall be the first Design Review after Notice to Proceed and is intended to verify that the design concepts proposed by the Contractor meet the technical criteria and performance requirements contained in the Contract Documents.

Prior to the Baseline Design Review, the Design Quality Manager shall verify and confirm the following:

1. The design concepts are consistent with Contract Document requirements;
2. The design concepts are substantiated and justified by adequate site investigation and analysis;
3. ROW requirements have been identified;
4. The specific standards applicable to the proposed concepts are identified and appropriate;
5. The proposed design concepts are constructible;
6. Required materials and equipment are available;
7. The design meets the specified quality and performance requirements; and
8. The required design QMP procedures have been followed.

Once accepted by the Department in writing, the Design Documents made available at the Baseline Design Review will constitute the Base Design documents for the purpose of evaluating changes in design scope.

If the Baseline Design is amended subsequent to the Baseline Design Review, the Contractor shall recheck and recertify the design as an additional Baseline Design Review. The Contractor will not be entitled to an increase in Contract Price or a time extension for the recheck and recertification, except when the amended design results from a Contract Change Order issued by the Department.

3.4.2 Interim Design Reviews

Design development occurring after the Department's acceptance of the Baseline Design but prior to the Readiness-for-Construction Review may call for Interim Designs. The Contractor shall notify the Department if it anticipates Interim Design Reviews will be necessary and shall incorporate such reviews in the Project Schedule. The Design Quality Manager shall independently review such design work prior to conducting the Interim Design Review with the Department.

The Contractor and the Department shall use interim design review(s) to verify that the concepts and parameters established and represented by the Baseline Design are being followed and that Contract

requirements continue to be met. The Contractor shall specifically highlight, check, and bring to the Department's attention any changes to information presented at the Baseline Design Review. Significant changes to the Baseline Design will require a resubmittal and Department review prior to the submittal of the Readiness-for-Construction Plans and Specifications.

3.4.3 Readiness for Construction Review

The Contractor and the Department shall use the Readiness for Construction Design Review to verify that the concepts and parameters established and represented by the approved Baseline Design are being followed and that Contract requirements continue to be met. The Contractor shall specifically highlight, check, and bring to the Department's attention any changes to information presented at the Baseline Design Review stage.

The Contractor shall only schedule a Readiness for Construction Review after satisfying the following conditions:

1. The Design Manager certifies in writing that the Readiness-for-Construction Plans and Specifications
 - a) Have undergone constructability reviews and are constructible, and
 - b) Are complete as to the level of detail required and are ready to be released for construction.
2. The Design Quality Manager certifies in writing that
 - a) Design checks have been completed in accordance with the approved QMP;
 - b) The design conforms to the Contract Documents and all applicable legal requirements;
 - c) Design Exceptions have been approved in writing by the Department;
 - d) Design QMP procedures have been followed; and
 - e) All outstanding issues and comments from the Design Review(s) have been resolved.
3. All design-related Nonconformance Reports have been addressed and resolved to the satisfaction of the Department.
4. The Engineer-of-Record has signed and sealed all drawings prepared under its direction. For those drawings and documents included in the submittal that are prepared by a manufacturer or supplier or other persons not under its direct supervision, the Engineer-of-Record shall affix a stamp that indicates the design shown on the sheet or document conforms to the overall design and Contract requirements. When necessary to meet regulatory and licensing requirements, the party responsible for preparation of specific elements of the design shall sign and seal all drawings and specifications prepared by them as part of the design document.

3.5 “Over-the-Shoulder” Reviews

In addition to the formal review process specified in Section 3.4, the Contractor shall provide opportunities for the Department to perform continuous, informal Over-the-Shoulder Reviews of the Contractor’s design and other documents while in progress. Such reviews will primarily be conducted in the Contractor’s Project Office, but may also take place in the offices of the Contractor’s consultants performing design services. Over-the-Shoulder Reviews may include the review of progress prints, computer images, draft documents, working calculations, draft specifications, reports, or other design documents. Over-the-Shoulder Reviews shall neither relieve the Contractor from its duty to submit design submittals at varying stages of design development for formal review and comment by the Department, nor be deemed as acceptance by the Department of the documents or other information reviewed.

In conducting Over-the-Shoulder Reviews, Agency personnel should be careful about offering, suggesting, or ordering solutions to design problems. Any suggestions offered should be made with the express provision that the Contractor is not required to accept the suggestion. Requiring otherwise may result in the Agency unintentionally assuming liability for aspects of the design that should remain with the Contractor.

3.6 Design Changes

Changes, including field changes, in the Baseline Design shall be subject to the same design quality management measures and procedures applied to the original design of the portion of the project being changed.

All such changes shall be approved in writing by the organization that performed the original design, with the additional written acknowledgement and concurrence of the change by the Design Manager and the Department.

3.7 Design Quality Records

The Contractor shall document and maintain an auditable record of all QMP procedures in a format that will allow an independent auditor to determine compliance with the QMP and Contract.

The Contractor shall submit all monitoring reports and records of checks and reviews within 7 days of the completion of the applicable review.

Sample forms shall be included in the QMP submitted to the Department for review and acceptance.

3.7.1 Records Maintained by the Design Manager

The Design Manager shall be responsible for preparing and maintaining the following design quality records:

1. Monitoring reports of all design issues and review comments resulting from the scheduled and additional checks and reviews, including Over-the-Shoulder Reviews, and final resolution of those issues and comments.
2. A log of design Nonconformance Reports indicating the date issued, reasons, status, and date of resolution.
3. Daily records of design activities.

3.7.2 Records Maintained by the Design Quality Manager

The Design Quality Manager shall be responsible for preparing and submitting, by the 5th day of the following reporting month, Monthly Design Reports that summarize the Design Reviews (both formal and informal) conducted during the reporting period, review and submittal activities planned for the upcoming reporting period, and all Nonconforming Work, including current status and disposition. The status information contained in the Monthly Design Reports shall be consistent with that reported in the Project Schedule and log of design Nonconformance Reports.

4 CONSTRUCTION CONTROL

4.1 General

Through its QMP, the Contractor shall be responsible for assuring that the quality of the work, including that performed by subcontractors, fabricators, suppliers, and vendors on site and off site, conforms to the Contract Documents.

The Contractor shall not begin construction work until the Readiness-for-Construction Plans and Specifications and Working Plans covering such work have been reviewed and accepted by the Department. The Contractor shall not amend or alter such plans and specifications, including making field changes, without the concurrence of the Design Manager, completion of the necessary Design Review processes, and acceptance by the Department.

4.2 Construction Quality Management Organization

4.2.1 Construction Quality Manager

The Contractor shall provide an on-site Construction Quality Manager to oversee, manage, certify and perform construction Quality Management activities in accordance with the Contract Documents and the Contractor's approved QMP. The Construction Quality Manager and staff shall report directly to the QMP Administrator.

The Construction Quality Manager shall have full authority to institute any and all actions necessary for the successful implementation of the QMP to ensure compliance with the Contract Documents.

The Construction Quality Manager shall be responsible for coordinating the schedules of construction inspectors and material samplers and testers with the Contractor's construction activities so as not to delay the Contractor's operations due to inspection, sampling, and testing activities.

If the Agency has a certification program in place for construction inspection and materials testing, the Contractor's quality management personnel should meet comparable standards.

The Construction Quality Manager shall be certified in all areas of construction inspection as outlined in the Department's Inspection Certification Program. In addition, the Construction Quality Manager shall either be certified in all areas of materials testing or shall have a supporting staff that is so certified. The supporting staff may consist of one or more individuals who collectively hold the required certifications. The QMP shall clearly outline the organization, certifications, authority levels, and responsibilities for the Construction Quality Control Manager and supporting staff.

4.2.2 Quality Control Technicians

The Contractor shall provide a sufficient number of technicians (i.e., inspectors and sampling and testing personnel) to adequately implement the QMP.

Technicians shall monitor each work activity at all times. Where material is being produced in a plant for incorporation into the work, separate plant and field technicians shall be provided at each plant and field placement location. The scheduling and coordinating of all inspection and testing must match the type and pace of work activity.

The technicians shall report directly to the Construction Quality Manager and shall perform the following functions:

1. Inspect all materials, construction, plant, and equipment for conformance with the construction plans and technical specifications and the QMP.
2. Perform all quality management testing as required by the technical specifications and the QMP.

The QMP shall identify all quality management activities that require technicians to hold specific certifications or have undergone specific training. It is the Contractor's responsibility to ensure that the technicians have the appropriate qualifications and certifications for the quality management activities being performed. A current list of technicians and their certifications shall be maintained in the QMP.

The Agency may wish to reference Agency-specific Training and Certification programs, noting that certification at an equivalent level by a state or nationally recognized organization [e.g., National Institute for Certification in Engineering Technologies (NICET)] may also be acceptable.

4.2.3 Laboratories

Laboratory testing shall be conducted by accredited testing laboratories.

Insert any Agency-specific laboratory certification requirements.

Satellites (field laboratories) of these laboratories may be used as appropriate for on-site testing. The accredited laboratory shall have written policies and procedures to ensure portable and satellite laboratories performing testing activities on the project are capable of providing testing services in compliance with applicable test methods. The policy and procedures shall address inspection and calibration of testing equipment as well as a correlation testing program between the accredited laboratory and portable or satellite facilities. The equipment in the satellite laboratories shall be certified at the start of the work and at such intervals necessary to ensure the calibration of the equipment to provide valid, accurate test results, at a minimum annually thereafter.

The Department reserves the right to check testing equipment for compliance with specified standards and to review testing procedures and techniques.

The Department also reserves the right to access the testing facilities of the testing laboratories, with no additional cost to the Department, to witness the testing and verify compliance of the testing procedures, testing techniques, tester certifications, and test results.

An Agency may require that the Contractor retain a third-party testing and inspection firm to provide construction quality management services, in which case language similar to the following can be used:

XXX Independent QC/QA Engineering Firm

The Contractor shall retain the services of an independent engineering consultant organization to oversee, manage, certify, and perform construction quality control and quality assurance activities as specified in the Contract Documents and the Contractor's approved QMP. The Independent QC/QA Engineering Firm (and any firm acting as a subconsultant to the QC/QA Engineering Firm), shall not be owned by or be an affiliate of the Contractor or construction subcontractor. The Independent QC/QA Engineering Firm shall be responsible for the management and scheduling of all quality control and quality assurance of all items of construction work for this Contract.

The Construction Quality Manager, all inspectors, and all sampling and testing personnel and their support staff shall be employees of the QC/QA Engineering Firm or employees of firm(s) acting as subconsultants to the QC/QA Engineering Firm. The QC/QA Engineering Firm shall work directly for the Contractor's QMP Administrator and shall not report to the Contractor's Project Manager.

4.3 Construction Control Procedures

Construction controls shall be adequate to cover all construction operations, including the selection of materials sources and suppliers, on-site and off-site fabrication of items to be incorporated in the work, on-site and off-site production of construction materials, work placement procedures, workmanship, inspection, and testing.

As a minimum, the QMP shall address three phases of inspection for all definable features of the work, as follows:

1. A preparatory inspection shall be performed prior to beginning any work on any definable feature of the work. It shall include a review of the Contract requirements; a check to ensure that all materials and/or equipment have been tested, submitted, and approved; a check to ensure that provisions have been made to provide required control testing; examination of the work area to verify that all preliminary work has been completed; and a physical examination of materials and equipment to ensure that they conform to approved shop drawings or submittal data and that all materials and/or equipment is on hand.
2. An initial inspection shall be performed as soon as a representative portion of the particular feature of work has been accomplished and shall include examination of the quality of workmanship and a review of the quality control testing for compliance with the Contract requirements, identification of defective or damaged materials and omissions, and verification of dimensional requirements.
3. Follow up inspections shall be performed daily to ensure continuing compliance with the Contract Documents and the approved QMP, until completion of the particular feature of work.

4.4 Construction Quality Records

The Contractor shall maintain current records throughout the life of the Contract, on appropriate approved forms, for all inspections and tests performed. The records shall provide an auditable basis for determining that the required inspections or tests have been performed, including type and number of inspections or tests involved.

Construction quality records shall include, but not be limited to, the following:

- quality control sampling data;
- factory tests and/or manufacturer's certifications;
- results of inspections or tests;
- non-conforming work reports, including nature of defects, causes for rejection, and proposed remedial action and corrective actions taken;
- monthly QC/QA summary reports; and
- records of quality control training.

The Contractor shall maintain all quality control records in a central on-site location and shall make records available to the Department for examination. The Contractor shall provide copies of specific tests and data as requested by the Department. All records shall be verified by the Construction Quality Manager or designated representative.

The Construction Quality Manager shall prepare and submit a report monthly, or at such intervals as agreed upon by the Contractor and the Department, which summarizes all construction quality control and quality assurance operations being performed. This summary report shall identify inspections made, results obtained, deficiencies found, and corrective action taken.

5 DEPARTMENT'S CONSTRUCTION QUALITY OVERSIGHT

5.1 Verification Inspection and Testing

Even though the Contractor may assume more responsibility for inspection and testing under a performance specification, this does not relieve the Agency of its responsibility to perform some level of independent sampling and verification testing to meet the intent of 23 CFR 637. Verification testing should be performed to validate any Contractor testing used in the Agency's acceptance decision.

On fast-paced DB projects, the Agency may wish to consider dedicating staff, and/or augmenting staff resources with outside consultants, to keep pace with Contractor testing.

The Department reserves the right to perform inspections and tests to validate the Contractor's inspections and tests and to ensure that the quality of the finished product meets the Contract requirements.

The Department will perform verification inspection and testing to confirm that the work and materials meet Contract requirements. These inspections and tests will be performed at times and places selected by the Department. They will be totally independent of the Contractor's inspections and tests. The Contractor shall address and rectify, as appropriate, any problems identified by the verification inspections and tests in a prompt and effective manner. The results of these verification inspections and tests along with the Contractor's inspections and test data will form the basis for Final Acceptance.

When comparing Agency and Contractor test results, it is important to compare both the variances and the means. The tests most often used are the F-test (comparison of variances) and the t-test (comparison of means), which are used together.

5.2 Independent Assurance

Independent assurance (IA) is unbiased testing the Department performs to ensure that sampling and testing is performed correctly and that testing equipment is operating correctly and is properly calibrated. The Department will perform IA testing using personnel other than those performing verification sampling and testing and Contractor sampling and testing, and will use equipment separate from equipment used on the verification testing and Contractor testing.

Testing personnel may be evaluated by observations and split samples or proficiency samples. Testing equipment may be evaluated using calibration checks, split samples, or proficiency samples.

If the Department identifies and, after further investigation, confirms a deficiency in the Contractor's sampling and testing program, the Contractor shall correct that deficiency. If the Contractor does not correct or fails to cooperate in resolving identified deficiencies, the Department may suspend production until action is taken.

5.3 Conflict Resolution

If a dispute between some aspect of the Contractor's and the Department's testing program occurs, the parties should seek a mutually agreeable solution. This may entail reviewing the data, examining data reduction and analysis methods, evaluating sampling and testing procedures, and performing additional or referee testing.

If the project personnel cannot resolve a dispute and the dispute affects payment or could result in incorporating nonconforming product, the Department will use third-party testing to resolve the dispute. A mutually agreed on independent testing laboratory will provide this testing. The Department and the Contractor will abide by the results of the third-party tests. The party in error will pay service charges incurred for testing by an independent laboratory. The Department may use third-party tests to evaluate the quality of questionable materials and determine the appropriate payment. The Department may reject material or otherwise determine the final disposition of nonconforming material as specified in [\[Standard Specification Section XXX\]](#).

5.4 Hold Points

The Contractor shall notify and provide the Department with complete access to those parts of the work designated in the QMP, or as otherwise identified by the Department, as construction Hold Points. The Department reserves the right to revise this construction Hold Point List during the course of this project, in collaboration with the Contractor.

At each Hold Point, the Contractor shall not proceed with any construction that will cover, conceal, or prevent access to such work until the Department has had an opportunity to observe the work. The Contractor shall incorporate enough time in its Project Schedule so that such observations do not delay the progress of the work.

The Contractor shall notify the Department in writing 48 hours before a Hold Point is available for observation. The Department will use its best efforts to observe the work that is the subject of the Hold Point within 24 hours of the commencement of the hold. If the Contractor fails to provide the Department

with timely notification as required by this paragraph, then the Contractor solely shall be responsible for all costs caused by the lack of such notification, including but not limited to uncovering, restoring, and reconstructing the work to facilitate the Department's observations.

Nothing in this paragraph shall be deemed to limit the Contractor's obligations to provide the Department access to all work as specified in other parts of this Contract, nor shall the Department's observations of the work at Hold Points be construed to relieve the Contractor of its obligations to correct the work if defects are discovered after an observation.

5.5 Right to Stop Work

If there is evidence that the QMP procedures are not adequate, or if a problem is encountered during the oversight reviews or becomes evident during construction, the Department may, at its sole discretion, stop work until appropriate quality procedures have been established and implemented. In addition, the Department retains authority to stop work without liability wholly or in part, if the Contractor fails to

1. Correct conditions that are unsafe for project personnel or the general public.
2. Correct unacceptable construction practices.

DESIGN AND IMPLEMENT WORK ZONE TRAFFIC CONTROL

This guide specification, developed under the SHRP 2 R07 project, provides a template from which a State Highway Agency can develop a performance specification for work zone traffic control. With modification, the specification can universally be applied to all project types and all project delivery methods [e.g., traditional design-bid-build (DBB), design-build (DB)]. The performance requirement(s) should be selected based on the goal(s) of the project, acceptable impacts to the public in both congestion and project duration, and any risks or allocation of risks that may be anticipated. Commentary is included with this guidance specification to assist the specifier with selecting performance parameters and performance measurement strategies that best align with the project's goals and the capabilities of the Agency and local industry. Customize the elements of the specification to fit the particular project conditions, jurisdiction, location, and environment, as not all elements of the specification are required for all projects. This specification can be implemented as a special provision or as an individual pay item special provision based on the preferences and practice of the Agency. The intent is that this work zone performance specification will act as a supplement to the Agency's standard specifications, and therefore it may be necessary for the specifier to incorporate specific references to the standard specifications to minimize any ambiguities.

1 DESCRIPTION

1.1 General

Insert references to standard specifications as required for this section.

Plan, implement, and manage all temporary work zone traffic control for the Contract in accordance with the specified performance requirements, standards and references, design and construction criteria, and required submittals. Provide for work zone traffic control throughout the project site for the duration of construction (for both active and inactive work zones), maximizing the safe and efficient movement of all modes of traffic while minimizing construction impacts to the traveling public, bicyclists, pedestrians, residents, and businesses. This work includes the development and implementation of a Traffic Control Plan (TCP), including details on project-specific staging, and Transportation Management Plan (TMP) (*if applicable*).

1.2 Standards And References

Use this Standards and References section to identify other applicable references, such as Agency design guidance, standard drawings, and Agency supplemental manuals.

Plan, develop, and implement traffic control measures in accordance with the requirements of the standards and references listed below. If there is any unresolved ambiguity in standards, it is the Contractor's responsibility to obtain clarification from the Department before proceeding with design and/or construction.

The version of the following standards or references in effect on the date of award of the Contract shall apply unless modified by addendum or change order:

1. FHWA – *Manual on Uniform Traffic Control Devices (MUTCD) (and Agency's supplement – if applicable)*
2. *(Agency's "Work Zone Safety and Mobility Policy" and FHWA TMP Development Manuals)*
3. AASHTO – *Roadside Design Guide*
4. AASHTO – *A Policy on Geometric Design of Highways and Streets*
5. ATSSA – *Quality Standards for Work Zone Traffic Control Devices*
6. National Cooperative Highway Research Program (NCHRP) Report 350

7. Transportation Research Board – *Highway Capacity Manual*

1.3 Definitions

Engineer. The Engineer is the Department’s Engineer, acting directly or through a duly authorized representative, such representatives acting within the scope of particular assigned duties or authority.

Traffic Control Design Engineer (TCDE). The Traffic Control Design Engineer is responsible for design and implementation of the project-specific traffic control plan and design of all supplements to the Transportation Management Plan. The Traffic Control Design Engineer shall serve as the Contractor’s liaison to the Department regarding all traffic control–related issues.

Transportation Management Plan (TMP). A set of coordinated strategies used to manage the work zone impacts of a project. These strategies will include a Temporary Traffic Control plan, a Transportation Operations component, and a Public Information component. The level of detail, content, and scope of the TMP will correspond with anticipated work zone impacts of the project.

Project-Specific Traffic Control Plan (TCP). This plan is considered the primary component of a Transportation Management Plan that addresses traffic control, construction staging, and safety throughout the work zone in compliance with the requirements of Part 6 of the *Manual on Uniform Traffic Control Devices* (MUTCD) latest edition and *[add Agency-specific references here]*.

Transportation Operations Plan (TOP). A secondary component of a Transportation Management Plan that addresses management of traffic operations in the work zone impact area. *[Indicate whether the Contractor will be responsible for development and implementation of the Transportation Operations Plan.]*

Public Information Plan (PIP). A secondary component of a Transportation Management Plan that addresses communications with the public and entities impacted by the work zone. *[Indicate whether the Contractor will be responsible for development and implementation of the Public Information Plan.]*

Immediate Work Site. Consider the area occupied by the Contractor’s work forces within a travel lane, the on- and off-ramps to and from, the median areas or the outside shoulders within **xx feet** of the near edge of an adjacent travel lane to include but not be limited to the presence of equipment, vehicles, materials and personnel as the Immediate Work Site. An Immediate Work Site will be defined by the presence of signs, channelizing devices, personnel, and/or work vehicles or equipment. An Immediate Work Site will be the area that extends from the first warning sign or high-intensity rotating, flashing, oscillating or strobe lights on a vehicle to the last traffic control channelizing device or 100 ft past the last vehicle or piece of equipment.

Add any additional definitions required to supplement information indicated in performance section or as needed to provide clarity.

2 MATERIALS

Conform to the Standards and References, Traffic Control Devices, and other performance and Contract requirements.

Furnish material and traffic control devices necessary for the maintenance and protection of traffic that conform to the standards and references specified in Section 1.2, in the approved TCP, and as follows:

Insert references to standard specifications as required for this subsection.

- Temporary Concrete Barrier
- Temporary Impact Attenuating Devices
- Channelizing Devices
- Painting Traffic Lines and Markings
- Bituminous Tack Coat
- Temporary Pavement
- Flat Sheet Signs
- Tubular Markers
- Temporary Pavement Delineators
- Arrow Panel
- Changeable Message Sign
- Temporary Traffic Signals
- Floodlights
- Warning Lights
- High-Level Warning Devices

Modify this list of materials as needed to address project-specific requirements and conform to Agency requirements. Add section references to material specifications from the Agency's standard specifications book for each item as required.

3 CONSTRUCTION

Insert references to standard specifications as required for this subsection.

3.1 General Requirements

- A. Implement the work zone traffic control for all modes of transportation within the project limits in a manner that safely and efficiently accommodates traffic, pedestrians, and bicyclists at all times. Provide all material, labor, equipment, and personnel to effectively carry out the proposed plan.
- B. Install and maintain traffic control devices, warning devices, and barriers to delineate workers within the work zone and the traveling public according to the approved TCP, project TMP (*if applicable*), and standard drawings. Submit traffic control plans that define typical installation and removal, and typical devices and equipment as part of the plan.
- C. Begin maintenance of traffic activities at the start of construction (including preparatory work), or when first hauling construction materials and/or equipment, whichever is earliest, and continue activities until final acceptance.
- D. Actively assist the Department with providing advance information to the public regarding construction phasing, detour routes, and expected travel impacts, as required in the TMP. Actively coordinate these activities through daily meetings with the *[Agency's public involvement representative]*. Coordinate with the *[Agency's public involvement representative]* regarding special events and construction activities that may affect traffic patterns through and around the project limits, and adjust the traffic control as needed.

3.2 Design Requirements

3.2.1 General

Develop the work zone traffic control in accordance with the following design requirements:

- Design the traffic control for all work zones and all phases/stages of construction in accordance with the standards and references specified in Section 1.2 and in accordance with the performance requirements specified herein.
- Design geometric aspects of temporary roadways or crossovers for assigned design speed.
- Design active roadways to accommodate drainage and have no potential for puddling, ponding, or icing of water on the traveled roadway or shoulders.
- Maintain and provide access to property by owners, customers, visitors, and emergency vehicles.
- Coordinate design of work zone traffic control plans with requirements for permitted or oversized loads.
- Coordinate design of work zone traffic control plans with any adjacent Department projects *[or projects by others]*.
- Provide rerouting of traffic to provide “driver friendly” detours to maximize the safety and minimize the delay of the traveling public by using regional advance warning systems and directional and informational signing, lighting, and striping.

Tailor this list of design requirements as needed to address project-specific requirements and conform to Agency requirements. Avoid including requirements that are unnecessarily prescriptive and that would limit the ability of contractors to develop a TMP and construction sequence that would be more conducive to their construction operations and resources.

3.2.2 Transportation Management Plan (TMP) (if required)

Determine during the project development process whether the Agency or Contractor will be responsible for preparing the TMP. The Agency will typically prepare the TMP for DBB project delivery. The responsible party for the preparation of the TMP will vary for DB project delivery. In some cases, the Agency may prepare the TMP during the design phase and the Contractor will be required to update the TMP based on the chosen traffic control scheme, including the project-specific traffic control plan and incident management plan.

If the Contractor is to prepare the TMP, the Agency and Contractor should have a preliminary meeting to discuss transportation management strategies before the Contractor develops the TMP and TCP. The Agency should use this section to specify the TMP requirements that the Contractor must consider and provide in its implementation of the work zone traffic control. These may include closures, access, or other factors identified in the work zone design strategy such as emergency services access, transit mobility, environmental commitments, or third-party concerns. Provide an outline of the TMP structure in this section.

- A. *TMP Preparation.* Comply with the Department’s “Work Zone Safety and Mobility Policy.” Prepare, submit, and maintain a project-level TMP over the course of the project. A TMP lays out

a set of coordinated transportation management strategies and describes how they will be used to manage the work zone impacts of a road project.

Coordinate all transportation management strategies for the work zone, including temporary traffic control measures and devices, public information and outreach, and operational strategies, with the Department and in accordance with the project-level TMP.

The Department will review the TMP within *[xx]* days.

Add, if applicable, a clause that the review of the TMP does not constitute approval or acceptance of the TMP document.

- B. *Re-Evaluate/Revise TMP.* If alternative construction phasing/staging plans or other management strategies are suggested, the Department will review the TMP to see if changes are needed. Revise the TMP when changes are warranted.
- C. *TMP Monitoring.* Monitor work zone performance on a continual basis to ensure that the traffic control performance requirements and TMP requirements are being met.

Monitoring the performance of the work zone and that of the TMP during the construction phase is important to see if the predicted impacts closely resemble the actual conditions in the field and if the TMP is working effectively. Performance measures that could be monitored are those indicated under Section 3.4, which could include volume, travel time, queue length, delay, number of incidents, incident response and clearance times, Contractor incidents, community complaints, user costs, and cumulative impacts from adjacent construction activities.

- D. *Update/Revise TMP.* If performance requirements cannot be met, revisit the TMP and consider alternate management strategies and staging *approach(es)* that meet the Department's approval.

3.2.3 Traffic Control Plan (TCP)

- A. *General.* Prepare and provide to the Department for review and acceptance a TCP, sealed by a Professional Engineer registered in the State *[or Commonwealth]* of *[State/Commonwealth name]*, prior to commencing construction activities and before installing temporary traffic control devices. The TCP shall identify stages and phases for the work zone and each work location, and provide appropriate operating procedures. Update the TCP, as necessary, throughout the construction activities. Use the TCP to identify the location, quantity, and type of temporary traffic-control devices to be used in the work zone at each work location. Plan sheets shall demonstrate the sequencing of construction. The TCP shall identify detours, temporary roadways, crossovers, or diversions required for each construction phase/stage.

The TCP shall address, but not be limited to

- Lane geometry, including alignment and superelevation as per the design speed
- Posted speed(s)
- Signing (information, guidance, warning, regulatory)
- Channelization
- Bicycle, pedestrian, and ADA accommodations
- Emergency vehicle and incident management accommodations
- Worker safety
- Motorist safety

- Construction vehicle and equipment traffic ingress and egress
- Changeable message signs

The Department will review the TCP within *[xx]* days.

The TCP shall identify the sequence for mobilization, construction staging, and diversion of traffic (if necessary) for the work zone and each work location, and shall include contingency plans for working with utility companies, railroad, and other third parties that have potential to disrupt the traffic flow.

Develop the TCP and project staging to minimize the length and durations of disruption to traffic. Stage operations to minimize motorist delay.

B. *Traffic Control Plans.* Include the following elements with the plan:

1. Narrative of the actual sequence of construction and the handling of traffic for all phases.
2. Work zone traffic control plan sheets for all construction phases showing roadway areas, traffic flow patterns, lane widths, cross sections, detour routes, road closures, work zone ingress and egress, and anything affecting the existing traffic patterns, including pedestrian and bicycle traffic. Also, address monitoring and maintenance of the TCP, including the frequency and procedures of reporting during construction.
3. Accommodation of seasonal and special events. Address specific requirements and traffic management commitments.

C. *Traffic Monitoring.* Provide the following to monitor traffic performance through the work zone:

1. Purpose, type, and maintenance requirements of monitoring strategy or method.
2. Locations for monitoring equipment, if utilized.
3. Reporting frequency and format of the traffic monitoring results.
4. Method of notification.

Specify any specifics on monitoring locations or requirements.

D. *Work Zone Safety.* Provide the following:

1. Identification and correction procedures for safety deficiencies.
2. Accident response procedures.
3. Accident (vehicle and worker) reporting procedures.
4. Contractor work zone training program/requirements.

Expand this section as needed to fit an individual project or to incorporate additional elements such as response to traffic inquires/complaints, accident report analysis, scheduling of traffic control meetings, monitoring of operations, law enforcement coordination, local agency coordination, and incident response.

3.3 Personnel Requirements

Provide the following key personnel for traffic control development and maintenance for the duration of the project. Certify that all key personnel with duties regarding traffic control development and maintenance have successfully completed work zone traffic control training commensurate with their assigned job duties.

Specify in this section personnel training requirements.

3.3.1 Traffic Control Design Engineer (TCDE)

Provide a TCDE to implement and manage the development of the Project-level TMP, the design of the TCP, and any modifications throughout the management and inspection of long-term temporary traffic control (phase/stage changes).

A. *Duties.* The TCDE shall

- Serve as the Contractor's point of contact with the Department for all TCP traffic management-related issues and design coordination.
- Lead the development of the Project-level TMP.
- Lead the design of the TCP for the appropriate construction sequence.
- Confirm TCP requirements and details with the Department.
- Be present in the field at the time of implementation of new phases/stages of construction to certify that the temporary traffic-control measures are in compliance with the TCP.
- Identify and document any deficiencies in the TCP and report findings to the Department.
- Lead in making necessary corrections to the TCP prior to implementation.
- Attend project meetings where traffic control measures and construction staging are discussed, as required.
- Work with the Traffic Control Supervisor (TCS) to coordinate traffic-control operations of contractors, subcontractors, utility owners, and other entities to ensure that their operations satisfy the following:
 - Their individual traffic-control needs and activities have been addressed.
 - Their TCP is coordinated with other measures in place within the project site.

B. *Certifications.* The TCDE must be a Professional Engineer (PE) registered in the State *[or Commonwealth]* of *[State/Commonwealth name]*, and shall have experience preparing TCPs in the State *[or Commonwealth]*.

Provide the specific years of experience or other experience requirements here; include the requirement to submit qualifications, or be prequalified to do work for the Agency, if applicable.

3.3.2 Traffic Control Supervisor (TCS)

The TCS shall provide traffic-control management in the field. Provide a full-time Traffic Control Supervisor or Supervisors and phone numbers where they can be reached on a 24-hour, 7-days-a-week basis for the duration of the project. The Traffic Control Supervisor must be knowledgeable of work zone traffic control, including incident management. The Traffic Control Supervisor must have a thorough understanding of the MUTCD and applicable Department traffic standards and be certified by an approved training organization.

A. *Duties.* The TCS shall

- Manage and supervise the implementation of the Traffic Control Plan.
- Manage and supervise the installation, moving, inspection, maintenance, replacement, and removal of all temporary traffic control devices on the project according to the TCP.
- Serve as the Contractor's point of contact with the Department for all TCP field coordination.
- Implement and revise the TCP when directed by the TCDE.
- Confirm TCP requirements and details with the TCDE.
- Conduct and document daily work zone traffic control reviews *[or frequency identified by Agency]*. The reviews shall include the performance of the listed requirements, traffic control signs, devices, law enforcement, and temporary pavement markings during the day and night, adverse weather conditions, and active and inactive construction operations, as directed. The TCS will present all negative findings to the Engineer within 24 hours. The TCS shall provide documentation of all work zone traffic control reviews to the Engineer in a monthly report. *[Indicate frequency of reporting.]*
- Work with the TCDE to coordinate traffic-control operations of contractors, subcontractors, utility owners, and other entities for adherence to contract requirements and standards.
- Attend all Project meetings where traffic-control measures and construction staging are discussed.
- Notify the Engineer *[or Agency's public relations contact]*, affected municipalities, and property owners of all traffic restrictions. Prepare News Releases and submit to the Department for implementation.
- Prepare and submit proposed corrective actions to the Department. Correct any deficiencies or damage discovered during the daily review immediately.
- Designate a representative to serve on the Incident Management Committee.
- Collect and review crash reports in the work zone on a weekly basis, and recommend corrective action and coordinate implementation with the TCDE, if required.

B. *Certification.*

Insert specific certification requirements for the TCS in this section.

3.4 Traffic Control Performance Requirements

This section defines performance parameters that the Contractor must meet to ensure the success of its TCP and its conformance with the project-level TMP. There are a number of performance measurements listed in this section that provide incentives (and possibly disincentives) to meet or exceed specified traffic control performance criteria. These incentives encourage the Contractor to minimize impacts and disruption to the traveling public.

Select one or more of the following subsections for measuring performance and set incentives and disincentives or go/no-go requirements. Note that not all of the parameters shown will necessarily be appropriate or beneficial for a given project. Include or exclude requirements based on the project's needs and goals, associated costs, and similar factors.

Alternatively, determine if it is appropriate to allow the Contractor to develop and set up the performance measurements that it plans to achieve for the duration of the construction. If the Agency allows the Contractor to determine its own performance measures, then incentives/disincentives should also be tied to those measurements.

The performance requirements listed below are theoretical in nature. Actual performance targets should be derived from Agency tables, analysis, policies, or procedures. For each performance measure selected, indicate the required performance targets and performance monitoring requirements. Performance targets should consider targets by time of day, if applicable, and allowable durations of missed targets, if any. Performance monitoring can include the requirements of the equipment selected, locations of the monitoring, frequency of monitoring, what information should be logged, communication requirements of alerts for missed performance, expectations for correction of missed performance, and treatment of items that affect performance that are beyond the Contractor's control. Action for continuous breach of the target requirement should be also indicated in this section.

Implement work zone traffic control in accordance with the performance requirements to provide a safe and efficient passage of traffic through construction zones as follows:

A. *Minimize Delay*

1. Travel Time Through Work Zone. The Department has specified a target travel time (T) through the work zone at the specified time periods. Monitor and provide documentation that the given target travel time (T) is being met for each time period anytime there is an active lane closure. Develop the TCP and designated work operations while maintaining the required performance at all times. Use monitoring techniques as specified in the TCP submittal.

If the travel time is outside the specified target travel time (T), adjust traffic control or construction operations as necessary to maintain the average specified target travel time (T).

<i>Time Period, X</i>	<i>Maximum Travel Time, T_x</i>
6:00 AM	$T_{6:00am}$
6:30 AM	$T_{6:30am}$

7:00 AM	T _{7:00am}
7:30 AM	T _{7:30am}
....etc.	

Populate the table through the results of the work zone impact analysis from the TMP × the Agency-determined allowable change based on the following equation, or similar.

$$T_x = \frac{\text{work zone length (ft)}}{\text{work zone speed limit } (\frac{ft}{s})} \times [1 + \text{allowable change for time period, X (\%)}]$$

Measure the travel time through the work zone, between points A and B, as indicated in the specification and the TCP.

2. **Minimum Speed.** The Department has specified a minimum target speed threshold (V) that must be maintained in advance and through the work zone at the specified time periods. Monitor and provide documentation that the given target speed (V) is being met for each time period. Use monitoring techniques as specified in the TCP submittal. Submit real/continuous volume reports monthly to the Department with requests for payment.

If less than the specified target speed (V) is met, adjust traffic control or construction operations as necessary to maintain the average above the specified target Speed (V).

Time Period, X	Minimum Speed, V _x
6:00 AM	V _{6:00am}
6:30 AM	V _{6:30am}
7:00 AM	V _{7:00am}
7:30 AM	V _{7:30am}
....etc.	

The Agency should populate the table or use the results of the work zone impact analysis from the TMP × the Agency-determined allowable change or use the following equation, or similar.

$$V_x = \text{Preconstruction Hourly Speed} \times [1 + \text{allowable change for time period, X (\%)}]$$

Measure the speed in advance and through the work zone as indicated in the specification and the TCP.

Utilize minimum speed by measuring speed at specific locations in advance of the lane closure and at the queue. The definition of a queue (based on stopped versus a minimal speed) will need to be specified.

3. **Queue Length.** The Department has specified the maximum Queue Length (L_x) based on project-specific conditions. [If the project affects traffic in two directions, the Agency may specify a queue length for each direction.] The maximum length is affected by requirements such as avoiding effects on intersections or exit ramps adjacent to the work zone, maintaining

safe traveling conditions, and other considerations. Monitor and provide documentation that the maximum allowable Queue Length (L_x) is being met for each time period.

When the queue length exceeds the maximum, immediately adjust traffic control or construction operations to reduce the queue length to less than the specified maximum.

<i>Time Period, X</i>	<i>Maximum Queue Length, L_x</i>
6:00 AM	L _{6:00am}
6:30 AM	L _{6:30am}
7:00 AM	L _{7:00am}
7:30 AM	L _{7:30am}
...etc.	

L_x = Allowable maximum queue to consider Agency methodology/preference, project conditions, and results of the TMP, if applicable.

Measure the queue length in advance of the work zone as indicated in the specification and the TCP.

The definition of a queue (based on stopped versus a minimal speed) will need to be specified.

4. Delay for Short-Term, Full Roadway Closure. The Department has specified a target travel time (T_x) through the work zone. Monitor and provide documentation that the given travel Time (T_x) is being met for each time period. Use monitoring techniques as specified in the TCP submittal.

If travel time is outside the specified target travel time (T_x), adjust traffic control or construction operations as necessary to maintain the average specified target travel time (T_x).

This performance parameter can be treated as similar to Travel Time Through Work Zone.

B. Maintain Access/Mobility

1. Incident Clearance Time. The Department has specified a target clearance time (T) to clear an incident. Provide records that indicate that the target clearance time has been met or exceeded. Maintain a maximum clearance time from notification to clear an incident that affects traffic and safety in the work zone of T .

The travel time through the work zone depends on the Contractor's ability to keep the work zone clear. If a crash, mishap, or failure of a traffic control device occurs within the work zone, the Traffic Control Supervisor shall have a response plan in place to minimize the impact on user travel time for specified time periods. The Agency may want to define acceptable times for incident response to crashes and maintenance of traffic control devices, for example, 20 minutes for a crash and 24 hours for devices. If the Contractor does not meet the criteria, the Agency may provide these services and deduct the costs for services from the Contract.

2. Minimize Impacts of Detours. The Department has specified a maximum length of detours based on Department standards (L), target travel time (T) of proposed detours, and the duration of the proposed detours (D). Provide documentation that indicated the following parameters have been met:
 - Maintain maximum detour length, ($L = \underline{\hspace{1cm}}$), as indicated.
 - Maintain maximum detour travel time ($T = \underline{\hspace{1cm}}$) or less, as indicated.
 - Maintain maximum detour duration ($D = \underline{\hspace{1cm}}$) or less, as indicated.
3. Incident Response (monitoring only). The Department has specified a target time to provide notification of incidents that occur within the work zone. Provide response to emergency personnel and the Department within the specified time period.
 - Maintain target minimum notification time ($T = \underline{\hspace{1cm}}$) or less, as indicated.

C. *Minimize Construction Duration*

The Agency can use this performance parameter to expedite the work to minimize the disruption to the public. Some possible methods that can be used to implement this type of performance parameter are as follows:

- *Nighttime/double shift/weekend work;*
- *Detours;*
- *Temporary roads/bridges;*
- *Construction sequencing; and*
- *Innovative contracting techniques (e.g., lane rental, incentives/disincentives, A+B).*

1. Project Duration. The Department has specified a maximum construction duration based on the construction schedule:
 - Maintain target duration ($D = \underline{\hspace{1cm}}$) or less for the project by X days.
2. Work Duration in Critical Locations/Segments/Stages. The Department has specified that work associated with designated critical segments or locations be completed within the duration specified. The work duration begins when the Contractor impedes traffic within the critical segment and ends when the Contractor opens the completed work to traffic.

<i>Location</i>	<i>Maximum Days</i>
Location A	xx
Location B	yy
Location C	zz
...etc.	

Use this parameter when seeking to minimize the time that a critical location (e.g., intersection, ramp, roadway, shoulder) of the project is affected by the work. For these segments of work, the Agency could determine the minimum acceptable durations for completion of this specific work or ask the Contractor to provide durations and attach an

incentive for beating or disincentive for failing to meet the durations. This approach is the same as a lane rental provision or an A+B provision for a critical segment of a project. An Incentive/Disincentive (I/D) can be calculated based on the Agency-calculated Road User Cost (RUC) for this portion of work.

D. *Minimize Ambient Impacts*

The following performance measurements are generally considered secondary performance requirements which can supplement the primary performance targets identified in paragraphs A through C.

Implement the work zone traffic control plan in accordance with the relevant performance requirements to minimize negative impacts on residents, commuters, and businesses as follows:

1. Minimize Construction Noise. The Department has specified a minimum allowable noise measurement. Provide monitoring and documentation that indicate the following parameter has not been exceeded:
 - Maintain noise below target noise level ($N_x = \underline{\quad}$) for specified time period ($X = \underline{\quad}$).
2. Minimize Light Pollution. The Department has specified a maximum allowable light output during nighttime work. Provide monitoring and documentation that indicate the following parameter has not been exceeded:
 - Maintain light below target light level ($L = \underline{\quad}$).

E. *Public Outreach*

The following performance measurements are generally considered secondary performance requirements which can supplement the primary performance targets identified in paragraphs A through C.

1. Lead Time.

Number of days of advance notice: The Department has specified a time duration (T) within which it needs to receive information to properly relay the notification to the appropriate agencies and/or users.

Maintain target time duration ($T = \underline{\quad}$) or more for notification of appropriate agencies and/or users.

2. Public Information Strategies.

Number of strategies employed: The Department has specified that a minimum of (S) public outreach strategies are to be employed, in accordance with the TMP.

Maintain target number of strategies ($S = \underline{\quad}$) or more for notification of appropriate agencies or users.

Maintain a lane closure or work site in place provided the performance target is being met. When the performance target is not being met, the Department may assess liquidated damages or a penalty in

accordance with Section 4, Measurement and Payment. The Department will use reported performance results to determine the I/D factor.

Liquidated damages may not be assessed against the Contractor when the performance target is not met during situations beyond the Contractor's control or when actions by the Contractor or the Contractor's representatives did not contribute to the cause of a situation as determined by the Engineer. However, in the event of such a situation, the Contractor shall be prepared to discontinue all work activities and vacate the roadway of all equipment, materials, personnel, etc., immediately upon receipt of notification from the Resident Engineer. Such situations may include but not be limited to traffic accidents.

3.5 Submittals

- A. Draft TMP that provides an overall plan of general traffic operations during construction within *[xx Days of notice to proceed (NTP) or yy Days from commencing construction]* to the Department, whichever occurs first.
- B. Final TMP, incorporating the Department's comments, to the Department at least 10 Days prior to the start of construction.
- C. Work zone traffic control plan to the Department at least 10 Days prior to the start of project or each phase of construction.

Determine if the traffic control plan is to be submitted and approved entirely prior to the start of the project and then adjusted as needed based on changes that occur during construction or submitted prior to the start of each phase of construction. Consider providing a review turnaround time to the specification if it is deemed that this could be a factor in the Contractor's bid.

- D. Weekly Performance Measurement Report

Modify the list of submittals to fit Agency and project-specific requirements.

3.6 Other Considerations

In this section, the Agency should specify any additional considerations that should be addressed by the Contractor, such as commitments made with local concerns (e.g., municipalities, the public, and law enforcement), any seasonal or event restrictions, and other restrictions to which the Contractor must adhere. These commitments must be provided to the Contractor to develop its traffic control plan.

4 MEASUREMENT AND PAYMENT

4.1 Lump-Sum Items

- A. *Design Work Zone Traffic Control*

The Department will pay an amount equal to ten percent (10%) of the total lump-sum cost for the design of the traffic control and the development of the traffic management plans according to the approved payment schedule. The Department will not *[will]* allow partial payments based on the estimated completion of work in each construction stage.

Determine if the traffic control plan can be submitted and approved entirely prior to the start of the project and then adjusted as needed based on changes that occur during construction, or if it should be submitted prior to the start of each phase of construction.

- Preliminary Plans Approval – 45%
- Final Plans Approval – 50%
- Revisions to Plans during Construction – 5%

Adjust percentages based on accepted practices or consider this a lump-sum payment, if desired.

B. *Implement Work Zone Traffic Control and Performance*

The Department will pay an amount equal to 90% of the total lump-sum cost. The Department will also measure and pay this portion in a proportionate manner based on current estimates and subject to the incentives and disincentives indicated in the contract.

The price includes, but is not limited to, all signs, furnishing appropriate personnel, all required tracking and monitoring equipment, all necessary power supply equipment, all hardware and software, Changeable Message Signs, and Speed Awareness Monitors. With the exception of separate pay items specified in the Contract documents and indicated in Section 4.2, if an item or device is required for maintenance and protection of traffic, the cost of the item or device is incidental to this lump-sum item.

The Department will adjust payment based on the satisfaction of the identified performance requirements as indicated.

Determine whether incentives or only disincentives will be applied to the contract.

Eliminate the appropriate sections below that are not applicable to the contract. Some performance payments can be applied as both incentives and disincentives. Determine, based on the number of performance parameters that have been specified, a weighting for each performance parameter as a total of the 90% portion of the lump-sum cost. For example, if two performance parameters have been selected for a particular project, both could be equally weighted and, therefore, would each represent 45% of the total payment. The weight factor should be applied to the appropriate payment equation in the subsequent sections, if applicable. Other disincentives can be applied as reduced payments, as indicated.

The Agency should determine whether independent verification of the data provided by the Contractor is required. This may depend on the reliability of the technology that the Contractor has employed. This should be determined on a case-by-case basis. In addition, the Agency may want to include some dispute resolution process in the specification to handle issues when the verification does not match the Contractor records.

1. Minimize Delay.

- a) Travel Time Through Work Zone. The Department will use the reported travel times to determine an incentive/disincentive (I/D) payment factor. The I/D is based on the following schedule:

Travel Time I/D Factor		
	Minutes	Payment Percentage Factor
Maximum Incentive \$	Y_{Min}	110%
Target Travel Time	Y T	0%
Maximum Disincentive \$	Y_{Max}	90%

Use an I/D provision to motivate the Contractor to maintain an acceptable travel time through the work zone. The Contractor is provided the opportunity to use current technology to monitor the travel time between two designated points determined by the Agency. The determination of an incentive or disincentive is based on the ratio of actual travel time to a minimum acceptable travel time. For example, the Contractor would earn an incentive if the travel time through a work zone were less than the travel time indicated and be assessed a disincentive if the travel time through a work zone was greater than the travel time indicated. Travel time would be calculated by measuring the time from two established points using available technology. The I/D amount is based on the Agency-provided payment schedule. If the Contractor reduces the travel time versus preconstruction conditions, it would earn the 110% incentive amount. Conversely, if the Contractor exceeds the preconstruction conditions, then it would incur a disincentive.

The Department will pay for the Travel Time through Work Zone for a given month based on the predetermined amount and the travel time payment factor.

$$\text{Travel Time Payment} = C_{TT} \times P_{TT} \times W_{TT}$$

C_{TT} = Monthly Contract Amount

P_{TT} = I/D Percent Payment Factor for Travel Time through work zone

W_{TT} = Weight Factor for Travel Time through work zone

- b) Minimum Speed. The Department will use the reported speeds to determine if the performance has been met. There will not be additional payment associated with this performance. The Department will assess liquidated damages for each infraction of the performance requirement as follows:

- xx Minute Liquidated Damages Penalty - \$x,xxx per infraction
- xx Minute Liquidated Damages Penalty - \$x,xxx per infraction

Adjust disincentive schedule based on Agency preferences.

The Department will subtract liquidated damages for each infraction from the total payment due for the scheduled payment.

- c) Queue Length. The Department will use the reported queue lengths to determine if the performance has been met. There will not be a payment associated with this performance. Correct any deficiencies in order to meet this parameter immediately at no additional cost to the Department.

This performance may be a go/no-go threshold, for which no I/D adjustment to payment is made; but the Contractor may incur added expense in adjusting its operations to reduce the queue length. Actions must be taken immediately by the Contractor to correct the problem. Differing queue lengths could occur on a project, for example, entering the work zone from opposite directions, an intersection or exit ramp that must be kept open, or other complications.

d) Delay for Short-Term, Full Roadway Closure. The Department will use the reported delays to determine if the performance has been met. There will not be a payment associated with this performance. The Department will assess liquidated damages for each infraction of the performance requirement as follows:

- xx Minute Liquidated Damages Penalty - \$x,xxx per infraction
- xx Minute Liquidated Damages Penalty - \$x,xxx per infraction

Adjust disincentive schedule based on Agency preferences.

2. Maintain Access/Mobility.

a) Incident Clearance Time. The Department will use the reported clearance times to determine if the performance has been met. There will not be a payment associated with this performance. Correct any deficiencies with meeting this parameter immediately at no additional cost to the Department, or the Department will provide the service and deduct the cost of the service from the payment.

b) Minimize Impacts of Detours. The Department will use the reported values to determine if the performance has been met. There will not be a payment associated with this performance. Correct any deficiencies with meeting this parameter immediately at no additional cost to the Department.

c) Incident Response (monitoring only). The Department will use the reported incident response times to determine an incentive/disincentive (I/D) payment factor. The I/D is based on the following schedule:

Incident Response I/D Factor		
	Incidence Response Time	Payment Percentage Factor
Maximum Incentive \$	IR _{Min}	110%
Target RUC	T	0%
Maximum Disincentive \$	IR _{Max}	90%

The Department will pay for the Incident Response for a given month based on the predetermined amount and the road-user cost payment factor.

$$\text{Incident Response Payment} = C_{IR} \times P_{IR} \times W_{IR}$$

C_{IR} = Monthly Contract Amount

P_{IR} = I/D Percent Payment Factor for Incident Response

W_{IR} = Weight Factor for Incident Response

3. Minimize Construction Duration.

- a) Project Duration. The Department will compare the construction duration to the performance value. The Department will use this data to determine the I/D. The I/D is based on the following schedule:

Project Duration I/D Factor		
	Project Duration	Payment Percentage Factor
Maximum Incentive \$	PD_{Min} PD	110%
Target Duration	T PD	0%
Maximum Disincentive \$	PD_{Max}	90%

The Department will pay for the Project Duration as specified for a given month based on the predetermined amount and the traffic volume payment factor.

$$\text{Traffic Volume Payment} = C_{PD} \times P_{PD} \times W_{PD}$$

C_{PD} = Monthly Contract Amount

P_{PD} = I/D Percent Payment Factor for Project Duration

W_{PD} = Weight Factor for Project Duration

- b) Work Duration in Critical Locations/Segments/Stages. The Department will compare the construction duration for critical locations to the performance value. The Department will use this data to determine the I/D. The I/D is based on the following schedule:

Work Duration I/D Factor		
	Work Duration	Payment Percentage Factor
Maximum Incentive \$	WD_{Min} WD	110%
Target Duration	T WD	0%
Maximum Disincentive \$	WD_{Max}	90%

The Department will pay for the Work Duration for critical locations as specified for a given month based on the predetermined amount and the traffic volume payment factor.

$$\text{Traffic Volume Payment} = C_{WD} \times P_{WD} \times W_{WD}$$

C_{WD} = Monthly Contract Amount

P_{WD} = I/D Percent Payment Factor for Work Duration of Critical Locations

W_{WD} = Weight Factor for Work Duration of Critical Locations

4. Minimize Ambient Impacts.

- a) Minimize Construction Noise. The Department will use the reported values to determine if the performance has been met. There will not be a payment associated with this

performance. Correct any deficiencies with meeting this parameter immediately at no additional cost to the Department. Work shall be suspended until the performance can be met.

- b) Minimize Light Pollution. The Department will use the reported values to determine if the performance has been met. There will not be a payment associated with this performance. Correct any deficiencies with meeting this parameter immediately at no additional cost to the Department. Work shall be suspended until the performance can be met.

5. Public Outreach.

- a) Lead Time. The Department will use the reported values to determine if the performance has been met. There will not be a payment associated with this performance. Correct any deficiencies with meeting this parameter immediately at no additional cost to the Department. If the deficiency extends [*x days*] beyond the target value, the Department will deduct a disincentive payment of [*\$x,xxx/day*] from the monthly Contract amount.
- b) Public Information Strategies. The Department will use the reported values to determine if the performance has been met. There will not be a payment associated with this performance. Correct any deficiencies with meeting this parameter immediately at no additional cost to the Department. Each day beyond [*x days*] that the deficiency exists below the target value, the Department will deduct a disincentive payment of [*\$x,xxx/day*] from the monthly Contract amount.

4.2 Separate Pay Items

Design and Implement Traffic Control	Lump Sum
Temporary Concrete Barrier	Linear Feet
Temporary Impact Attenuating Devices	Each
Channelizing Devices	Each
Warning Lights	Each
Arrow Panel	Each
Changeable Message Sign	Each
Flood Lights	Each
Temporary Traffic Signals	Each
Signs	Square Feet
Flaggers	Man-days

The Agency should remove and/or add to the above list of separate pay items to fit Agency and project-specific requirements.