

Quality Assurance Manual

TABLE OF CONTENTS

CHAPTER 1

Preface	1
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CHAPTER 2

Purpose and Scope	2
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CHAPTER 3 - INTRODUCTION OF STATISTICAL METHODS

3.1	Purpose of Making Tests on Materials and Construction	3
3.2	Theory of Risks	3
3.3	Proper Approach to Sampling	4
3.4	Theory of Sampling	5

CHAPTER 4 - REALISTIC LIMITS AND ACCEPTANCE CRITERIA

4.1	Basic Requirements for Numerical Limits in Acceptance Plans8
4.2	Source of Difficulty8
4.3	Need for Measurement of Variation8
4.4	Benefits of Statistical Methods8

CHAPTER 5 - INDEPENDENT ASSURANCE PROGRAM

5.1	Introduction	10
5.2	Independent Assurance Samples	10
5.3	Aggregate Independent Assurance - POM B.6.20	10
5.4	Asphalt Independent Assurance - POM B.6.19	12
5.5	Concrete Independent Assurance - POM B.6.18	13

CHAPTER 6 - QUALITY ASSURANCE PROGRAM

6.1	Introduction	18
6.2	Responsibilities of Construction Quality Assurance Section Chief, Construction Quality Assurance Section Teams, Structural Materials Engineers and New Products and Innovations Section	18
6.3	Quality Assurance Samples	20
6.4	Procedures for Quality Assurance Inspection & Sampling	20
6.5	Quality Assurance Documentation	22
6.6	Required Actions for Quality Assurance Report Findings and Material Deviations	23
6.7	Straight-Line Analysis Chart	23
6.8	Environmental Compliance Commitments for Quality Assurance	24

CHAPTER 7 - PROJECT MATERIALS CERTIFICATION

7.1	Purpose and Scope	25
7.2	Certification Procedure	25

APPENDIX A - BASIC STATISTICAL CONCEPTS

A.1	Use of Normal Distribution Curve	31
A.2	Sources of Variance.	33
A.3	Treatment of Outliers.	37

**APPENDIX B - ELECTRONIC CONSTRUCTION AND MATERIALS MANAGEMENT SYSTEM
(eCAMMS)**

B.1	Introduction	39
B.2	Sample Classifications	39
B.3	Sample Status	39
B.4	County Codes	39
B.5	Material Codes and Classifications.	39
B.6	TR-447 Sample Set-Up	39

**APPENDIX C - EXAMPLE PROBLEMS EMPLOYING THE RANDOM NUMBER CONCEPT
(PTM No.1)**

C.1	Introduction	40
C.2	Discussion of PTM No. 1	40
C.3	EXAMPLE 1 - Sampling by Time Sequence.	44
C.4	EXAMPLE 2 - Sampling by Material Tonnage	46
C.5	EXAMPLE 3 - Sampling by Planer Framework	48

APPENDIX D - STRAIGHT-LINE ANALYSIS CHARTS

D.1	Introduction	50
D.2	Plotting of Daily Acceptance or Quality Control Tests.	50
D.3	Plotting of Quality Assurance Tests.	50
D.4	Examples of Straight-Line Analysis Charts.	51

APPENDIX E - GLOSSARY AND NOTATION

E.1	Glossary and Notation	50
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Chapter 1

PREFACE

The Quality Assurance Manual defines the Quality Assurance Program and the Independent Assurance Program as per the Department's Material Acceptance Program (M.A.P.) in accordance with Federal-Aid Policy Guide CFR 637B.

The intent of the Quality Assurance Program is to assure that construction materials, construction practices, contract administration, and contract inspection procedures are consistent with contract requirements and Department policies.

For the Quality Assurance Program to be effective, there must be good coordination, response, and cooperation among all parties involved. Most important is the cooperation of the individual Contractors, Materials Producers, Fabricators and the Districts' contract administration and inspection personnel in utilizing information obtained by the quality assurance sampling and evaluation activities.

There are areas in this program open to engineering judgment because of wide variation in conditions. The Construction Quality Assurance Engineers must use their common sense and good judgment to attain the intended results.

Chapter 2

PURPOSE AND SCOPE

In this manual, **Quality Control** relates to a production line or process in action and indicates when a process should be examined for correction. **Quality Control Sampling, Testing, and Inspection** are primary responsibilities of the Contractor and/or Producer. **Acceptance Sampling Testing, and Inspection** relate to the entire lot of product or construction and enable the buyer (Department) to decide on the basis of tests or observations whether to accept a given lot from a supplier (Contractor and/or Producer). Acceptance sampling, testing, and inspection are primary responsibilities of the Department. The **Quality Assurance Program** is a management method intended to evaluate the quality of materials and construction procedures through an unbiased and independent inspection of the system of quality control and acceptance sampling and testing. The Department Management will be provided with continuous reporting of the effectiveness and proficiency of the quality control (Contractor and/or Producer) and inspection and acceptance (Department) programs by the eCAMMS, QARS, and EQMS reporting procedures.

The goal of the entire program is to achieve and maintain an acceptable quality level for highway construction. Quality level is defined as the desired standard as established in the specification limits of a measurable characteristic for a given material. This program is separate from and is not a substitute for the acceptance testing and inspection, which is the heart of construction control. It is planned to produce information on the preservation of the quality of materials and construction activities. Therefore, when practical, it includes the sampling of materials in place on the roadway and the observation of the construction, contract inspection and administrative activities. Provisions are also made for obtaining samples of certain raw materials as they are being used, where it is not possible or practical to obtain samples from the completed work. Thus, assurance sampling will consist of both kinds of samples as well as witnessing field tests and measurements when possible. Samples obtained by the Construction QA teams will be designated as Quality Assurance (QA) Samples. Samples obtained by the Structural Materials Section will be designated as either Acceptance Samples (AS) or Quality Review (QR) samples. The results of this testing will also provide a comparison of laboratory and field tests. Thus, the need for comparison samples to be sent from the field to the laboratory on a routine basis is eliminated. Field samples should only be submitted for confirmation of field results when deemed necessary by the engineer, when investigational samples are required by the engineers, or when the necessary test cannot be made in the field.

The concept of **Assurance and Acceptance Sampling** involves the use of statistical or probability methods. Careful study and application of these methods will demonstrate that they are mathematical applications of judgment which you have most likely been applying for some time. Excerpts from "Development of Guidelines for Practical and Realistic Construction Specifications," National Cooperative Research Program Report 17, sponsored by the American Association of State Highway and Transportation Officials, have been included in this manual.

Chapter 3

INTRODUCTION OF STATISTICAL METHODS

3.1 PURPOSE OF MAKING TESTS ON MATERIALS AND CONSTRUCTION

During construction of a highway, many tests are made for two purposes. First, to provide a permanent record evidencing that full value has been received for the monies expended on behalf of the taxpayer. Second, to make sure that unsatisfactory material or construction is not incorporated into the work. Engineering and testing consume a significant part of the total cost of highway construction, and the basic problem is how to best spend the testing monies to afford the greatest protection of quality.

Obviously, it is not practical to test all the material or construction items incorporated into a highway. When the tests are destructive, it would be impossible. For example, if all reinforcing steel were tested to the breaking point, there would be no steel left for use in construction. The only feasible method of estimating quality is to make tests on samples of material or units of construction.

In the past, these samples or units were often chosen so as to be representative; that is, to show average conditions. The result of this procedure is commonly called a Representative Sample. The choice of the material in the sample depends on the judgment of the sampler, and the results of tests on such samples can be biased by their attitude or procedure at the time of sampling. Representative samples may show only one aspect of a variable condition and not give a true picture of overall quality. For these reasons, an improperly taken representative sample can be misleading.

3.2 THEORY OF RISKS

An important use of the normal curve theory is in estimating the probable risks involved in making an acceptance decision. These risks are inherent in any decision where a sample is used to approximate a population because the sample statistics, even though reasonably accurate, are very seldom identical to the "true" population parameters. Two types of risk occur each time a decision is made. Unsatisfactory material may be accepted, or a satisfactory material may be rejected, merely because of the probable errors in estimating the values. If a decision is made to reject a material when it is satisfactory, it is said that a Type I error has been made. If the material is accepted when it is unsatisfactory, a Type II error has been made.

In highway construction, the risk of a Type I error is that of the contractor and/or producer; while the Type II error is the risk that the Department takes each time a decision is made concerning compliance to specifications.

The use of proper statistical methods will minimize, within practical limits, the probability of making either type error. However, one of the big advantages of statistical methods is that the risks that are run by both the contractor and the Department can be controlled. This control is obtained by the design of the sampling plan in that the quality of the measurement, the number of measurements made, and the level of quality can be equated to the risks which are acceptable to both parties.

The following relationship of the factors controlling the risks can be cited:

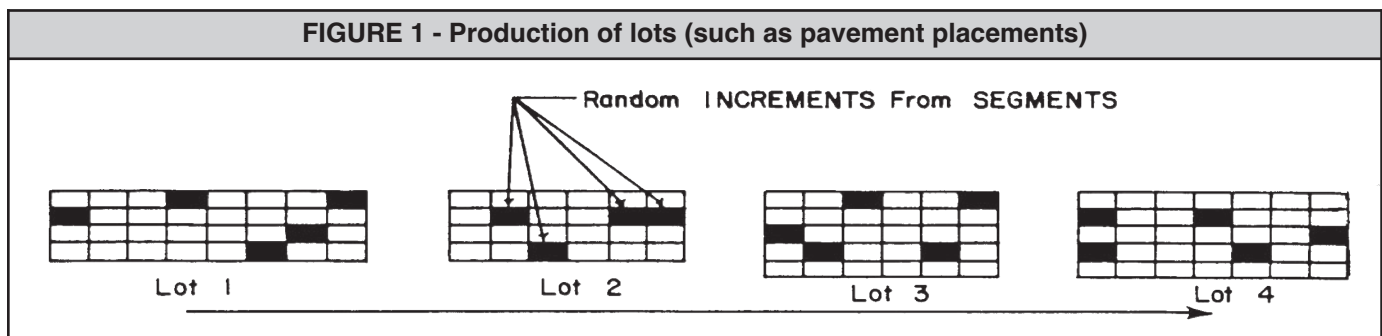
1. In the well designated acceptance sampling plan, the chance of rejecting a lot of poor quality is many times greater than rejecting a lot of good quality. It is usually possible to establish this relationship on the order of from 9:1 to 99:1.
2. The risk of making an error of either type can be decreased by increasing the number of measurements (or samples) or by increasing the precision of measurements.
3. The contractor's risk can be decreased by increasing either quality or uniformity, or both.

3.3 PROPER APPROACH TO SAMPLING

In military and industry situations similar to those that exist in connection with highway construction, it has been found that it is more efficient to use a statistically derived **Acceptance Sampling Plan**.

This approach involves the concept of **Lot-by-Lot** testing for the purpose of protection against acceptance of unsatisfactory materials or construction. A **lot** is any well-defined quantity of material or construction produced by essentially the same process. Examples are the number of square yards of stone base constructed in a day, or the number of cubic yards of concrete in a continuous placement. The lot is also the unit of material or construction which is accepted or rejected when an **Acceptance Plan** is used to determine compliance with specifications. An **Acceptance Plan** is an agreed-upon method of taking and making measurements on a sample, for the purpose of determining the acceptability of a lot of material or construction.

Under the concept of **Lot-by-Lot** testing, the process of constructing a highway may be thought of as the production of a succession of lots, which are presented to the engineer for acceptance or rejection, as shown in Figure 1. By use of an acceptance plan the engineer protects the quality of the construction by rejecting any lots that the samples indicate are not of the specified quality.



To implement the acceptance plan, each lot must be considered to be made up of subdivisions of various sizes. The largest of these are the **segments**, or **sublots** which may be well-defined subdivisions of a **lot** as in the case of mixer-truck loads of concrete, or whose limits are arbitrary as in the case of a square yard of base course.

A **sample** is that portion of the **lot** taken to represent the whole. Examples are the total number of groups of concrete test cylinders made during a day's placement or the total number of bags of soil obtained when sampling a sandpit.

Here the term **sample** is defined in the statistical sense. This term is often confused by engineers with the individual **increments of the sample** which are small quantities of material taken from different sublots in the lot.

Samples usually are made up of several **increments**, such as groups of concrete cylinders made during a day's placement, or density cores removed from a lot of pavement. One **sample increment** represents one **segment** such as a square yard of pavement, or a batch, or a truckload. In the case of some materials, such as a batch of concrete or asphalt, **increments** are made up of small portions taken from different locations in the batch, which is considered to be a **segment**.

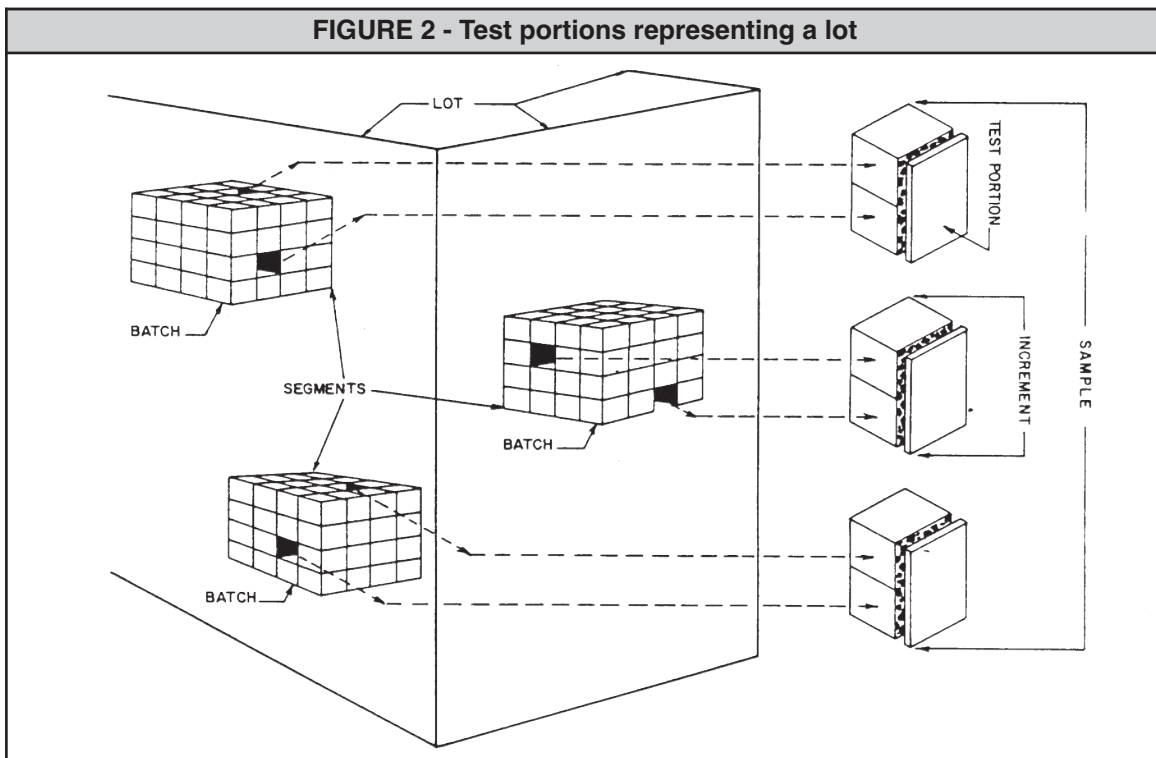
When making some chemical and physical tests, where it is not practical to measure the entire bulk of the **increment**, the bulk is reduced by quartering or splitting. The part of an increment on which measurements are made is called a **test portion**.

The relationship of the lot and its subdivision is shown in Figure 2. The advantages of **Lot-by-Lot Acceptance Testing** are:

1. A much better indication of the acceptability of **lots** of construction is obtained than by the method of representative sampling, as previously described.
2. Testing load is not affected by variations in rate of construction, and inspector's time can be utilized more efficiently.

3. The quantity of testing required is related to the consequences of acceptance of a **lot** of material or type of construction of unsatisfactory quality.
4. Unsatisfactory **lots** are quickly detected before a large quantity of unacceptable material or construction has been produced and at a time when corrective action is most apt to be feasible.

These benefits can only be obtained if the **Acceptance Plan** is based on practical and realistic numerical **Specification Limits** with which the measurements on the sample from each lot are compared. These **Acceptance Plans** will be developed and will appear in the specifications.



3.4 THEORY OF SAMPLING

Positive assurance as to the value of the measurement of some characteristic of a lot can be obtained only by measuring each of the smallest subdivisions of the lot. Because this is impractical, particularly in the case of destructive tests, the value of the characteristic must be estimated from measurements on a sample, which has been defined as that portion of a lot taken to represent the whole.

The most important factor in obtaining information on which to base realistic specifications, or for the purpose of enforcing specifications, is the action of sampling. Although such action is often delegated to inexperienced and uninstructed personnel, it should be realized that precision of measurement and accuracy of computation are wasted effort if the sample is not taken in a way that will ensure its function.

Life would be much simpler for the engineer if all materials, products, and construction were made up of bits having the uniform arrangement of (A) in Figure 3. If this were the case, any test portion, wherever removed, would represent the entire lot. With the possible exception of some homogeneous materials, such as some kinds of well-mixed liquids, this is never the case. The best that can be hoped for is the random arrangement shown in (B) and even this is an idealized condition obtainable only under rare conditions. It must be accepted that the condition shown in (C) is the usual state of affairs in the real world and that a certain amount of segregation is inevitable in all lots of mixed material or product. The art of sampling is to recognize this fact and to take precautions that will overcome the effects of temporary segregation.

The objectives of sampling are to estimate from a limited number of measurements, the value of the mean, and the variation of measurements about the mean, in the lot itself. These objectives cannot be realized if "representative" samples are taken. For example, if an equal number of increments of white spots and black spots were taken from (D) in Figure 3 and these increments were combined to form a sample, measurements on the sample would yield the true mean value. However, the entirely segregated condition would not be revealed. In the case of (C), it is clear that no one increment can represent the lot and that many increments must be taken and measured individually, to find the true mean value and the variation of the measurements.

The way that these increments are taken is extremely important. It must be clearly understood that unless the increments are chosen by **probability sampling**, the methods of statistics cannot be applied. The locations or units from which the increments are obtained must be entirely random. Random in this case does not mean haphazard but does mean that the locations be predetermined without bias, such as by the use of a table of **random numbers**. In addition, every possible increment in the lot must have a known probability of being chosen. This means that a lot must be sampled at some stage of a process when all parts of the lot are accessible. For example, it is impossible to obtain a probability sample from a stockpile of aggregate because increments cannot be taken from the interior of the pile. To sample such material properly, it must be passed over a belt, and increments taken from the stream at randomly determined intervals.

Table I from PTM No. 1 is a brief example of **random numbers** which can be used to determine increment location. More extensive tables are available in textbooks and Federal Publications.

To use such a table to locate increments for a probability sample in space or time, the lot is divided into real or imaginary segments. If the segments are successive, as in the case of truckloads of material departing from a plant or arriving at a job site, the total number of truckloads in the lot is first estimated. The random numbers are considered as decimal fractions and, in any desired fashion, fractions equal in number to the intended number of increments are selected from the table. By multiplying the total number of truckloads by these fractions, and rounding the results, the sequence numbers of the truckloads from which increments are to be taken are designated. Similarly, the times at which increments are to be taken are found by multiplying the total time required for production of the lot by the decimal numbers.

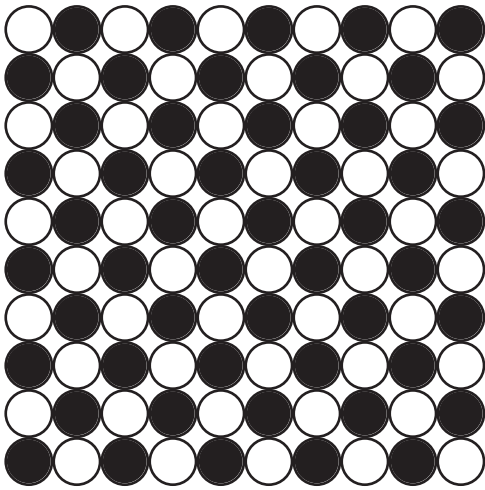
If the lot exists in the form of an area, such as a day's construction of subbase, two random numbers are required to locate each increment. By multiplying the length of the construction by one set of decimals the stationing of the square yard of pavement is determined, and the offset from one side is found by multiplying the width of the construction by another set of decimals. (See Appendix C for example problems employing the random number concept).

FIGURE 3 - Particle arrangements

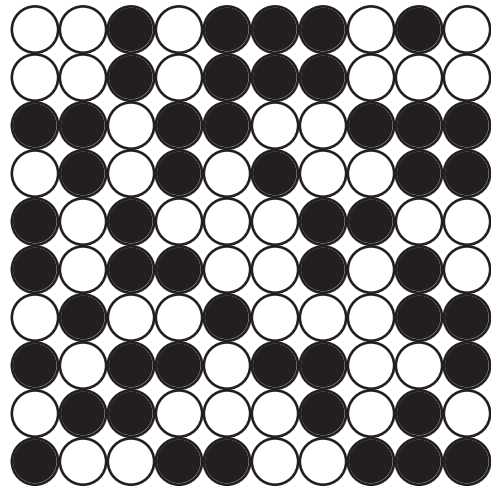
The white and black spots represent particles, or groups of particles, having unlike characteristics in an infinite population or combinations of such particles. The different arrangements represent the degree of dispersal of like particles throughout the mixture.

A - ORDERED

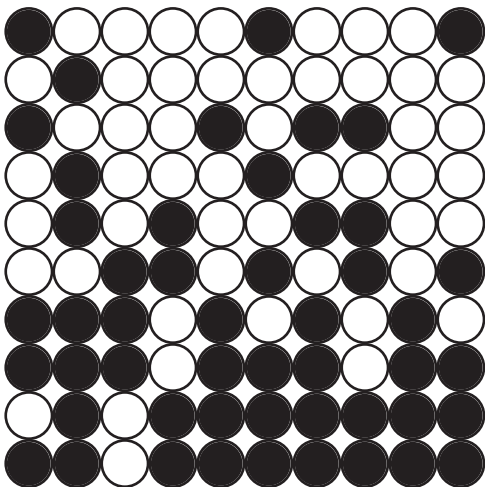
Non-random arrangement which can be formed only by particle-by-particle placement.

**B - RANDOM**

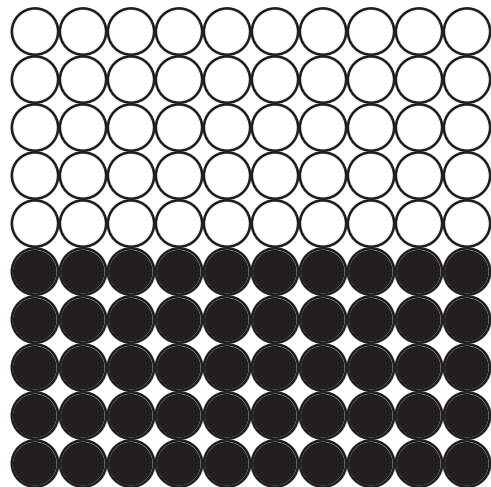
Completely random arrangement produced by perfect mixing.

**C - PARTLY SEGREGATED**

Arrangement intermediate between completely random and completely segregated. The type of mixture commonly found in practice.

**D - COMPLETELY SEGREGATED**

Complete separation of types of particles resulting in a very high limiting, or parent, variance.



Chapter 4

REALISTIC LIMITS AND ACCEPTANCE CRITERIA

4.1 BASIC REQUIREMENTS FOR NUMERICAL LIMITS IN ACCEPTANCE PLANS

One facet of the overall problem of designing an **Acceptance Plan** is how best to set numerical specification limits for measured characteristics of lots of materials and construction, and how to determine substantial compliance with these requirements. Appropriate limits must minimize risk of failure to meet performance standards and must ensure maximum use value.

The associated acceptance criteria must provide a means of effective enforcement with reasonably low risks of either accepting poor material or rejecting good material. Also, the **Acceptance Plan** must be capable of discriminating between acceptable and unacceptable material by means of a practical number of samples and tests.

4.2 SOURCE OF DIFFICULTY

The principal obstacle to meeting these requirements easily is **variation**. Many of the materials used in construction have characteristics that vary over wide limits. Construction equipment and methods have definite limitations as to how closely the exact plan, grade and dimensions can be maintained. The methods of measuring the characteristics of materials and construction, in some cases, are in themselves inaccurate and a source of variation.

It is well recognized that measurements (the results of tests) made to determine compliance with highway specifications show some variation. However, the actual extent of this variation is not definitely known, due to the frequent practice of taking "representative samples," discarding measurements of test results that show unusually high or low values, or of combining several small samples to form an "average" sample. As a result, recorded data tend to reflect average values, and the extent of variation normally associated with single measurement of a characteristic of a material or process is unknown. If independent measurements are made on a **random basis**, values may vary widely from that usually expected.

Although this variation exists, and tests made under some conditions appear to indicate non-compliance with specification requirements, completed construction usually provides satisfactory performance. It is obvious that certain measurements or tests which show non-compliance with specification requirements indicate that further checking or action is necessary.

4.3 NEED FOR MEASUREMENT OF VARIATION

To realistically evaluate measurements in such a situation, there must be available some way of measuring variation and expressing it as a number. Furthermore, there should be some way of estimating what percentage of high or low values can be expected from **assurance and acceptance samples** so that it can be estimated in advance about how many of a group of values will fall outside of some given **specification limit or limits**.

With a method of measuring variation at hand, it is possible to distinguish between the normal variation that is and always has been present in acceptable construction, and an actual decrease in quality that would result in a loss of use value. When the pattern of normal variation is known, it is possible to design acceptance criteria that can be rigidly enforced to ensure acceptable quality, and at the same time will allow for the always-present percentage of measurements (test results) that will fall outside of the specified numerical limits. The tool for accomplishing these objectives is already at hand in the method of **statistics**.

4.4 BENEFITS OF STATISTICAL METHODS

Statistics is a scientific method that deals with the analysis of averages and variation around the averages as found in numerical **data**. The methods of statistics provide an indispensable tool for dealing with variation and of estimating probabilities. When understood, these methods are easy to use, and a knowledge of arithmetic is all that is required to make the necessary computations. **Realistic specification limits and tolerances** can be set accurately, and statistical methods also establish guidelines for the practical interpretation and enforcement of specifications. Appendix A contains basic statistical concepts and information pertinent to assurance and acceptance.

Chapter 5

INDEPENDENT ASSURANCE PROGRAM

5.1 INTRODUCTION

As per Federal-Aid Policy Guide CFR 637B, the Department implemented an Independent Assurance (IA) program, during the 2001 construction season, for concrete, asphalt, and aggregate materials. The details of the program for each material type are outlined in the following pages and are also incorporated into the Project Office Manual (POM).

The Bureau of Project Delivery (BOPD), Construction Quality Assurance Section (CQAS) administers the IA program in conjunction with the existing Quality Assurance program. The IA program provides an unbiased and independent evaluation of the sampling and testing personnel, the testing equipment, and the sampling and testing procedures used in the Department's material acceptance program. Sampling and testing for IA is at the direction of the CQAS staff.

5.2 INDEPENDENT ASSURANCE SAMPLES

As part of the IA program, CQAS staff members obtain samples of concrete, asphalt, and aggregate materials that are forwarded to the Laboratory Testing Section (LTS) for testing. The IA sample test results are used in the assessment of the sampling and testing personnel, the testing equipment, and the sampling and testing procedures. Because IA sample test results are administered differently than random QA samples, an "IA" Sample Class was added to the Construction and Materials Management System (CAMMS) and implementation began with the submission of IA samples obtained in calendar year 2002.

The differences in processing IA and QA sample test results are most significant for aggregate materials. For IA aggregate samples with Material Code 203 or 207, eCAMMS will assign an "O" for **Other** in the **Pass/Fail** indicator and the **QA Rating** will remain blank. CQAS personnel will compare the IA aggregate sample results to those obtained at the review site and determine the follow-up action, when required.

eCAMMS will process concrete and asphalt IA sample test results in the same manner as it has for QA sample results. The main differences for these materials are the comparisons of the IA sample and review site test results and the resulting follow-up actions, when required.

5.3 AGGREGATE INDEPENDENT ASSURANCE - POM B.6.20

The Bureau of Project Delivery (BOPD), Construction Quality Assurance Section (CQAS) will administer the Independent Assurance program at aggregate sources supplying Department construction projects. The Independent Assurance program provides an unbiased and independent evaluation of the sampling and testing personnel, the testing equipment, and the sampling and testing procedures used in the Department's aggregate acceptance program. Independent Assurance samples will be tested by the BOPD, and the test results will be compared with companion test results run at the aggregate source to verify that results are within established tolerance limits.

During each construction season, the BOPD, CQAS will perform a minimum of ten (10) Aggregate Independent Assurance reviews in each District at aggregate sources shipping material to Department projects. Included among these reviews are aggregate sources shipping material to Federal-Aid projects on the National Highway System meeting the following minimum project quantities:

- | | |
|----------------------------|-----------------------------------|
| No. 2A Aggregate Subbase: | 1 Review > 50,000 yd ² |
| No. 57 Structure Backfill: | 1 Review > 5,000 yd ³ |

Note: The source does not need to be producing or shipping material at the time of the review to satisfy this requirement. Material must be obtained from a Department approved stockpile. Sources shipping material for both items require only 1 review. Sources shipping to multiple projects meeting the above requirements require only one review per construction season.

Aggregate Independent Assurance reviews are not limited to aggregate sources shipping to Federal-Aid projects on the National Highway System. Independent Assurance reviews are not limited to No. 2A or No. 57 aggregates.

CQAS will determine the sources to be reviewed. Sampling and testing for Independent Assurance will be coordinated with the District Materials Engineer/District Materials Manager (DME/DMM) or their staff to coincide with a scheduled District Quality Assurance (DQA) review, or at a mutually agreed upon time with the DME/DMM, such as when the District is at the source to test project verification samples.

The following process will constitute an Independent Assurance review. An Independent Assurance sample (n=1) will be taken from an approved Department stockpile at a source supplying aggregate to a Department project under the direction and supervision of the DME/DMM or their staff. The Independent Assurance sample will be split in accordance with AASHTO R 76 to obtain two (2) equivalent samples for testing. In addition, a representative sample will be obtained for an IA Wash Test to be performed by the BOPD, Laboratory Testing Section (LTS).

To obtain the required minimum sample size after splitting, the initial sample for each aggregate must be as follows:

AGGREGATE	SAMPLE SIZE
No. 57	35 kg (75 lbs.)
No. 67	30 kg (65 lbs.)
No. 8	14 kg (30 lbs.)
No. 2A	45 kg (100 lbs.)

Only one (1) aggregate is required to be tested per each Independent Assurance review.

Sampling and testing at the source will be performed by certified aggregate technicians.

One sample will be tested by the DME/DMM or their staff at the source and one sample will be tested by the source technician, both using the same equipment. The sample tested by the source technician will then be rebagged and sent for testing to the LTS. Samples will be tested for compliance with Publication 408, Section 703, Tables C & D, plus the Crushed Fragments Test of Table B, when applicable.

A CQAS representative does not need to be present for the entire process of Independent Assurance sampling and testing at the source. Whenever a CQAS representative does not witness any portion of the process of Independent Assurance sampling and testing at the source, the test results obtained at the source by the DME/DMM or their staff and the source technician should be forwarded to the appropriate CQAS representative in a timely manner.

Arrangements for the transportation of the Independent Assurance sample to LTS will be coordinated by a CQAS representative with the DME/DMM or their staff. The CQAS representative coordinating the review will complete the TR-447 for the LTS sample and identify it as an Independent Assurance sample. The method used to perform the Wash Test (Manual or Automatic Aggregate Washer / Plain Water or Wetting Agent) should be reported in the remarks section of the TR-447.

Test results from the source will be compared to the Independent Assurance precision tolerances by CQAS immediately upon receipt from the District. Those results will then be compared with the test results obtained by LTS for compliance with the Independent Assurance precision tolerances (see Figure A).

INDEPENDENT ASSURANCE PRECISION TOLERANCES		
	SIEVE SIZE	MAXIMUM DIFFERENCE BETWEEN TEST RESULTS
Gradation	2.36 mm (No.8) sieve and larger	6%
	1.18 mm (No.16) through 150 μ m (No.100)	4%
	75 μ m (No.200) sieve	2%
Coarse Aggregate Crush Count	- - -	12%

When test results vary from the allowed precision tolerances or problems with sampling and testing personnel or equipment are discovered, CQAS will immediately inform the DME/DMM. The District will perform an investigation of the discrepancies and take appropriate corrective action where necessary. The District will inform CQAS with the results of their investigation and what corrective actions were taken. Where necessary, a CQAS representative will perform a follow-up review of the source to ensure all deficiencies have been corrected.

Independent Assurance review results will be maintained by the CQAS for each District. The BOPD will summarize the Independent Assurance review results at the conclusion of each construction season and submit the results to FHWA in an annual report.

5.4 ASPHALT INDEPENDENT ASSURANCE - POM B.6.19

The Bureau of Project Delivery (BOPD), Construction Quality Assurance Section (CQAS) will administer the Independent Assurance program at asphalt sources supplying Department construction projects. The Independent Assurance program provides an unbiased and independent evaluation of the sampling and testing personnel, the testing equipment, and the sampling and testing procedures used in the Department's asphalt acceptance program. Independent Assurance samples will be tested by the BOPD and the test results will be compared with companion test results run at the source by the source technician to verify that results are within established tolerance limits.

During each construction season, the BOPD, CQAS will perform a minimum of ten (10) Asphalt Independent Assurance reviews in each District where practical at asphalt sources shipping base courses, binder courses, or wearing courses to Department projects. In Districts where the number of active asphalt sources are limited, a minimum of one (1) but no more than two (2) Asphalt Independent Assurance reviews will be conducted at each source per construction season. Included among these reviews are asphalt sources shipping material to Federal-Aid projects on the National Highway System meeting the following minimum project quantities:

Asphalt Wearing Course: 1 Review > 100,000 yd² (or equivalent tonnage)

Note: The plant may be producing base, binder, or wearing courses at the time of the review and satisfy this requirement.

Asphalt Independent Assurance reviews are not limited to asphalt plants shipping to Federal-Aid projects on the National Highway System.

CQAS will determine the sources to be reviewed. Independent Assurance sampling and testing will normally be performed in conjunction with a Quality Assurance review of the plant operations.

With one of the Quality Assurance samples lifted during the review, a companion sample will be lifted and tested by the plant technician. The companion sample will normally be lifted with the first QA increment. The TR-447 will designate which increment was lifted with the companion sample.

During the review, the CQAS representative and the plant technician will take a minimum of three (3) temperatures from the same location. A comparison will be performed to evaluate the precision of the thermometers.

Corrective measures will be implemented immediately if the temperatures are outside the tolerance.

The plant technician will test the companion loose box sample and the results will be recorded by the CQAS representative.

Sampling and testing at the source will be performed by a PennDOT Certified Asphalt Plant Technician.

Upon receipt of the test results from LTS, a CQAS representative will compare the test results to the Independent Assurance precision tolerances specified below (see Figure B).

INDEPENDENT ASSURANCE PRECISION TOLERANCES		
Temperature	$\pm 5^{\circ}$ F	
Asphalt	± 0.5 %	
Graduation	SIEVE SIZE	MAXIMUM DIFFERENCE BETWEEN TEST RESULTS
	2.36 mm (No.8) sieve and larger	6%
	1.18 mm (No.16) through 150 μ m (No.100)	4%
	75 μ m (No.200) sieve	2%

When test results vary from the allowed precision tolerances or problems with sampling and testing personnel or equipment are discovered, CQAS will immediately inform the District Materials Engineer/Manager. The District will perform an investigation of the discrepancies and take appropriate corrective action where necessary. The District will inform CQAS with the results of their investigation and what corrective actions were taken. Where necessary, a CQAS representative will perform a follow-up review of the source to ensure all deficiencies have been corrected.

Independent Assurance review results will be maintained by CQAS for each District. The BOPD will summarize the Independent Assurance review results at the conclusion of each construction season and submit the results to FHWA in an annual report.

5.5 CONCRETE INDEPENDENT ASSURANCE - POM B.6.18

The Bureau of Project Delivery (BOPD), Construction Quality Assurance Section (CQAS) will administer the Independent Assurance program at construction projects receiving concrete for paving, patching, shoulders, or structures. The Independent Assurance program provides an unbiased and independent evaluation of the sampling and testing personnel, the testing equipment, and the sampling and testing procedures used in the Department's concrete acceptance program. Independent Assurance samples will be tested by the BOPD and the test results will be compared with companion test results run at the project to verify that results are within established tolerance limits.

The BOPD, CQAS will annually perform a minimum of ten (10) Independent Assurance reviews in each District on construction projects receiving concrete for paving, patching, shoulders, or structures. Included among these reviews are Federal-Aid projects on the National Highway System meeting the following minimum project quantities:

Pavement / Shoulders / Patches: 1 Review > 20,000 yd² (combined quantity for each contract)

Structural Concrete: 1 Review > 1,000 yd³

Note: Projects receiving concrete from the same source for paving, patching, shoulders, and structures require only 1 review.

Projects for review are not limited to Federal-Aid projects on the National Highway System.

CQAS will determine the projects to be reviewed. Independent Assurance sampling and testing will normally be performed in conjunction with a Quality Assurance review of the construction operation.

Sampling and testing will be performed by a PennDOT certified field testing technician.

During the review, the CQAS representative and the contractor's PennDOT certified field testing technician will take a temperature from the same sample. A comparison will be performed to evaluate the precision of the thermometers. Corrective measures will be implemented immediately if the temperatures are outside the tolerance.

Air meters must be calibrated a maximum of two weeks before beginning concrete placement. Recalibrate all air meters every two weeks during concrete placement. Document the results of air meter calibrations in the Concrete Inspectors Daily Record Book.

Independent Assurance plastic air content testing will be performed by a CQAS PennDOT certified field testing technician. The technician will perform plastic air testing with the equipment used for acceptance testing. From the same sample of concrete, the CQAS technician will perform plastic air testing using the contractor's back-up air meter. A comparison will be performed to evaluate the precision of the plastic air content testing. Corrective measures will be implemented immediately if the results are outside the tolerance.

The CQAS PennDOT certified field testing technician will also mold five (5) Quality Assurance cylinders from one of the samples tested for plastic air content. The cylinders will be field cured with the 28-day quality control cylinders used for acceptance. Two (2) cylinders will be tested for compressive strength at 28 days on the compression machine used for acceptance and verification testing. The compressive strength of the sample will be determined as the average of the compressive strength testing of two (2) individual cylinders.

Three (3) cylinders will be forwarded to the Laboratory Testing Section (LTS) in time for 28-day compressive strength testing and for hardened air content. The hardened air content will be for informational purposes.

Upon receipt of the 28-day compressive strength test results from the project and LTS, a CQAS representative will compare the test results to the Independent Assurance precision tolerances specified below (see Figure C).

As a part of the Independent Assurance review, a CQAS representative will review project records to ensure verification and acceptance test results have remained within the prescribed precision tolerances.

INDEPENDENT ASSURANCE PRECISION TOLERANCES	
Temperature	± 5° F
28-day Compressive Strength	± 500 psi
Plastic Air Content	± 1.0 %

When test results vary from the allowed precision tolerances or problems with sampling and testing personnel or equipment are discovered, CQAS will immediately inform the Project Manager. The District will perform an investigation of the discrepancies and take appropriate corrective action where necessary. The District will inform CQAS with the results of their investigation and what corrective actions were taken. Where necessary, a CQAS representative will perform a follow-up review to ensure all deficiencies have been corrected.

Independent Assurance review results will be maintained by CQAS for each District. The BOPD will summarize the Independent Assurance review results at the conclusion of each construction season and submit the results to FHWA in an annual report.

FIGURE A

**Aggregate I.A. Review
District**

Sample Date	
SR-Sec.	
Contract No.	
Supplier Code	
Material Class	
TR 447 #	
QA Report #	
QA Engineer	

Federal-Aid N.H.S. Required Review (Y/N)	
F.P.N.	

Final Tolerance Check TRUE

Sieve Size	Gradation (% passing)			Tolerance Check	Precision
	District Results	Plant Results	MTD Results		
4" (100mm)				TRUE	6%
3 1/2" (90mm)				TRUE	6%
2 1/2" (63mm)				TRUE	6%
2" (50mm)				TRUE	6%
1 1/2" (37.5mm)				TRUE	6%
1" (25mm)				TRUE	6%
3/4" (19mm)				TRUE	6%
1/2" (12.5mm)				TRUE	6%
3/8" (9.5mm)				TRUE	6%
#4 (4.75mm)				TRUE	6%
#8 (2.36mm)				TRUE	6%
#16 (1.18mm)				TRUE	4%
#100 (150um)				TRUE	4%
#200 (75um)				TRUE	2%

Crush Count Results (10%)

District	
Plant	
MTD	

**Crush Count Tolerance Check
TRUE**

Final Tolerance Check = **False** requires corrective action or explanation. Document below in remarks.

Remarks:

FIGURE B

Asphalt I.A. Review
District _____

Date	
SR--Sec	
Contract No.	
Supplier Code	
Material Class	
TR 447 #	
QA Report #	
QA Engineer	

Federal-Aid N.H.S. Required Review (Y/N)	
F.P.N.	

Record all results in English units
Multiply Degrees (C) by 1.8 + 32 to obtain Degrees (F)

Final Tolerance Check TRUE

Gradation (% passing)

Sieve Size	Plant Results	MTD Results	Check	Precision
2" (50mm)			TRUE	6%
1 1/2" (37.5mm)			TRUE	6%
1" (25mm)			TRUE	6%
3/4" (19mm)			TRUE	6%
1/2" (12.5mm)			TRUE	6%
3/8" (9.5mm)			TRUE	6%
#4 (4.75mm)			TRUE	6%
#8 (2.36mm)			TRUE	6%
#16 (1.18mm)			TRUE	4%
#30 (600um)			TRUE	4%
#50 (300um)			TRUE	4%
#100 (150um)			TRUE	4%
#200 (75um)			TRUE	2%

Temperature (5 *F)

# 1	# 2	# 3

Plant
QA

Asphalt Content (0.5%)

Plant
MTD

Tolerance Check TRUE TRUE TRUE

TRUE

Final Tolerance Check = **False** requires corrective action or explanation. Document below in remarks.

Remarks:

FIGURE C

Concrete I.A. Review District _____

Review Date	
SR-Sec	
Contract #	
Contractor Code*	
Supplier Code	
Material Class	
TR-447 #	
QA Report #	
QA Engineer	

Federal-Aid N.H.S. Required Review (Y/N)	
F.P.N.	

*Prime or subcontractor placing the concrete

Record all results in English units

Multiply Degrees (C) by 1.8 + 32 to obtain Degrees (F)

Multiply (Mpa) by 145 to obtain p.s.i.

Final Tolerance Check TRUE

Field Test Results

Temperature (5°F)

Air Content (1.0%)

Acceptance/Quality Control
Independent Assurance

#1	#2	#3

#1	#2	#3

Tolerance Check TRUE TRUE TRUE

TRUE TRUE TRUE

28-Day Strength Results (500 p.s.i.)

28-Day QC Average	
28-Day QA Average	

Tolerance Check TRUE

Final Tolerance Check = **False** requires corrective action or explanation. Document below in remarks.

Remarks:

Chapter 6

QUALITY ASSURANCE PROGRAM

6.1 INTRODUCTION

Reduced to its simplest form, **Quality Assurance (QA)** for highway construction and materials requires the proper answer to the question "How do we know we are getting what we specified?" To provide a sufficient answer, we must know the specific characteristics that must be controlled and the needs with respect to the quality level of the characteristic or its uniformity with respect to some performance level.

Answers to these questions can be provided, as mentioned previously, by proper sampling techniques and using statistical methods to determine the average quality and the variation of the quality from average conditions. Once these have been set, available statistical methods can be employed to express the requirements of quality in specific terms and provide methods by which compliance of the construction and/or materials to these specifications can be measured. The following sections describe the responsibilities of the Construction Quality Assurance Section (CQAS) Chief, the Construction QA teams, the New Products and Innovations Section (NPIS), the Structural Materials Engineers, and the District Materials Engineer/District Materials Managers (DMD/DMM) in the Quality Assurance Program, along with the procedures to follow when sampling material or making test observations.

6.2 RESPONSIBILITIES OF CONSTRUCTION QUALITY ASSURANCE SECTION CHIEF, CONSTRUCTION QUALITY ASSURANCE SECTION TEAMS, STRUCTURAL MATERIALS ENGINEERS, AND NEW PRODUCTS AND INNOVATIONS SECTION

The QA program applies to all projects where State and/or Federal funding is involved. The Quality Assurance Program as outlined herein shall be a primary responsibility of the Construction Quality Assurance Section (CQAS). The CQAS Chief and the Chief Structural Materials Engineer have the responsibility to assure that adequate reviews are performed on construction operations and during prefabricated material production respectively and that a sufficient number of material samplings and tests are performed to determine that the quality of construction meets the Department's specifications. The CQAS Chief also has the responsibility to assure that all construction operation and material deviations are satisfactorily resolved, and that proper documentation is contained in project records and in the Bureau of Project Delivery (BOPD) files to certify the quality of construction for each Federal aid project to the Federal Highway Administration

The CQAS Teams will make random visits to construction projects, asphalt and concrete plants, aggregate quarries, cement mills, refineries, and miscellaneous manufacturers on a statewide basis. The CQAS Teams will perform in-depth inspections and evaluations at the plants, quarries and projects. Similarly, while work is in progress, the Structural Materials Engineers and materials technicians will make periodic, random visits to inspect and evaluate approved structural steel and prestressed/precast concrete fabrication plants. They will observe sampling and testing procedures to assure conformance with Department policies and procedures. The reporting of these evaluations will be made utilizing the Quality Assurance Reporting System (QARS) or the Electronic Quality Management System (EQMS). The CQAS Teams will lift QA samples. These samples, in addition to offering a comparison to quality control and acceptance tests, provide data to be used by the quality assurance data bank to analyze existing specifications and develop new ones.

Structural Material reviews for prefabricated steel and concrete products are scheduled to provide Independent Assurance (IA) checks of the acceptance process conducted by the Structural Materials Section. This includes sampling, testing and over inspection. Active fabrication plants have their certified component materials sampled at least twice a year. Each review will be noted in EQMS reports. All required samples will be noted on Form TR-447 for each sample lifted at the time of each review.

During each calendar year, CQAS Teams perform a minimum of 60 reviews per District on construction projects or at material suppliers.

Concurrent construction operation and materials source reviews are conducted when possible.

Prior to the start of each construction season, the CQAS analyzes material test results and operational findings from prior construction seasons for each District and reviews each District's proposed letting schedule. A District-specific workload, prioritizing review areas for the upcoming construction season, is developed. Projects selected for review are not influenced by the type of funding or dollar amount. This flexibility allows the CQAS to focus on problem areas that may be District-specific as well as randomly review other areas to provide an accurate assessment of the construction and material quality in each District.

The "Construction Project Status Report" issued monthly and the development of a good working relationship with each DME/DMM and the District construction staff and/or project staffs will provide specific and timely knowledge of the current progress status of construction in each District. The Construction Project Status Report is a tool used to identify cost accounting information, and it provides general information on calendar days used and estimate amounts paid for each project statewide. In addition, QARS obtains contract quantities from the Engineering and Construction Management System (ECMS). Bid items for major areas of work are summarized in an Items Report for each contract in QARS Workload Calculations files. This items report is then used to create a workload record for each District that provides a summary of these work quantities based on project funding type and the size of the work.

Reviews on construction projects may be conducted for the following operations: Bridge Construction Loadings, Certification and Acceptance of Materials, Project Documentation, Work Orders, Project Labor Compliance, Project Safety Compliance, Embankment, Subgrade, Cement Treated Permeable Base Course (CTPBC), Superpave Asphalt Base Course, Subbase, Asphalt Treated Permeable Base Course (ATPBC), Asphalt Pavement Ride Quality, Superpave Asphalt Pavements, Asphalt Seal Coat, Micro-Surfacing, Cement Concrete Pavement, Bridge Approach Slabs, Concrete Pavement Patching, Cement Concrete Pavement (RPS), Concrete Pavement Ride Quality, Pipe Culverts, Guide Rail, Concrete Median Barrier, Gabions, Cement Concrete Shoulders, Incidental Cement Concrete, Maintenance and Protection of Traffic, Highway/Sign Lighting, Traffic Signals, Prefabricated Retaining Walls, Cement Concrete Structures – Substructures, Cement Concrete Structures – Bridge Decks, Cement Concrete Structures – Bridge Barriers, Structure Backfill, Piles, Drilled Caissons, Latex Bridge Decks, Epoxy Overlay for Bridge Decks, Steel Bridge Superstructure, Painting Structural Steel, Precast Reinforced Concrete Box Culvert, Sound Barriers, Asphaltic Plug Expansion Dam System, Concrete Beam Erection, ADA Curb Ramp Compliance, DME Project Certification, Environmental Compliance, Project Sampling, and Miscellaneous Construction.

QA reviews at concrete and asphalt sources are coordinated in the manner stated above. Active asphalt and concrete sources in each District are reviewed at least once every three to five years.

CQAS Teams randomly sample construction materials during their reviews.

Sample results of various manufactured materials are reviewed on a regular basis. Reviews of manufacturers of various construction materials are based on the test result history of the individual products. The manufacturer's quality control program is reviewed as well as the manufacturing process.

CQAS reviews aggregate sources based on the test history of the source. CQAS personnel scrutinize aggregate sources that have a marginal quality test result history (PWL < 90%). A QA sample is lifted off the PennDOT production pile and tested by the BOPD, Laboratory Testing Section (LTS) for compliance with Publication 408, Section 703.1, Table A or Publication 408, Section 703.2, Table B. This process provides independent assurance of the quality parameters of the aggregate.

Reviews at asphalt projects and plants may include lifting 3 box samples for submission to the BOPD for gradation, minus 200 material, and asphalt content. These results are tested for compliance with specification requirements. In addition, at asphalt plants, QA witnesses a companion sample tested for gradation, minus 200 material, and asphalt content. Mix temperatures are also checked.

Project reviews for concrete operations include witnessing or performing: molding of five (5) cylinders, mix temperature checks, and plastic air content tests, all from the same sample. The machine used for concrete strength testing on the project is used to perform strength tests on two (2) of the QA cylinders. The other three (3) QA cylinders are submitted to the BOPD. Two (2) of the cylinders are tested for compressive strength and one (1) cylinder is tested for air content of the hardened concrete.

Construction reviews of aggregates or soils operations may include witnessing or performing three (3) density tests.

Reviews at concrete plants include a review of the overall plant operations and may include sampling of the various components of the mix.

The BOPD, LTS in Harrisburg tests the IA and QA samples. Specific items to be evaluated during a QA review are outlined in the individual QARS checklists for each operation. The results of tests and QARS or EQMS reports concerning Assurance sampling are processed through the New Products and Innovations Section (NPIS).

QA samples are obtained under the direction of the CQAS Chief, Structural Materials Section Chief or assigned staff. The Quality Assurance Program is intended to be an unbiased evaluation of quality control and acceptance sampling and testing. The actual sampling must be performed or witnessed by a Quality Assurance team member. The Quality Assurance team members witness, as time permits, the testing of the acceptance or quality control samples and report the results on the QARS or EQMS report.

6.3 QUALITY ASSURANCE SAMPLES

All **assurance samples** are tested by the BOPD, LTS. The results of tests and QARS or EQMS reports concerning **assurance sampling** are processed through the New Products and Innovations Section.

The principal objectives of the **Quality Assurance Program** may be outlined as follows:

1. To improve routine materials and construction control through evaluation of job control inspection and engineering practices.
2. To improve communication between project personnel and supervisory personnel by effective reports.
3. To promote at all levels an awareness of the project control status, by means of prompt presentation and comparison of data derived from plant, or project acceptance tests, quality assurance witness tests, and quality assurance laboratory results of quality assurance sampling.
4. To provide data for study and statistical analysis which can be used for the modification or revision of specifications, standards, methods and processes.
5. To provide a record of documentation of the acceptability of materials for those projects evaluated either by plant or project acceptance tests for final certification by the CQAS Chief.

All **assurance samples** should be obtained under the direction of the CQAS Chief, Chief Structural Materials Engineer or assigned staff. Since the QA Program is intended to be an unbiased evaluation of quality control and acceptance sampling and testing, the actual sampling must be performed or witnessed by a CQAS team member. The CQAS Team members will, as time permits, witness the testing of the acceptance sample or quality control sample and report the results on the QARS or EQMS report. Appendix B contains general information relative to the QARS system. All sampling locations shall be chosen at random in accordance with the **Probability Sampling Procedure, PTM No. 1**. Appendix C contains example problems employing the random number concept.

6.4 PROCEDURES FOR QUALITY ASSURANCE INSPECTION & SAMPLING

The following procedure is a guideline to be utilized when conducting a QA review and/or when sampling materials. Specific items to be evaluated are listed on the individual QARS and EQMS checklists. The following list includes general categories that are subject to review:

A. Construction Quality Assurance Section

1. Review the contract, Publication 408, and appropriate Bulletin requirements for the specific operation being reviewed.
2. Review the quality and quantity of inspection and contractor personnel.
3. Review safety and traffic control procedures.

4. Review documentation that pertains to the operation that is being observed.
5. Review testing and sampling procedures.
6. Lift QA samples of all materials incorporated into the operation being reviewed, if applicable.
 - a. Lift 3 increments of all non-certified materials in accordance with Section 6.2 and 3 increments of all asphalt mixes.
 - b. Lift 1 increment of all types of certified materials (EXCEPT: Rebar and Bolts, Nuts and Washers, where 3 increments are required).
- Note:** Do not lift QA samples of pre-inspected items (precast products, RC Concrete pipe, etc.) or raw aggregates at asphalt plants.
7. Review the physical construction on the operation.
8. Review the contractor's process control.
9. Review work orders.
10. Review Labor and Equal Employment Opportunity, Disadvantaged Business Enterprise, Small Business Enterprise, and Diverse Business Compliance.

B. Structural Materials Section

1. Review the fabricator's quality control plan, weld procedures or concrete mix designs.
2. Review Publication 408 and any applicable supplements or special provisions.
3. Review the quality and quantity of inspection.
4. Review the required inspection and quality control documentation that pertains to the operation being observed.
5. Verify current AISC certification, where applicable.
6. Review sampling and testing procedures.
7. Lift Quality Review samples (QA samples for non-certified materials) incorporated into the operation being reviewed, at least twice a year at active plants, or more frequently, if quality issues are suspected.
8. Review the physical construction of the operation.
9. Review the fabricator's quality control process.
10. Review the non-destructive testing and repair procedures if applicable.

C. Construction Loadings on Bridges

The bridge construction loading QA process is comprised of concurrent reviews performed by staff from the Bridge Design and Technology Division (BDTD) and the CQAS. District participation is also required and consists of providing documentation and responses to questions regarding construction loading analysis and facilitating information collection during on-site visits.

If construction loading analysis(es) are determined to be inadequate or load placement/vehicle operation are determined to be inconsistent with the contract documents, work on the bridge shall not be permitted until corrective action (relocation/reduction of loading, approval of revised analysis) has been completed and accepted by the Department.

Part A. Bridge Structural Analysis Verification

1. The CQAS and the BDTD will jointly select one project per District every two years for review from the five candidate projects submitted by each District.

2. BDTD will verify that the existing bridge and condition of the load carrying elements can safely support traffic loads based upon the planned location and magnitude of the planned construction loads.
3. The details of the structural analysis verification are located in Publication 15M, Design Manual Part 4.

Part B. Construction Loads Verification

1. The CQAS will perform a QA Construction Operation Review (COR) using the QA review checklist created exclusively for this process. A TR-200 will be generated for each review.
2. The CQAS will verify the actual construction loads placed on the bridge, at the time of the review, are equivalent to the contractor's planned construction loads with regards to magnitude and location.
3. The process specific checklist-COR 105.17 BRIDGE CONSTRUCTION LOADINGS is located in Publication 2, Project Office Manual (POM), Appendix A.

Part C. Written Assessment

1. A coordinated written assessment in memorandum form will be sent to the Assistant District Executive-Construction addressing the construction loading analysis and field operations for each project reviewed. This memorandum will be jointly signed by the Chiefs from Central Office BDTD and CQAS. The memorandum shall be retained in the project files.

In addition, all samples lifted will be identified on a TR-447, marked as quality assurance samples or quality review samples (structural materials) and submitted to the Laboratory Testing Section, Harrisburg, for testing.

6.5 QUALITY ASSURANCE DOCUMENTATION

All QARS reports require completion of Form TR-200 by the CQAS Engineer. The QARS and EQMS review checklists were developed to review field and plant operations to determine if the Department's specifications are being followed for installation procedures, material sampling and testing frequencies, material certifications, project office documentation, project staffing, safety and maintenance, protection of traffic, and prefabricated structural materials production.

The engineer or technician utilizes the appropriate QARS or EQMS checklist for the operation or material source being reviewed. The report is then built into the QARS or EQMS system electronically. By inserting the contract ECMS number, the report heading data is automatically inserted by the system. Upon completion of each report, the data is uploaded into QARS or EQMS. The TR-200 report in QARS is then in either a "presubmit" or "submit" status. In "presubmit" status the author's immediate supervisor will review the report and, when acceptable, submit it to the CQAS Chief for approval. If in "submit" status, the report goes directly to the CQAS Chief. If the Section Chief rejects the report, appropriate comments are provided to the author for revision and resubmission. For Structural Materials (EQMS) reports, the report may be submitted directly to the immediate supervisor for approval in either the "presubmit" or "submit" status. When approved in QARS, the TR-200 report is incorporated into the system in an approved status for electronic distribution to CQAS, and the District. QARS TR-200 reports for Federal-Aid non - Exempt projects are electronically distributed to FHWA.

If the District questions an approved report and a correction is requested, the CQAS Chief must agree to the request. If a correction is agreed to, the author of the original report must revise and resubmit a corrected report.

When QA samples are obtained, they are submitted to the LTS with a completed form TR-447. Detailed instructions for completion of form TR-447 are included in the Project Office Manual. Upon arrival at LTS, each sample is logged in and the appropriate Lab Unit assigns a lab number that is entered into eCAMMS. Each specific material has a preset series of tests that will be performed. Tests are completed, and the results entered into eCAMMS, where the required calculations are automatically done. The appropriate Lab Manager must approve and initial each test screen. The test result is then placed in "Finalized with Final Report Distributed" status and available in eCAMMS. The data is also available in eCAMMS for use in summary or management reports.

If a correction is requested, the process is repeated.

Each TR-200 checklist statement is assigned a status of "In Compliance" (quality rating 10), "Close Compliance" (quality rating 7-9), "Non-Compliance" (quality rating 0-6) or a status of "Not Applicable" or "Not Witnessed". A "Causative Factor" and "Detailed Causative Factor" is also assigned. A narrative is provided to describe any findings and to offer recommendations for corrective action and to explain any corrective action taken to correct the finding at the time of the review.

For QARS reports, each statement assigned a value from 0 to 3 requires an automatic "Written Response Required" (WRR). Additionally, the author or the CQAS Chief can request a written response for any quality rating when they feel it is appropriate. The WRR response is from the District to the Construction and Materials Division Chief and should be completed in eCAMMS within 30 days from the time the report is released to the District.

Field test results witnessed or performed during a review are also captured in the TR-200 as well as a list of samples taken for testing at LTS.

For EQMS reports, the rating system for prefabricated materials is used to identify serious Quality Control issues, specification deviations and/or rejected materials. Written responses to these issues from the fabricator are at the discretion of the Chief Structural Materials Engineer. Distributed reports do not include the stated numerical values. They are retained in the eCAMMS database for future reporting purposes.

LTS test results, other than for Bulletin 15 materials accepted on certification, which are identified as "Major Deviations" require a written response from the District to the Construction and Materials Division Chief and should be completed in eCAMMS within 30 days from the time the results are released to the District.

6.6 REQUIRED ACTIONS FOR QUALITY ASSURANCE REPORT FINDINGS AND MATERIAL DEVIATIONS

The policy describing the assignment of material deviations to the results of QA and IA samples, the assignment of required responses to QA and IA operational reviews, and the resulting actions required by the District is described in the POM Section B.9.6, Quality and Independent Assurance Deviations.

6.7 STRAIGHT-LINE ANALYSIS CHART

The District shall maintain ***straight-line analysis charts of Acceptance, Verification, QA, and IA*** tests as required. The Contractor and Material Producer shall maintain straight-line analysis charts of quality control tests for required items. The plotting shall be accomplished at the plant or project and shall be considered part of the project records.

These ***straight-line analysis charts*** play an important role in the Department program. They are a management tool to enable the Contractor, Material Producer, and others responsible for control of materials to review large masses of test data in a short time; and they are a means TO ASSURE TIMELY POSITIVE ACTION ON MATERIALS FROM DAY TO DAY. It is recommended that the analysis charts be reviewed by the DME/DMM and Project Construction Staffs on a regular basis and discussed with the Contractor and Material Producer.

Project or plant control problems can be accurately detected by diligent testing, inspection and prompt plotting of all accurate results. The vertical scales of the analysis charts are generally chosen so that a result falling outside the limits of the graph is also outside the specification limits. A date is assigned to each vertical line. The design value for the material is assigned to the central or "heavy" center line. Large differences between the plotted points on the curves demand ***increased inspection to determine the probable cause(s) and corrective action or measures to be taken***. When investigational samples are obtained as part of the inspection, the result shall be plotted on the straight-line analysis charts and referenced as such. Appendix D illustrates straight-line analysis charts and the plotting of pertinent data.

A statistical straight-line analysis chart may be viewed as a normal curve turned on its side. For a normal curve, practically all measured results should fall between the limits of ± 3 standard deviations of the mean. Therefore, an action line should be included at +3 and at -3 standard deviations of the mean, and the producer is required to take appropriate corrective action whenever one test result falls outside of either action line.

It is essential that all personnel involved should frequently compare the results of the **acceptance, quality assurance, and independent assurance samples** with the **quality control samples**, for timely evaluation of material compliance with the specifications.

Appendix D explains the procedure for comparing these tests. The DME/DMM staff shall periodically visit the project and plant with the Assistant Construction Engineer/Manager to discuss the comparisons and make recommendations as required. **The QA Teams shall indicate on the appropriate witness report form whether or not the analysis charts are being kept up-to-date by the project personnel and/or material producer and what corrective actions, when necessary, have been taken to assure materials control.**

6.8 ENVIRONMENTAL COMPLIANCE COMMITMENTS FOR QUALITY ASSURANCE

In 2018, as part of a consent agreement with the US EPA, the Department agreed to implement a Stormwater Self-Audit (SSA) Program to improve the efficacy of construction stormwater runoff inspections. The program applies to any project that has active earth disturbance activities and is required to obtain coverage under a National Pollutant Discharge Elimination System (NPDES) Permit for Stormwater Discharges Associated with Construction Activities.

The CQAS will perform an Environmental Compliance review on all construction projects with active earth disturbance and an NPDES Permit, each construction season. These reviews are to be unannounced. Every quarter, the CQAS Chief will submit a report to the Department Compliance Manager containing a list of projects, self-audit dates, and discrepancies in inspection findings.

In 2018, as part of the Department's Action Plan to address issues identified during an FHWA IOP review of Environmental Commitments, it was agreed to have CQAS staff review the project's Environmental Commitment and Mitigation Tracking System (ECMTS) construction signature sheet during COR reviews to ensure all commitment activities that should have been addressed at that stage of construction have been implemented and signed off on by the contractor and the construction inspection staff.. To fulfill this commitment, CQAS created an ECMTS quality statement that was included on approximately 65% of all COR reviews. At the end of each calendar year, the CQAS Chief will submit a report to the Department's Environmental Planning Manager containing the number of times the ECMTS construction signature sheet was reviewed, the number of projects reviewed, and discrepancies in inspection findings.

Chapter 7

PROJECT MATERIALS CERTIFICATION

7.1 PURPOSE AND SCOPE

The Department is required to certify to the Federal Highway Administration (FHWA) that all materials used on a Federal-Aid project and the construction operations controlled by sampling and testing of the materials were in conformity with specification requirements.

7.2 CERTIFICATION PROCEDURE

The District Materials Engineer/District Materials Manager (DME/DMM) initiates the required project certification with completion of Form TR-4238A, District's Letter of Project Materials Certification, in eCAMMS for each Federal-Aid project. Upon the entry of the Physical Work Complete (PWC) date for a project in ECMS, a Project Material Certification record is created in eCAMMS. The eCAMMS Project Material Certification record and Form TR-4238A are the basis for the New Products and Innovations Section (NPIS) and the Construction Quality Assurance Section (CQAS) actions to provide PennDOT management and FHWA the required project certification documents. eCAMMS auto-populates a TR-4238A for each project based on the project sample and review activity. The DME/DMM has the ability to add additional notes to the Form TR-4238A using the Remarks section of the Project Material Certification record in eCAMMS. All required signatures on the TR-4238A are obtained through the eCAMMS workflow. Additional information regarding completion of Form TR-4238A can be found in the Project Office Manual (POM), Section D.3.7.

For prefabricated materials, the Assistant District Executive - Construction (ADE-C) is responsible to notify the Structural Materials Section whenever quality assurance inspection is required, by completing Form CS-430, Notification of Inspection, for each Federal-aid and/or 100% State project. There are 3 options for completion and submission of Form CS-430: 1) generation and submission of the form through Source of Supply in ECMS, 2) submission through PPCC, and submission by email. Detailed instructions for proper completion and submission of Form CS-430 are provided in POM Section B.7.18. Form CS-430 is used to assign quality assurance consultant inspection and Department independent assurance to the prefabricated structural steel, and prestressed and precast concrete plant(s) selected by the contractor.

Forms CS-4171 and CS-439 are used by the Structural Materials unit to indicate approval of prefabricated materials to the Engineering Districts and projects.

A. New Products and Innovations Section's Responsibilities. The *District's Letter of Project Materials Certification*, Form TR-4238A, will be submitted in eCAMMS by the District and forwarded through the workflow in eCAMMS to NPIS. As part of the certification system, NPIS will review the project records for any unresolved QA findings or material failures for that project. If documentation requirements are found to be unsatisfactory, further processing of the certification will be terminated until NPIS receives the necessary documents.

The *District's Letter of Project Material Certification*, Form TR-4238A, and all pertinent information from the project file contained in the Project Material Certification record will then be forwarded through the eCAMMS workflow to the CQA Section Chief for approval and project close out.

Upon the approval of the TR-4238A in eCAMMS, the system will automatically generate a TR-4238B or TR-4238C for the project. A TR-4238B is generated for PennDOT Oversight NHS projects and PennDOT Oversight Non-NHS projects. A TR-4238C is generated for Federal Oversight projects. If the project contains any TR-200 reports or Quality Assurance sample reports, a statement will be added to the TR-4238B or TR-4238C, indicating Central Office QA activity (Figure 7). If the project file contains no TR-200 reports or QA sample reports, a statement will be added to the TR-4238B or TR-4238C indicating no QA activity (Figure 8).

eCAMMS will generate the final letter of materials certification, Forms TR-4238B or TR-4238C. The letter will be signed by the CQAS Chief on behalf of the Construction and Materials Division Chief. Form TR-4238B (Figure 9)

will be addressed to the Deputy Secretary for Highway Administration. This form is to be utilized for all projects governed by the Department's exemption procedures as defined in the FHWA/PennDOT Stewardship & Oversight Agreement located in Appendix C of Publication 10X (DM-1X). Form TR-4238C (Figure 10) will be addressed to the Division Administrator, Federal Highway Administration, Harrisburg, Pennsylvania. This form will be used exclusively for Federal-Aid Interstate highways and all other non-exempt federal projects. Form TR-4238C will be forwarded to the Bureau's Contract Management Section by email for posting in ECMS.

The CQAS Teams will be responsible for randomly selecting projects that have been previously certified and performing a detailed review of the certification process. This will be done in accordance with the "7-step outline" followed by the DME/DMM when initiating the materials certification process at the District level. The review will be performed at the District Office. Any discrepancies noted during this review will be brought to the District Engineer's attention in writing. The District is responsible for documenting any and all actions taken to avoid similar occurrences on future projects.

B. Construction Quality Assurance Section Chief's Responsibilities. The number and type of federally funded projects evaluated by the CQAS Teams is left to the discretion of the Section Chief. Considerable judgment must be utilized in determining the projects to be evaluated. Projects that demonstrate questionable organization, inspection or potential material control problems are to be evaluated by the CQAS Teams. Consideration of the available staffing will also dictate the quantity of projects evaluated.

Therefore, the Chief must be constantly aware of existing conditions on projects by their contact with the CQAS Teams and the District Construction personnel. The Chief's approval is required for all *District's Letter of Project Materials Certifications* (Form TR-4238A). On those projects where no QA reports or samples were obtained, it is the responsibility of the Chief to ascertain if proper material control procedures were implemented based on the DME/DMM's and NPIS reviews. This will be completed during the certification process and based on their prior knowledge about the materials incorporated in, and the inspection performed on, the project.

C. Structural Materials Section's Responsibilities. Each Federal and/or State funded project will receive in-plant quality assurance inspection for qualifying prefabricated structural steel and prestressed/precast concrete products. The Structural Materials Engineer will be responsible for ensuring that fabrication is performed only in approved plants, and in accordance with an approved Quality Control plan.

Projects are evaluated by the structural materials engineers and technicians on a cyclic basis depending on staffing availability, project complexity and product quality as reported by our consultant inspection agencies. Projects involving new materials or fabrication processes, which are fabricated by producers receiving disciplinary measures for deviations or poor quality, are evaluated on a more consistent basis.

FIGURE 7

Statement added to Form TR-4238B or TR-4238C when TR-200 Reviews or QA Samples are on File:

Independent Quality Assurance Inspections and/or Sampling were conducted on this project. This certifies that a review of CMD project files indicated no unresolved material problems. Exceptions and documentations are on file at CMD.

FIGURE 8

Statement added to Form TR-4238B or TR-4238C when NO TR-200 Reviews or QA Samples are on file:

Independent Quality Assurance Inspections and/or Sampling were not conducted on this project. This certifies that a review of CMD project files indicated no unresolved material problems. Exceptions and documentations are on file at CMD.

FIGURE 9

FORM TR-4238B**DATE:****SUBJECT: TR-4238B, PROJECT MATERIALS CERTIFICATION**

Contract:
S.R. SEC.
County:
FPN:
Contractor:

TO: Deputy Secretary for Highway Administration

FROM: Chief, Construction and Materials Division
Bureau of Project Delivery

This is to certify that all the materials used on the above listed project and the construction operations controlled by sampling and testing were in conformity with pertinent specification requirements of the contract, as indicated by the test results obtained on plant and project acceptance samples.

All of the materials, except those listed on Form TR-4238A, District's Letter of Project Materials Certification, were properly covered by samples tested and accepted in accordance with the State's established procedures, as reviewed by our quality assurance program. The items listed on Form TR-4238A, which received less than the State's usual requirements for sampling and testing, were accepted under the conditions stated.

Appropriate reports covering tests or certification as to conformity with specifications of materials used on the project are on file by county and project number at our District Office and the Construction Quality Assurance Section.

FIGURE 10

FORM TR-4238C

DATE:

Division Administrator
Federal Highway Administration
228 Walnut Street
Harrisburg, Pennsylvania 17101-1720

RE: TR-4238C, LETTER OF PROJECT MATERIALS CERTIFICATION

Contract:

SR: SEC:

County:

FPN:

Contractor:

Dear _____,

This is to certify that all the materials used on the above listed project and the construction operations controlled by sampling and testing were in conformity with pertinent specification requirements of the contract, as indicated by the test results obtained on plant and project acceptance samples.

All of the materials, except those listed on Form TR-4238A, District's Letter of Project Materials Certification, were properly covered by samples tested and accepted in accordance with the State's established procedures, as reviewed by our quality assurance program. The items listed on Form TR-4238A, which received less than the State's usual requirements for sampling and testing, were accepted under the conditions stated.

Appropriate reports covering tests or certification as to conformity with specifications of materials used on the project are on file by county and project number at our District Office and the Construction Quality Assurance Section.

Sincerely,

Chief, Construction and Materials Division
Bureau of Project Delivery

APPENDIX A

BASIC STATISTICAL CONCEPTS

A.1 USE OF NORMAL DISTRIBUTION CURVE

A. Method of Picturing Variation. It is a common practice among engineers to plot the individual measurements as points on some type of graph, then fit the best possible curve to the scatter of points. Once this has been done, it is possible to draw inferences from the curve, and to interpolate and extrapolate values that do not appear in the data. A very similar approach is used in statistics, but here the objective is to measure the variation of the individual measurements from their average. To do this, a special type of curve, called a **distribution curve**, must be fitted to the data. To understand how this is done, the concept of a **distribution** must first be visualized.

One way to get a picture of variation is to place each value on a tally sheet. For example, if 50 cores are cut from an asphalt surface course at random locations and the thickness of each core is measured, the results might look like those in Table 2a.

The tally in Table 2b gives a picture of the way the data are grouped; that is, it shows the distribution of the measurement, but it is not to scale and does not provide a means of computing a numerical value, which is a measure of the variation. A way to draw this picture to scale is to plot the data in the form of a bar chart, called a **histogram**, so that each measurement is a unit of height of the bar representing a particular value of the measurement (Figure 13).

Figure 13 shows that once the data have been plotted to scale, in histogram form, a bell-shaped curve can be applied, and a fairly good fit obtained. This curve is called the **normal distribution curve**. Although this curve retains its characteristic shape, the ratio of height to width of base can change radically, depending on the values of two **parameters** that completely define the shape and location of the curve. These parameters are the mean, \bar{x} , which is a measure of central tendency, and the **standard deviation**, s , which is a measure of variability. Another statistical parameter for measuring variability or dispersion is the coefficient of variation (V). It is defined as the ratio of the standard deviation, (s), to the mean (\bar{x}). The coefficient of variation expresses a relative measure of the dispersion of spread from the mean.

In as much as the shape of the curve, and its position on a numerical scale, can be changed by changing the values of \bar{x} and s , the curve can be fitted to almost any set of data, and each set of data will have a unique distribution curve. The more measurements there are in a set of data, the better the fit will be. Sometimes a small set of data, when plotted in histogram form, will have a very irregular distribution and it appears that the normal curve cannot be fitted. However, it should be visualized that these few measurements are only a small part of a very large number of possible measurements and that, if all measurements were available and were plotted, the normal curve would fit.

TABLE 2.
EXAMPLE OF MEASUREMENT DISTRIBUTION BY TALLY.

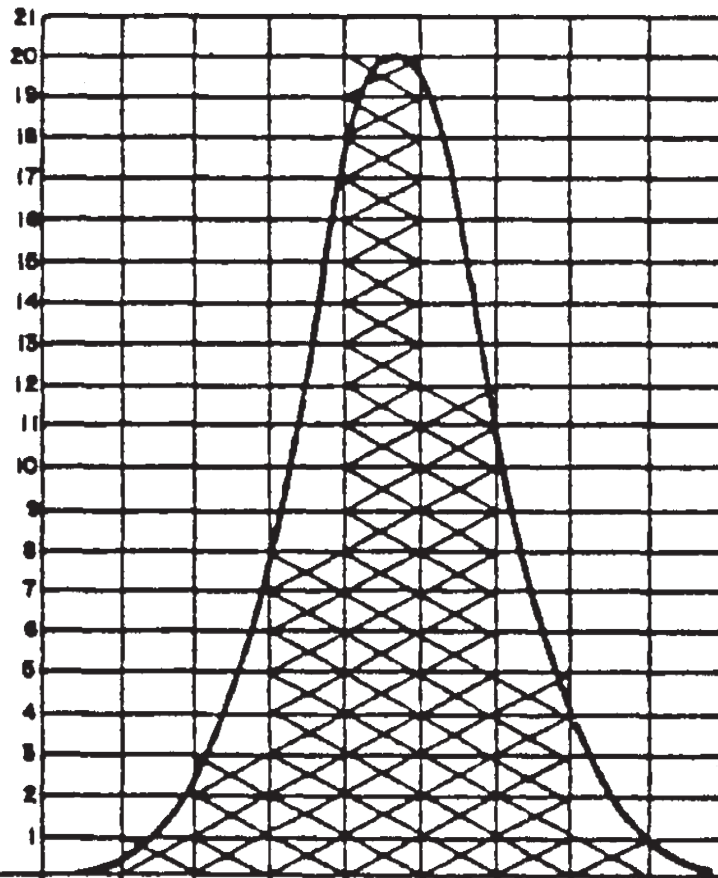
(a) PAVEMENT CORE THICKNESS (in.)

1.8	2.1	2.0	2.0	1.9
2.0	2.0	1.7	2.1	2.0
1.9	2.2	2.0	2.0	2.1
2.2	1.9	2.0	2.0	2.0
1.8	2.2	2.1	2.0	2.1
2.1	2.2	2.3	1.8	2.0
2.1	2.2	1.9	2.0	2.0
1.9	2.0	2.0	2.0	2.1
2.1	1.9	2.0	2.1	2.0
2.0	2.1	2.1	1.9	1.9

(b) TALLY of PAVEMENT CORE THICKNESS
(No of measurements)

1.7	I			
1.8	III			
1.9	IIII	III		
2.0	IIII	IIII	IIII	IIII
2.1	IIII	IIII	II	
2.2	IIII			
2.3	I			

FIGURE 13 - Normal curve fitted to histogram



1. Pavement Thickness (in.)		1.7	1.8	1.9	2.0	2.1	2.2	2.3		Totals
2. Frequency		1	3	8	20	12	5	1		50
3. Frequency x (Line 1)		1.7	5.4	15.2	40.0	25.2	11.0	2.3		100.8
4. Deviation from Average		.316	.216	.116	.016	.084	.184	.284		
5. (Deviation) ²		.0999	.0467	.0135	.0002	.0071	.0339	.0807		
6. (Line 2) x (Line 5)		.0999	.1401	.1080	.0040	.0452	.1695	.0807		.6874

$$\text{Average} = \frac{\text{Total of Line 3}}{\text{Total frequency}} = \frac{100.8}{50} = 2.016$$

$$\text{Standard Deviation} = \sqrt{\frac{\text{Total of Line 6}}{\text{Total of frequency}}} = \sqrt{\frac{.6874}{50}} = \sqrt{.013748} = .11725$$

This is an important concept, as it can be seen that the individual values obtained by making a small number of measurements on a lot do not, in themselves, provide much information. If a large number of measurements were made, there would be many both smaller and larger than those obtained from the sample. What is really important is the overall distribution of all possible measurements on the lot, and this can be estimated from the measurements on the sample by utilizing the properties of the normal curve, provided it can be assumed that the sample mean, \bar{x} , and the sample standard deviation, s , are sufficiently good estimates and \bar{x} and s , the true (unknown) values.

B. Properties of Normal Curve. The objective of fitting the normal curve to data is to draw statistical inferences from the curve. One of the properties of this curve is that, regardless of its shape, a definite percentage of the total area beneath the curve is defined by vertical lines spaced a measured distance from the centerline of the curve. This distance must, however, be measured in standard deviation (s) units. The approximate percentages of area that correspond to the standard deviation measurements of the normal curve are shown in Figure 14. Figure 14 indicates that if a large number of pavement cores were taken and the thickness measured, about 95 percent of the measurements would be between 1.79 and 2.25 inches.

C. Practical Application of Normal Curve. To make use of the properties of a normal curve that has been fitted to a set of data, the standard deviation, s , of the curve that would best fit the data must be computed from the data.

Once the value of s has been estimated, data units such as pounds, inches, or percentages, can be converted to s units by:

$$Z = \frac{(x_i - \bar{x})}{s} \quad (1)$$

in which Z is a distance measured along the base of the normal curve in either direction from the centerline, in standard deviation units; x_i is a particular value, in data units; \bar{x} is the average of the data, in the same units; and s is the standard deviation, also in data units.

For example, Figure 15 shows that if $Z = 1.282$, then from the table of area of the normal curve (Figure 16), 10 percent of the measurements would be expected to have a value greater than x_i . More detailed tables can be found in textbooks dealing with the subject of statistics.

D. Method of Utilizing Properties of Normal Curve. The point has now been reached where practical applications of the properties of the normal curve can be made. These applications include the setting of realistic numerical specification limits and the design of acceptance plans that provide protection against large risks of either accepting poor material or construction or rejecting good material or construction. For example, suppose that from measurement on a sample, it has been estimated that some characteristic of a lot has a standard deviation of five ($s=5$) and that the average value of the characteristic is 30 ($\bar{x}=30$). By converting from the data scale to the Z scale, as shown in Figure 16, the percentage of a large number of measurements that will be larger or smaller than a certain value (X_i) can be predicted. If the specification had an upper limit of 36.4 ($X_i = 36.4$), it can be seen from Figure 16 that 90 percent of the lot would be within this limit. The percentage of the lot that would be included by other limiting values also is shown in Figure 16.

A.2 SOURCES OF VARIANCE

In the vast majority of construction materials there is variation. This is especially true of those materials which constitute the bulk of the work such as Concrete, Asphalt, Base Courses of all types, Subbases, Soil and Rock. A primary reason for this variation is that these materials are produced from largely naturally occurring materials. Their manufacturing is necessarily crude due to the large amounts of materials required. Thus, we encounter wide variations when we compare values measured on different increments for a day's production. This results in large overall standard deviation. We should be aware of the components which contribute to this overall standard deviation. Certain deviations occur due to assignable causes such as a change in crushing procedure, a malfunction in equipment or other obvious reasons. There is also the natural or random non-homogeneity which will occur, which is described as an inherent variance. In addition, there are possible variances due to sampling procedures. In order to minimize this type of variance, the standard sampling procedures outlined in the appropriate PTM should be uniformly followed. The same applies to testing procedures.

Investigations as to the relative sizes of the sources of variance will be accomplished when necessary. Such studies have already been accomplished for asphalt and will be continued for this product and others. There are several statistical analytical methods used in this work.

FIGURE 14 - Approximate percentage of area within stated sigma limits.

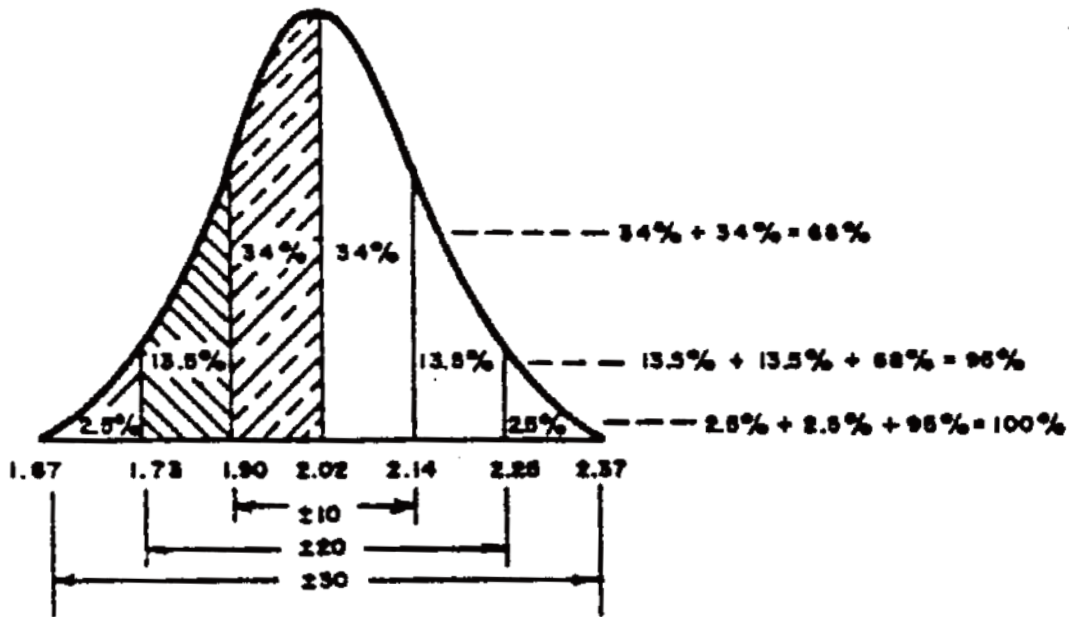


FIGURE 15 - Elements of normal curve.

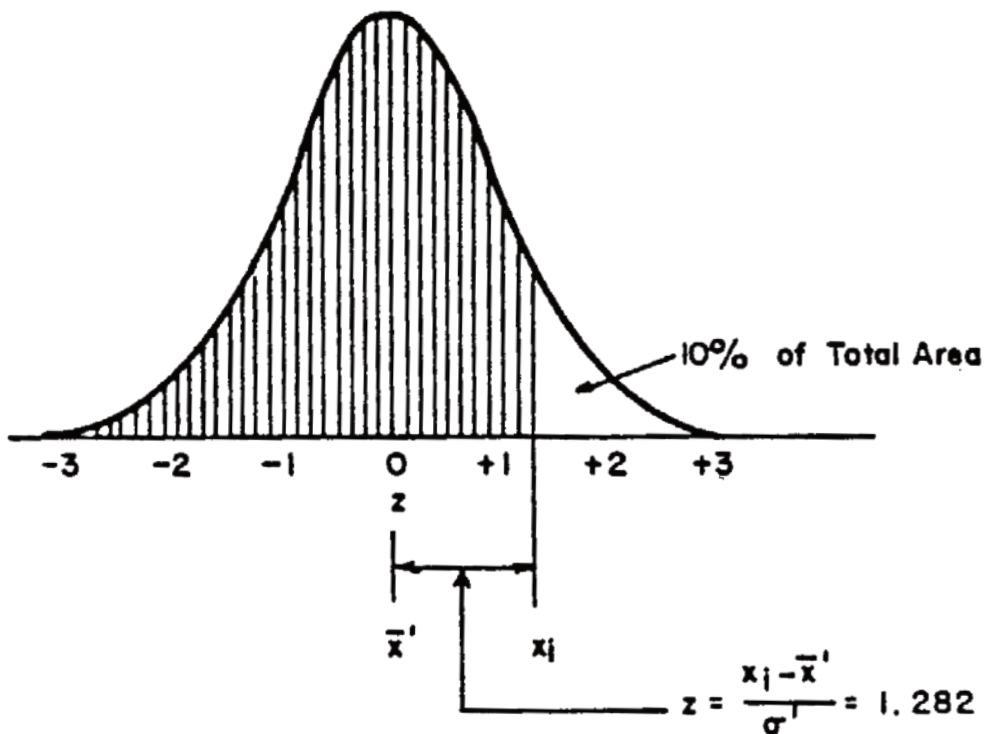
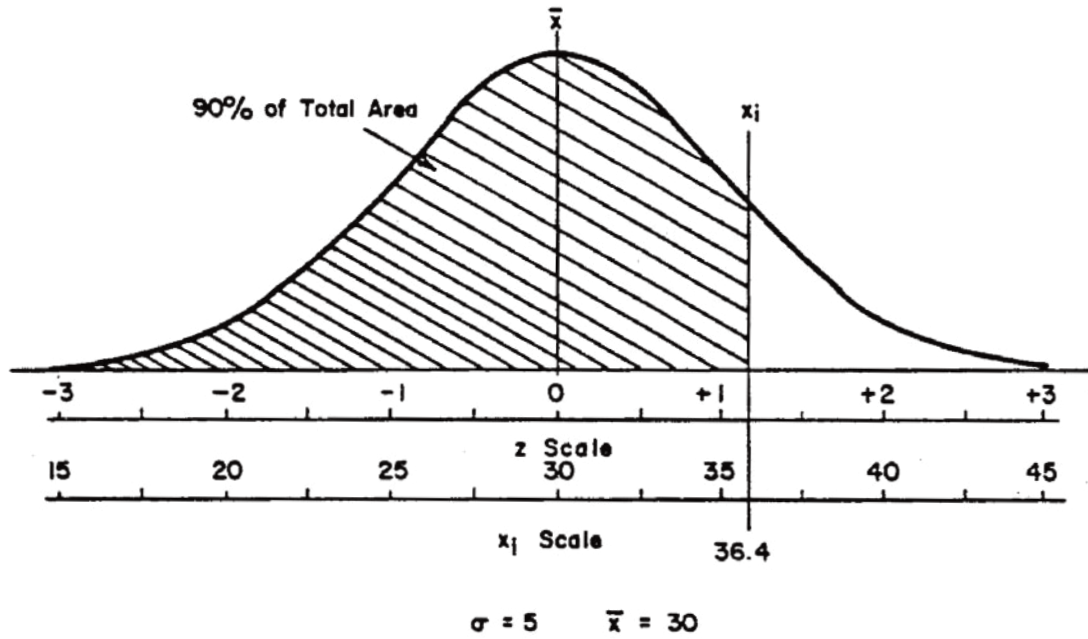


FIGURE 16 - Relationship of numerical (xy) scale to percent total area.



x_i	$x_i - \bar{x}$	$z = \frac{x_i - \bar{x}}{\sigma}$	% of Area
15.0	- 15.0	- 3.00	0.135
23.6	- 6.4	- 1.28	10.0
25.8	- 4.2	- 0.84	20.0
27.4	- 2.6	- 0.52	30.0
28.75	- 1.25	- 0.25	40.0
30.00	0.00	0.00	50.0
31.25	+ 1.25	+ 0.25	60.0
32.6	+ 2.6	+ 0.52	70.0
34.2	+ 4.2	+ 0.84	80.0
36.4	+ 6.4	+ 1.28	90.0
45.0	+ 15.0	+ 3.00	99.865

A.3 TREATMENT OF OUTLIERS

Whether or not to include values from a collection of measurements that vary greatly from the average, \bar{X} , in computations is often a perplexing problem. If these outliers stem from errors of technique or prior computation, there is no question but that they should be excluded. When there are no such known assignable (findable) causes, it is questionable whether any values not obviously impossible should be discarded without further investigation. However, when one or more very large or very small values appear in a small collection of measurements made for **assurance** or **acceptance sampling purposes**, it is not practical to determine the cause by a lengthy investigation.

The decision as to whether or not to exclude outliers must usually be based on the data that contain them. The problem is to decide whether the outliers stem from an assignable cause, or really belong in another set of data; that is, they happen to belong to another lot and were included by mistake or are the result of improper sampling, preparation, or testing, or whether they would be expected to occur if a large number of measurements were made.

For example, a sample of five bricks is tested in compression. The compression strengths are, respectively: 2,900, 2,600, 4,400, 2,500, and 2,600 psi, and the average is 3,000 psi. If the measurement on specimen 3 is included in the average, the brick will meet the requirements for AASHTO Grade SW, which is acceptable. If this measurement is excluded, the brick must be classed as Grade MW, which is not acceptable. Assuming no other specimens are available, the decision as to retaining the measurement must be based on the data.

There are various ways of dealing with this problem. A generally accepted philosophy is that the valid measurements belong to a lot described by some type of distribution. Therefore, outliers may have a position far enough behind the "tails" of this distribution to make it obvious that they should not be included. Accordingly, the first step is to find how many standard deviation (s) units the largest value is away from the sample average. First, the value S is computed from the square of the deviations from the average.

$(x_i - \bar{x})$	Deviation (1,000)	Square of Deviation
$3,000 - 2,900 =$	1.0	1.0
$3,000 - 2,600 =$	4.0	16.0
$4,400 - 3,000 =$	14.0	196.0
$3,000 - 2,500 =$	5.0	25.0
$3,000 - 2,600 =$	4.0	16.0
		254.0

$$S = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{254}{4}} = \sqrt{64} = 8 \times 100 = 800$$

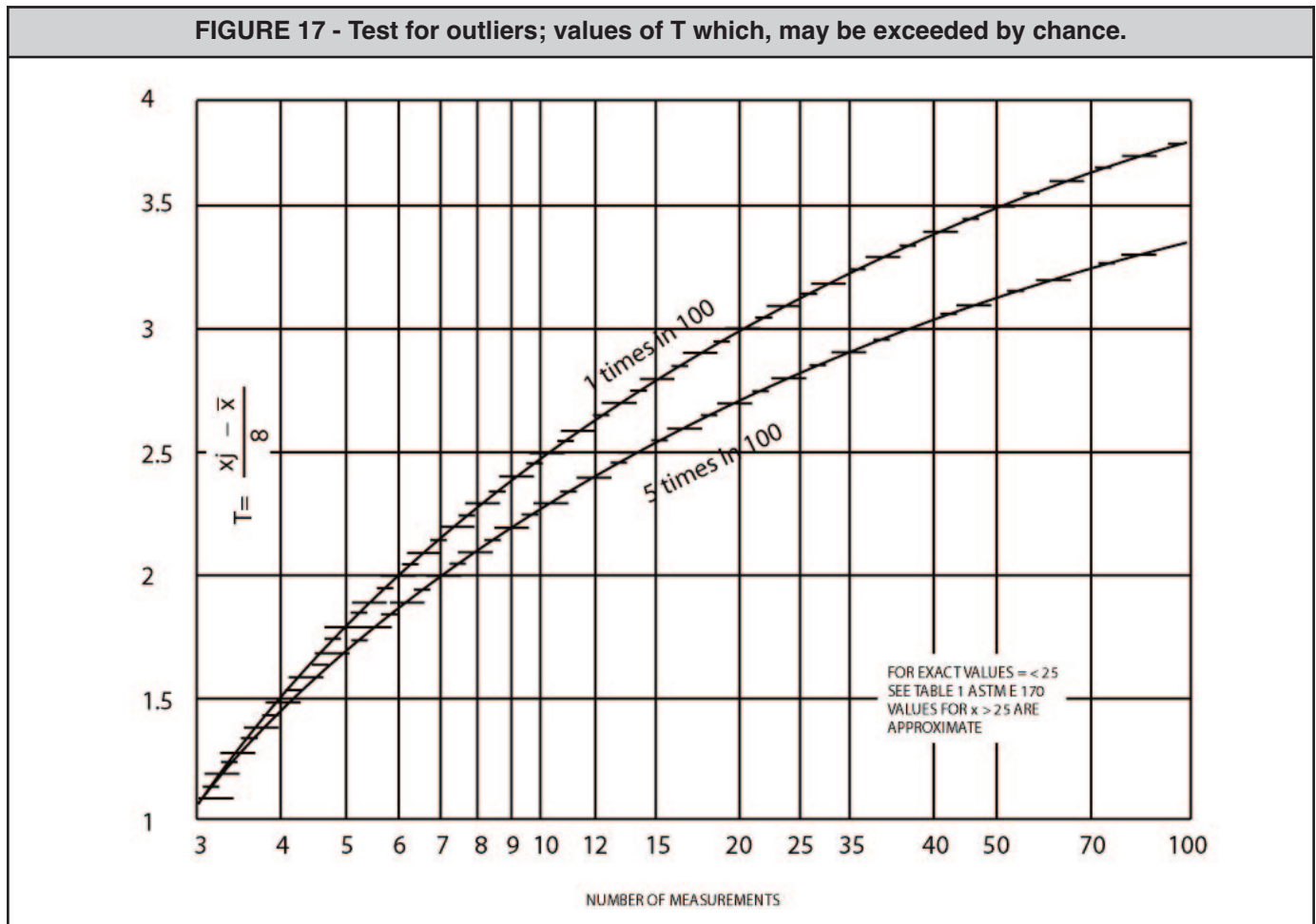
To find the distance, T , of the outlier in estimated standard deviation units from the average, the difference between the outlier, X_i , and the average, \bar{x} , is divided by the standard deviation, s , estimated from the data. Thus:

$$T = \frac{(x_i - \bar{x})}{S} = \frac{(4,400 - 3,000)}{800} = \frac{1,400}{800} = 1.75$$

Assuming the valid measurements belong to a lot described whether or not this value should be expected depends on the number of measurements in the collection. The concept is that if there are a few persons in a room the chance that one of them is 6 inches taller than the average is very small. However, in a large group of people, such as the spectators at a baseball game, it is quite probable that there will be an exceptionally tall person in the crowd. From Figure 17 which is based on this principle, it is seen that 1.75 for 1 percent significance.

This means that a value as large as 4,000 psi could occur by chance about 2 times in 100. Because it is not very probable that this value came from the same lot as the others (the brick may have been accidentally taken from a batch burned in another kiln) there would be justification for discarding it and classifying the brick represented by the sample as Grade MW and unacceptable.

Inasmuch as the presence of a very high or a very low value in the group of measurements made on a lot can have an important influence on the acceptance decision, any such value not meeting the criteria previously given should be investigated. Unless it can be established that the measurement is valid, it is probably best to take another complete set of measurements. If this is not practical, another measurement obtained on the same basis as the rest of the group must be substituted for the measurement which does not meet the outlier criteria.



This method of screening data provides a scientific basis, independent of personal judgment, for deciding whether or not an unsuspected "fluke" should be discarded when making an acceptance decision.

PTM No. 4 provides guidance in evaluating chance cause and assignable cause variation. It states that an outlier may occur due to random variability inherent in data. In other words, no assignable reason can be determined to cause the variation. In such cases the outlier should be discarded, when practical, and another test taken. If it is not practical to obtain another test, the outlier should be discarded, and the lot evaluated on the basis of the reduced number of tests.

APPENDIX B

ELECTRONIC CONSTRUCTION AND MATERIALS MANAGEMENT SYSTEM (ECAMMS)

B.1 INTRODUCTION

The Department developed the electronic Construction and Materials Management System (eCAMMS) to support the administration and testing of material samples lifted from projects and plants by PennDOT inspectors and quality assurance personnel. The Quality Assurance Reporting System (QARS) utilizes eCAMMS databases to allow for on-line inquiries, analyses, and management summary reporting. The eCAMMS functions include: Administration; Laboratory Testing; Source Quality Control; Field Testing; District Quality Assurance; Central Office Quality Assurance; Material Deviation Tracking; Project Material Certification; Job Mix Formula reviews; Plant Shipment information; and New Product Evaluations.

The following provides some additional information about eCAMMS.

B.2 SAMPLE CLASSIFICATIONS

eCAMMS has identified twenty-seven sample classifications which are defined on the back of Form TR-447. They include the various sample types such as Acceptance, District and Central Office Quality Assurance, Verification, Product Evaluation, Research and Requalification. Examples are (QA) for Quality Assurance and (FV) for Field Verification and (QR) for Quality Review samples taken at prefabrication plants.

B.3 SAMPLE STATUS

As the title indicates, the Sample Status indicates the location and progress of the sample at any given time. An example is 'Sample is Setup but not Received at Dock', for samples that are still in transition from the field or plant to the testing facility.

B.4 COUNTY CODES

This is a preset county code which is generally alphabetized with one exception. 1 is Adams County, 66 is York and 67 is Philadelphia.

B.5 MATERIAL CODES AND CLASSIFICATIONS

Any material test performed in the Laboratory Testing Section (LTS) has a material code and material description/material classification. Examples are: PGS-22 for Asphalt Cement; NTT for anionic, non-tracking tack; STRAND for prestressing wire strand; B57SL for Type B, AASHTO Number 57 Slag Aggregate; and AAPAVE for Class AA Pavement Concrete.

B.6 TR-447 SAMPLE SETUP

Samples are set up in eCAMMS. eCAMMS is designed to facilitate the entry of sample information from the paper Form TR-447 directly into eCAMMS.

APPENDIX C

EXAMPLE PROBLEMS EMPLOYING THE RANDOM NUMBER CONCEPT (PTM NO. 1)

C.1 INTRODUCTION

The concept of **randomness** should be clearly understood before the details of random sampling are discussed. **Randomness** is an intuitive concept referring to a natural condition of disorder and unpredictability of individual results. In other words, when a sample is taken at **random** every individual in the population has an **equal** and **independent** chance of being chosen as part of the sample.

The procedure by which the **increments** of a sample are taken is extremely important. It must be clearly understood that unless the **increments** are chosen on a **random** basis (i.e. by **probability sampling**) the methods of statistics cannot be applied. The locations or units within a lot from which the increments are obtained must be entirely random. Random in this case does not mean haphazard but does mean that the locations are predetermined without bias. In addition, every possible **increment** in the **lot** must have an equal probability of being chosen. This means that a lot must be sampled at some stage of the process when all parts of the lot are accessible.

Randomness can be obtained in a number of ways. PennDOT will utilize a table of random numbers to predetermine without bias the location of the **sample increments**. A **random number** is a number selected entirely by chance. A **random number table** is defined as a set of numbers chosen at random which are generated from an infinite population of numbers.

C.2 DISCUSSION OF PTM No. 1

PennDOT's **random number table** is contained in PTM No. 1. This method of test outlines the procedures for selecting sampling locations in accordance with accepted probability sampling techniques. PTM No. 1 is shown on the following pages. Section 3 (Random Number Table) of PTM No. 1 is a primary concern for our immediate discussion. The table provides a listing of the random numbers. The random numbers are presented in decimal fractions accurate to two places.

Notice that there are X and Y columns. In the Y column each number is preceded by an L or R. These letters indicate that the sample increment is located with respect to the left edge or right edge of the pavement. The random numbers are used to select the location for obtaining the sample increments based on the most appropriate parameter (time, quantity, etc.) for the review.

Commonwealth of Pennsylvania
Department of Transportation

PA Test Method No. 1
November 2018

LABORATORY TESTING SECTION
Method of Test for

PROBABILITY SAMPLING

1. SCOPE

1.1 This method of test outlines the procedures for selecting sampling sites in accordance with accepted probability sampling techniques. It is intended that all Department samples, regardless of size, type or purpose shall be selected in an unbiased manner, based entirely on chance.

2. SECURING SAMPLES

2.1 Department samples shall be taken as directed by the engineer or their authorized representative.

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 and the sample taken precisely as directed by the appropriate PTM.

3. RANDOM NUMBER TABLE

3.1 For test results or measurements to be meaningful, it is necessary that the SUBLOTS 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.

3.2 Determine the LOT size and the number of SUBLOTS Per LOT by referring to the PTM for the material being sampled.

3.3 For each LOT, use five consecutive two-digit random numbers from Table I. For example, if the PTM for a particular material specifies five sublots 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.

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 as specified in the appropriate PTM.

PTM No. 1
November 2018
Page 2

3.5 In situations where coordinate locations do not apply (i.e., plant samples, stockpile samples, etc.), use only those decimal values from Column X or Column Y as specified in the appropriate PTM.

4. SAMPLING PROCEDURE

4.1 After the appropriate number of random locations has been determined, refer to the proper PTM for special sampling procedure instructions and examples.

5. DEFINITION OF TERMS

5.1 LOT - an isolated quantity of a specified material from a single source or a measured amount of specified construction assumed to be produced by the same process. The LOT size is specified in the PTM for the material being sampled.

5.2 SUBLOT - a portion of a LOT; the actual location from which a sample is taken. The size of the subplot and the number of sublots per LOT are specified in the PTM for the material being sampled.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
TABLE I
RANDOM POSITIONS IN DECIMAL FRACTIONS (2 PLACES)

	X	Y		X	Y		X	Y			
1.	0.29	R	0.66	34.	0.61	L	0.87	67.	0.93	R	0.17
2.	0.74	R	0.49	35.	0.76	R	0.16	68.	0.40	R	0.50
3.	0.89	L	0.79	36.	0.87	L	0.10	69.	0.44	R	0.15
4.	0.60	R	0.39	37.	0.41	L	0.10	70.	0.03	L	0.60
5.	0.88	R	0.31	38.	0.28	R	0.23	71.	0.19	L	0.37
6.	0.72	L	0.54	39.	0.22	L	0.18	72.	0.92	L	0.45
7.	0.12	R	0.08	40.	0.21	L	0.94	73.	0.20	L	0.85
8.	0.09	L	0.94	41.	0.27	L	0.52	74.	0.05	R	0.56
9.	0.62	L	0.11	42.	0.39	R	0.91	75.	0.46	R	0.58
10.	0.71	R	0.59	43.	0.57	L	0.10	76.	0.43	R	0.91
11.	0.36	L	0.38	44.	0.82	L	0.12	77.	0.97	L	0.55
12.	0.57	R	0.49	45.	0.14	L	0.94	78.	0.06	R	0.51
13.	0.35	R	0.90	46.	0.50	R	0.58	79.	0.72	L	0.78
14.	0.69	L	0.63	47.	0.93	L	0.03	80.	0.95	L	0.36
15.	0.59	R	0.68	48.	0.43	L	0.29	81.	0.16	L	0.61
16.	0.06	L	0.03	49.	0.99	L	0.36	82.	0.29	R	0.47
17.	0.08	L	0.70	50.	0.61	R	0.25	83.	0.48	R	0.15
18.	0.67	L	0.68	51.	0.87	L	0.36	84.	0.73	R	0.64
19.	0.83	R	0.97	52.	0.34	L	0.19	85.	0.05	L	0.94
20.	0.54	R	0.58	53.	0.37	R	0.33	86.	0.43	L	0.05
21.	0.82	R	0.50	54.	0.97	L	0.79	87.	0.87	R	0.98
22.	0.66	R	0.73	55.	0.13	R	0.56	88.	0.37	L	0.71
23.	0.06	L	0.27	56.	0.85	R	0.64	89.	0.94	L	0.26
24.	0.03	L	0.13	57.	0.14	L	0.04	90.	0.57	L	0.63
25.	0.55	L	0.29	58.	0.99	R	0.74	91.	0.26	R	0.80
26.	0.64	L	0.77	59.	0.40	L	0.76	92.	0.01	L	0.79
27.	0.30	R	0.57	60.	0.37	L	0.09	93.	0.83	R	0.59
28.	0.51	R	0.67	61.	0.90	R	0.74	94.	0.71	L	0.21
29.	0.29	R	0.09	62.	0.09	L	0.70	95.	0.65	L	0.63
30.	0.63	R	0.82	63.	0.66	L	0.97	96.	0.65	L	0.87
31.	0.53	L	0.86	64.	0.89	L	0.55	97.	0.72	R	0.92
32.	0.99	R	0.22	65.	0.67	L	0.44	98.	0.85	L	0.78
33.	0.02	R	0.89	66.	0.02	R	0.65	99.	0.04	L	0.46
								100.	0.29	L	0.95

X = Decimal fraction of the total length measured along the road from the starting point.
 Y = Decimal fraction measured across the road from either outside edge towards the centerline of the paved lane.
 R = Indicates measurement from the right edge of the paved lane.
 L = Indicates measurement from the left edge of the paved lane.

End of Text PTM 1

Examples of Random Sampling Using PTM No. 1. It should be noted that the location of the sample increments may be determined within a time, material tonnage, or distance framework (i.e.: linear, planer, 3-dimensional). To demonstrate the use of PTM No.1 Random Number Table and the differences between each of the aforementioned techniques, the following examples are provided.

C.3 EXAMPLE 1 - SAMPLING BY TIME SEQUENCE

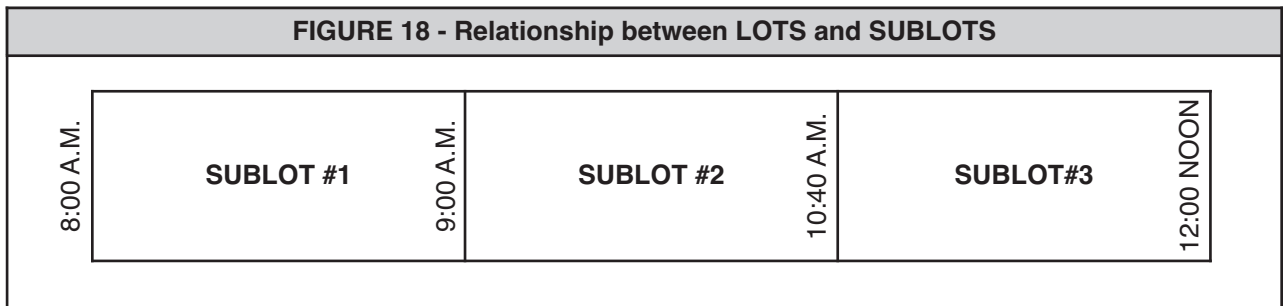
Suppose a sample of coarse aggregate for use in a concrete mix is to be sampled. Sampling will be done at the plant. The sample increments will be selected on a **time** basis from a delivery or a "feed" belt. The assumption is made that the sample increments will be obtained over a 4-hour period starting at 8:00 a.m. and ending at 12 noon. The sample will be a Quality Assurance Sample and will be selected on a lot basis.

SOLUTION

1. **Lot Size** - The first item that needs to be determined is the lot size. The lot size is left to the discretion of the QA Team member. The assumption in this example is that the lot size is a four-hour production period.
2. **Sublot size** - Since the sampling will be accomplished utilizing a time sequence, the four-hour lot must be divided into equal **increments** or **sublots**. From Figure 18, the number of **sublots** or **sample increments** per **lot** for coarse aggregate utilized in asphalt paving is three. Therefore, the **lot** must be divided into three equal **sublots**. The **time interval** for each **sublot** is found to be:

$$\text{Sublot Time Interval} = \frac{(4 \text{ hours per lot})(60 \text{ minutes per hour})}{3 \text{ sublots per lot}} = 80 \text{ minutes per sublot}$$

The division of the four hours of production time into three equal **sublots** is shown diagrammatically in Figure 18. This figure indicates that Sublot #1 begins at 8:00 a.m. and ends at 9:20 a.m. Sublot #2 begins at 9:20 a.m. and ends at 10:40 a.m., etc.



3. **Sample Increments** - Up to this point nothing has been randomized. Only the **lot size** and the **time interval** for each **sublot** has been determined. The exact time at which each **sample increment** should be taken within the sublot is not known. The times when the **sample increments** are to be obtained must be selected on a **random** basis. PTM No. 1 will be employed in order to provide for the randomization of the SAMPLE INCREMENTS. According to Section 3.5 of PTM No. 1, **random numbers** must be chosen from the X or Y columns. In this case, use will be made of column X.

Note: It should be understood that column Y could also have been used. Since three **sample increments** are to be taken, choose the first three numbers from Column X.

These numbers are: 0.29 0.74 0.89

In order to randomize the sampling times within each **sublot**, use will be made of the **time interval** (80 minutes) computed in Step 2. This **time interval** is multiplied by each of the three **random numbers** selected previously.

Sublot #1: $0.29 \times 80 = 23$ minutes

Sublot #2: $0.74 \times 80 = 59$ minutes

Sublot #3: $0.89 \times 80 = 71$ minutes

The computed times are added to the starting times for each **sublot**. This results in the **randomized time** at which the **sample increment** is to be obtained. The sampling times can be summarized as follows:

NO.	SUBLOT NUMBER	SAMPLING TIME
1	8:00am + 23 minutes	8:23 a.m.
2	9:20am + 59 minutes	10:19 a.m.
3	10:40am + 71 minutes	11:51 a.m.

These results may be interpreted to indicate that the first **sample increment** is obtained from Sublot #1 at 8:23 a.m. Sublot #1 begins at 8:00 a.m. and ends at 9:20 a.m. Therefore, the second **sample increment** is not until Sublot #2 is in production. Sublot #2 begins at 9:20 a.m. and the second **sample increment** is obtained at 9:20 a.m. plus 59 minutes (i.e., at 10:19 a.m.). The same reasoning can be applied to the remaining **sample increments** for the last **sublot** of production.

C.4 EXAMPLE 2 - SAMPLING BY MATERIAL TONNAGE

As another illustration of PTM No. 1, assume that a Quality Assurance Sample is to be taken of a asphalt wearing course mix for use in paving. The sampling shall be done from the hauling units at the manufacturing plant. The sampling shall be done randomly on a tonnage basis.

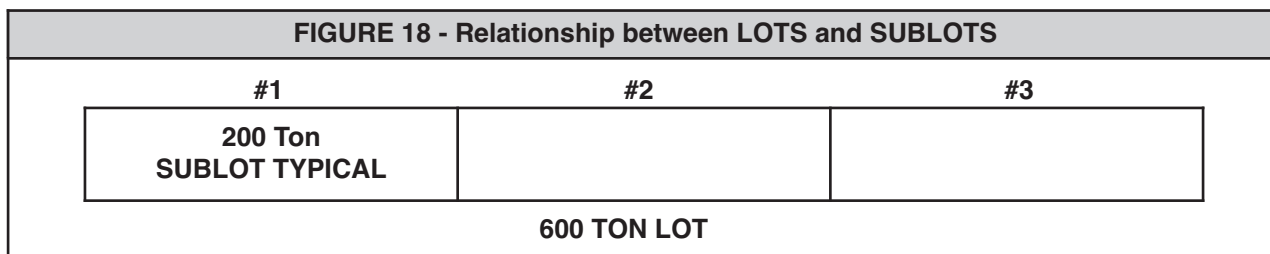
SOLUTION

This solution follows the same basic pattern as the solution given for the previous example. First identify the LOT and SUBLOT SIZE and finally the POINT AT WHICH THE SAMPLE INCREMENT WILL BE OBTAINED.

1. **Lot Size** - Based on the Quality Control Plan for asphalt plants, the plant lot size for this example will be 600 tons. This is the minimum **lot size** to sample..
2. **Sublot size** - Figure 19 shows that an asphalt mix sampled at the plant requires three **sublots** or **sample increments per lot**. Therefore, each sublot size is found as follows:

$$\text{Sublot Size} = \frac{[600 \text{ Tons per lot}]}{3 \text{ sublots per lot}} = 200 \text{ Tons per sublot}$$

The relation between **lot** and **sublot** size is shown in Figure 19.



3. **Sample Increments** - There shall be one **sample increment** per **sublot** as in the previous example problem. The tonnage shall be sampled from the trucks, but it is not known what tonnage (i.e., which load) shall be sampled for the first **sample increment** since the **sample increments** have not been randomized. Again, referring to PTM No. 1, choose the first three **random numbers** (Table 2) for this randomization process. These numbers are then multiplied by each of the three **sublots** [200 tons] as follows:

SUBLOT	RANDOM NUMBER	SUBLOT SIZE TONS	TON TO BE SAMPLED
1	0.29	200	58th
2	0.74	200	148th
3	0.89	200	178th

As noted earlier, each **sublot** contains 200 tons. The first **sample increment** is obtained at approximately the 58th ton of the first **sublot**.

A waiting period must take place until the first **sublot** is completed [200 tons] before the selection of the **second sample** increment at the 148th ton of the second **sublot**. The same reasoning is followed for obtaining the remaining three **sample increments**.

If a cumulative lot of the tonnage being produced is kept, it would appear as follows:

<p>Sublot #1: 58th ton</p> <p>Sublot #2: 200 + 148 = 348th ton</p> <p>Sublot #3: (2) (200) + 178 = 578th ton</p>

C.5 EXAMPLE 3 - SAMPLING BY PLANNER FRAMEWORK

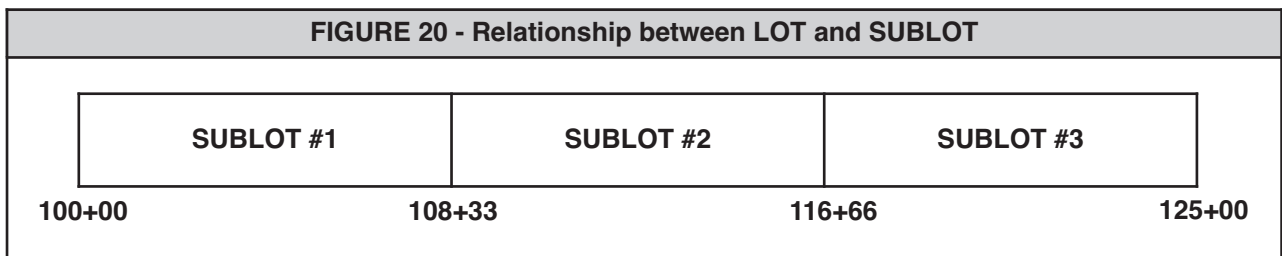
A Quality Assurance Sample of 2A subbase material is to be taken from the roadway. The sample is to be obtained before compaction. The sample is to be used for gradation information. The sample increments comprising this sample are to be obtained at random on a lot basis. The paving operation places 2500 linear feet in four hours. Assume that the pavement width is twelve feet and that the project begins at station 100+00.

SOLUTION

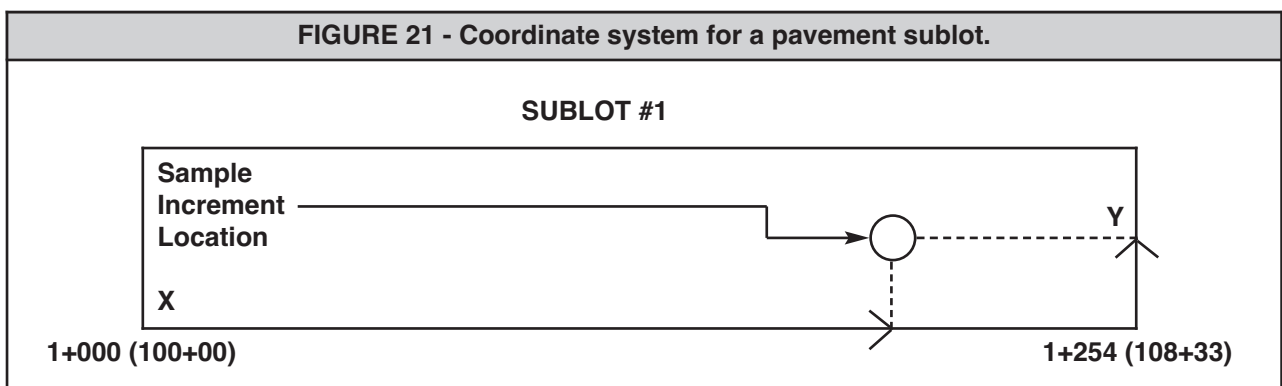
1. **Lot Size** - The **lot size** for this subbase placement is 1/2 day's or four hours placement. Therefore, in this example, the lot size is 2500 linear feet.
2. **Sublot Size** - The beginning station for the **lot** is 100+00. This **lot** ends at Station 125+00, since 2500 linear feet of subbase are being placed in four hours. Figure 20 shows that three **sublots** or **sample increments** per **lot** are required for subbase.

$$\text{Sublot Size} = \frac{[2,500 \text{ feet per lot}]}{3 \text{ sublots per lot}} = 833 \text{ feet per sublot}$$

Figure 20 indicates how this **lot** is divided.



3. **Sample Increments** - The point at which each **sample increment** will be obtained must now be randomized. To accomplish this task, the location must be randomized in the **longitudinal (x) direction** as well as in the **transverse (y) direction**. This is illustrated in Figure 21.



PTM No. 1 is used for randomizing the **sample increment** locations. The procedures employed in the first two examples will also be utilized in this example. However, there is one slight difference. Both Column X and Column Y must be used in this calculation. Choose the first three **random numbers** from Column X as well as the first three numbers from Column Y (including the L or R preceding the Y value).

These values are shown below:

X		Y
0.29	R	0.66
0.74	R	0.49
0.89	L	0.79

These X and Y **random numbers** are multiplied by the **sublot length** and **paving width**, respectively, as shown below:

Sublot #1: [Starting Station 100+00]
Coordinate X = $0.29 \times 833 \text{ ft} = 242 \text{ ft}$
Coordinate Y = $R \ 0.66 \times 12 \text{ ft} = 7.9 \text{ ft R}$

Therefore, the sample increment location for the first sublot is at Station 100+00 plus 242 ft [i.e. Station 102+42] and is located 7.9 ft from the right edge of the paving lane.

Sublot #2: [Starting Station 108+33]
Coordinate X = $0.74 \times 833 \text{ ft} = 616 \text{ ft}$
Coordinate Y = $R \ 0.49 \times 12 \text{ ft} = 5.9 \text{ ft R}$

Therefore, the **sample increment location** for the second **sublot** is at Station 108+33 plus 616 ft [i.e. Station 114+49] and is located 5.9 ft from the *right edge of the paving lane*.

The same procedure is followed for Sublot #3. It should be pointed out that in the development of a sampling procedure, a person need not go completely through the **random number table** of PTM No. 1 before using the same numbers over again.

APPENDIX D

STRAIGHT-LINE ANALYSIS CHARTS

D.1 INTRODUCTION

Straight-line analysis charts are a means for detecting systematic variation from the material quality to be expected in a continuous production process; that is, variation greater than the random fluctuation which is inevitable and allowable. Straight-line analysis charts should be used as indicators when a process should be examined for trouble. These charts not only show when the established limits have been exceeded, but also provide means of anticipating and correcting whatever causes may be responsible for defective material.

D.2 PLOTTING OF DAILY ACCEPTANCE OR QUALITY CONTROL TESTS

The use of straight-line analysis charts or straight-line diagrams for construction site quality control, acceptance or quality assurance monitoring is at the discretion of the project's Assistant Construction Engineer/Assistant Construction Manager. Material Producers must maintain straight-line analysis charts of quality control tests for the items listed in the Project Office Manual, Part B, Section 7. The sample size shall be $n = 1$ for quality control purposes unless the Contractor and/or Material Producers elects to use statistical control charts.

Examples of plotting quality control gradation tests for subbase materials are shown on subsequent pages. The plotting of the daily quality control tests provides the plant or project inspector with a pictorial presentation of the material quality. Plant and/or project control problems can be accurately detected by diligent testing and inspection and prompt plotting of **all** test results. The vertical scales of the analysis charts are generally chosen so that a test result falling outside the limits of the graph is also outside the specification limit. A date is assigned to each vertical line. The design value for the material is assigned to the central or "heavy" center line.

Knowledge of the behavior of chance variations is the foundation of straight-line chart analysis. If a group of data varies on a pattern which conforms to a **random** pattern (See Figure 3, Section 3.3 Theory of Sampling), it is assumed that no assignable causes are present. These data are said to be "in control." If the data does not follow a random pattern, it is assumed that **assignable** causes may be at work and that the process is "out of control."

An important consideration in choosing the sampling and testing frequency is the **uniformity** of production and inspection conditions. These conditions should be kept as alike as possible while the material represented in the sample is being produced. The more variability in the material during production, the more frequent the sampling and testing must be in order for the plant and/or project technician to be assured that the material is within specification requirements. Further, corrections in the production process necessitate frequent sampling and testing to assure uniformity.

D.3 PLOTTING OF QUALITY ASSURANCE TESTS

The Construction Quality Assurance Section (CQAS) Team personnel are responsible for taking quality assurance samples and for witnessing tests. The number of quality assurance visits to any project, and hence the number of quality **assurance samples** or witness tests, will be independent of the size and type of project funding.

When a project on which the contractor's staff and equipment are properly organized and functioning under experienced supervision, and where the assigned inspection staff is properly functioning, the frequency of visits will normally be decreased. If it is found that a project has questionable organization, experience or inspection, the number of Quality Assurance visits will be increased to ensure improved quality.

All samples are to be taken randomly. It is recommended that Contractor's and/or Material Producer's personnel obtain a **quality control sample** during the time of sampling for quality assurance. This will enable a comparison between laboratory and field tests.

Copies of all **quality assurance test results** are forwarded to the DME and the District Construction Staff, the Contractor and/or the Materials Producer. It is essential that all personnel involved compare the test results of the **quality assurance sample** with the **quality control sample** for timely evaluation of **job control**. This is accomplished by plotting the quality control test result and comparing it with the **average** and **range** (highest and lowest value) of the quality assurance sample increments.

The average of the quality assurance sample increments shall be represented by the symbol \circ . The range of the sample increments shall be represented by two horizontal parallel lines (\equiv). The upper line will represent the highest value of the sample increments and the bottom line the lowest value. The average will always be between these two values.

When the **quality assurance samples** or **quality control samples** indicate a potential material control problem may exist at the point of manufacture, source of supply and/or project site, the Contractor and/or Material Producer shall increase their frequency of sampling and testing to determine if such a condition continually exists. The CQAS Team personnel shall indicate on the appropriate witness report form whether or not the analysis charts are being kept up-to-date by the Contractor (if required) and/or Materials Producer, any recommendations made by CQAS, and what corrective actions (when necessary) have been taken by the Contractor and/or Material Producer to assure material control.

D.4 EXAMPLES OF STRAIGHT-LINE ANALYSIS CHARTS

The primary objective of sampling is to estimate the population parameters (arithmetic mean, variance, etc.). There is a much higher probability that a sample of size $n > 1$, is closer to the true arithmetic mean and variance than a sample of size $n = 1$. Also, the chance of finding extreme values associated with the material variability is much greater for a sample of $n > 1$.

Since the range is simple to calculate, it will be employed to depict the variability of the material. Consequently, since **quality assurance samples** of $n > 1$ will be taken for most construction materials, a **quality control samples** of $n = 1$ should fall within the range of the **quality assurance sample increments** provided it comes from the same production process. This is the reason for obtaining a **quality control sample** during the time that the **quality assurance sample** increments are lifted.

EXAMPLE #1

In this example the gradation and percent compaction of subbase material are plotted on the straight-line analysis charts. Twenty-one days of production or placement are shown (May 25 to June 20). On May 28 and June 19, **quality assurance samples** were taken. Also, **quality control samples** were lifted at the same time. The average of the **quality assurance sample** is shown as the symbol \circ for each screen and the percent compaction. The range of the **quality assurance samples** is indicated by two horizontal parallel lines (\equiv). The **quality control sample** is represented by a dot connected with a straight line from the previous **quality control sample**. The underlying principle behind sampling is the relationship that exists between the distribution of sample means and the normal distribution. Although a sample average or mean of size $n > 1$ would not necessarily be exactly equal to the population mean, it would have a better chance of being closer to the true mean than a single sample of $n = 1$.

The same reasoning is followed for plotting the range of values for a sample of size $n > 1$. The chance of locating extreme values (low and/or high) is much greater for a sample of size $n > 1$. The range is established by subtracting the lowest value from the highest value in a set of data. This can be employed as an indicator of the material variability: that is the expected spread, provided the sample increments come from the same production process and the tests are conducted according to the appropriate PTM. The average of the **quality assurance sample increments** will always be between the range values. If the **quality control sample** is from the same production process and the test is conducted in accordance with the appropriate PTM, then the result of this sample can be expected to be between the range values of the **quality assurance sample increments**.

Upon receipt of the **quality assurance** test results, the Contractor and/or Materials Producer or construction staff should compare the **assurance** results with the daily field **quality control** results. This is done to determine if the **quality control** results are within the range of values shown by the **quality assurance sample increments**. Notice that in this example where two **quality assurance** samples were obtained, that the **quality control** samples obtained at the same time in the production process fell within the range values. Also notice that on June 5 and 6 the production process indicated a problem with the 1.18 mm (Number 16) material and the percent compaction. Corrections were made by the plant and/or project personnel and noted on the charts. To verify that uniformity had been established, the plant and/or project personnel increased the frequency of sampling.

EXAMPLE #2

This example is similar to the first example except that the **quality control sample** indicates that the 1.18 mm (Number 16) and 150 mm (Number 100) sieves are outside the range (variability) established by the **quality assurance sample increments**. This is shown for June 28. The **quality control sample** indicates that the material is within specifications. Notice that the **quality control results** for the 1.18 mm (Number 16) and 150 mm (Number 100) sieves after June 28 are fluctuating, for the most part, between the range values established by the **quality assurance samples**. If the **quality control results** after June 28 continually plotted outside the range established by the **quality assurance results**, then the condition of the screens should be checked and/or compliance with the test method (PTM) should be evaluated. If the **quality control results** plotted outside the specification limits at any time, corrective actions must be taken to bring the material within specification limits. In addition, the frequency of sampling should be increased to assure that the material is being produced continually within the specification limits. Once this is established, the frequency of sampling can be reduced.

Another **quality assurance sample** was lifted on July 22 and the average and range determined. Notice that the **quality control results** fell within the range value as did the preceding **quality control results**. This indicates that there is uniformity in the sampling and testing process as well as uniformity in the production process.

EXAMPLE #3

In this example, the gradation tests were being performed utilizing a badly worn 1.18 mm (Number 16) sieve. Notice that the percent passing the 1.18 mm (Number 16) sieve tends toward the coarse side from July 25 to August 4. A **quality assurance inspection** was made on August 4. It was observed that a timer was not being employed while conducting the gradation tests. Also, the 1.18 mm (Number 16) sieve was worn excessively. Both of these conditions were noted on the straight-line analysis charts. A heavy line was drawn vertically through the straight-line analysis charts corresponding to August 4. This indicates that the quality control tests to the right of this line are performed properly. Notice that two **quality control tests** (increased sampling frequency) were run after the corrections were made. In addition, a **quality assurance sample** was lifted to establish the process average and range. Moreover, a "follow-up" **quality assurance inspection** was made on August 16 to evaluate the **quality control tests**. Notice that the **quality control tests** fall approximately within the range of values established by the **quality assurance tests**. This indicates uniformity exists both in the sampling and production process.

EXAMPLE #4

In this example, the quality control tests and the running average are plotted on the straight-line analysis chart for the # 4 sieve for 2A aggregate utilizing a computer program at a material supplier's laboratory. The straight-line chart shows the target value, action points and specification limits. In this example several individual test results and one running average exceeded the established action points and corrective actions should have been taken. All test results met the specification limits.

EXAMPLE #5

These examples cover only the more common conditions that might occur. No attempt has been made to cover every situation that may be encountered at the plant and/or project level. In most cases, the straight-line analysis charts, coupled with engineering judgment, will dictate when a production process is in trouble and when it should be examined in depth. Since establishment of **uniformity** is paramount in any production process, it should be kept in mind that any change to the production process necessitates increased frequency of sampling to assure uniformity is maintained. When **quality control results** plot outside the specification limits, corrective actions must be taken immediately to assure the material is being produced within the desired specification limits. All corrective actions must be indicated on the straight-line analysis charts.

**EXAMPLE #2
SUBBASE GRADATION AND COMPACTION**

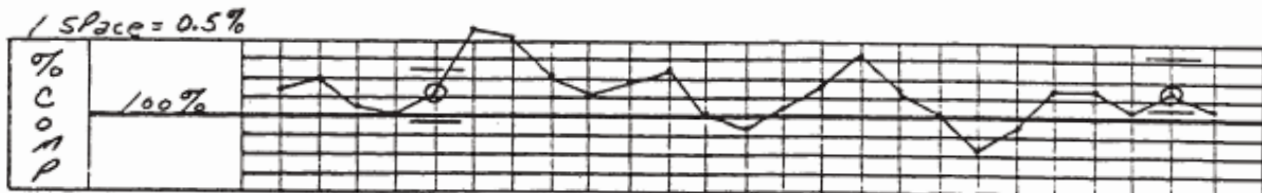
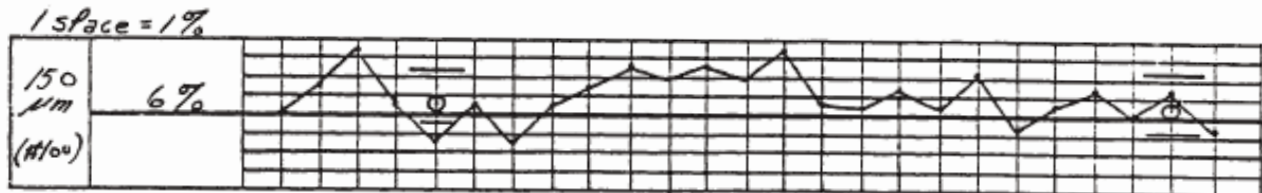
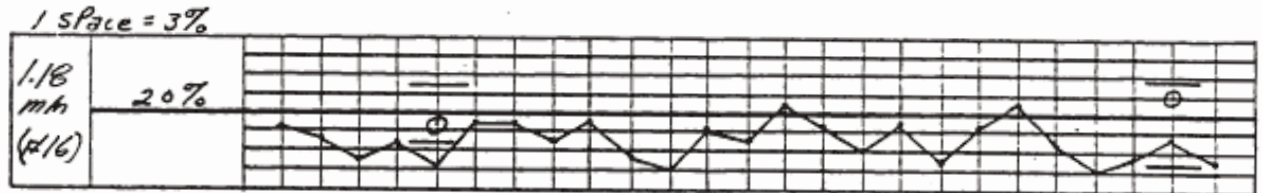
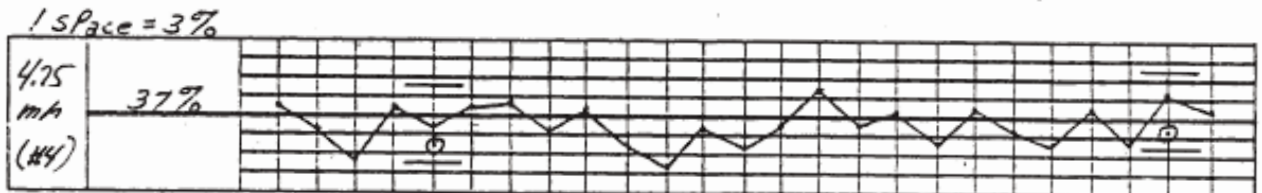
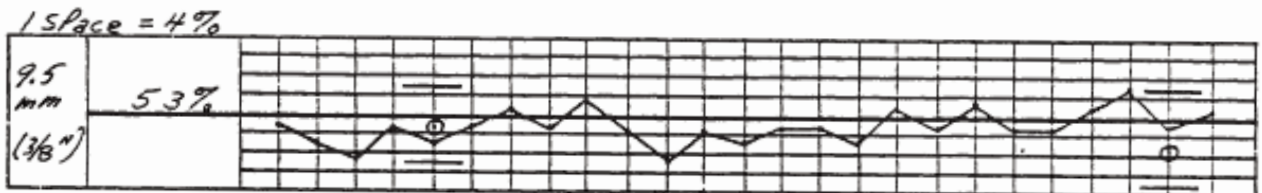
TR-4254 (9-72)



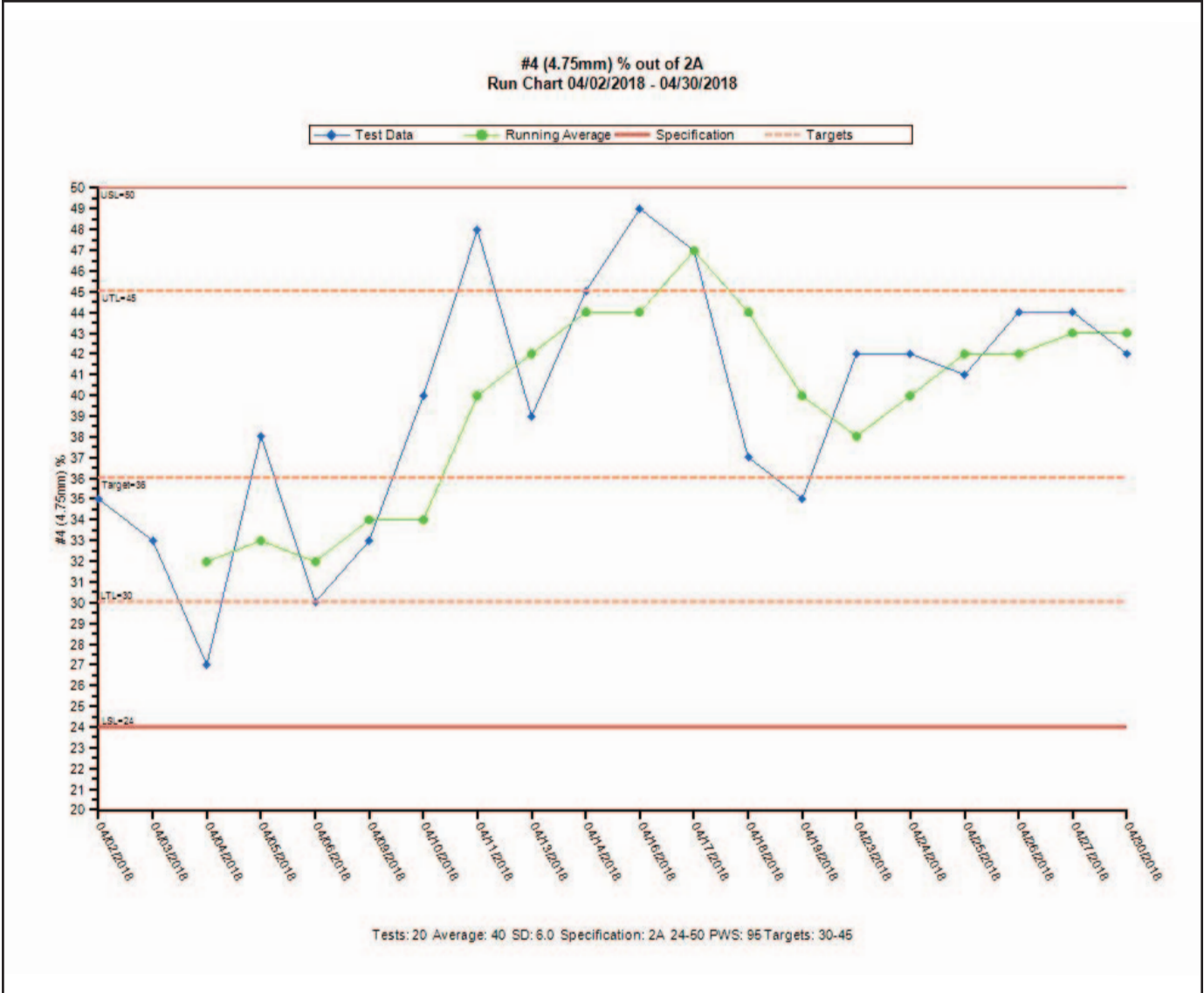
EXAMPLE #2 SUBBASE
STRAIGHT LINE ANALYSIS CHART
GRADATION AND COMPACTION

District _____
County _____
Route _____
Date _____ to _____

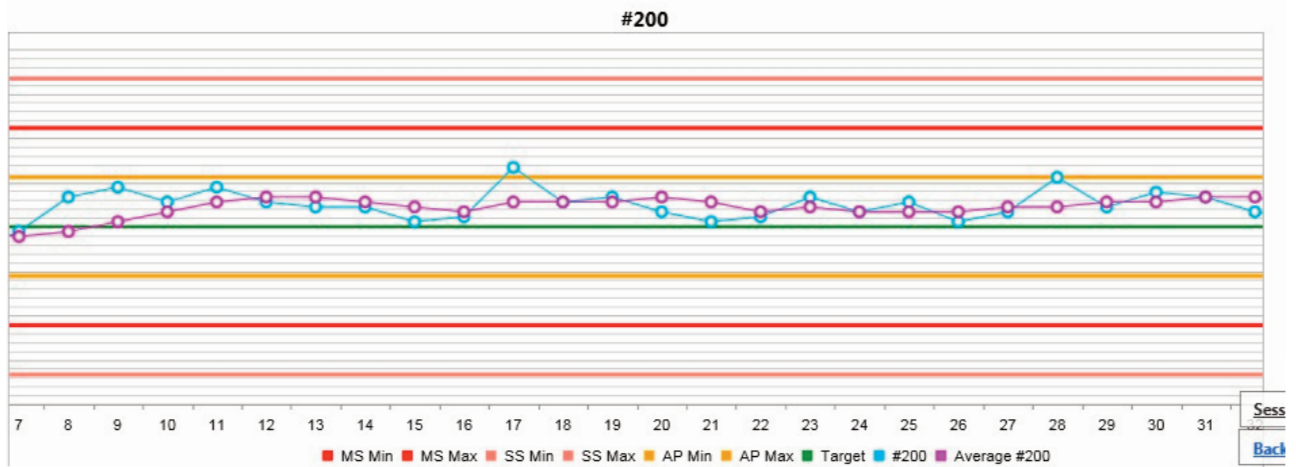
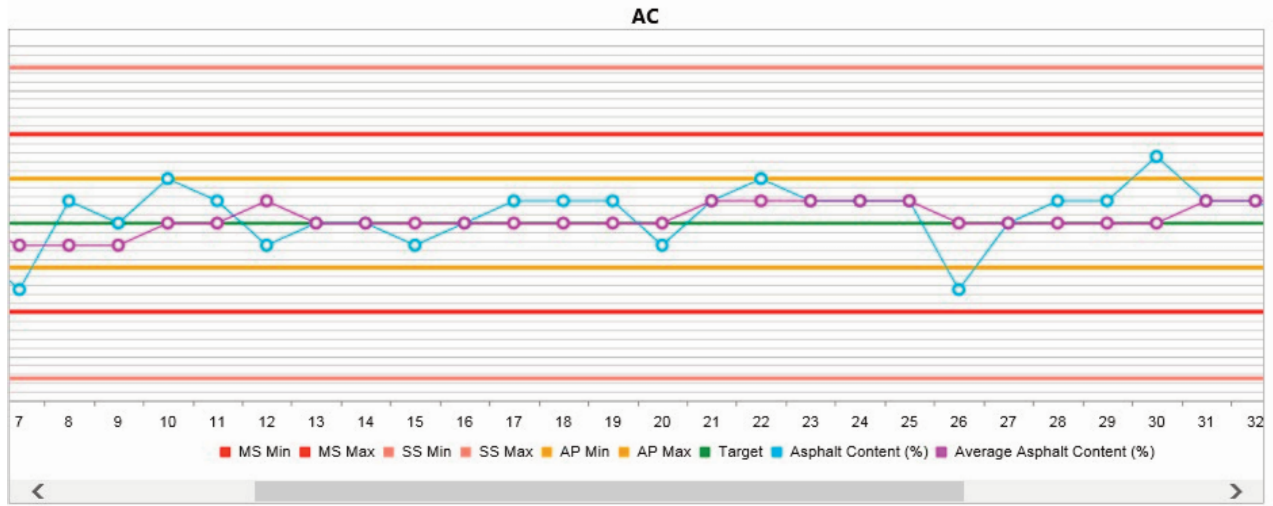
Section _____ Project No. _____ Contractor _____



EXAMPLE #4



EXAMPLE #5



APPENDIX E

GLOSSARY AND NOTATION

- Acceptable quality level** - The maximum percent defective that can be considered satisfactory as a lot average.
- Acceptance plan** - An agreed upon method of taking and making measurement on a sample, for the purpose of determining the acceptability of a lot of material or construction.
- Acceptance sampling (inspection or testing)** - A prescribed procedure applied to a series of lots, to give a specified risk of accepting lots on a given quality.
- Analysis Charts (Control Charts)** - A graphical means for detecting systematic variation from the quality to be expected in a continuous production line process.
- Assignable cause** - A relatively large factor, usually due to error or process change, which contributes to variation and whose effects are of such importance as to justify time and money required for its identification.
- Average (\bar{x})** - A measure of central value which usually refers to the arithmetic mean.
- Batch** - A quantity of material produced at one operation or by the same process.
- Bias** - An error, constant in direction, common to each of a set of values, which cannot be eliminated by any process of averaging.
- Biased Sample** - A sample obtained by a biased sampling process, that is, a process which incorporates a systematic component of error, as distinct from random error which balances out on the average. Non-random sampling may be subject to bias.
- Buyer's Risk (Department)** - The probability of accepting poor or unsuitable material or construction as a result of using a particular acceptance plan.
- Coefficient of Variation (CV)** - The ratio of the standard deviation (s) and the arithmetic mean (\bar{x}); gives a relative measure of dispersion or spread relative to the mean. Generally expressed as a percentage.
- Confidence Interval** - An interval that has a designated chance of including the universe value.
- Confidence Limits** - The end points of a confidence interval.
- Conformance** - The fidelity with which the product meets the specification.
- Control** - A device that directs, influences, restrains or commands a process. A standard of comparison against which to check the results, or a state of uniformity as determined by a statistical test.
- Controlled Process (Job)** - A material or construction is said to be controlled when the mean and variability of the material or construction remains stable. Variation is then due to random effects or combinations of non-cumulative kind.
- Data** - Suitable measurements collected for a planned purpose and for the inference of conclusions.
- Dispersion** - The extent of the data scattered about the zone of central tendency.
- Distribution** - Arrangement of data showing the frequency of occurrence for successive individual measurements or range of measurements.
- Distribution Curve** - The smooth curve enclosing an arrangement of data that shows the frequency of occurrence.
- Experimental Error** - The difference between measurements on two identically treated experimental units.

Frequency - The number of items or observations that occur within a given interval.

Histogram - A bar chart displaying the relative number of measurements of different classes in terms of area. The width of the bar represents the class interval; the height represents the number of measurements.

Increments - Portions of a material taken to form a sample.

Independent Assurance Precision Tolerances - The maximum difference between test results that provides confidence that the results are being achieved in a consistent manner. Results exceeding the tolerances will be cause for a review of the sampling and testing personnel, the testing equipment, and the sampling and testing procedures.

Independent Assurance Program - A program implemented by the Construction Quality Assurance Section to provide an unbiased and independent evaluation of the sampling and testing personnel, the testing equipment, and the sampling and testing procedures used in the Departments material acceptance program.

Independent Assurance Samples - Samples obtained by the Construction Quality Assurance Section Teams used in the assessment of the sampling and testing personnel, the testing equipment, and the sampling and testing procedures used in the Department's material acceptance program.

Inherent Variance - The effect of random or inconsequential causes in a given process.

Inspection - The process of measuring, examining, testing, gauging or otherwise comparing the results of the process with the applicable requirements.

Lot - An isolated quantity of material from a single source. A measured amount of construction assumed to be produced by the same process.

Mean (\bar{x}) - Average of all possible measurements made on a lot. Often used as the desired value.

Normal Curve - A curve, having a bell-shaped form, that is determined by values of x' and s' and is often used to describe the distribution of individual measurements.

Outlier - An extreme individual or extreme mean.

Parameter - A constant or coefficient that describes some characteristic of the distribution of a series of measurements.

Performance Level - The level at which the characteristic of a material or construction is actually measured, to determine conformance with a given requirement.

Population - Any set of individuals (or measurements) having some common observable characteristic. The set may be finite or infinite. In many cases, a population will be finite but so large that it must be treated as though it were infinite.

Probability - The relative frequency of occurrence of objects within a given class or set.

Probability Sampling - A method of making use of the laws of chance for the purpose of selecting increments on which measurements are to be made.

Quality - The degree to which a specific product satisfies the wants of a specific consumer.

Quality Assurance Program - A management method intended to evaluate the quality of materials and/or construction through an unbiased inspection system of the quality control and acceptance sampling and testing.

Quality Assurance Sampling - Samples obtained by the Construction Quality Assurance Section Teams to provide a comparison of Quality Control and Acceptance Testing. All Quality Assurance samples will be submitted to the Laboratory Testing Section (LTS).

- Quality Control** - The function of a system of collection, analysis and use of quality data of a final product and comparing the results with a specification to decide whether the product is of the desirable quality by the Contractor and/or Materials Producer.
- Quality Level** - See Performance Level
- Random** - Without aim or reason, depending entirely on chance.
- Random Distribution** - A distribution of values resulting from chance alone.
- Random Sample** - A sample chosen in such a manner that each increment in the lot has an equal probability of being selected.
- Random Error** - Accidental errors which consist of a large number of very small effects, such as imprecision in an estimate of a fraction of a division on a scale. Some of these effects are positive, others negative.
- Randomness** - An intuitive concept referring to a condition of disorder and unpredictability of individual results.
- Random Number** - A number selected entirely by chance as from a table of Random Sampling Numbers.
- Random Number Table** - A set of numbers chosen at random which are generated from an infinite population of members. Every digit has an equal chance of occurrence.
- Range** - The difference between the largest and smallest measurements in a set of data.
- Residual Variation** - The remaining variation in a set of data after the variation due to certain effects, factors and interactions has been removed.
- Sample** - A small part of a lot which represents the whole. A sample may be made up of one or more increments or test portions.
- Sampling Distribution** - Distribution of a given statistic in the set of all possible samples which can be chosen according to specified sampling scheme.
- Sampling Plans** - Procedures which specify the number of units of product from a lot which are to be inspected, and the criterion for acceptability of the lot.
- Segments** - Arbitrary divisions of a lot which may be either real or imaginary.
- Segregation** - Separation of portions of a mixture from the total.
- Seller's Risk (Contractor, Producer or Supplier)** - The probability of having acceptable material or construction rejected as a result of using a particular acceptance plan.
- Specifications (Standards)** - A statement containing a description of requirements or enumeration of particulars, such as terms of a contract or details required of materials and/or construction.
- Specification Limits (Upper, Lower)** - Limits established by statistical analysis for material production control. When values of the material characteristics fall within these limits, the process is "under control." When values fall outside the limits, there is an indication that some assignable cause is present causing the process to be "out of control."
- Standard Deviation(s)** - A term used in statistics to indicate the value calculated from the differences between the individual measurements in a group and their average.
- Standard Error** - The standard deviation of a sampling distribution.
- Statistical Significance** - An effect is said to be statistically significant if its magnitude relative to an appropriate average residual is so large that there is little risk that the explained effect is actually a residual effect.
- Statistics** - The science which deals with the treatment and analysis of numerical data. Also, a collection of numerical data.
- Systematic Errors** - Errors arising from causes which act consistently under given circumstances, such as a rule calibrated at one temperature and used and read at another.

Test Portion - The part of a sample increment actually tested. Usually obtained by reducing the sample increment by some means.

Universe - See population

Variable - A measurement that can have a series of different values.

Variance (s^2) - A measure of dispersion found by adding the squares of individual deviations from their average and dividing by the number of them less one. Also, the square of the standard deviation.

Variation - Differences in measured values of a characteristic within a stable pattern due to chance, or outside this normal pattern due to assignable cause.

Witness Sample (Test) - Sampling of materials in the presence of the QA Engineer.

n - The number of measurements in a set of data.

s - Standard deviation, which is a measure of the dispersion of measurements from their average and is an estimate of the true value (s') of the population; the square root of the sum of the squares of the deviations from their average, divided by their number less one.

s' - The true value of the standard deviation of the population.

T - A test criterion for outliers, expressed in standard deviation units.

x - The average, or arithmetic mean, found by dividing the sum of n measurements by n . It is an estimate of the true population mean.

x' - The true arithmetic mean or average of the population.

x_i - An individual measurement from a series of such measurements.

Z - Distance from the centerline to a point on the base of the normal distribution curve, expressed in standard deviation units.