# Supplement: Testing Facilities and Technician Experience

This supplement to the *MDOT Research Consultant Manual* includes information for proposals that include testing facilities or staff with technical expertise. It consists of the following sections:

[Items for Consultant Proposal](#_Proposal_Items)

[Test Standard Designation and Name for Tests Included in HMA Certifications](#_Test_Standard_Designation)

[MDOT Certified Soil, Aggregate and CSM Test Procedures](#_MDOT_Certified_Soil,)

[AASHTO re:source Proficiency Sample Program](#_AASHTO_re:source_Proficiency)

[References](#_References) (Note: Parenthetical citations throughout the Supplement appear in this section.)

# Items for Consultant Proposal

MDOT practice for obtaining materials test data for pavement, bridge and other design applications, and subsequent construction quality control/quality assurance (QC/QA) follow industry accepted testing standards. The **Testing Facilities and Technician Experience** section of the proposal allows the Consultant to convey to the MDOT how the proposing Consultant’s laboratory and technician qualifications meet these same standards when construction materials testing tasks are included in the research work plan. The premise is the same level of quality in test results will be realized to support research study conclusions and recommendations as for design and construction QC/QA applications of similar test data.

## Identify all Laboratories

The research proposal will identify all laboratories that will be employed for construction materials testing. In those cases where more than one laboratory is included, the proposal will identify which tests will be performed in each laboratory.

## All Laboratory Tests Conducted in either an MDOT Certified or AASHTO re:source Accredited Laboratory

All laboratory construction material testing will be conducted in either an MDOT certified or an AASHTO re:source accredited laboratory. AASHTO stands for “American Association of State Highway and Transportation Officials.” The proposal will address whether the proposed laboratory is certified by MDOT and/or accredited by AASHTO re:source to perform the tests listed in the proposal. In those cases where the proposing laboratory does not meet either of these qualifications at the time of submission of the proposal, a plan will be included in the proposal outlining the steps the proposing laboratory will follow to meet one of these qualifications.

The MDOT Research Division will not compensate a private testing firm to obtain either of these credentials; however, accommodation is made for university laboratories and student conduct of tests. See Section 11, “Universities.”

If the proposing laboratory is not certified or accredited, and the proposal does not include a plan to obtain one of these credentials prior to conducting the tests, the RSC will determine whether to allow use of that laboratory. If the RSC does allow use of a laboratory that is not either certified or accredited, the RSC will provide the rationale for this decision to the MDOT State Research Engineer through the proposal review process.

## Determining if a Laboratory is certified by MDOT

If a private; i.e., non MDOT, laboratory is included in a research proposal to provide testing services for a research study, it is the responsibility of the RSC to ensure that laboratory is either certified by MDOT, or accredited by AASHTO re:source, to perform the requisite testing services. The MDOT Materials Division maintains a list of laboratories that are certified by MDOT; however, this list is not available online. The RSC may contact the MDOT Materials Division Laboratory Operations Engineer to verify if the proposed laboratory is certified by MDOT to perform the tests included in the research proposal.

## Determining if a Laboratory is accredited by AASHTO re:source

AASHTO re:source maintains a Directory of AASHTO re:source Accredited Laboratories at <http://www.aashtoresource.org/aap/accreditation-directory> (1).

The RSC will confirm if a laboratory is accredited for the particular test(s) listed in the proposal by accessing this website and entering the name of the laboratory. If the PI or RSC is in need of specific testing, but has not yet selected a laboratory, the website allows a search for all accredited laboratories that offer the required testing service.

## MDOT Certified or AASHTO re:source Accredited Laboratories

The process followed by a laboratory to obtain MDOT certification is similar to that used to obtain AASHTO re:source accreditation in that both require an inspection of the laboratory and verification that the technicians can perform the required test procedures. However, AASHTO re:source accreditation includes a third significant requirement, laboratory participation in a Proficiency Sample Program, (PSP).

The process that an entity must go through in order to initially obtain AASHTO re:source accreditation for specific test procedures conducted in its laboratory, and the subsequent maintenance of that accreditation, fosters high end user confidence in the quality of test results provided by that laboratory. [Section E-4](#_AASHTO_re:source_Proficiency) of this supplement provides the rationale for preferring the use of an AASHTO re:source Accredited Laboratory in studies where construction material test results have a significant impact on the implemented deliverables of those studies.

## Subcontract to AASHTO re:source Accredited Laboratory

Those agencies that are otherwise qualified and interested in performing a study for the Department, but do not have direct access to a qualified laboratory, may subcontract their testing needs to an AASHTO re:source Accredited Laboratory. This option is not available to a principal investigator (PI) working through the Mississippi State University Master Contract for Research, Technology Development and Engineering Services because that contract does not allow for subcontracting any work related to the conduct of a university study.

## Sampling and Testing – General Requirements

All material sampling and testing shall be in accordance with an industry accepted test standard such as an AASHTO, American Society for Testing and Materials (ASTM), or Mississippi Test (MT) procedure. The conditional exceptions to this requirement are when the objectives of the given study are either revising an existing test procedure, or developing a new test procedure.

The proposal will list all applicable AASHTO, ASTM, or MT sampling/testing standards included in the research effort. When selecting test standards, preference will be given to the AASHTO standard in those cases where a comparable ASTM standard exists, unless final application of the test data dictates use of the ASTM version of the test standard.

Any planned deviation from the prescribed standard test methods; i.e., AASHTO, ASTM, or MT, shall be clearly defined in the proposal and ultimately discussed in the final report. During the conduct of the tests any unplanned deviation from the prescribed standards shall be immediately brought to the attention of the RSC. Reporting of test results shall be in accordance with the requirements set forth in AASHTO R18 – Standard Recommended Practice for Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories.

## Field Sampling Plan

For research studies that call for field sampling of construction materials, the Consultant and RSC will develop a detailed sampling plan that includes sampling locations, types of materials to be sampled, and the number of samples to be obtained. This information will be compiled into one or more associated work tasks in the research study scope of work.

This section will also include a description of the Consultant’s equipment to perform any material sampling, sample processing, and sample storage as part of the conduct of the research study. For example, if the proposed study is evaluating the engineering properties of soil cement base layers, using six-inch diameter cores taken from existing pavement sections, the proposal will provide details of the drill rig and associated apparatus/equipment to be used for the pavement coring and sample extraction operations. This would allow the RSC to evaluate whether the Consultant’s proposed drilling/sampling equipment is actually capable of obtaining intact testable cores.

## Field Testing Plan

For research studies that call for field testing of construction materials, the Consultant and RSC will develop a detailed testing plan that includes test locations and types of testing to be conducted. This information will be compiled into one or more associated work tasks in the research study scope of work. This section will also include a description of the Consultant’s equipment to perform any field testing as part of the conduct of the research study.

This plan is based on anticipated field conditions; however, deviation from this plan may be required at the time the field work is conducted due to differences between anticipated and actual field conditions. When such a situation occurs the Consultant will advise the RSC and both entities will collaborate in an attempt to develop a revised plan that both accommodates the actual field conditions and provides the required test data to achieve the research study objectives. In certain cases the RSC may allow the Consultant to deviate from the field testing plan solely at the discretion of the Consultant; however, this will be agreed upon between the two entities prior to such occurrence.

Any deviations from the original plan will be reported in the quarterly progress report (QPR) in which such deviation occurred along with the reason(s) for their occurrence. The potential impact on achieving the research study objective(s) will also be documented in this QPR for future reference. The final report will include discussion of any deviations and their corresponding impact(s) on achievement of the research study objective(s).

## Laboratory Testing Plan

For research studies that call for laboratory testing of construction materials, the Consultant and RSC will develop a detailed testing plan that includes a list of proposed test procedures and an estimated number of tests to be performed following each of those procedures. This information will be compiled into one or more associated work tasks in the research study scope of work.

### Laboratory Test Equipment

The laboratory test equipment shall meet the following requirements before performing any tests for a given research study:

* Laboratory will be fully equipped to perform the test.
* Laboratory will have equipment that meets the requirements of the specified test.
* Equipment will be set up.
* Equipment will be calibrated according to the procedures and frequencies given in AASHTO R18. For equipment not listed in R18, calibration will be in accordance with the manufacturer’s recommendations.
* PI or laboratory manager will maintain proof of testing equipment calibration.
* All test equipment will be inspected by either AASHTO re:source or MDOT.

## Personnel

The proposal shall include a personnel organizational chart for the laboratory that displays each individual’s name and corresponding job description involved with providing field sampling, field testing, and laboratory testing services for the study. This includes both laboratory management and technician personnel.

### Laboratory Management

At the request of the TAC, the testing entity shall provide a resume for the laboratory manager and any other supervisory technical staff listed in the research proposal. If the proposed research is funded by MDOT the PI will advise the TAC of any change in laboratory management staff occurring between initial submission of the proposal and completion of all tasks associated with field sampling/testing or laboratory testing for that study. At the request of the TAC, the testing entity shall provide a resume for the new manager/supervisory technical staff member(s).

The requirements discussed in this section should not be confused with those for the PI. PI qualifications are considered in Section 10, “Qualifications and Experience of Principal Investigator(s),” while the focus in the current section is on the laboratory, including its management, technicians, and testing equipment. This distinction does not preclude the PI from assuming laboratory management responsibilities. If the PI does assume such responsibility, it will be conveyed in Section 11 along with his/her qualifications to perform in this capacity.

## MDOT Certified Technicians

All of the field sampling, field testing, and laboratory testing tasks shall be conducted by an MDOT certified technician, or under the direct supervision of an MDOT certified technician. The research proposal shall identify all certified technicians proposed to conduct/oversee sampling or testing for the study. In those cases where more than one laboratory is included, the proposal will identify the certified technicians in each laboratory. The RSC may confirm that each of the listed technicians are certified prior to the conduct of any materials sampling/testing tasks.

Hot mix asphalt (HMA) and concrete construction materials are tested by technicians that may be certified at one or more of several available levels of certification. Each level of certification includes a list of corresponding test procedures. A technician who is certified at a given level has demonstrated proficiency in the performance of those tests included in that certification level. Soils, aggregates, and cementitious stabilized materials (CSMs) are not included in particular certification levels per se, but are covered under an MDOT certification program.

The PI and RSC will determine which type and level of construction material certification is required by the technician(s) to perform all sampling and testing tasks listed in the proposal. The MDOT Materials Division Laboratory Operations Engineer may also be consulted to aid in evaluating the level of expertise required by the technician(s).

The following sections provide details for the various levels of certification available for both HMA and concrete, and the corresponding test procedures, to aid the PI and RSC in selecting the appropriate type and level of certification for the study. These sections also provide means by which the RSC may confirm requisite certification of technicians.

## HMA Technicians

Table 1, “HMA Technician Certification Levels and Corresponding Test Procedures,” may be used to aid in determining which level of certification is necessary to perform the HMA tests and/or mix designs included in the research proposal. This table provides the HMA technician tasks and set of test procedures that correspond to each of three levels of available certification for HMA materials. Note that obtaining the Certified Mixture Design Technician (CMDT) certification will also satisfy the requirements for Certified Asphalt Technician (CAT) CAT-I certification. [Section E-2](#_Test_Standard_Designation) of this supplement provides a correlation of each of the test standard designations included in Table 1 to test title; i.e., AASHTO T2, Sampling of Aggregates.

It is anticipated that the course content and corresponding test procedures included in each level of HMA certification training will change with advances in HMA mix and pavement design technologies. Therefore, the information in this table needs to be checked on a periodic basis to ensure it is up to date when it is used to confirm the level of certification(s) required for a given study.

A Board of Directors oversees the HMA Certification Program. Paragraph 1.3.3.2, “Program Administration,” included in reference (2) describes the responsibilities of this Board, one of which is the content of each of the courses used to train individuals to become certified HMA technicians. The content of these courses in turn dictates the information included in Table 1.

Whenever an HMA related research study is funded, the MDOT Research Division TAC member for that study should request the HMA subject matter expert (SME) TAC member to review the content of Table 1 and advise of any required changes. Typically the HMA SME will be employed in the MDOT Materials Division and either have access to the latest information or know the current instructor of the HMA certification classes.

If the HMA SME cannot provide this information, the MDOT Research Division TAC member should contact the MDOT Materials Division Laboratory Operations Engineer and this person should be able to provide the contact information for either the current instructor of the HMA certification classes, or for one of the members of the Board of Directors overseeing the HMA Certification Program.

**Table E-1. HMA Technician Certification Levels and Corresponding Test Procedures**

|  |  |  |
| --- | --- | --- |
| **HMA Technician’s Tasks** | **Test Method Required** | **Certification Required** |
| Responsible for daily sampling, testing, data calculations, charting and process monitoring at the HMA plant | AASHTO Designation: T2, T11, T27, T166, T209, T269, T275, T308, T312, T331 ASTM Designation: D3665, D5821, MT Designation: 6, 31,59,63,76, and CSD-50-70-54-00  | Certified Asphalt Technician – I (CAT-I) |
| Responsible for the successful operations of the QC program at the HMA plant and the necessary adjustments to the process to maintain the mixture within the required control limits | AASHTO Designation: T2, T11, T27, T84, T85, T166, T209, T269, T275, T308, T312, T331 ASTM Designation: D3665, D5821, MT Designation: 6, 31, 59, 63, 76, and CSD-50-70-54-00 | Certified Asphalt Technician – II (CAT-II) |
| Responsible for testing according to MDOT design procedures for the development of a job mix formula for HMA mixtures | AASHTO Designation: T2, T11, T27, T37, T84, T85, T88, T90, T166, T209, T269, T275, T308, T312, T331 ASTM Designation: C1252, D3665, D4791, D5821, MT Designation: 6, 24, 31, 59, 63, 76, 78 | Certified Mixture Design Technician (CMDT) |

## Determining if a Technician is certified to Test HMA

The Mississippi Asphalt Pavement Association (MAPA) maintains a list of certified HMA technicians within the state. This list can be accessed through the MAPA website. The list provides the name, level of certification, company, and other relevant information for each of these technicians. During the review of a research proposal that includes HMA testing, the RSC should access the MAPA website to ensure that the PI has included a certified technician who is qualified to either directly perform, or oversee the performance of, the specific HMA test(s) listed in the proposal.

## Concrete Technicians

The Mississippi Concrete Association (MCA) document, “Certified Concrete Technicians,” includes a list of test procedures evaluated in each of following MCA certification programs:

* MDOT Class 1 or ACI Grade 1 Field Testing Technician Grade 1
* MDOT Class 2 or ACI Aggregate Testing Technician Level 1
* ACI Strength Testing Technician

The MDOT Class 3 Concrete Technician Certification emphasizes developing, approving, and adjusting concrete mix designs. The referenced document may be accessed through the MCA website.

The information contained in the Certified Concrete Technicians document may be used to aid in determining which level of certification is necessary to perform the concrete tests and/or mix designs included in the research proposal. As for HMA, it is anticipated that the MCA certification course content and corresponding test procedures will change with advances in concrete mix and pavement design technologies; therefore, RSCs should access the online version of this document each time a new concrete research study is funded to confirm level of certification(s) required for the given study.

## Determining if a Technician is certified to Test Concrete

MCA maintains a list of certified concrete technicians within the state. This list is included in the MCA document, “Certified Concrete Technicians,” which can be accessed through the MCA website. The list provides the name, level of certification, company, and other relevant information for each technician. During the review of a research proposal that includes concrete testing, the RSC should access the MCA website to ensure that the PI has included a certified technician who is qualified to either directly perform, or oversee the performance of, the specific concrete test(s) listed in the proposal.

## Soils, Aggregates, and CSMs Technicians

The MDOT Soil Certification Program (SCP) allows a technician to be certified for specific test procedures rather than a suite of tests such as those included in the various HMA and concrete certification levels. A list of the test procedures and specifications included in the MDOT SCP is included in [Section E-3](#_MDOT_Certified_Soil,) of this supplement. During the development of a research proposal that includes soil, aggregate, and/or cementitious stabilized material (CSM) testing, the PI and RSC should refer to this supplement to determine which of the proposed tests are available for MDOT certification. CSMs are a class of pavement construction materials including lime, lime-fly ash, and cement stabilized soils, each requiring mix designs that are performed in the MDOT Soils and Physical Laboratory.

It is anticipated that the list of test procedures included in the MDOT SCP will change with time thus requiring periodic review and possible update to the list of test procedures included in Section E-3. Whenever a soils, aggregates, or CSM related research study is funded, the MDOT Research Division TAC member for that study should review the content of the MDOT SCP, and when appropriate, update the content of Section E-3. The MDOT Soils, Geotechnical, Aggregates, Physical Testing Engineer can provide the current list of test procedures included in the MDOT SCP at the time of the review.

## Determining if a Technician is certified to Test Soils, Aggregates and/or CSMs

The MDOT Soils, Geotechnical, Aggregates, Physical Testing Engineer maintains a list of technicians certified to test soils, aggregates and CSMs. The RSC should contact this engineer to ensure that the PI has included a certified technician who is qualified to either directly perform, or oversee the performance of, the specific soil, aggregate, and/or CSM test(s) listed in the proposal.

## Cases Where Proposed Test Procedure(s) are not included in either the MDOT Certification or AASHTO re:source Accreditation Program

Research studies may employ test procedures that are not included in either the MDOT Certification or AASHTO accreditation programs. Two other variations of this theme include:

* Modifications to an existing test standard that is part of one of the aforementioned certification/accreditation programs,
* Development of a new test standard.

Several factors may be considered to enhance the confidence of an RSC in test results obtained in these cases. The following text discusses five factors.

1. The status of the laboratory’s certification or accreditation to perform supporting tests.
2. Certified technicians performing the supporting tests.
3. The proposed tests are performed by technicians certified in the same type of construction material.
4. Calibration of equipment not included in either of these programs.
5. Interlaboratory side-by-side testing.

### Status of the laboratory’s certification or accreditation to perform supporting tests

Test procedures that are not included in either the MDOT certification or AASHTO accreditation programs often utilize supporting test results derived from use of other test procedures that are included in one of these programs. For example, AASHTO T307, “Determining the Resilient Modulus of Soils and Aggregate Materials,” is not included in either of these programs; however, in order to conduct the procedure outlined in T307, a number of other AASHTO test procedures must to be employed to properly characterize the material, and then prepare a test specimen of same – these are supporting test procedures. Many of these supporting test procedures are included in either the certification or accreditation program. If an RSC is considering use of a particular laboratory to perform AASHTO T307, that laboratory should be certified or accredited to perform all supporting tests for which certification or accreditation is available.

The majority of proposed test procedures will require use of laboratory equipment that is included in either the MDOT certification or AASHTO accreditation program, such as electronic balances, loading frames, and sieves. This laboratory equipment is supposed to meet industry-accepted standards if it has been inspected via one of these programs. Therefore, even if the proposed test procedure is not included in either the certification or accreditation program, knowing that any associated test equipment has been checked via one of these programs can enhance the confidence of an RSC in the test results from use of that procedure.

In summary, the first factor may be addressed by performing each of the following steps:

* Identify required supporting tests to perform the test in question.
* Determine if supporting tests are included in either the MDOT certification or AASHTO accreditation programs.
* Determine if the proposing laboratory is certified or accredited to perform those supporting test procedures.

### Certified technicians performing the supporting tests.

The laboratory should have certified technicians performing any supporting tests for which certification is available. For example, AASHTO T307 includes a supporting test, AASHTO T89, “Determining the Liquid Limit of Soils.” A technician can be certified to perform this test procedure via the MDOT SCP. The RSC should confirm that the proposed technician is certified to perform this supporting test prior to his/her performance of the test.

### The proposed tests are performed by technicians certified in the same type of construction material.

The proposed test procedure should be performed by a technician that is certified in the same type of construction material as that being used in the test procedure, and at a level of certification that most closely corresponds to the requirements of the proposed procedure. For example, if the objective of a proposed research study is to develop a new way of designing HMA mixes, the PI and RSC should require a CMDT to be responsible for performing the requisite testing, not a CAT I.

### Calibration of equipment not included in laboratory inspections.

Proof of proper calibration of any specialized testing equipment not included in the laboratory inspections associated with MDOT certification or AASHTO re:source accreditation enhances the laboratory’s qualifications to perform the proposed test(s). For example, a local engineering firm uses an Interlaken Soil & Asphalt Test System to perform the resilient modulus (MR) test. This particular test apparatus is not included in a current laboratory inspection program; however, the manufacturer of this equipment provides detailed guidelines for how this equipment should be calibrated. In addition, the services of a private testing firm that specializes in MR testing can be employed to ensure proper calibration of this equipment. The RSC should request the proposing laboratory to provide proof of calibration of such equipment.

### Interlaboratory side-by-side testing.

The Federal Highway Administration (FHWA), a private testing firm, or university experienced in the conduct of a proposed test procedure may participate in a side-by-side testing arrangement with the laboratory employed to perform the proposed test procedure for the research study. Using this approach, the test is conducted in both laboratories and then a comparative analysis of the test results is performed to evaluate the level of agreement between the two sets of laboratory data. Reasonable agreement between the two sets of data enhances the confidence of an RSC in the test results from the laboratory employed for the research study.

For example, MDOT funded a laboratory study with a local engineering firm entitled “Laboratory Data to Determine Impact of Coarse Aggregate Type and Cementitious Materials on Design Thickness of PCC Pavements.” “PCC” refers to Portland cement concrete. In this study twenty concrete mixes were tested for their requisite pavement design properties.

Elastic modulus, (E) and coefficient of thermal expansion, (CTE) are required PCC material property inputs to the AASHTOWare Pavement ME Design software when designing a PCC or “rigid” pavement. Changes in the values input to the software for E and CTE impact the level of calculated stresses that develop in the PCC pavement slab due to traffic loading and changes in moisture and temperature within the slab. These calculated stresses in turn are used to predict amount of cracking that will be observed in the surface of the rigid pavement over time; i.e., more cracking is observed in the surface of the pavement as the pavement ages. Total amount of cracking at a given point in time is a performance criteria used to design the thickness of a PCC slab and underlying base layer. Therefore, E and CTE need to be measured as accurately as possible to minimize error; i.e., either over or under designing this type pavement.

E and CTE are not measured on a routine basis for the design of PCC pavements; therefore, two interlaboratory side-by-side testing arrangements were employed to evaluate the quality of the test data using subsets of the twenty mix designs. E was evaluated for all twenty mix designs by the local engineering firm. For five of the twenty mix designs E was also evaluated by the Federal Highway Turner Fairbanks Highway Research Center in McLean, Virginia. A comparison of the five E test results between these two laboratories resulted in a high level of confidence for use of the E value for each of the twenty mixes measured at the local engineering firm as input to AASHTOWare Pavement ME Design.

Since CTE is not measured at the local engineering firm an out-of-state independent laboratory was selected to perform CTE testing for all twenty mixes. The CTE of four of the twenty mixes was also evaluated by the Turner Fairbanks laboratory. A comparison of CTE test results between these two laboratories resulted in a high level of confidence for use of the CTE value for each of the twenty mixes measured by the independent laboratory as input to AASHTOWare Pavement ME Design. Additional details of the comparison of the two sets of test data; i.e., one set for E and one set for CTE, may be found in the MDOT SS No. 260, “Guidelines for PCC Inputs to AASHTOWare Pavement ME.”

## Test Reports and Supporting Records

All reports of test results and supporting test records will be provided to the Department as study deliverables. The content of the test reports shall be in accordance with the requirements of the specific test procedure(s) employed in the conduct of the study. The following quote from paragraph 6.7.2 of AASHTO R18 provides details of what constitutes “supporting test records:”

Test Records – The laboratory shall maintain test records that contain sufficient information to permit verification of any test reports. Records pertaining to testing shall include original observations, calculations, derived data, and an identification of personnel involved in sampling and testing. (3)

Laboratory test methods used for measuring the stiffness of soils, unbound aggregates, and HMA under varying environmental and loading conditions entail multiple observations and calculations to generate the test data. As an example, consider AASHTO T307. It entails a relatively complicated test procedure requiring sophisticated equipment to condition a test sample, and then record a large number of load and displacement measurements on that sample. The test results that it produces must then be subjected to a numerical optimization routine to produce a value for each of three “k” coefficients. These “k” coefficients are in turn used in the generalized equation for predicting the resilient modulus of a soil under varying stress conditions.

Another example is AASHTO T342, “Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures,” that provides test data used in numerical optimization routines to derive fitting parameters for developing an HMA master curve. Both of these examples illustrate the generation of large sets of data that are digitally recorded and stored during testing for subsequent use in calculating final test results and products.

In these and similar cases, both the test data and derived data will be provided in electronic format to the Department as a research study deliverable. The final report should clearly convey to the RSC the techniques used to reduce the test results to the form(s) required for final application.

All test records and reports will be included in the electronic versions of the final report submitted to the Department. However, at the discretion of the RSC, the paper copy version of the final report may omit these records and reports.

## Experience

The proposal will describe similar type work completed during the past five (5) years which qualifies the laboratory, laboratory management, and technicians to perform the proposed testing tasks. The five-year period coincides with the minimum time required for an accredited agency to retain the various type records listed under section 5.9, “Records Retention:” of AASHTO R18. These records include technician training and evaluations.

## Performance Charts

Depending on how critical high quality test results are to the successful implementation of a research study, an RSC may want to know how the proposing laboratory has performed over time for one or more of the proposed tests. This information can be found in the form of a performance chart provided to that laboratory each time it participates in a round of proficiency testing. Details of laboratory proficiency testing and an example of a sample performance chart with some interpretive text are included in Section E-4 of this supplement.

An example of a general category of research studies, where an RSC may consider requesting performance charts, would be when the implementable deliverable of these studies is some sort of predictive equation. In this example category of studies, the predictive equations would be used to estimate fundamental engineering material properties from the results of relatively inexpensive and easy to perform routine tests.

As a specific example, consider AASHTO T307. It can be used to predict the resilient modulus (MR) of a soil; however, as previously discussed, it is a relatively complicated test procedure. The MR of a soil can be estimated from the results of routine laboratory soil tests, such as those used in the following predictive equation for fine-grain soils found in Mississippi (4):

MR = 16.75((LL/wc X ɣdr)2.06 + (#200/100)-0.59)

 Where: MR  = Resilient modulus, MPa;

 LL = Liquid Limit, %;

 wc = Moisture content, %;

 ɣdr = dry density/maximum dry density;

 ɣd  = dry density, kN/m3;

 #200 = Passing #200 sieve, %

In this equation five test results are required to estimate a value for the MR, each according to an AASHTO test standard. The routine soil test results used to initially develop such an equation must be of the highest quality because the intended end use of the equation is to provide input values for pavement design.

AASHTO re:source will not provide to the public a laboratory’s ratings from the last round of proficiency sample testing or the corresponding performance chart for a given test procedure; however, this does not preclude the RSC from requesting this information directly from the laboratory in question. It would be informative if that laboratory refused to share its last ratings or its performance chart with the RSC. In this situation the RSC may want to consider using another laboratory to obtain the required testing services.

## University Laboratories and Qualified Personnel to perform Tests

An MDOT certified laboratory is one in which the laboratory facility, test equipment, and personnel responsible for producing quality test data are approved by the MDOT Materials Division Central Laboratory. University laboratories and personnel employed to perform materials testing as part of the conduct of a given research study must meet requirements similar to those maintained by private laboratories that are certified by the MDOT Central Laboratory.

When a PI from a university proposes a research study that includes materials testing by his/her university laboratory and personnel, both the laboratory and the personnel managing the performance of materials testing shall be approved by the MDOT Central Laboratory prior to the conduct of any testing in support of that research study. MDOT approval is based on an inspection of the university’s laboratory facility and equipment by personnel from the MDOT Central Laboratory and demonstration to the MDOT inspectors of the proficiency by which the laboratory managers conduct the various tests included in the research proposal. The following sections provide details for cases where a PI from a university proposes to use his/her university laboratory and personnel to provide test data for a given MDOT funded research study.

## MDOT Inspection and Approval of University Laboratories

When a PI submits a research proposal that incorporates use of a university laboratory that is not currently approved by MDOT to perform the test standards and procedures listed in that proposal, the PI will include a task in the research plan for an MDOT Central Laboratory inspection of that laboratory facility and equipment. The same requirements for the laboratory facility and equipment in a private laboratory apply to a university laboratory. See section “Laboratory Test Equipment.” Any deficiencies noted during the inspection will be corrected by the university. The MDOT Central Laboratory will confirm that any observed deficiencies are corrected prior to approving the university laboratory facility and equipment as meeting the requirements for use in conducting the proposed test standards or procedures.

MDOT approval of the university laboratory facility and equipment is applicable for three years and only for the equipment actually inspected by the Central Laboratory. If additional studies are proposed during that three-year period of time that involve test equipment that was not subject to the previous laboratory inspection, the MDOT Central Laboratory will inspect such equipment and approve same prior to its use.

It is the responsibility of the RSC to ensure that the university laboratory facility and equipment related to the conduct of the research study is approved by the MDOT Central Laboratory prior to the conduct of any materials testing. Any issues that prevent the Central Laboratory from approving this equipment will be reported to the MDOT State Research Engineer. In these cases the MDOT State Research Engineer may discontinue further consideration for funding the study, or if the study is already under contract, the contract may be terminated by MDOT. The MDOT Research Division TAC member will provide administrative assistance to the RSC to help facilitate this process.

## MDOT Approval of University Laboratory Manager(s) Performance in Testing Construction Materials

When a PI submits a research proposal that employs university laboratory managers that are not currently approved by MDOT to perform the test standards and procedures listed in that proposal, the PI will include two tasks in the research plan. One of these two tasks is performed by MDOT Central Laboratory inspectors where they observe the university laboratory managers perform each of the test standards or procedures listed in the research scope of work.

The second task is performed by the university to account for the university manager(s) demonstration in performing each test included in the research proposal to the satisfaction of the MDOT inspectors. These two tasks may be conducted at the MDOT Central Laboratory or at the university. In the former case, the PI will be responsible for making all arrangements to ensure that his/her managers are provided requisite transportation, food and lodging. The MDOT Research Division will compensate the university via the research work assignment for all manager travel associated costs with this task. Note that such compensation will only be rendered in support of approving university laboratory managers, not managers employed in private testing laboratories.

In certain instances the PI may employ one or more students who have not demonstrated proficiency in performing tests included in the scope of work. This is acceptable so long as these individuals are working under the direct supervision of a laboratory manager who has demonstrated proficiency.

The RSC will ensure that the manager(s) are approved by the Central Laboratory prior to conducting/overseeing any tests requiring such approval. Any issues that prevent the Central Laboratory from approving the performance of the laboratory manager(s) will be reported to the MDOT State Research Engineer. In these cases the MDOT State Research Engineer may discontinue further consideration for funding the study, or if the study is already under contract, the contract may be terminated by MDOT. The MDOT Research Division TAC member will provide administrative assistance to the RSC to help facilitate this process.

## University PIs shall maintain MDOT approved University Laboratory Managers throughout duration of Testing Phase for each Research Study

A PI may function as the university laboratory manager if he/she provides **direct** oversight of the students performing any tests associated with the proposed research. Or the PI may require a student to function in this capacity. In either case, the laboratory manager is approved for a period of three years and then must again demonstrate proficiency in the performance of specific test procedures associated with any ongoing or new proposed research studies at the end of that three-year period.If the PI is not approved to function as the laboratory manager and an approved student manager leaves the university during the duration of a given study, the new student tasked with oversite responsibilities shall be approved by MDOT inspectors before assuming the role as laboratory manager.

## Enhancing Quality of University Student Test Results Using AASHTO re:source extra Proficiency Samples

Typically the private engineering/testing firms employed in a Department funded research study are AASHTO re:source accredited and have experienced technicians on staff to provide reliable test data. However, university students typically do not have the testing experience of these practicing technicians. Depending on how critical quality test results are to implementing the findings of a study funded with a university, the MDOT Central Laboratory may arrange for the students to perform tests using extra proficiency samples provided by the AASHTO re:source Proficiency Sample Program. These samples are not available for all test standards but when available, allow the students to test split samples of materials that have been tested in a multitude of laboratories using the same test standards. See the following section for a definition and discussion of use of split samples.

For example, if the PI includes AASHTO T 89, Determining the Liquid Limit of Soils and AASHTO T 90, Determining the Plastic Limit and Plasticity Index of Soils in the research proposal, an extra proficiency sample may be provided for the student to perform these tests. If the student’s test results fall within two standard deviations of the mean of the results from all of the laboratories participating in the AASHTO re:source Sample Proficiency Program, the student is performing these tests as well as any full time technician.

## Enhancing Quality of University Student Test Results Using Precision Statements

In those cases where high quality test results are critical to implementing the findings of a study funded with a university and no AASHTO re:source extra proficiency samples are available for the test standards, two additional steps may be required by the RSC to help ensure quality test results are provided by the students.

Assuming step one is MDOT inspection and approval of the university laboratory facility and equipment and step two is MDOT approval of the university laboratory manager(s) proficiency performance of the tests, steps three and four employ the use of test standard precision statements. A review of these statements is included in Section E-4 of this supplement.

The third step is for the student to practice the test procedure at the university laboratory until he/she achieves a measurable level of proficiency at performing the test. Measuring this level of proficiency is made by considering the repeatability of test measurements within the same laboratory. Note that not all test procedures have such a statement, but if the test under consideration does, then it should be used to help ensure quality test results.

After the student has practiced the test procedure to the point that he/she is able to repeat the test result in the university laboratory to within the tolerance allowed by the applicable test procedure within-laboratory precision statement, then the fourth step of the solution is for that student to demonstrate proficiency at performing the given test by participating in split sample testing with an MDOT technician. Corresponding to the **within**-laboratory precision statement is a **between**-laboratory precision statement for the same test standard.

The MDOT technician would run the particular test on his/her half of the split sample at the MDOT laboratory, and the student would run the same test on the other half of the sample at the university laboratory. The two test results should be within the prescribed tolerance of the applicable between-laboratory precision statement. Again, not all test procedures include a precision statement, but when it does, it should be utilized in this fourth step.

If the RSC requires these two additional steps, they will be included in the appropriate research study tasks.

# Test Standard Designation and Name for Tests Included in HMA Certifications

AASHTO T2 Sampling of Aggregates

AASHTO T11 Materials Finer Than 75-um (No. 200) Sieve in Mineral Aggregates by Washing

AASHTO T27 Sieve Analysis of Fine and Coarse Aggregates

AASHTO T331 Bulk Specific Gravity (Gmb) and Density of Compacted Hot Mix Asphalt (HMA) Using Automatic Vacuum Sealing Method

AASHTO T37 Sieve Analysis of Mineral Filler for Hot Mix Asphalt (HMA)

AASHTO T84 Specific Gravity and Absorption of Fine Aggregate

AASHTO T85 Specific Gravity and Absorption of Coarse Aggregate

AASHTO T88 Particle Size Analysis of Soils

AASHTO T90 Determining the Plastic Limit and Plasticity Index of Soils

AASHTO T166 Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens

AASHTO T209 Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)

AASHTO T269 Percent Air Voids in Compacted Dense and Open Asphalt Mixtures

AASHTO T275 Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens

AASHTO T308 Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

AASHTO T312 Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

ASTM C1252 Test Method for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)

ASTM D3665 Standard Practice for Random Sampling of Construction Materials

ASTM D4791 Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate

ASTM D5821 Standard Test Method for Determining the Percentage of Particles in Coarse Aggregate

MT-6 Nuclear Determination of Bitumen Content of Bituminous Paving Mixtures

MT-24 Determination of the Specific Gravity of Fine Aggregate Using the Le Chatelier Flask

MT-31 Quantitative Analysis of Hot Bituminous Mixtures

MT-59 Determination of Loss of Coating of HMA (Boiling Water Test)

MT-63 Resistance of Bituminous Paving Mixtures to Stripping Vacuum Saturation Method)

MT-76 Microwave Method of Determining the Moisture Content of Hot Bituminous Mixtures

MT-78 Volumetric Mix Design of Hot Bituminous Paving Mixtures Using The Superpave Gyratory Compactor

CSD-50-70-54-00 Random Sampling

# MDOT Certified Soil, Aggregate and CSM Test Procedures

AASHTO M145 Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

AASHTO R58 Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test

AASHTO T88 Particle Size Analysis of Soils

AASHTO T89 Determining the Liquid Limit of Soils

AASHTO T90 Determining the Plastic Limit and Plasticity Index of Soils

AASHTO T92 Shrinkage Factors of Soils (Using Mercury)

AASHTO T99 Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in) Drop

AASHTO T100 Specific Gravity of Soils

AASHTO T180 Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in) Drop

AASHTO T191 Density of Soil In-Place by the Sand-Cone Method

AASHTO T217 Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester

AASHTO T265 Laboratory Determination of Moisture Content of Soils

AASHTO T288 Determining Minimum Laboratory Soil Resistivity

AASHTO T310 In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

ASTM D1140 Amount of Material in Soils Finer than No. 200 (75-um) Sieve

ASTM D2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)

ASTM D2488 Description and Identification of Soils (Visual-Manual Procedure)

MT-7 Moisture-Density Relations of Soils (using family of curves)

MT-8 Moisture-Density Relations of Soils

MT-9 Moisture-Density Relations of Treated Soils

MT-10 In-Place Density of Soil

MT-11 Preparation of Field Specimens of Soil Cement

MT-16 Nuclear Method for Field In-Place Density Determination

MT-22 Sieve Analysis of Granular Materials

MT-23 Hydrometer

MT-61 Method of Test for Determining Soil Resistivity

MT-92 Shrinkage Factors by Spray Wax

# AASHTO re:source Proficiency Sample Program

If the standards for performing a particular test are adhered to, i.e., if the same method for making a particular measurement is followed each time the measurement is made, then is it possible to numerically characterize the quality of each test result. By virtue of knowing that the test procedure is being followed correctly, the RSC can have a quantifiable level of confidence in the test results provided for a given research study. Use of an AASHTO re:source accredited laboratory allows an RSC this confidence because the laboratory participates in the AASHTO re:source Proficiency Sample Program (PSP). This confidence is derived from three results of laboratory participation in a PSP:

* Laboratory Z-score
* Laboratory Performance Chart
* Precision Statements

The AASHTO re:source PSP provides laboratory equipment inspection, observation of technician competency, and a review of the quality management system for those laboratories engaged in the testing of asphalt cement, hot mix asphalt, emulsified asphalt, aggregate, soil, metals, plastic pipe, and sprayed-applied fire-resistive materials (SFRM) (5). The Cement and Concrete Reference Laboratory (CCRL) provides similar services for those laboratories engaged in the testing of cement, concrete, aggregate, steel reinforcing bars, pozzolan, and masonry materials (mortar and solid units) (6).

Both AASHTO re:source and CCRL sponsor a PSP for their respective spheres of construction materials. This program is essentially the same for both entities. Multiple test samples of the same material are produced and distributed to participating laboratories in the respective PSP. Each laboratory performs the same test(s) on the samples and returns the test results to the sponsoring agency for analyses. The end result of following this procedure allows the participating laboratories a way for comparing a given laboratory test result to the collective, or average, result of all of the laboratories for the given test standard – such a comparison is numerically expressed in terms of the standard deviation of the data. AASHTO T89, the test standard for determining the liquid limit (LL) of a soil, is part of the AASHTO re:source PSP and will be used as an example to illustrate in more detail the general procedure used for all construction materials included in either the AASHTO re:source or CCRL PSP.

Each year AASHTO re:source procures two large bulk samples of soil for processing and distribution to the laboratories participating in the AASHTO re:source PSP soil series of tests. AASHTO T89 is one of the tests included in the soil classification and compaction test series. Each bulk sample is processed to remove impurities and then thoroughly mixed to ensure homogeneity of soil composition throughout the respective sample. Each sample is assigned a number, such as 165 and 166. Typically the composition of both bulk samples are very similar, but not exactly the same.

Each bulk sample is then subdivided into smaller samples. Due to the way the soil was processed, each of the smaller samples from sample 165 are essentially the same in composition – likewise with the smaller samples from sample 166. A pair of the smaller samples, one from 165 and one from 166, is then distributed to each of the participating laboratories. In this example, each laboratory performs AASHTO T89 on the two samples and then reports the LL test results to AASHTO re:source. A single cycle of sample distribution to, and testing by, the various laboratories is called a “round of proficiency testing.” All of the samples that are distributed in this cycle are collectively referred to as a “round sample.”

AASHTO re:source compiles all of the LL test results from sample 165 into one data set, and all of the results from sample 166 into a second data set. A four-step series of analyses is then performed on each set of data to extract two core sets of the best quality data (test results) and ultimately quantitatively characterize that quality (7).

## Laboratory Z-Score

In the context of the current discussion, a Z-score is a laboratory performance indicator. Numerically, it is the number of standard deviations a laboratory’s test result is located from the average value of all the test results included in a given core set of test data. Two Z-scores are calculated for each laboratory for a given round of proficiency testing – for the LL example, this would one Z-score corresponding to the laboratory’s sample 165 test result, and a second Z-score for the laboratory’s sample 166 test result.

## Laboratory Rating

A laboratory’s ratings for a given test procedure are dependent on the laboratory’s proficiency sample test results for that procedure. If a laboratory delivers a poor proficiency sample result, the AASHTO re:source Accreditation Program (AAP) Procedures Manual prescribes a procedure the laboratory must follow to address that poor result:

The laboratory shall, within 60 calendar days of the date of issuance of a proficiency sample report, (1) investigate to determine the possible reason(s) for results beyond 2 standard deviations of the grand average (i.e. z-scores greater than 2.0), (2) take action to correct any issues that are uncovered in the investigation, and (3) document and maintain records of the investigation and corrective actions taken. (8)

Note that poor test results are supposed to be documented along with the results of investigations, and any corrective actions taken. This process fosters the future delivery of quality test results in rounds of proficiency testing, and of significant interest to the RSC, quality test results to support research study conclusions and recommendations.

Laboratory ratings are based on a set of defined ranges in Z-scores. A rating is assigned by determining which range in Z-scores a given test result Z-score is located. From reference (9) the following is the laboratory rating scheme for AASHTO re:source sponsored tests based on the Z-Score:

 If Z-Score ≤ 1 then Rating = 5

 If Z-Score > 1 and ≤ 1.5 then Rating = 4

 If Z-Score > 1.5 and ≤ 2 then Rating = 3

 If Z-Score > 2 and ≤ 2.5 then Rating = 2

 If Z-Score > 2.5 and ≤ 3 then Rating = 1

 If Z-Score > 3 then Rating = 0

For example, if a sample 165 test result had a Z-score of 0.74, then the laboratory rating would be a five for that test result because 0.74 is located in the range of Z-scores from 0 to 1. Figure K1, copied from reference (10), graphically illustrates this relationship between a given range of Z-scores and the corresponding laboratory rating. This laboratory rating scheme provides for higher ratings as the value of the Z-score is reduced; i.e., as the corresponding individual test results approach the average value of the data set; therefore, the closer the individual test result to the average, the better the quality of the test result.

In summary, a laboratory Z-score is one basis for numerically characterizing the quality of a test result, and can be used to develop a level of confidence on the part of an RSC in future test results provided by the proposing laboratory. A given Z-score should be between -2 and +2 for it to be acceptable to AASHTO re:source, with preferred values approaching zero.



**Figure E-1: The Normal Distribution of AMRL Proficiency Sample Data (10)**

The key point from the current discussion is that if a laboratory maintains its AASHTO re:source accreditation for a given test method, then an RSC can have a quantifiable level of confidence in the test results provided by that laboratory. Generally speaking, that laboratory will provide results at least within two standard deviations of an average value from multiple laboratories performing the same test on the same, or similar, test sample. If it is not accredited, then there is no level of certainty in any range for the spread of test data because there is no basis for comparative analyses to quantify it; i.e., the laboratory is not participating in a PSP.

## Performance Chart

Depending on how critical high quality test results are to the successful implementation of a research study, an RSC may want to know how the proposing laboratory has performed over time in multiple rounds of proficiency testing for one or more of the proposed tests. This information can be found in the form of a performance chart provided to that laboratory each time it participates in a round of proficiency testing.

Figure K2 is a performance chart copied from reference (10) for total material passing the No. 8 sieve. An LL test performance chart would be developed the same way; i.e., the ordinates of each data point in a performance chart consist of a Z-score and the sample number corresponding to that Z-score. Since pairs of samples are tested at specific intervals of time, the y-axis is analogous to time.

Should an RSC obtain a performance chart for any test procedure, reference (10) stresses that one “bad” result from the laboratory in question is inevitably going to periodically occur:

Performance charts provide an easy way to gauge your laboratory’s proficiency testing performance over time (see Figure 3). As stated above, too much emphasis should not be placed on an occasional low rating. However, patterns in performance charts should be analyzed carefully, as they are usually good indicators of testing problems. The ideal scenario is to have all points over the center line – results right on the average time after time. Generally speaking however, points scattered within the bands of +2 and -2 are indicative of good testing performance. Points drifting away from the centerline and points consistently on one side of the centerline are indicative of performance problems. (10)



**Figure E-2: Sample Performance Chart (10)**

## Precision Statements

Up to this point in the discussion, the focus has been on considering a large number of test results from an AASHTO re:source or CCRL round of proficiency testing to numerically characterize the inherent variability in the test results of a given test procedure. The Z-score is the basis for numerically characterizing the quality of one of the test results included in the core set of data relative to all of the other test results included in that core set.

Quantifying inherent variability in test results also allows for comparison of one test result to another, such as between those submitted by two different accredited laboratories. Comparison of individual test results is an indispensable component of any successful quality control/quality assurance (QC/QA) program, and it offers an integral part of the solution to address use of non-accredited university laboratories employing students to perform testing for MDOT funded research studies.

AASHTO T89, as for many other test standards, includes what is referred to as a “Precision Statement.” The following quote defines “precision:”

Precision is the closeness of agreement between test results obtained under prescribed conditions. A statement on precision allows potential users of the test method to assess in general terms its usefulness in proposed applications. A statement on precision is not intended to contain values that can be duplicated in every user’s laboratory. Instead the statement provides guidelines as to the kind of variability that can be expected between test results when the test method is used in one or more reasonably competent laboratories. (11)

The precision statement for AASHTO T89:

17. PRECISION STATEMENT

17.1. This precision statement applies to soils having a liquid limit range from 21 to 67.

17.2. Repeatability (Single Operator) – Two results obtained by the same operator on the same sample in the same laboratory using the same apparatus, and on different days, should be considered suspect if they differ by more than 7 percent of their mean.

17.3. Reproducibility (Multilaboratory) – Two results obtained by different operators in different laboratories should be considered suspect if they differ from each other by more than 13 percent of their mean. (12)

The values 7% and 13% of the respective means for allowable ranges in LL test results were derived from analyzing sets of LL test data, such as those considered in rounds of proficiency sampling and testing.

A precision statement only applies if the two laboratories are measuring a given parameter the same way. If they are, the precision statement provides the contractor, MDOT, and an RSC a numerical characterization of the quality of those two results based on an industry accepted difference between them for the given test procedure. If the LL test is performed in accordance with AASHTO T89, then the RSC can be confident that 95% of the time a particular LL test result from one laboratory is reproducible in another laboratory within a spread of 13% of the average of the two results. In other words, the LL test standard precision statement conveys to the user of the test data that the indicated spreads in allowable values will not be exceeded by 19 out of 20 laboratories (13).

In summary, the precision statement provides an RSC with a quantifiable level of quality he/she can expect in the test results from a given test procedure. That quantifiable level of quality is the allowable spread between two test results, each derived from using the same test procedure on a split sample of a given material. Assuming AASHTO re:source accredited laboratories are performing the tests, an RSC can be confident that 95% of the time two test results will be within the applicable precision statement allowable spread.

# References

1. Accreditation Directory Search. AASHTO re:source. Retrieved March 1, 2019 , from <http://www.aashtoresource.org/aap/accreditation-directory>

1. Section 1 – Certification of Plants, Labs, and Testing Personnel. Materials Division Inspection, Testing and Certification Manual. (April 1, 2010) Retrieved March 1, 2019 from [http://sp.mdot.ms.gov/Materials/Manuals/Inspection,%20Testing,%20and%20Certification%20Manual/Entire%20Manual.pdf](http://sp.mdot.ms.gov/Materials/Manuals/Inspection%2C%20Testing%2C%20and%20Certification%20Manual/Entire%20Manual.pdf)
2. Standard Recommended Practice for Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories. AASHTO Designation: R 18-18. Part 1: Specifications (2018). American Association of State Highway and Transportation Officials. Washington, DC. Accessed MDOT online AASHTO subscription August 14, 2018
3. Rahim, A.M., and George, K.P. (2004). “Subgrade Soil Index Properties to Estimate Resilient Modulus,” Annual Meeting of Transportation Research Board (CD-ROM), National Research Council, Washington, DC.
4. AASHTO Accreditation. AASHTO Materials Reference Library. Retrieved March 1, 2019 from <http://www.amrl.net/amrlsitefinity/default/aap.aspx>
5. History of CCRL. Retrieved March 1, 2019, from <http://www.ccrl.us/Lip/About-CCRL.html>
6. Holsinger, et. al. Precision Estimates for AASHTO Test Method T308 and the Test Methods for Performance-Graded Asphalt Binder in AASHTO Specification M320. NCHRP Web-Only Document 71 (Project 09-26). National Cooperative Highway Research Program, Transportation Research Board of the National Academies, Washington, DC, February 2005. Retrieved March 1, 2019 from <http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w71.pdf>
7. The AASHTO Accreditation Program: Procedures Manual for the Accreditation of Construction Materials Testing Laboratories (June 2017). Retrieved March 1, 2019, from <http://aashtoresource.org/docs/default-source/publicdocuments/aap-procedures-manual.pdf>
8. PSP Analysis Description. AASHTO re:source. Retrieved March 1, 2019, from <http://www.aashtoresource.org/psp/analysis-description>
9. Johnson, B., Proficiency Sample Ratings: Being Average Has Never Been So Good. AMRL In-Focus Newsletter – Fall 2010. AASHTO Materials Reference Laboratory. Retrieved March 1, 2019, from <http://aashtoresource.org/university/newsletters/newsletters/2016/08/02/proficiency-sample-ratings>
10. Form and Style for ASTM Standards. (October 2018) Retrieved March 1, 2019, from <http://www.astm.org/COMMIT/Blue_Book.pdf>
11. Standard Test Method for Determining the Liquid Limit of Soils – AASHTO Designation: T 89-10. Standard Specifications for Transportation Materials and Methods of Sampling and Testing. 32nd Edition. Part 2A: Tests (2012). American Association of State Highway and Transportation Officials. Washington, DC.
12. Norris, R., The Skinny on Precision and Bias: Aiming Our Sights on Precision. AMRL In-Focus Newsletter – Spring 2012. AASHTO Materials Reference Laboratory. Retrieved March 1, 2019, from <http://aashtoresource.org/university/newsletters/newsletters/2016/08/03/the-skinny-on-precision-and-bias-aiming-our-sights-on-precision>