Proposed Standard Practice

To Develop a Quality Control/Quality Assurance Plan
For
Hot Mix Asphalt

AASHTO PP qq

1. Introduction

1.1. This standard practice presents specific details necessary to effectively control the production and lay down of Superpave mixes.

1.2. This procedure may involve hazardous materials, operations, and equipment. This procedure does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

2. Scope

2.1. This Standard provides framework for a Quality Control Plan that establishes minimum requirements and activities for a Contractor’s quality control system related to Superpave Hot Mix Asphalt mix design, production, and placement. These requirements include a listing of the inspections and tests necessary to substantiate material and product conformance to the mixture design. The primary method of field quality control employs the use of the Superpave Gyratory Compactor and evaluation of the volumetric properties of the mix.

2.2. This Standard also provides framework for a plan that establishes requirements for a SHA’s assessment and acceptance of a Hot Mix Asphalt project. This plan, coupled with the Contractor’s Quality Control Plan, provides the necessary Quality Assurance Plan for control, verification, and acceptance of the pavement.

2.3. The values stated in SI units are to be regarded as the standard.

3. Referenced Documents

3.1. AASHTO Designations.

3.1.1. MP 1, Performance Graded Asphalt Binder

3.1.2. MP 1(a), Performance Graded Asphalt Binder.

3.1.3. MP 2, Superpave Volumetric Mix Design.
3.1.4. PP 26, Certifying Suppliers of Performance Graded Asphalt Binders.

3.1.5. PP 28, Superpave Volumetric Design for Hot Mix Asphalt.

3.1.6. R 9, Acceptance Sampling Plans for Highway Construction.

3.1.7. R 10, Definition of Terms for Specifications and Procedures.


3.1.9. T 2, Sampling of Aggregates.

3.1.10. T 27, Sieve Analysis of Fine and Coarse Aggregates.

3.1.11. T 30, Mechanical Analysis of Extracted Aggregates.


3.1.13. T 164, Quantitative Extraction of Bitumen from Bituminous Paving Mixtures


3.1.15. T 166, Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.


3.1.17. T 209, Maximum Specific Gravity of Paving Mixtures.

3.1.18. T 248, Reducing Samples of Aggregates to Testing Size.

3.1.19. T 255, Total Moisture Content of Aggregate by Drying.

3.1.20. T 287, Asphalt Cement Content of Asphalt Concrete Mixtures by the Nuclear Method.


3.1.22. T 312, Method for Preparing and Determining the Density of HMA Specimens by Means of the SHRP Gyratory Compactor.

3.2. ASTM Standards.

3.2.1. C 702, Standard Practice for Reducing Field Samples of Aggregate to Testing Size.
3.2.2. D 8, Terminology Relating to Materials for Roads and Pavements.

3.2.3. D 2950, Test Method for Density of Bituminous Concrete in Place by Nuclear Method.

3.2.4. D 3665, Random Sampling of Construction Materials.

3.2.5. D 3666, Minimum Requirements for Agencies Testing and Inspecting Bituminous Paving Materials.

3.2.6. D 5361, Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing.

3.2.7. D 5821, Determining the Percentage of Fractured Particles in Coarse Aggregate.

3.2.8. E 29, Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.


3.2.10. E 122, Choice of Sample Size to Estimate the Average Quality of a Lot or Process.

3.2.11. E 141, Acceptance of Evidence Based on the Results of Probability Sampling.

4. Terminology

4.1. The terminology used in this standard is in accordance with R 10 unless otherwise specified.

4.2. HMA, Hot Mix Asphalt is defined as a mixture of aggregate and asphalt binder produced from a hot mix asphalt plant.

4.3. DMF, Design Mix Formula is defined as the single point target value for percent passing designated sieve sizes and volumetric properties developed in the laboratory before the start of production.

4.4. JMF, Job Mix Formula is defined as the single point target value for percent passing designated sieve sizes and volumetric properties established after the field verification process to be used by the contractor for production quality control.

4.5. PGAB, Performance Graded Asphalt Binder is an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers graded to temperature regimes and performance.

4.6. QC, Quality Control is a schedule of tests performed by the contractor to control product quality during the manufacturing and laydown operation.
4.7. QC Plan, is a project specific plan that identifies methods of sampling, testing, calibration, QC monitoring, construction controls, paving plans, process balancing and overall operations.

4.8. QA, Quality Assurance is a schedule of tests performed by the owner or owner’s representative to assure that the materials, and workmanship incorporated on a project are in conformity with the SHA plans and specifications.

4.9. SHA, State Highway Agency or owner of the roadway.

4.10. Definition of many common terms relating to HMA are contained in D 8.

4.11. Definition of terms used in reference to other Standards are as defined therein.

4.12. Definition of terms used in mathematical expression are as generally used in standard practice. Unique terms are defined in the section containing the first presentation of such terms.

5. Summary

5.1. This standard presents a procedure containing minimum requirements for QC and QA Plans applicable to the production, placement, and acceptance of HMA. It incorporates the use of other available standards, which are appropriate to the accomplishment of this task. The requirements allow tailoring to accommodate the needs of individual SHA’s.

6. Significance and Use

6.1. Quality cannot be tested nor inspected into an HMA pavement. It must be built in through the implementation of properly designed QC and QA Plans. The Contractor shall have a properly designed Quality Control Plan and the SHA shall have a properly designed Quality Assurance Plan. The design and use of the plans is a critical step toward the successful manufacture, placement, and performance of HMA pavements.

6.2. This standard is used to aid in the completion of tasks noted in 6.2.1 and 6.2.2.

6.2.1. Implementation of a Quality Control Plan for a Contractor(s).

6.2.2. Implementation of a Quality Assurance plan for a SHA.

6.3. QC and QA Plans conforming with this standard are applicable to construction project using HMA pavement. If an inconsistency exists between the contract documents and either plan, the contract documents shall govern.

7. Apparatus
7.1. Laboratory requirements.

7.1.1. Personal safety equipment required by the Laboratory or OSHA for work in the laboratory HMA design and testing areas.

7.1.2. Laboratory apparatus listed in standards referenced as requirements in this practice.

7.1.3. All other laboratory apparatus needed to control the quality of HMA mix production and placement in accordance with project specifications.

7.2. Field requirements.

7.2.1. Personal safety equipment required by the field organization or OSHA.

7.2.2. Field apparatus listed in standards referenced as requirements in this practice.

7.2.3. All other field apparatus needed to control the quality of HMA mix production and placement in accordance with project specifications.

7.3. Apparatus required in sections 7.1 and 7.2 shall be furnished in the quantity necessary to assure that the materials and products used can be shown to conform to the HMA specification requirements without undue delay of the production and placement process.

7.4. Additional apparatus required for use by SHA representatives for verification and acceptance activities shall be provided by the SHA unless otherwise specified.

8. Standardization

8.1. Laboratories conducting work shall satisfactorily participate in the AASHTO Materials Reference Library (AMRL) and should also be AMRL inspected. Inspections or tests not covered by AMRL shall comply with the applicable requirements of R 18 and ASTM D 3666.

All apparatus shall be calibrated, and the calibration verified at established intervals, relevant to AASHTO, ASTM or SHA standards.

8.2. Sampling and testing personnel shall be qualified through procedures developed by the SHA for obtaining samples, processing samples, inspection of work, operation of testing equipment and test equipment validation.

8.3. Verify the calibration of the nuclear density gauge(s) using ASTM D 2950, or another system approved by the SHA.

8.4. Records demonstrating compliance with the equipment, personnel, and QC requirements shall be
available during construction for SHA review.

9. Functions and Responsibilities on HMA Projects

9.1. State Highway Agency

9.1.1. The SHA shall review and approve HMA volumetric mix designs proposed by the Contractor and assess the adequacy of the Contractor's QC Plans. The SHA or a representative of the SHA is responsible for all QA testing.

9.2. Contractor

9.2.1. The Contractor shall be responsible for the development and formulation of the DMF using MP 2, PP 28 and T 312, which shall be submitted to the SHA for approval. The Contractor shall be responsible for the QC of all materials during the handling, blending, mixing and placing operations. In addition, Contractor’s test may be used for QA when a Contractor acceptance program is developed in accordance with Section 14.5.

10. Sampling

10.1. DMF Verification Samples

10.1.1. The Contractor and the SHA shall obtain samples of mixture from plant-produced materials in accordance with T 168, and the applicable procedures contained in Section 12.3 and Appendix A-I.

10.1.2. The Contractor and the SHA shall select sample locations on the test strip in accordance with Section 12.3 and Appendix A-I. These locations are used for in-place density testing.

10.2 Mix Production Samples

10.2.1. The Contractor shall obtain samples for QC using a stratified random sampling plan in accordance with Section 13.3, T 168, or ASTM D 3665.

10.2.2. The SHA shall obtain samples for QA in accordance with T 168, using a stratified random sampling plan in accordance with Section 13.3, T 168, or ASTM D 3665.

10.3. Sample Locations for In-place Coring or Testing

10.3.1. The SHA representative shall select in-place sample locations in accordance with Section 13.3, Appendix A-I, and when cores are required, ASTM D 5361.

Note 1. In addition to the random number tables in Appendix A-I, ASTM D 3665 also contains a table of random numbers, including instructions for use. AASHTO R 9 and ASTM E 105, E 122, and E 141 contain additional
information concerning sampling practices.

11. **Material Requirements**

11.1 Performance-Graded Asphalt Binder

11.1.1. PGAB shall conform to the requirements of MP 1 or MP 1(a)

11.1.2. Quality control of PGAB from all suppliers shall be in accordance with PP 26 or other programs approved by the SHA.

11.2. Aggregates

11.2.1. The SHA shall develop a testing program to ensure that aggregates meet specification requirements. The Contractors QC Plan shall include as a minimum discussion on the proposed processing, transportation, stockpiling, and plant charging operations.

12. **Field Verification and Adjustment to the DMF**

12.1. **Summary**

12.1.1. Field verification includes several steps to assure the plant produced mix will meet the design requirements. Verification of the mixture is completed using the same equipment that will be used for QC testing.

12.1.2. The Contractor shall be responsible for the operation of the HMA plant, and the production of the HMA within the DMF tolerances in Table 1. The DMF may be adjusted within the limits of Table 1 (adjustment tolerances) to bring the DMF into the requirements of MP 2.

**Table 1 - DMF Adjustments for Field Verification**

<table>
<thead>
<tr>
<th>Mix Composition Property</th>
<th>Adjustment Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Binder Content (Pb)</td>
<td>+/- 0.4</td>
</tr>
<tr>
<td>Gradation Passing 4.75 mm and Larger Sieves</td>
<td>+/- 4.0</td>
</tr>
<tr>
<td>Gradation Passing 2.36 mm to 0.150 mm Sieve</td>
<td>+/- 4.0</td>
</tr>
<tr>
<td>Gradation Passing 0.075 mm Sieve</td>
<td>+/- 2.0</td>
</tr>
</tbody>
</table>
12.2. Field Verification Production Lot

12.2.1. At the beginning of production of each mixture required in the contract, a verification lot shall be used for mixture verification. The verification lot shall be divided into four sub-lots as specified in Table 2 depending on the mixture type. The properties of the sub-lots will be measured and compared to the DMF. If the deviation in air voids in any sub-lot exceeds +/- 3 percent or in any two sub-lots exceeds +/- 1.5 percent, the production shall cease and a new DMF shall be developed in accordance with Section 11.2. If the deviation for any single property exceeds two times the limits shown in Table 1 or any two sub-lots exceed the limits shown in Table 1, the production shall cease and a new DMF shall be developed in accordance with Section 11.2.

<table>
<thead>
<tr>
<th>Mix Composition Property</th>
<th>Adjustment Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voids in Mineral Aggregate (VMA)</td>
<td>+/- 1.0</td>
</tr>
</tbody>
</table>

12.2.2. By the end of the lot, the mixture shall be within the limits of Table 1. The field verification lot shall be closed out and the contractor shall declare a JMF. Acceptance of the verification lot shall be in accordance with Section 14 except that a pay factor of 1.00 shall be used.

12.3. Field Verification Samples

12.3.1. The Contractor shall obtain, using the methods required by Section 10, a sample of plant-produced HMA from each sub-lot. Samples may be obtained from haul trucks at the plant or from the mat behind the screed. Since the evaluation criteria are based on in-place measurements it is recommended that QC testing be completed on road samples. If QA testing is performed on road samples, and the QC testing is based on truck samples taken at the HMA plant, the Contractor shall develop appropriate correlation factors.

12.3.1.1. Determine binder content and combined aggregate gradation of the HMA samples in accordance with T 164 and T 30 respectively.

12.3.1.2. Determine maximum specific gravity of the HMA samples in accordance with T 209.

### Table 2. Field Verification Lots and Sub-lots

<table>
<thead>
<tr>
<th>Nom Max Size</th>
<th>Sub-Lot</th>
<th>Lot (Mg or tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75</td>
<td>300</td>
<td>1200</td>
</tr>
<tr>
<td>9.5</td>
<td>400</td>
<td>1600</td>
</tr>
<tr>
<td>12.5</td>
<td>500</td>
<td>2000</td>
</tr>
<tr>
<td>19.0</td>
<td>500</td>
<td>2000</td>
</tr>
<tr>
<td>25.0</td>
<td>500</td>
<td>2000</td>
</tr>
<tr>
<td>37.5</td>
<td>500</td>
<td>2000</td>
</tr>
</tbody>
</table>
12.3.1.3. Compact samples of HMA according to T 312.

12.3.1.3.1. Determine bulk specific gravity in accordance with T 166, using the SSD method.

12.3.1.3.2. Determine the air void content, in accordance with PP 28, at Nini, and Ndes gyrations.

12.3.1.3.3. Determine the voids in the mineral aggregate and the voids filled with asphalt in accordance with PP 28.

12.4. Control Chart Initiation

12.4.1. A process control chart is needed to determine whether the manufacturing process is in control. Individual data points and moving averages are plotted. The individual data points indicate variability and the moving average indicates conformance to the target value.

12.4.2. Control charts shall comply with the requirements of Appendix A-II.

12.4.3. When a HMA field verification lot has been produced; the Contractor shall establish initial control charts using single point target values from the JMF in accordance with the requirements of Appendix A-III.

12.4.4. Control charts are used to graphically represent the continuous control process. They include the target value that is to be achieved for a certain material property and acceptable upper and lower limits. When a measured value is determined and plotted on the control chart, it should fall within the control limits. Mixture adjustment can be made in response to the values plotted on these control charts.

12.4.5. Control limits are established based on statistical concepts that assume the material parameter in question follows a normal distribution. Typically, the upper and lower control limits (UCL and LCL) are based on ± 2s (warning control limits) and ± 3s (action control limits), where "s" is the typical industry standard deviation listed in Table A-III.1.

12.5. Establishment of compaction rolling pattern (HMA control strip)

12.5.1. The Contractor shall place and compact the mixture produced during the field verification production lot in order to establish compaction patterns and verify that the equipment and the processes planned for placement and compaction are satisfactory.

12.5.2. The HMA control strip shall be placed at the thickness required by the pavement cross-section design. The Contractor shall employ a nuclear density gauge, in accordance with ASTM D 2950, or other method approved by the SHA, to establish a compaction pattern that meets the specification criteria for in-place density.

12.5.3. The control strip shall be a minimum of 150 m (500 ft) long.
12.5.4. The normal behavior pattern of HMA is that as the number of roller passes over a given area increases the density will also increase. This will occur up to a certain point after which a very small increase in density can be obtained with additional roller passes. At this point the density is presumed to have reached it's maximum and is then considered to have peaked. Density is peaked when additional rolling does not increase the density by more than 20 kg/m$^3$ (1 lb/ft$^3$).

12.5.5 Following application of the roller or rollers, five random tests with the non-destructive gauge will be taken. Caution should be taken not to set test locations near the edge of the lay. The locations will be marked so that re-testing after additional rolling may be taken at the exact same location. If more than 20 kg/m$^3$ (1 lb/ft$^3$) increase in density was obtained, apply additional roller passes and test again. Once the density has peaked, five additional random non-destructive tests will be taken (a total of 10 locations). Alternatively, the ten tests may be taken in a pattern as shown in Figure 1. The pattern should be spaced to accommodate the actual test section length.

![Figure 1 Alternate Coring Pattern for Control Strip](image)

12.5.6. After non-destructive testing is completed, one core shall be taken at each non-destructive test location to determine the corresponding density. Density of the cores will be determined in accordance with T 166.

12.5.7 Density results from the non-destructive and the cores shall be plotted on a graph with core density plotted on the x-axis and non-destructive density plotted on the y-axis. A straight-line regression analysis shall be completed. This line shall be used to convert non-destructive test results into expected core density test results. The rolling pattern will be considered acceptable when the average core density meets or exceeds contract specifications.

13. Quality Control System

13.1. General Requirements

13.1.1. The Contractor shall provide and maintain a quality control system that will provide reasonable assurance that all materials and products conform to the specification requirements whether manufactured or processed by the Contractor or procured from suppliers or subcontractors. The Contractor shall perform or have performed the inspection and tests required to substantiate product conformance to the mix design requirements, and shall also perform or have performed all inspections and tests otherwise required by the
project specifications. The Contractor’s quality control procedures, inspections, and proposed testing shall be documented in a written QC Plan. The plan shall be approved by the SHA and be available for review through the life of the contract.

13.1.2. The Contractor’s QC Plan shall be based on tests performed to determine compliance of the mixture with the JMF. The tests shall be performed on samples obtained using statistically sound, randomized sampling procedures in accordance with Section 10.

13.1.3. QC mixture properties include the binder content, maximum theoretical bulk specific gravity, specimen bulk specific gravity, percent air voids, percent VMA, percent VFA, moisture content and percent passing key sieves in the combined gradation. Target values for these mix properties shall be those from the JMF. JMF values developed from the Section 12.2.1 shall be the control values.

13.1.4. Quality control testing will be based on samples from individual sub-lots and lots. Sub-lots and lots of plant-produced HMA will be defined the same as the sub-lots and lots of the in-place HMA, or they may be independent of each other.

13.1.5. In accordance with SHA requirements, the Contractor shall record the quantities of asphalt binder, aggregate, mineral filler and (if required) fibers, as well as the quantities of HMA produced, and the production temperature.

13.2. Quality Control Components

13.2.1. The QC plan shall be contract specific and state how the Contractor proposes to control the materials, equipment and operations of the project and shall include the following:

13.2.1.1. Personnel including management personnel and plant and roadway technicians.

13.2.1.2. Plant operations including stockpile management, material feed systems, mixture storage and truck loading procedures, materials and finished product sampling and testing procedures.

13.2.1.3. Transportation of mixture including truck types, release agents, load cover and truck discharge procedures.

13.2.1.4. Roadway operations including use of material transfer devices or windrow pickup machines, paver setup such as paver speed, slope and grade control and screed extensions.

13.2.1.5. Compaction operations including roller type and number, roller setup, e.g. amplitude, frequency or tire pressure, and roller speed.

13.3. Lots and Sub-lots for Quality Control

13.3.1. The QC plan shall indicate lot and sub-lot size for field verification and production lots.

13.3.2. Production lots will be based on mixture as delivered to the roadway. Recommended lot will be
defined as 5000 Mg (5000 t) of 19.0 mm or larger NMPS mixtures or 3000 Mg (3000 t) of 12.5 mm or less NMPS mixture. Lots will be further sub-divided into five sub-lots not to exceed 1000 Mg (1000 t) of 19.0 mm or larger mixture or 600 Mg (600 t) of 12.5 or smaller mixture. Partial sub-lots of 100 Mg (100 t) or less will be added to the previous sub-lot. Partial sub-lots greater than 100 Mg (100 t) constitute a full sub-lot. Lots that contain a single sub-lot shall be combined with the previous lot for acceptance purposes.

13.3.3 If a delay of more than 48 hours occurs in any one sub-lot, a partial sub-lot should be declared and a new sub-lot shall start when production resumes.

13.4. Quality Control Laboratory

13.4.1. The HMA Producer shall provide and maintain a laboratory for QC testing. The laboratory shall have the necessary space, equipment, and supplies for the tests to be performed. The laboratory testing equipment shall meet the requirements of the test methods identified for the required sampling and testing. The SHA shall have the right to observe all QC testing.

13.5. Test Equipment Calibration

13.5.1. The test equipment furnished by the Contractor shall be properly calibrated or verified and maintained within the limits described in Appendix III.2.

13.6. Quality Control for Plant Operations

13.6.1. The Contractor shall designate the sampling and sample reduction procedures, sampling location, and size of samples necessary for testing. Sampling shall be performed on each sub-lot. Sample locations shall be selected randomly according to Appendix A-I. The Contractor may select random numbers independently of SHA locations for QA or may match the SHA locations. If Contractor tests are to be used for QA, the sampling requirements shall be governed by 14.5.

13.6.3.1 Contractor shall utilize QC Charts that show test results for critical sieves, binder content, maximum theoretical specific gravity, Gsb, air voids, and VMA to identify variability in the HMA production. Target values, warning and action limits shall be shown on the same charts.

13.6.3.2 Details regarding QC for Plant Operations and QC Charts are located in Appendix A-III.

13.8. Quality Control for Roadway Operations

13.8.1. The Contractor shall control the HMA laydown and compaction process to ensure compliance with the project specifications. Details regarding QC for roadway operations are located in Appendix A-III.

13.9. Documentation

13.9.1. The Contractor shall maintain adequate records of all tests. The records shall indicate the test
results and the nature of corrective action taken as appropriate. All charts and records documenting the Contractor’s QC operations and tests shall be available to the SHA during the performance and upon the completion of the work. The Contractor shall keep the test results on file for a minimum period of three years following completion of the work.

13.9.2. Test properties for the various materials and mixtures shall be charted on forms or other appropriate means, which are in accordance with the applicable requirements of the SHA.

14. HMA Acceptance Procedures

14.1. General Requirements

14.1.1. QA sampling and testing of an HMA involves stratified random sampling that is applied to a series of sub-lots of HMA. The objective of QA is to verify that the product meets contract specifications.

14.1.2. The SHA will obtain, using the methods required by Section 10, a sample of HMA from each sub-lot.

14.1.3. QA mixture properties typically include the percent asphalt binder, air voids, and VMA. Target values for these mixture properties shall be those from the JMF. QA testing also includes density on the roadway. The target value for density shall be that obtained from the HMA control strip in accordance with 12.5.

14.1.4. QA testing will be based on independent samples from the same sub-lots that are used for QC. Lots and sub-lots will be based on mixture as delivered to the roadway.

14.1.5. The method of acceptance should be statistically based to evaluate the acceptability of the HMA. Statistically based methods recommended are the Percent Within Limits using Standard Deviation, Percent Within Limits using Conformal Index, or Mean and Range.

14.1.5.1. Percent Within Limits Calculated Using Standard Deviation. The percent with limits process is a method to statistically evaluate the percentage of mixture within industry established quality limits. See Appendix A-IV.

14.1.5.2. Percent Within Limits Using Conformal Index. The conformal index process is a method to statistically evaluate the percentage of the mixture within quality limits referenced to target values in the JMF. See Appendix A-V.

14.1.5.3. Mean and Range. The target and range specification limits process is a statistically based method to evaluate the mean value and variability of material properties. See Appendix A-VI.

14.2. Quality Assurance for Mixture Properties (AV, VMA, Pb)

14.2.1. Point of Sampling: The SHA representative in accordance with Section 10.2 shall obtain
stratified random acceptance samples. The samples shall be taken obtained from the mixture behind the screed prior to initial rolling. If a correlation factor between samples taken from a truck at the plant and samples from the roadway behind the screed has been developed, the sample may be taken from the haul truck at the plant.

14.2.2. Number of Samples: One sample per sub-lot in accordance with Section 10.2.2.

14.2.3. Lot Size. Lots will be defined as 5000 Mg (5000 t) of 19.0 mm or larger NMPS mixtures or 3000 Mg (3000 t) of 12.5 mm or less NMPS mixture. Lots will be further sub-divided into five sub-lots not to exceed 1000 Mg (1000 t) of 19.0 mm or larger mixture or 600 Mg (600 t) of 12.5 or smaller mixture. Partial sub-lots of 100 Mg (100 t) or less will be added to the previous sub-lot. Partial sub-lots greater than 100 Mg (100 t) constitute a full sub-lot. Lots that contain a single sub-lot shall be combined with the previous lot for acceptance purposes.

14.3. Quality Assurance for In-place Density (%Gmm)

14.3.1. Point of Sampling: The SHA representative in accordance with Section 10.3 shall determine stratified random acceptance sample locations. The locations shall be determined after rolling operations are completed.

14.3.2. Number of Tests: Two (2) core samples or two (2) non-destructive in-place tests per sub-lot are used in accordance with Section 10.3.1.

14.3.3. Lot Size: Lot and sub-lot sizes are to be the same as the mixture lots and sub-lots in accordance with Section 14.2.3.

14.3.4. Acceptance Testing: Obtain cores in accordance with ASTM D 5361 from each location and transport the cores to a laboratory for testing. From the mixture sample in each sub-lot, determine the maximum specific gravity. For each core, measure the bulk specific gravity in accordance with T 166, and calculate density as percent of theoretical maximum density. Alternately, a calibrated nuclear density gauge can be used to determine the bulk specific gravity at each location, in accordance with ASTM D 2950, and used to calculate density as percent of theoretical maximum density (%Gmm).

14.4. SHA Acceptance Process

14.4.1. The SHA will determine acceptable quality limits for mixture properties and in-place density using one of the statistical methods in Section 14.1.5.

14.4.2. Smoothness is also an important acceptance property. The SHA should select a method of measuring smoothness (i.e., rolling straight edge, light weight or high speed profilometers) and will develop specific acceptance criteria.

14.4.3. The SHA may also use subjective measures such as segregation to determine the acceptability of the HMA. The SHA would add specific criteria that may not be statistically based.
14.5. Contractor Tests Used for Quality Assurance

14.5.1. The use of Contractor tests for project acceptance is permitted when the SHA has developed an Acceptance Program in accordance with Section 14.1.5 that includes independent verification and statistical evaluation of the Contractor’s test results.

14.5.2. The Contractor shall maintain an acceptable testing program that includes the use of a qualified laboratory and qualified testing personnel, established material sampling frequencies and testing protocols, and reporting procedures.

14.5.3. The SHA shall establish a verification sampling and testing program that includes testing of materials by a qualified laboratory and qualified testing personnel on samples taken independently of the Contractor’s QA tests but within the same population as the Contractor’s tests.

14.5.4. The SHA shall develop a statistical method of comparing the Contractor’s QA and the SHA verification tests to verify the Contractor’s QA test results, such as comparison of means or standard deviations of the means.

14.5.5. The SHA shall develop a dispute resolution system that addresses the disposition of discrepancies occurring between the Contractors QA and the SHA verification tests.

14.5.6. The SHA Independent Assurance program shall include the evaluation of the Contractor’s qualified laboratory and qualified testing personnel.

14.6. Pay Factors

14.6.1. The SHA shall develop a table of pay factors based on the selected method of acceptance.

14.7. Documentation

14.7.1. The SHA shall maintain adequate records of all QA tests. The records shall indicate the test results and the acceptance decisions.

14.7.2. When Contractor test results are used for QA they shall be available to the SHA during the performance of the work. Test results shall be submitted to the SHA on forms or other appropriate means in accordance with SHA requirements.

15. Key Words

15.1. acceptance plan, contractor acceptance, control charts, hot mix asphalt, percent within limits, quality control, quality assurance, stratified random sampling, Superpave, conformal index.
Appendix A-I. Stratified Random Sampling
(Mandatory Information)

A-I.1. Scope

A-I.1.1. This method outlines the procedures for selecting sampling sites in accordance with appropriate random sampling techniques. Random sampling is the selection of a sample in such a manner that every portion of the material or construction to be sampled has an equal chance of being selected as the sample. It is intended that all samples, regardless of size, type or purpose, shall be selected in an unbiased manner, based entirely on chance.

A-I.2. Securing Samples

A-I.2.1. Samples shall be taken as directed by the Contractor's representative for QC purposes and the SHA representative for acceptance purposes.

A-I.2.2. Sample location and sampling procedure are as important as testing. It is essential that the sample location be chosen in an unbiased manner.

A-I.3. Random Number Table

A-I.3.1. For test results or measurements to be meaningful, it is necessary that the material to be sampled or measured, be selected at random, which means using a table of random numbers. The following table of random numbers has been devised for this purpose. To use the table in selecting sample locations, proceed as follows.

A-I.3.2. Determine the lot size and stratify the lot into a number of sub-lots per lot for the material being sampled.

A-I.3.3. For each lot, use consecutive two-digit random numbers from Table A-I.1. For example, if the specification specifies five sub-lots per lot and the number 15 is randomly selected as the starting point from Column X (or Column Y) for the first lot, numbers 15-19 would be the five consecutive two-digit random numbers. For the second lot, another random starting point, number 91 for example, is selected and the numbers 91 through 95 are used for the five consecutive two-digit random numbers. The same procedure is used for additional lots.

A-I.3.4. For samples taken from the roadway, use the decimal values in Column X and Column Y to determine the coordinates of the sample locations.

A-I.3.5. In situations where coordinate locations do not apply (i.e., plant samples, stockpile samples, etc.), use those decimal values from Column X or Column Y.
A-I.4. Random Sample

A-I.4.1. A random number table is a collection of random digits. The random numbers that are presented in this annex are shown in a two-place decimal format. Note that there are two columns, labeled X and Y. The numbers in either column can be used to locate a random sample when only a single dimension is required to locate the sample (e.g., time, tonnage and units). When two dimensions are required to locate the sample, the number in the X column is used to calculate the longitudinal location, and the number in the Y column is used to calculate the transverse location. In the Y column, each number is preceded by an L or R, designating that the sample increment is to be located transversely from the left or right edge of the pavement. Figure A-I.1 illustrates the procedure. An example demonstrating the use of the random sampling technique follows

![Figure A-I.1. Determination of Sample Location Using Random Numbers](image)

A-I.4.2 Sampling Example by Material Mass

A-I.4.2.1 HMA for use in paving must be sampled to determine the binder content and other mixture related criteria. The definitions which define the lot and sub-lot size are located in 13.3.3 and 14.2.3. The total tonnage for the example project is 21,700 Mg (tons).

A-I.4.2.2 First, identify the lot size and then determine the number of lots, sub-lot size and finally the point at which samples will be obtained.

A-I.4.2.3 Lot Size and Number of Lots. For example, with a 19.0 mm NMPS mixture, the lot size is 5,000 Mg (tons). Assuming there are 21,700 Mg (tons) of HMA required for the project, the total number of lots is:

\[
\text{Number of Lots} = \frac{21,700 \text{ Mg (tons)}}{5,000 \text{ Mg (tons)/lot}} = 5 \text{ lots}
\]
A-I.4.2.4. Sub-lot Size. Based on 14.2.3 the sub-lot size is 1000 Mg (tons). The relationship between lot
and sub-lot size is shown in Figure A-I.2. The actual number and size of sub-lots in a lot could depend on
specific conditions if partial sub-lots are declared during construction.

![Figure A-I.2. Relationship between Lot and Sub-lots](image)

A-I.4.2.5. Sub-lot Samples. For example, for mixture property samples, the number of samples per lot is
five, one per sub-lot. Five random numbers are selected from the table of random numbers. A block of
numbers from the random number table (Table A-I.1) is reproduced below.

<table>
<thead>
<tr>
<th>Sequence Number</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>67.</td>
<td>0.93</td>
<td>R 0.17</td>
</tr>
<tr>
<td>68.</td>
<td>0.40</td>
<td>R 0.50</td>
</tr>
<tr>
<td>69.</td>
<td>0.44</td>
<td>R 0.15</td>
</tr>
<tr>
<td>70.</td>
<td>0.03</td>
<td>L 0.60</td>
</tr>
<tr>
<td>71.</td>
<td>0.19</td>
<td>L 0.37</td>
</tr>
</tbody>
</table>

A-I.4.2.6. Select random numbers from the Y column only (disregard the L or R). These numbers are
0.17, 0.50, 0.15, 0.60 and 0.37. Multiply the numbers by the size of each sub-lot as follows to determine
the megagram to be sampled in the sub-lot.

<table>
<thead>
<tr>
<th>Sub-lot</th>
<th>Sub-Lot Random Number</th>
<th>Size Mg (ton)</th>
<th>Sample from Mg (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.17</td>
<td>1000</td>
<td>170</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>0.15</td>
<td>1000</td>
<td>150</td>
</tr>
<tr>
<td>4</td>
<td>0.60</td>
<td>1000</td>
<td>600</td>
</tr>
<tr>
<td>5</td>
<td>0.37</td>
<td>1000</td>
<td>370</td>
</tr>
</tbody>
</table>

A-I.4.2.6.1. The technician must obtain the first sample at approximately the 170th Mg (tons). of the
first sub-lot. The technician must then wait until the first sub-lot is completed, 1,000 Mg (tons), before
selecting the second sample at the 500th Mg (tons) of the second sub-lot. The same sequence is followed
for obtaining the remaining three samples.
A-I.4.2.6.2. The sampling sequence for the lot of 5,000 Mg (tons) should be:

- Sub-lot 1: 170th Mg (ton)
- Sub-lot 2: $1,000 + 500 = 1,500$th Mg (ton)
- Sub-lot 3: $2,000 + 150 = 2,150$th Mg (ton)
- Sub-lot 4: $3,000 + 600 = 3,600$th Mg (ton)
- Sub-lot 5: $4,000 + 370 = 4,370$th Mg (ton)

Sub-lot sampling based on mass is illustrated in Figure A-I.3..

<table>
<thead>
<tr>
<th>sub-lot # 1</th>
<th>sub-lot #2</th>
<th>sub-lot #3</th>
<th>sub-lot #4</th>
<th>sub-lot #5</th>
</tr>
</thead>
<tbody>
<tr>
<td>sample #1</td>
<td>sample #2</td>
<td>sample #3</td>
<td>sample #4</td>
<td>sample #5</td>
</tr>
<tr>
<td>170 Mg (ton)</td>
<td>1500 Mg (ton)</td>
<td>2150 Mg (ton)</td>
<td>3600 Mg (ton)</td>
<td>4370 Mg (ton)</td>
</tr>
</tbody>
</table>

<--------------------------5000 Mg (ton) lot-------------------------->

**Figure A-I.3. Sub-lot Sample**
Table A-I.1. Random Positions in Decimal Fractions (Two Places).

<table>
<thead>
<tr>
<th>Sequence No.</th>
<th>X</th>
<th>Y</th>
<th>Sequence No.</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.29</td>
<td>R 0.66</td>
<td>51.</td>
<td>0.87</td>
<td>L 0.36</td>
</tr>
<tr>
<td>2.</td>
<td>0.74</td>
<td>R 0.49</td>
<td>52.</td>
<td>0.34</td>
<td>L 0.19</td>
</tr>
<tr>
<td>3.</td>
<td>0.89</td>
<td>L 0.79</td>
<td>53.</td>
<td>0.37</td>
<td>R 0.33</td>
</tr>
<tr>
<td>4.</td>
<td>0.60</td>
<td>R 0.39</td>
<td>54.</td>
<td>0.97</td>
<td>L 0.79</td>
</tr>
<tr>
<td>5.</td>
<td>0.88</td>
<td>R 0.31</td>
<td>55.</td>
<td>0.13</td>
<td>R 0.36</td>
</tr>
<tr>
<td>6.</td>
<td>0.72</td>
<td>L 0.54</td>
<td>56.</td>
<td>0.85</td>
<td>R 0.64</td>
</tr>
<tr>
<td>7.</td>
<td>0.12</td>
<td>R 0.08</td>
<td>57.</td>
<td>0.14</td>
<td>L 0.04</td>
</tr>
<tr>
<td>8.</td>
<td>0.09</td>
<td>L 0.94</td>
<td>58.</td>
<td>0.99</td>
<td>R 0.74</td>
</tr>
<tr>
<td>9.</td>
<td>0.62</td>
<td>L 0.11</td>
<td>59.</td>
<td>0.40</td>
<td>L 0.76</td>
</tr>
<tr>
<td>10.</td>
<td>0.71</td>
<td>R 0.59</td>
<td>60.</td>
<td>0.37</td>
<td>L 0.09</td>
</tr>
<tr>
<td>11.</td>
<td>0.36</td>
<td>L 0.38</td>
<td>61.</td>
<td>0.90</td>
<td>R 0.74</td>
</tr>
<tr>
<td>12.</td>
<td>0.57</td>
<td>R 0.49</td>
<td>62.</td>
<td>0.09</td>
<td>L 0.70</td>
</tr>
<tr>
<td>13.</td>
<td>0.35</td>
<td>R 0.90</td>
<td>63.</td>
<td>0.66</td>
<td>L 0.97</td>
</tr>
<tr>
<td>14.</td>
<td>0.69</td>
<td>L 0.63</td>
<td>64.</td>
<td>0.89</td>
<td>L 0.55</td>
</tr>
<tr>
<td>15.</td>
<td>0.59</td>
<td>R 0.68</td>
<td>65.</td>
<td>0.67</td>
<td>L 0.44</td>
</tr>
<tr>
<td>16.</td>
<td>0.06</td>
<td>L 0.03</td>
<td>66.</td>
<td>0.02</td>
<td>R 0.65</td>
</tr>
<tr>
<td>17.</td>
<td>0.08</td>
<td>L 0.70</td>
<td>67.</td>
<td>0.93</td>
<td>R 0.17</td>
</tr>
<tr>
<td>18.</td>
<td>0.67</td>
<td>L 0.68</td>
<td>68.</td>
<td>0.40</td>
<td>R 0.50</td>
</tr>
<tr>
<td>19.</td>
<td>0.83</td>
<td>R 0.97</td>
<td>69.</td>
<td>0.44</td>
<td>R 0.15</td>
</tr>
<tr>
<td>20.</td>
<td>0.54</td>
<td>R 0.58</td>
<td>70.</td>
<td>0.03</td>
<td>L 0.60</td>
</tr>
<tr>
<td>21.</td>
<td>0.82</td>
<td>R 0.50</td>
<td>71.</td>
<td>0.19</td>
<td>L 0.37</td>
</tr>
<tr>
<td>22.</td>
<td>0.66</td>
<td>R 0.73</td>
<td>72.</td>
<td>0.92</td>
<td>L 0.45</td>
</tr>
<tr>
<td>23.</td>
<td>0.06</td>
<td>L 0.27</td>
<td>73.</td>
<td>0.20</td>
<td>L 0.85</td>
</tr>
<tr>
<td>24.</td>
<td>0.03</td>
<td>L 0.13</td>
<td>74.</td>
<td>0.05</td>
<td>R 0.56</td>
</tr>
<tr>
<td>25.</td>
<td>0.55</td>
<td>L 0.29</td>
<td>75.</td>
<td>0.46</td>
<td>R 0.58</td>
</tr>
<tr>
<td>26.</td>
<td>0.64</td>
<td>L 0.77</td>
<td>76.</td>
<td>0.43</td>
<td>R 0.91</td>
</tr>
<tr>
<td>27.</td>
<td>0.30</td>
<td>R 0.57</td>
<td>77.</td>
<td>0.97</td>
<td>L 0.55</td>
</tr>
<tr>
<td>28.</td>
<td>0.51</td>
<td>R 0.67</td>
<td>78.</td>
<td>0.06</td>
<td>R 0.51</td>
</tr>
<tr>
<td>29.</td>
<td>0.29</td>
<td>R 0.09</td>
<td>79.</td>
<td>0.72</td>
<td>L 0.78</td>
</tr>
<tr>
<td>30.</td>
<td>0.63</td>
<td>R 0.82</td>
<td>80.</td>
<td>0.95</td>
<td>L 0.36</td>
</tr>
<tr>
<td>31.</td>
<td>0.53</td>
<td>L 0.86</td>
<td>81.</td>
<td>0.16</td>
<td>L 0.61</td>
</tr>
<tr>
<td>32.</td>
<td>0.99</td>
<td>R 0.22</td>
<td>82.</td>
<td>0.29</td>
<td>R 0.47</td>
</tr>
<tr>
<td>33.</td>
<td>0.02</td>
<td>R 0.89</td>
<td>83.</td>
<td>0.48</td>
<td>R 0.15</td>
</tr>
<tr>
<td>34.</td>
<td>0.61</td>
<td>L 0.87</td>
<td>84.</td>
<td>0.73</td>
<td>R 0.64</td>
</tr>
<tr>
<td>35.</td>
<td>0.76</td>
<td>R 0.16</td>
<td>85.</td>
<td>0.05</td>
<td>L 0.94</td>
</tr>
<tr>
<td>36.</td>
<td>0.87</td>
<td>L 0.77</td>
<td>86.</td>
<td>0.43</td>
<td>L 0.05</td>
</tr>
<tr>
<td>37.</td>
<td>0.41</td>
<td>L 0.10</td>
<td>87.</td>
<td>0.87</td>
<td>R 0.98</td>
</tr>
<tr>
<td>38.</td>
<td>0.28</td>
<td>R 0.23</td>
<td>88.</td>
<td>0.37</td>
<td>L 0.71</td>
</tr>
<tr>
<td>39.</td>
<td>0.22</td>
<td>L 0.18</td>
<td>89.</td>
<td>0.94</td>
<td>L 0.26</td>
</tr>
<tr>
<td>40.</td>
<td>0.21</td>
<td>L 0.94</td>
<td>90.</td>
<td>0.57</td>
<td>L 0.63</td>
</tr>
<tr>
<td>41.</td>
<td>0.27</td>
<td>L 0.52</td>
<td>91.</td>
<td>0.26</td>
<td>R 0.89</td>
</tr>
<tr>
<td>42.</td>
<td>0.39</td>
<td>R 0.91</td>
<td>92.</td>
<td>0.01</td>
<td>L 0.79</td>
</tr>
<tr>
<td>43.</td>
<td>0.57</td>
<td>L 0.10</td>
<td>93.</td>
<td>0.83</td>
<td>R 0.59</td>
</tr>
<tr>
<td>44.</td>
<td>0.82</td>
<td>L 0.12</td>
<td>94.</td>
<td>0.71</td>
<td>L 0.21</td>
</tr>
<tr>
<td>45.</td>
<td>0.14</td>
<td>L 0.94</td>
<td>95.</td>
<td>0.65</td>
<td>L 0.63</td>
</tr>
<tr>
<td>46.</td>
<td>0.50</td>
<td>R 0.58</td>
<td>96.</td>
<td>0.65</td>
<td>L 0.87</td>
</tr>
<tr>
<td>47.</td>
<td>0.93</td>
<td>L 0.03</td>
<td>97.</td>
<td>0.72</td>
<td>R 0.92</td>
</tr>
<tr>
<td>48.</td>
<td>0.43</td>
<td>L 0.29</td>
<td>98.</td>
<td>0.85</td>
<td>L 0.78</td>
</tr>
<tr>
<td>49.</td>
<td>0.99</td>
<td>L 0.36</td>
<td>99.</td>
<td>0.04</td>
<td>L 0.46</td>
</tr>
<tr>
<td>50.</td>
<td>0.61</td>
<td>R 0.25</td>
<td>100.</td>
<td>0.29</td>
<td>L 0.95</td>
</tr>
</tbody>
</table>

Note:  
X = Decimal fraction of total length measured along the road from starting point.  
Y = Decimal fraction measured across the road from either outside edge towards centerline of the Paved lane.
A-II. Statistical Control Charts

A-II.1. Process Control

A-II.1.1. The process control procedure recommended is the use of control charts, particularly statistical control charts. Control charts provide a means of verifying that a process is in control. It is important to understand that statistical control charts do not get or keep a process under control. The process must still be controlled by the plant or construction personnel. Control charts simply provide a visual warning mechanism to identify when the Contractor or material supplier should look for possible problems with the process.

A-II.1.2. Variation of construction materials is inevitable and unavoidable. The purpose of control charts, then, is not to eliminate variability, but to distinguish between the inherent or chance causes of variability and a system of assignable causes. Chance causes are a part of every process, and can be reduced but generally not eliminated. Assignable causes are factors that can be eliminated, thereby reducing variability. Chance causes are something that a Contractor or material supplier must learn to live with. They cannot be eliminated, but it may be possible to reduce their effects. The second cause of variation, assignable causes, can create major problems. However, assignable causes can be eliminated if they can be identified. Examples of assignable causes might be when the gradation for an aggregate blend goes out of specification due to a hole in one of the sieves or because the cold feed conveyor setting is incorrectly adjusted.

A-II.1.3. The statistical control chart enables the Contractor to distinguish between chance and assignable causes. Based upon statistical theory, construction materials, when under production control, exhibit a “bell-shaped” or normal distribution curve.

A-II.1.4. The data, therefore, can be assumed to be within $\pm 3\sigma$ of the mean or target when the process is in control and only chance causes (variability that the Contractor cannot control) are acting on the system. Statistical control charts for average or means rely on the fact that, for a normal distribution, essentially all of the values fall within $\pm 3$ standard deviations from the mean. The normal distribution can be used because the distribution of sample means is normally distributed.

A-II.1.5. A statistical control chart can be viewed as a normal distribution curve on its side (Figure A-II.1). For a normal curve, only about 0.27% (1 out of 370) of the measurements should fall outside $\pm 3$ standard deviations from the average or mean. Therefore, control limits (indicating that an investigation for an assignable cause should be conducted) are set at $+3\sigma$ and $-3\sigma$. 
A-II.1.6. A statistical control chart includes a target value, UCL and LCL and a series of data points that are plotted. The target is based on either the production mean or design value and the control limits are established from typical standard deviation as shown in Figure A-II.2.

A-II.2. Form of Statistical Control Charts

A-II.2.1. There are many forms to statistical control charts, but the form most practical and useful for construction materials and processes is a control chart which shows individual test data points and a moving average. This process control chart is typically used to control the production process about the target value.

The process control chart also includes individual test data points. Highly variable individual test data points indicated variability in the process even though the moving average may be acceptable.
The process control chart has five reference lines which are determined as follows.

- target value is the value of the property from the declared JMF.
- warning upper control limit is the target value plus 2 standard deviations (Table A-III.1) divided by the square root of the number of samples in the moving average. Typically five samples are used.
- warning lower control limit is the target value minus 2 standard deviations (Table A-III.1) divided by the square root of the number of samples in the moving average. Typically five samples are used.
- action upper control limit is the target value plus 3 standard deviations (Table A-III.1) divided by the square root of the number of samples in the moving average. Typically five samples are used.
- action lower control limit is the target value minus 3 standard deviations (Table A-III.1) divided by the square root of the number of samples in the moving average. Typically five samples are used.

Figure A-II.3 shows a process control chart for asphalt binder content. The target for asphalt binder content, 5.7%, is obtained from the JMF.

![Control Chart for Asphalt Binder Content](image)

- from Table A-III.1 the standard deviation for asphalt binder content determined by extraction is 0.25%.
- the deviation from the target value for the warning limits for a moving average of five points is
  \[ \frac{2 \times 0.25}{\sqrt{5}} \]
  \[ = 0.22 \]
- the warning control limits are
  \[ UCL = 5.7 + 0.22 = 5.9 \]
  \[ LCL = 5.7 - 0.22 = 5.5 \]
- the deviation from the target value for the warning limits for a moving average of five points is
= 3 x 0.25 / (square root 5) 
= 0.33

- the action control limits are
  UCL = 5.7 + 0.33 = 6.0
  LCL = 5.7 - 0.33 = 5.4

The individual test data points from each sub-lot are plotted on the chart and connected. This series of data points provides a visual indication of variability. If variability is high the process can be refined to reduce variability. The moving average of five data points is calculated starting with the fifth data point and plotted on the chart. The moving average data points provide a visual indication of conformance with the target value. It is also possible to detect trends in the production and adjust the operation bring the moving average closer to the target.

Figure A-II.4 shows a process control chart in which variability is higher than that shown in Figure A-II.3. The higher variability is indicated by the individual test results. In addition, the moving average is consistently above the target. Steps should be taken to reduce variability and bring the moving average closer to the target.

Figure A-II.3 Control Chart for Asphalt Binder Content
A-III. Quality Control Requirements for Hot Mix Asphalt

A-III.1. Scope

A-III.1.1. This Appendix provides the details for Contractor quality control activities for HMA.

A-III.2. Test Equipment Calibration

A-III.2.2. The equipment calibration or verification documentation shall include:

A-III.2.2.1. Name of the person performing the calibration or verification.

A-III.2.2.2. Identification of the calibration equipment used, i.e., standard weights, proving rings, thermometers, etc.

A-III.2.2.3. Last date calibration or verification was performed.

A-III.2.2.4. A reference to the calibration procedure used.

A-III.2.2.5. Records showing the results of the calibration or verification performed.

A-III.3 Materials Sampling and Testing

A-III.3.1. Sampling shall be performed on each sub-lot on a random basis. The test methods and minimum frequencies of the QC tests for each mixture design shall be designated. Test results shall be rounded in accordance with ASTM E 29 using the rounding method.

A-III.3.2. Blended Aggregate. A minimum of one sample shall be obtained and tested for gradation in accordance with T 27 performed on each sub-lot on a random basis. The procedure for determining the blended aggregate gradation shall be stated by the Contractor.

A-III.3.2.1. Batch Plants. The blended aggregate gradation shall be determined by calculating the combined gradation of the aggregate from each hot bin.

A-III.3.2.2. Drum Plants. The blended aggregate gradation shall be determined using aggregate samples from the cold feed belt. The moisture content of the samples shall be determined in accordance with T 255.

A-III.3.3. Recycled Materials. A minimum of one sample for each 1000 Mg (1000 t) of recycled asphalt materials shall be obtained and tested for binder content in accordance with T 164 or T 308, gradation in accordance with T 30, and moisture content in accordance with T 255.

A-III.3.4. Hot Mix Asphalt. Samples shall be obtained to determine the asphalt binder content, voids and VMA of the mixture. Obtain a sample in accordance with Section 10.2. The sample should
be reduced to testing size in accordance with T 248 or ASTM C 702, Method B. Place the test specimen mass into a heated mold and compact to Ndes in accordance with T 312 and determine the bulk specific gravity in accordance with T 166. If the mixture requires re-heating to achieve compaction temperature, the mixture shall be placed in a sealed covered container. The maximum specific gravity shall be determined in accordance with T 209. One sample shall be tested for moisture content in accordance with T 255, binder content in accordance with T 164 or T 308, gradation in accordance with T 30 and coarse aggregate angularity in accordance with ASTM D 5821. Alternately the binder content may be determined in accordance with T 287 in which case the gradation shall be determined from the combined cold feed aggregates in accordance with T 27.

A-III.4 Control Charts

A-III.4.1. The Contractor shall use control charts for critical sieves, asphalt binder content, maximum theoretical specific gravity, Gsb, air voids, and VMA to identify variability in the HMA production process. All test results shall be recorded on the control chart the same day the tests are conducted. The charts are to be used to determine if the HMA production is in control.

A-III.4.2. Target values and warning and action limits for the control charts are determined from the JMF mix properties and plotted on the control charts. The warning and action limits are determined using typical industry standard deviations for mixture properties as shown in Table A-III.1.

<table>
<thead>
<tr>
<th>Mix Composition Property</th>
<th>Extraction</th>
<th>Nuclear Gauge</th>
<th>Ignition Furnace</th>
<th>Cold Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Binder Content (Pb)</td>
<td>+ 0.25</td>
<td>+ 0.18</td>
<td>+ 0.13</td>
<td>---</td>
</tr>
<tr>
<td>Gradation Passing 4.75 mm (No. 4) and Larger Sieves</td>
<td>+ 3</td>
<td>--</td>
<td>--</td>
<td>+ 3</td>
</tr>
<tr>
<td>Passing 2.36 mm (No. 8) to 0.150 mm (No. 100) Sieve</td>
<td>+ 2</td>
<td>--</td>
<td>--</td>
<td>+ 2</td>
</tr>
<tr>
<td>Passing 0.075 mm (No. 200) Sieve</td>
<td>+ 0.7</td>
<td>--</td>
<td>--</td>
<td>+ 0.7</td>
</tr>
<tr>
<td>Maximum Theoretical Specific Gravity (Gmm)</td>
<td></td>
<td></td>
<td></td>
<td>+ 0.015</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gyratory Compacted Mix Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids (Va)</td>
</tr>
<tr>
<td>Voids in Mineral Aggregate (VMA)</td>
</tr>
<tr>
<td>Voids Filled With Asphalt (VFA)</td>
</tr>
<tr>
<td>Bulk Specific Gravity (Gmb)</td>
</tr>
<tr>
<td>In-Place Density (%Gmm)</td>
</tr>
</tbody>
</table>
A-III.4.3. Individual test results and the moving average of the current most five test results shall be plotted. Five consecutive individual test results plotted on either side of the target value indicate a mix composition change. If a mixture compositional change has occurred, changes should be made to adjust the mixture property back to the target value. If a mixture compositional change has occurred in a non-pay element, the Contractor may elect to change the target value instead of adjusting the mixture property back to the target value.

A-III.4.4. For a pay element, if one moving average point falls outside the warning limit an investigation should be completed and adjustments made to bring the property back within the warning limit and the adjustment should be documented. If two consecutive moving average points fall outside the warning limit or one moving average point falls outside the action limit production shall be terminated and a new DMF shall be established in accordance with Section 9.2.1.

Note A-III.1. In the event that one moving average point moves outside the warning limit, individual data points typically will indicate that the mixture property has been shifting over multiple sub-lots. If no action is taken to bring the mixture property back to the target value, a second moving average point will fall outside the limits; therefore, a new DMF is needed. In the event one moving average point moves outside the action limit the individual data point is indicative of a major change in the mixture property. Production shall cease and an investigation shall be initiated to determine the cause. If significant changes have occurred in the materials a new DMF should be developed.

A-III.4.5. For a non-pay element, if one moving average point falls outside the warning limit, the Contractor may elect to change the target value or adjust the property back to the target value. Mixture production should be adjusted within the limits of Table 1, Section 12.1.2. If, after making the adjustment, the mixture property remains outside the warning limit a new DMF should be developed in accordance with Section 9.2.1.

A-III.5. Roadway Operations

A-III.5.1. Location of in-place sample or test sites shall conform to the requirements of Section 10.3.1 on each sub-lot.

A-III.5.2. The Contractor shall utilize standard nondestructive industry equipment and procedures to provide suitable estimates of the in-place density. QC charts shall be developed in accordance with Appendix A-II for the percent of maximum theoretical density. The target values shall be set equal to the average density achieved during the establishment of the rolling pattern in accordance with Section 12.5 as measured by the cores. The LCL shall be set at 0.8 percent below the target value but not less than the contract specifications.

A-III.5.3. For purposes of QC for in-place density, lots and sub-lots shall be in accordance with Section 13.3.2.

A-III.5.4. Individual in-place density test results and the moving average of the current most five-test results shall be plotted. When five consecutive individual test points are on one side of the target value the
compaction operation is be judged to be out of control. The Contractor shall adjust the process to bring it back into control.

A-III.5.5. When one moving average test point is outside of the LCL the control of the lay down and compaction process shall be considered unsatisfactory. The Contractor shall terminate production. Prior to resuming production, the Contractor shall provide the SHA with the assignable cause for the unsatisfactory density test results, and develop a new control strip in accordance with Section 12.5.
A-IV. Percent Within Limits (PWL) for HMA Calculated Using Standard Deviation

A-IV.1. Scope

A-IV.1.1. This Appendix provides the procedure for determination of the percent of material that is within the specification limits established for the HMA using the mean and standard deviation of the lot.

A-IV.2. Significance and Use

A-IV.2.1. The PWL is a calculation used in the SHA Acceptance Plan to determine the acceptability of materials on the project.


A-IV.3.1. SHA’s set upper and lower specification limits using typical industry standard deviations for the property and allowing three standard deviations from the target. Table A-IV.1 provides typical industry standard deviation values. The values in Table A-IV.1 were developed for individual samples \((n = 1)\). When setting specifications that use a larger number of samples per lot, such as 5, the standard deviation values in the table must be adjusted by the following equation:

\[
s_{(n)} = \frac{s}{\sqrt{n}}
\]

where:

- \(s_{(n)}\) = Standard deviation based on sample size \(n\)
- \(s\) = Standard deviation from Table A-IV.1
- \(n\) = Sample size

A-IV.3.2 For example, if the SHA sets the specification limits for asphalt binder content by extraction at plus and minus three times the standard deviation with a lot size of five:

\[
s_{(n)} = \frac{0.25}{\sqrt{5}} = 0.11
\]

The specification limits are set at plus/minus three times the standard deviation. For three standard deviations, the specification limits would be plus/minus 0.3%.
### Table A-IV.1. Typical Industry Standard Deviations for Mixture Properties
(Mixture Composition and Gyratory Properties)

<table>
<thead>
<tr>
<th>Mix Composition Property</th>
<th>Extraction</th>
<th>Nuclear Gauge</th>
<th>Ignition Furnace</th>
<th>Cold Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Binder Content (Pb)</td>
<td>± 0.25</td>
<td>± 0.18</td>
<td>± 0.13</td>
<td>---</td>
</tr>
<tr>
<td>Gradation Passing 4.75 mm (No. 4) and Larger Sieves</td>
<td>± 3</td>
<td>--</td>
<td>--</td>
<td>± 3</td>
</tr>
<tr>
<td>Passing 2.36 mm (No. 8) to 0.150 mm (No. 100) Sieve</td>
<td>± 2</td>
<td>--</td>
<td>--</td>
<td>± 2</td>
</tr>
<tr>
<td>Passing 0.075 mm (No. 200) Sieve</td>
<td>± 0.7</td>
<td>--</td>
<td>--</td>
<td>± 0.7</td>
</tr>
<tr>
<td>Maximum Theoretical Specific Gravity (Gmm)</td>
<td></td>
<td></td>
<td>± 0.015</td>
<td></td>
</tr>
</tbody>
</table>

#### Gyratory Compacted Mix Property

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids (Va)</td>
<td></td>
<td>± 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voids in Mineral Aggregate (VMA)</td>
<td></td>
<td>± 1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voids Filled With Asphalt (VFA)</td>
<td></td>
<td>± 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk Specific Gravity (Gmb)</td>
<td></td>
<td>± 0.022w</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A-IV.3.3. For Air voids, VMA, and AC, the Upper and Lower Specification Limits (USL and LSL) are calculated as above. For in-place density, the Lower Specification Limit is usually specified as 92% Gmm rather than a distance from a target.

### Table A-IV.2. Recommended Specification Limits for Mixture Properties
(With Five Sub-lots and Limits at Three Standard Deviations)

<table>
<thead>
<tr>
<th>Mix Composition Property</th>
<th>Extraction</th>
<th>Nuclear Gauge</th>
<th>Ignition Furnace</th>
<th>Cold Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Binder Content (Pb)</td>
<td>± 0.3</td>
<td>± 0.2</td>
<td>± 0.2</td>
<td>---</td>
</tr>
</tbody>
</table>

#### Gyratory Compacted Mix Property

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids (Va)</td>
<td></td>
<td>± 1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voids in Mineral Aggregate (VMA)</td>
<td></td>
<td>± 1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voids Filled With Asphalt (VFA)</td>
<td></td>
<td>± 7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A-IV.4. PWL Calculation

A-IV.4.1. Estimate the PWL in accordance with Sections A-IV.5.1.1 through A-IV.5.1.10.

A-IV.4.1.1. Locate "n" sampling positions on the sub-lot by use of Appendix A-I, or other appropriate random number tables.

A-IV.4.1.2. Perform tests on each sample taken behind the screed (mixture properties) and each core taken from the roadway (density).

A-IV.4.1.3. For each test property, determine the average, $\bar{x}$, of the lot measurements.

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i
\]

A-IV.4.1.4. For each test property, determine the standard deviation, "s", of the lot.

\[
s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}
\]

A-IV.4.1.5. For Air voids, VMA, and AC, calculate both Upper and Lower Quality Indices and the associated PWL. For in-place density, calculate the Lower Quality Index and the associated PWL. The method to determine the quality indices follows.

A-IV.4.1.6. Determine the Upper Quality Index, $Q_u$, by subtracting the average ($\bar{x}$) of the measurements from the Upper Specification Limit (USL) and dividing the results by "s".

\[
Q_u = \frac{USL - \bar{x}}{s}
\]

A-IV.4.1.7. Determine the Lower Quality Index $Q_l$ by subtracting the Lower Specification Limit (LSL) from the average ($\bar{x}$) and dividing the result by "s".

\[
Q_l = \frac{\bar{x} - LSL}{s}
\]

A-IV.4.1.8. PWL$_{U}$. Estimate the percentage of material that will fall within the upper tolerance limit by entering Table A-IV.3, with $Q_u$, using the column appropriate to the total number "n" of measurements.

A-IV.4.1.9. PWL$_{L}$. Estimate the percentage of material that will fall within the lower tolerance limit by entering Table A-IV.3 with $Q_l$ using the column appropriate to the total number "n" of measurements.
A-IV.4.1.10. For AV, VMA and AC, where both upper and lower limits are used, determine the percent of material that will fall within the limits by adding the percent within the upper specification limit (PWL\(_U\)) to the percent within the lower specification limit (PWL\(_L\)), and subtract 100 from the sum.

\[
\text{Total PWL} = (\text{PWL}_U + \text{PWL}_L) - 100
\]

A-IV.4.1.11. For in-place density, determine the percent of material that will fall above the lower specification limit (PWL\(_L\)).

\[
\text{Total PWL} = \text{PWL}_L
\]

**A-IV.5.2. Example of Percent Within Limits Using Standard Deviation**

A-IV.5.2.1. Determine the PWL for air voids, where the average air voids (\(\bar{x}\)) of the lot is 3.7%, the standard deviation is 0.6% and the number of samples is 5. The range of allowable air voids is 3.0% to 5.0%.

A-IV.5.2.2. Calculate an upper and lower quality index value \(Q_U\) and \(Q_L\) using the following:

\[
Q_U = \frac{5.3 - \bar{x}}{s} = \frac{5.3 - 3.7}{0.6} = 2.67
\]

\[
Q_L = \frac{\bar{x} - 2.7}{s} = \frac{3.7 - 2.7}{0.6} = 1.67
\]

A-IV.5.2.3 Determine an upper and lower PWL using Table A-IV.3 with the number of the samples and the calculated values of \(Q_U\) and \(Q_L\).

For \(n = 5\) and \(Q_U = 2.67\), the \(\text{PWL}_U = 100\).

Note: Since the value of \(Q_U\) exceeds the highest value, under the column of \(n = 5\), the \(\text{PWL}_U\) equals 100.

For \(n = 5\) and \(Q_L = 1.67\), the \(\text{PWL}_L = 99\).

\[
\text{PWL} = (\text{PWL}_U + \text{PWL}_L) - 100
\]

\[
\text{PWL} = (100 + 99) - 100 = 99
\]

where,

- \(s\) = Sample standard deviation
- \(Q_L\) = Lower quality index value
- \(Q_U\) = Upper quality index value
- \(\text{PWL}_U\) = Percent within limits on upper side of specification
\[ PWL_4 = \quad \text{Percent within limits on lower side of specification} \]
\[ PWL = \quad \text{Total percent within limits} \]
Table A-IV.3. Quality Index Values for Estimating Percent Within Limits

<table>
<thead>
<tr>
<th>PWL</th>
<th>n = 3</th>
<th>n = 4</th>
<th>n = 5</th>
<th>n = 7</th>
<th>n = 10</th>
<th>n = 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1.16</td>
<td>1.47</td>
<td>1.69</td>
<td>1.80</td>
<td>1.93</td>
<td>1.93</td>
</tr>
<tr>
<td>98</td>
<td>1.15</td>
<td>1.44</td>
<td>1.61</td>
<td>1.77</td>
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<td>1.41</td>
<td>1.55</td>
<td>1.67</td>
<td>1.74</td>
<td>1.80</td>
</tr>
<tr>
<td>96</td>
<td>1.15</td>
<td>1.38</td>
<td>1.49</td>
<td>1.59</td>
<td>1.64</td>
<td>1.69</td>
</tr>
<tr>
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<td>114</td>
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<td>1.45</td>
<td>1.52</td>
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</tr>
<tr>
<td>93</td>
<td>1.12</td>
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<td>1.27</td>
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<td>0.88</td>
<td>0.87</td>
<td>0.85</td>
<td>0.85</td>
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<td>0.87</td>
<td>0.85</td>
<td>0.83</td>
<td>0.82</td>
<td>0.82</td>
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<td>78</td>
<td>0.89</td>
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<td>0.82</td>
<td>0.80</td>
<td>0.79</td>
<td>0.78</td>
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<td>0.87</td>
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<td>0.79</td>
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<td>0.55</td>
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</tr>
<tr>
<td>69</td>
<td>0.65</td>
<td>0.57</td>
<td>0.55</td>
<td>0.53</td>
<td>0.51</td>
<td>0.51</td>
</tr>
<tr>
<td>68</td>
<td>0.62</td>
<td>0.54</td>
<td>0.52</td>
<td>0.50</td>
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<td>0.48</td>
</tr>
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<td>67</td>
<td>0.59</td>
<td>0.51</td>
<td>0.49</td>
<td>0.47</td>
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<td>0.45</td>
</tr>
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<td>66</td>
<td>0.56</td>
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<td>0.46</td>
<td>0.44</td>
<td>0.43</td>
<td>0.42</td>
</tr>
<tr>
<td>65</td>
<td>0.53</td>
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<td>0.41</td>
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<td>64</td>
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<td>0.39</td>
<td>0.37</td>
<td>0.35</td>
<td>0.35</td>
<td>0.34</td>
</tr>
<tr>
<td>62</td>
<td>0.43</td>
<td>0.36</td>
<td>0.34</td>
<td>0.33</td>
<td>0.32</td>
<td>0.31</td>
</tr>
<tr>
<td>61</td>
<td>0.39</td>
<td>0.33</td>
<td>0.31</td>
<td>0.30</td>
<td>0.30</td>
<td>0.29</td>
</tr>
<tr>
<td>60</td>
<td>0.36</td>
<td>0.30</td>
<td>0.28</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Note 1: For negative values of $Q_U$ or $Q_L$, $P_U$ or $P_L$ is equal to 100 minus the tabular $P_U$ or $P_L$.

Note 2: If the value of $Q_U$ or $Q_L$ does not correspond exactly to a value in the table, use the next higher value.
A-V. Percent Within Limits (PWL) for HMA Calculated Using Conformal Index (CI)

A-V.1. Scope

A-V.1.1. This Appendix provides the procedure for the determination of percent within limits (PWL) using conformal index (CI), a statistic similar to standard deviation.

A-V.2. Significance and Use

A-V.2.1. CI is calculated and used in the determination of PWL as part of a SHA Acceptance Plan to determine the acceptability of materials or construction on the project.

A-V.3. Terminology

A-V.3.1. CI, n - Conformal Index; a statistic that is similar to standard deviation except that the deviation is calculated relative to the target value, not the mean of the lot. It can be used to estimate the size and incidence of deviations (variations) from the target in the same way that standard deviation measures the deviation from the mean of a lot.

A-V.4. Calculation

A-V.4.1. The CI, like the standard deviation, is a statistical measure of variation. Standard deviation is a measure of precision, while the CI is a measure of precision and accuracy. In equation form standard deviation and conformal index are:

\[
s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}
\]

\[
CI = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - T)^2}
\]

The value “T” in the CI equation refers to the target value of the property being measured (air voids, asphalt binder content, etc.).

A-V.5. Setting of Upper and Lower Specification Limits Based on Conformal Index

A-V.5.1. SHA’s usually set upper and lower quality limits based on typical industry standard deviations for the property. If an agency chooses to use PWL calculated with conformal index, the quality limits should be set using industry standard conformal limits. Table A-V.1 provides typical industry CI Values. The values in Table A-V.1 were developed for individual samples (n = 1), so when setting specifications that use a larger number of samples per lot, such as 5, the CI values in the table must be adjusted by the following equation:

\[
CI_{(n)} = \frac{CI}{\sqrt{n}}
\]
where:
\[ \text{CI}(n) = \text{Conformal index based on sample size } n \]
\[ \text{CI} = \text{Conformal index from Table A-V.1} \]
\[ n = \text{Sample size} \]

A-V.5.2 For example, if the SHA sets the specification limits for asphalt binder content by extraction at plus and minus three times the conformal index with a lot size of five:

\[ \text{CI}(n) = 0.31 / \sqrt{5} \]
\[ = 0.14 \]

For three conformal indices the specification limits would be plus/minus 0.4.

**Table A-V.1. Typical Industry Conformal Indices for Mixture Properties**  
(Mixture Composition and Gyratory Properties)

<table>
<thead>
<tr>
<th>Mix Composition Property</th>
<th>Extraction</th>
<th>Nuclear Gauge</th>
<th>Ignition Furnace</th>
<th>Cold Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Binder Content (Pb)</td>
<td>± 0.31</td>
<td>± 0.24</td>
<td>± 0.18</td>
<td>---</td>
</tr>
<tr>
<td>Gradation Passing 4.75 mm (No. 4) and Larger Sieves</td>
<td>± 4</td>
<td>--</td>
<td>--</td>
<td>± 4</td>
</tr>
<tr>
<td>Passing 2.36 mm (No. 8) to 0.150 mm (No. 100) Sieve</td>
<td>± 3</td>
<td>--</td>
<td>--</td>
<td>± 3</td>
</tr>
<tr>
<td>Passing 0.075 mm (No. 200) Sieve</td>
<td>± 0.8</td>
<td>--</td>
<td>--</td>
<td>± 0.9</td>
</tr>
<tr>
<td>Maximum Theoretical Specific Gravity (Gmm)</td>
<td></td>
<td></td>
<td></td>
<td>± 0.015</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gyratory Compacted Mix Property</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids (Va)</td>
<td></td>
<td></td>
<td>± 1.0</td>
<td></td>
</tr>
<tr>
<td>Voids in Mineral Aggregate (VMA)</td>
<td></td>
<td></td>
<td>± 1.5</td>
<td></td>
</tr>
<tr>
<td>Voids Filled With Asphalt (VFA)</td>
<td></td>
<td></td>
<td>± 5</td>
<td></td>
</tr>
<tr>
<td>Bulk Specific Gravity (Gmb)</td>
<td></td>
<td></td>
<td>± 0.028w</td>
<td></td>
</tr>
</tbody>
</table>

A-V.5.3. For Air voids, VMA, and AC, the Upper and Lower Specification Limits (USL and LSL) are calculated as above. For in-place density, the Lower Specification Limit is usually specified as 92% Gmm rather than a distance from a target.
Table A-V.2. Recommended Conformal Index Specification Limits for Mixture Properties
(With Five Sub-lots and Limits at Three Conformal Indices)

<table>
<thead>
<tr>
<th>Mix Composition Property</th>
<th>Extraction</th>
<th>Nuclear Gauge</th>
<th>Ignition Furnace</th>
<th>Cold Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Binder Content (Pb)</td>
<td>+ 0.4</td>
<td>+ 0.3</td>
<td>+ 0.3</td>
<td>---</td>
</tr>
</tbody>
</table>

Gyratory Compacted Mix Property

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids (Va)</td>
<td>± 1.3</td>
</tr>
<tr>
<td>Voids in Mineral Aggregate (VMA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>± 2.0</td>
</tr>
<tr>
<td>Voids Filled With Asphalt (VFA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>± 7</td>
</tr>
</tbody>
</table>

A-V.6. Procedure

A-V.6.1. The procedure for determining percent within limits (PWL) using the conformance index is very similar to that using standard deviation. The only difference is that CI is used in place of standard deviation.

A-V.6.2. Calculate the conformal index using the formula in A-V.4.1.

A-V.6.3. Determine the Upper Quality Index, \( Q_U \), by subtracting the average (\( \bar{x} \)) of the measurements from the Upper Specification Limit (USL) and dividing the results by the CI.

\[
Q_U = \frac{USL - \bar{x}}{CI}
\]

A-V.6.4. Determine the Lower Quality Index \( Q_L \) by subtracting the Lower Specification Limit (LSL) from the average (\( \bar{x} \)) and dividing the result by the CI.

\[
Q_L = \frac{\bar{x} - LSL}{CI}
\]

A-V.6.5. PWL\(_U\). Estimate the percentage of material that will fall within the upper tolerance limit by entering Table A-IV.3, with \( Q_U \), using the column appropriate to the total number "n" of measurements.

A-V.6.6. PWL\(_L\). Estimate the percentage of material that will fall within the lower tolerance limit by entering Table A-IV.3 with \( Q_L \) using the column appropriate to the total number "n" of measurements.

A-V.6.7. For AV, VMA and AC, where both upper and lower limits are used, determine the percent of material that will fall within the limits by adding the percent within the upper specification limit (PWL\(_U\)) to the percent within the lower specification limit (PWL\(_L\)), and subtract 100 from the sum.
A-V.6.8. For in-place density, determine the percent of material that will fall above the lower specification limit (PWL\_L).

\[ \text{Total PWL} = \text{PWL}_u + \text{PWL}_L - 100 \]

A-V.7. Example of Percent Within Limits Using Conformal Index

A-V.7.1. Determine the PWL for air voids, where the average air voids (\( \bar{x} \)) of the lot is 3.7%, the conformal index is 0.7% and the number of samples is 5.

A-V.7.2. Calculate an upper and lower quality index value \( Q_u \) and \( Q_L \) using the following:

\[
Q_u = \frac{5.3 - \bar{x}}{\text{CI}} = \frac{5.3 - 3.7}{0.7} = 2.28
\]

\[
Q_L = \frac{\bar{x} - 2.7}{\text{CI}} = \frac{3.7 - 2.7}{0.7} = 1.42
\]

A-V.7.3 Determine an upper and lower PWL using Table A-IV.1 with the number of the samples and the calculated values of \( Q_u \) and \( Q_L \).

For \( n = 5 \) and \( Q_u = 2.28 \), the PWL\_U = 100.

Note: Since the value of \( Q_u \) exceeds the highest value, under the column of \( n \) equals 5, the PWL\_U equals 100.

For \( n = 5 \) and \( Q_L = 1.42 \), the PWL\_L = 95.

\[ \text{PWL} = (\text{PWL}_U + \text{PWL}_L) - 100 \]

where,

\[ \text{PWL} = (100 + 95) - 100 = 95 \]
A-VI. Target and Range Values for Superpave-Designed HMA

A-VI.1. Scope

A-VI.1.1. This Appendix provides the procedure for determination of the mean and range of material or construction processes that are within the specification limits established for the Superpave-designed HMA.

A-VI.2. Significance and Use

A-VI.2.1. The mean and range is a calculation used in the SHA Acceptance Plan to determine the acceptability of materials or construction on the project.

A-VI.3. Terminology

A-VI.3.1 Mean and range is a method to evaluate the quality of material based on the average value of the property in a lot and the range of individual values in the average. Mixture is accepted based on how close the mean is to the target and how dispersed the individual test data is.

A-VI.3.2 Historical standard deviation is used to define the limits placed on the mean and range. Historical standard deviation is calculated on an agency-wide pool of projects and typically is re-evaluated every five years. Standard deviations are calculated from a representative population of projects, i.e. similar mixtures in one or more calendar years. Mixtures within the population would typically be the same nominal maximum size. For these mixtures the SHA shall calculate the standard deviation of the individual measurements of all projects in the population. Standard deviations are calculated for each of the acceptance properties listed in 14.1.3.

A-VI.4. Calculation

A-VI.4.1. Calculate the mean and range for each lot of material. The mean is the average of the sub-lots in the lot and range is the absolute difference between the highest and lowest individual values among the sub-lots.

A-VI.4.1.1. Average the sub-lot measurements.

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i
\]

A-VI.4.1.2. Identify the highest and lowest value among the sub-lot measurements and subtract the smaller from the larger.

A-VI.4.2. Calculation of Historical Standard Deviation

A-VI.4.2.1. For the representation population of projects, pooled standard deviations is calculated
from the following equation:

\[ s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \]

The values calculated above are for individual samples (n = 1). When setting specifications that use a larger number of samples per lot, such as 5, the standard deviation values must be adjusted by the following equation:

\[ s_{(n)} = \frac{s}{\sqrt{n}} \]

where:
- \( s_{(n)} \) = Standard deviation based on sample size \( n \)
- \( s \) = Standard deviation from Table A-IV.1
- \( n \) = Sample size

A-VI.4.3. Project Acceptance Limits

A-VI.4.3.1. The SHA shall set acceptance limits for mean and range of each acceptance property listed in Section 14.1.3. Acceptance limits shall be set using the historical standard deviation. For mean a lot size of \( n = 5 \) shall be used. Acceptance limits for range shall be set using \( n = 1 \).

A-VI.4.4. Example for Asphalt Binder Content using Mean and Range

A-VI.4.4.1. For example, to set the acceptance limits for the mean of asphalt binder content a standard deviation for a lot size of five needs to be calculated. If the pooled standard deviation for asphalt binder content by extraction is 0.25%, the standard deviation for a lot is:

\[ s_{(n)} = \frac{0.25}{\sqrt{5}} = 0.11 \]

The specification limits for the mean are set at plus/minus 1.5 times the standard deviation, which is 0.2%.

The specification limits for the range use standard deviation for \( n = 1 \) and are set at +/- 2 standard deviations, a total range of 4 standard deviations. For the example of asphalt binder content, the standard deviation for \( n = 1 \) is 0.25 percent and the allowable range is 1.0 percent.

A-VI.4.4.2 For in-place density, acceptance limits for mean should be based on a lot size of 10 (2 cores each for five sub-lots).

A-VI.4.5. Example for In-Place Density using Mean and Range
A-VI.4.5.1. For example, to set the acceptance limits for in-place density a standard deviation for a lot size of ten samples (2 cores each for 5 sub-lots) needs to be calculated. If the pooled standard deviation for in-place density is 0.12%, the standard deviation for a lot is:

\[
s(n) = \frac{1.2}{\text{square root (10)}} = 0.4
\]

In-place density has only a lower specification limit. The lower specification limit for the mean is set at 1.5 times the standard deviation below the target density (from the control strip, Section 12.5) but not less than 92.0 percent Gmm. If the control strip density was 92.5 percent the lower specification limit is set at the minimum of 92.0 percent instead of 91.9 percent which is 0.6 percent less than the target density.

The lower specification limit for the range uses standard deviation for \( n = 1 \) and are set at +/- 2 standard deviations, a total range of 4 standard deviations. For the example of in-place density, the standard deviation for \( n = 1 \) is 1.2 percent and the allowable range is 4.8 percent.