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16. Abstract
The objective of this research is to develop a methodology for determining the optimal sample size and appropriate testing frequencies for construction materials on the basis of a statistically sound approach. By conducting a review of the state-of-the-art in testing procedures and frequencies used by various transportation departments and other agencies, a formula is established to define the relationship between required sample size and the parameters involved. Statistically, the optimal sample sizes or appropriate testing frequencies are primarily based on four issues: The variability of the quality characteristic being measured, the risks that a state DOT or a contractor is willing to take, the tolerable errors each is willing to accept, and the cost of the testing to be performed. A sensitivity analysis is conducted to show how sensitive the sample size is to the change of material variability, confidence level, and tolerable error. Using the data collected from TxDOT districts and the methodology developed under the project, the frequencies for certain TxDOT testings are developed and compared to the current TxDOT Testing Schedule. Recommendations are also made to implement the research results.

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Development of a Methodology to Determine the Appropriate Minimum Testing Frequencies for the Construction and Maintenance of Highway Infrastructure

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for the Guide to Minimum Testing for Construction and Maintenance

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Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

The quality of highway materials has always been a major concern for highway engineers and contractors. It is undeniable that the overall performance of a highway structure is greatly influenced by those materials used during its construction, maintenance and rehabilitation. Recently, Departments of Transportation (DOTs) and contractors have implemented Quality Control/Quality Assurance (QC/QA) techniques in order to improve, among other aspects of highway construction, the quality of the materials being used. QC/QA programs play an essential role in assuring the quality of construction and maintenance of the transportation infrastructure and, material sampling and testing procedures must be performed as part of QC/QA programs.

The Texas Department of Transportation (TxDOT) publication, *Contract Administration Handbook*, includes the “Minimum Guide to Sampling and Testing” (hereafter referred to as the Guide Schedule) for projects in Texas (Appendix A). The Guide Schedule provides a sound foundation on which appropriate frequencies for key tests of construction materials are based. However, these schedules are generally based on experience rather than statistics. This is the case of many state DOTs which use empirical testing procedures with a basis on experience only. It is generally believed that when experience-based methods are combined with the skills of engineers and the complete cooperation of contractors, a good product can be produced. However, a method with a basis in historical experience is workable only under ideal conditions. From a practical point of view, there is actually a high probability that something will go wrong. For example, the confidence level is not often quantitatively defined. The degree of acceptable variation differs from lot to lot. Sampling and testing errors are often so large that the true variations of the materials may be obscured. Some tests may not measure the true quality of a product.

Such non-statistically based methods cannot be used to optimize the sample size and testing frequencies of materials. Besides, to be cost-effective, appropriate testing frequencies should be based on desired reliability and developed with the use of statistically valid sampling and testing procedures [FHWA 85].

1.2 Statistics-Based Methods

Sampling and testing are essential parts of QC/QA programs. Because of the potential benefits, some agencies have implemented the use of statistical concepts to develop methodologies for establishing testing frequencies. Statistics-based methodologies have been successfully used in several industries, such as the aerospace industry, chemical industry, construction industry, and transportation area.

There are many statistical methods for determining the sample size, such as the Bootstrap method, the Assume Normal-Pool Variance method, the Noether method, and the Risk-based method [Duncan 86]. Among these methods, the Risk-based method is the most popular and effective. The Risk-based method is based on the considerations of two types of risk: producer's risk (type I error) and customer's risk (type II error). The sample size calculated by this method is associated with material variability, the probability of acceptance, the probability of rejection, and the tolerable error [Mendenhall 81]. The method can be used in two forms: One form considers the type I error only and the other form considers both type I error and type II error. A type I error affects the contractor because it is possible that the agency may reject what is, in fact, acceptable work or materials. A type II error affects the agency, since it is possible that the agency may accept what is, in fact, unacceptable work or materials.

The approach considering type I error only is more common because it is easier to apply. In contrast, balancing type I error and type II error is more difficult. The methodologies that control type I error only are the most common because contractors or other sellers are more concerned with their own risk than with the customer's risk. These methodologies are easily defined and applied. However, type II error is very important to transportation agencies because this type of error occurs when a bad lot is accepted. It causes dissatisfaction and increased future costs (repair cost, maintenance cost, and rehabilitation cost) as a result of the low-quality product. Therefore, a type II error is just as important as a type I error in QC/QA programs. The next problem is balancing these two types of errors. It is a difficult but essential issue in determining the testing frequencies.

The American Association of State Highway and Transportation Officials (AASHTO) points out that the choice between type I error and type II error should be dependent on the consequences of a product's failure to perform its intended function. This determinant is referred to as the *level of criticality* of the characteristic under consideration. If the product failure results in loss of life or in the complete uselessness of the unit in which the product is incorporated, it is critical failure. In such cases, the type II error is normally set almost to zero. When the failure of a product causes minor consequences, the type II error can be set larger and the type I error can be set smaller [AASHTO 90].

A statistically based methodology to determine the appropriate testing frequencies would help minimize (within practical limits) and balance the risks for both parties. Again, statistically appropriate testing frequencies, also referred to as the optimum sample size, should be based primarily on four issues:

1. The variability of the quality characteristics being measured
2. The risks that state DOTs or contractors are willing to take
3. The tolerable errors each can accept
4. The cost of the testing to be performed

1.3 Objective and Scope

The objective of this research is to develop a methodology to statistically determine appropriate testing frequencies. TxDOT can use this methodology to examine the effectiveness of its Guide Schedule for testing highway materials.

The developed methodology should take into account the relationships among sample size, material variability, tolerable error, agency risk, and contractor risk. Such a methodology will help TxDOT optimize testing frequencies and improve the effectiveness and efficiency of construction quality control. This methodology will help increase the service life of highway infrastructure in Texas by minimizing the percentage of accepted defective materials.

The research can be applied to all highway infrastructures, including flexible and rigid pavements. It will benefit TxDOT as well as other state DOTs and transportation agencies. In order to achieve the stated objectives, the following specific tasks were outlined:

- Review the current TxDOT testing frequencies and procedures.
- Survey the current sampling and testing procedures used by state DOTs and other agencies.

- Review the relevant literature on QC/QA for highway construction and other industries.
- Establish sample size relationships.
- Develop a statistically-based methodology for determining the testing frequencies.
- Conduct a sensitivity analysis of optimum sample size on available data from TxDOT.

Thus, TxDOT will be able to justify changes in its proposed testing schedule as required. These changes will result in the optimum use of field and laboratory manpower, increase construction quality, and lead to lower overall life-cycle costs.

2. Methodology

Sample size and testing frequency directly affect the reliability of a test program in characterizing the population. Using a large sample produces a more reliable decision (i.e., lower failure rate). However, an increase in sample size is more costly. In reality, economic constraints generally force engineers to keep the sample size as small as possible. Figure 2.1 illustrates the trade-off between material testing costs and sample size.

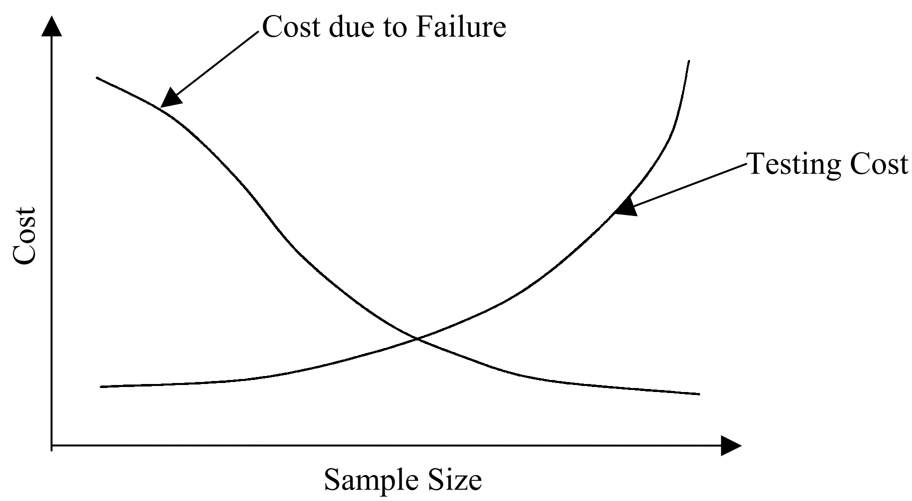


Figure 2.1 The Trade-Off Between Material Testing Costs and Costs due to Failure

Two issues must be addressed to balance testing costs and failure rate:

1. How many tests are required to ensure the product is acceptable at an established confidence level?
2. Is the resulting test frequency cost effective?

The objective of this chapter is to present a methodology for determining the optimal sample size and appropriate testing frequencies for materials used in TxDOT. In order to achieve this objective, statistical analysis procedures and reliability concepts were employed. An overview of the fundamental statistics and concepts underlying the optimum sampling plan is presented briefly, as follows.

2.1 Fundamental Principles

2.1.1 Quality Control and Quality Assurance (QC/QA)

A QC/QA program is important to the proper construction of highway projects. Quality control has existed since the time when people first began to take an interest in the quality of manufactured goods. The most significant advancements in quality control have occurred since 1920, with the development of statistical quality control methods [O'Brien 89]. Statistical quality control is an aspect of total quality control that combines statistical theory with quality control objectives to enhance the decision-making process.

A QC/QA program has many objectives. From the perspective of producers and customers, an essential aim is to improve the quality of manufactured goods. Here, quality means not only adherence to the required specifications of quality characteristics, but includes such characteristics as uniformity and stability, thus giving the customer a uniform product at all times. To the producer, quality is, indeed, part of the overall project. Another important objective is to reduce the cost of construction by reduction in waste, unnecessary work, etc. In general, the objectives of quality control can be summarized as follows [Estivill 92]:

1. To improve quality, including important elements such as uniformity, stability, and desirable distributions.
2. To reduce the cost of construction or maintenance by reducing waste, rework, spoilage, etc.
3. To reduce the cost and time of inspections and testing.
4. To achieve stable, controlled construction methods with better specifications and tolerances.
5. To promote a mutual goal for all personnel toward doing a better job, including all levels of management.

The term *quality assurance* is defined as "all planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily and conform with project requirements" [O'Brien 89].

Reasonable quality assurance should be cost effective and serve as an aid to good productivity. It is the process or procedures selected to achieve design specifications as well as the policies, strategies, and procedures chosen to define and monitor quality.

A quality assurance program is defined by Stebbing as “a documented set of activities, resources, and events serving to implement the quality system of an organization” [Stebbing 89]. It is generally implemented to satisfy customer requirements and to improve the overall business efficiency of the organization. A QA program also has other aims, such as:

1. Increasing customer confidence
2. Enhancing the company’s corporate image
3. Improving employee participation and morale

For transportation agencies, quality assurance involves economic studies to select the types of materials and methods to be included in the design, construction, and maintenance of transportation infrastructure. Sampling and testing procedures are important issues in any quality assurance program.

The criteria of the QC/QA standards are largely directed toward the construction of facilities. Such standards are published by the American Society for Testing and Materials (ASTM) and by the American National Standards Institute (ANSI).

2.1.2 Variability of Transportation Materials

Variability is key for both quality control and quality assurance. Variability is an important parameter of material quality and it is used in determining the percentage of material within (or outside) specification limits.

Pavement variability refers to the quantification of typical variation found in values or parameters related to pavements [Willenbrock 76]. The variability of materials and construction process is one of the measures used to assess quality. Usually, standard deviation is used to quantify variability.

There are five major types of variability in transportation materials:

1. Inherent variability
2. Sampling and testing variability

3. Within-batch variability
4. Batch-to-batch variability
5. Overall variability

The *inherent variability* is the true random variation of the value or parameter being measured [Willenbrock 76]. It is a function of the characteristics of the product itself. It may vary in magnitude, but it is generally one of the smallest sources of variability. Inherent variability can be determined only by the process of sampling and testing. However, it should be recognized that sampling and testing introduce additional sources of variability.

Sampling variability is a function of sampling technique and is detected when the test result of a sample increment taken from one part of a batch does not match the test result of a sample increment taken from another part of the same batch. *Testing variability* is the lack of repeatability of testing results among testing portions. Different operators, equipment condition, calibration, and test procedures can all cause testing variability. These two separate sources of variability are often combined into one source, and they are sometimes difficult to separate from other sources of variability because sampling and testing are necessary procedures in estimating the variability of a product [Willenbrock 76]. As a result, sampling and testing are integral parts of the overall variability of the product.

Within-batch variability depends on the magnitude of the difference in the measurement results between two samples taken from the same batch. Examples of contributors to within-batch variability are aggregate segregation, slump change from the front of the load to the back, and variability in core depths of a concrete pavement for adjacent cores in the same location [Willenbrock 76].

Batch-to-batch variability is usually the largest source of variability in some processes. It represents the difference in test results from one batch to other batches of the same product from the same process. It is always caused by the process and is greatest when the process is “out of control”.

Overall variability is the sum of all of the individual sources of variability. Generally, when the standard deviation of a population is measured, it is the overall standard deviation that is obtained. The overall variability is the primary value that should ultimately be related to the specification limit within the lot. It should be noted, however, that in developing a methodology, each component should be examined [Anglade 98].

2.1.3 Random Sampling and Sampling Distribution

Random sampling and sampling distribution are fundamental concepts in QC/QA. The purpose of sampling is to select and observe a portion of the population so that an estimate can be made about the entire population. The integrity of obtaining a representative sample must be firmly established and must not be compromised to a conventional approach of simply acquiring material to perform tests [Schilling 82]. With careful attention to the sampling design, estimates such as the population mean and standard deviation can be obtained that are unbiased for population quantities.

Randomization is extremely important to the sampling process. Although many QC/QA specifications have definitive procedures for random sampling, the essential purpose of randomization must always be remembered. Randomization should allow each part of the population an equal chance of being selected and protected against unsuspected sources of bias. Violation of the randomization principle can produce biased samples that will inaccurately reflect true characteristics of the population [Lohr 99].

Violation of the random sampling principle may occur when too many samples are collected and when certain samples are selectively discarded or not tested [Schilling 82]. Samples can be taken constantly during production; however, samples should be collected with the presumption that they will be tested. The tested samples must align with the principles of simple random sampling or a modified version, such as stratified random sampling or cluster random sampling [Lohr 99]. Discarding certain samples from the population because of insufficient testing can violate the randomization principle. If samples are discarded, the random sampling procedure must be taken into account.

An inconsistent sampling/testing frequency also contributes to the possibility of violating the estimation of population properties and may not conform to principles of random sampling. If the sampling frequency is very high and there are insufficient resources to test the samples, then consideration must be given to modifying the sampling rate to avoid violation of randomization principles.

Statistics can be used to draw conclusions about a population using a sample from that population. As stated before, random samples should be used, which means, “If the population contains *N* elements, and a sample of *n* of them is to be selected, then if each of the *N!/(N−n)!n!* possible samples has an equal probability of being chosen, the procedure employed is called random sampling” [Montgomery 76].

Statistical theory makes considerable use of quantities computed from the observations in the sample. Montgomery defines a statistic as any function of the observations in a sample that does not contain unknown parameters. For instance, suppose that $y_1, y_2, \ldots, y_n$ represents a sample. In this example, the sample mean is

$$\overline{y} = \frac{\sum_{i=1}^{n} y_i}{n} \tag{2.1}$$

and the sample variance is

$$S^2 = \frac{\sum_{i=1}^{n} (y_i - \overline{y})^2}{n-1} \tag{2.2}$$

These two equations represent the central tendency of the sample and dispersion of the sample, respectively. The sample standard deviation is described as

$$s = \sqrt{S^2} \tag{2.3}$$

The sampling distribution (the probability distribution of a statistic) can be determined if the probability distribution of the population from which the sample was drawn is known. Probability distribution is useful in computing the probabilities associated with several sampling characteristics.

Transportation material characteristics are generally assumed to be normal by distribution. This is true for acceptance sampling taken from a large number of units.

The normal distribution is completely specified by two parameters, μ and σ, where

$\mu =$ mean,

$\sigma =$ standard deviation, and

$x =$ measurement distribution.

Its frequency function is

$$f\left(x\right)=\frac{1}{\sigma\sqrt{2\pi}}e^{-[(x-\mu)/\sigma]^2} \tag{2.4}$$

Its distribution function is

$$F\left(x\right)=\frac{1}{\sigma\sqrt{2\pi}}\int_{-\infty}^{x}e^{-[(t-\mu)/\sigma]^2}dt \tag{2.5}$$

The obvious feature of the normal distribution is the symmetrical distribution on each side of the mean. The grouping data of normal distribution follow a theorem known as the *central limit theorem*. The central limit theorem is defined as follows: “If a population has a finite variance σ^2 and a mean μ, the distribution of the sample mean approaches the normal distribution with variance σ^2/n and mean μ, as the sample size increases” [Ostle 54].

The properties of most materials used by the highway industry seem to be close to the normal distribution. Therefore, normal distribution is assumed for the analysis of this study.

2.1.4 Acceptance Sampling

Acceptance sampling is a major part of statistical QC/QA. Acceptance sampling permits the determination of a course of action by establishing the risk of accepting lots of given quality [Collins 74]. A common procedure is to consider each submitted lot separately and to base the decisive action on the evidence provided by inspection of one or more random samples chosen from the lot.

2.1.4.1 Objectives of Acceptance Sampling.

There are three objectives in acceptance sampling:

1. To protect the agency against the acceptance of a certain quantity of defective items
2. To ensure the suppliers will improve their product when necessary
3. To assist quality control in the reduction of production costs

To achieve these objectives, the control chart method is often used by transportation agencies. The control chart supplies useful information about the quality level of the product and about the degree of control of the various production processes. The most obvious advantage of the acceptance sampling is to exert more effective pressure for quality improvement than with pure inspection [Schilling 82].

2.1.4.2 The Operating Characteristic Curve (OC Curve)

The OC curve plays an important role in acceptance sampling. The OC curve is a popular technique used to evaluate customer and producer risks in accepting or rejecting a lot of materials. It is a graphical presentation of a sampling technique that shows the relationship between the quality of a lot and the probability of its acceptance or rejection [Anglade 98].

Figure 2.2 shows an OC curve. Although the OC curve provides useful information to highway agencies and contractors, it is often viewed in the sense of an adversarial relationship between the producer and the consumer. The vertical axis shows the probability of acceptance of a product; the horizontal axis depicts the quality measure.

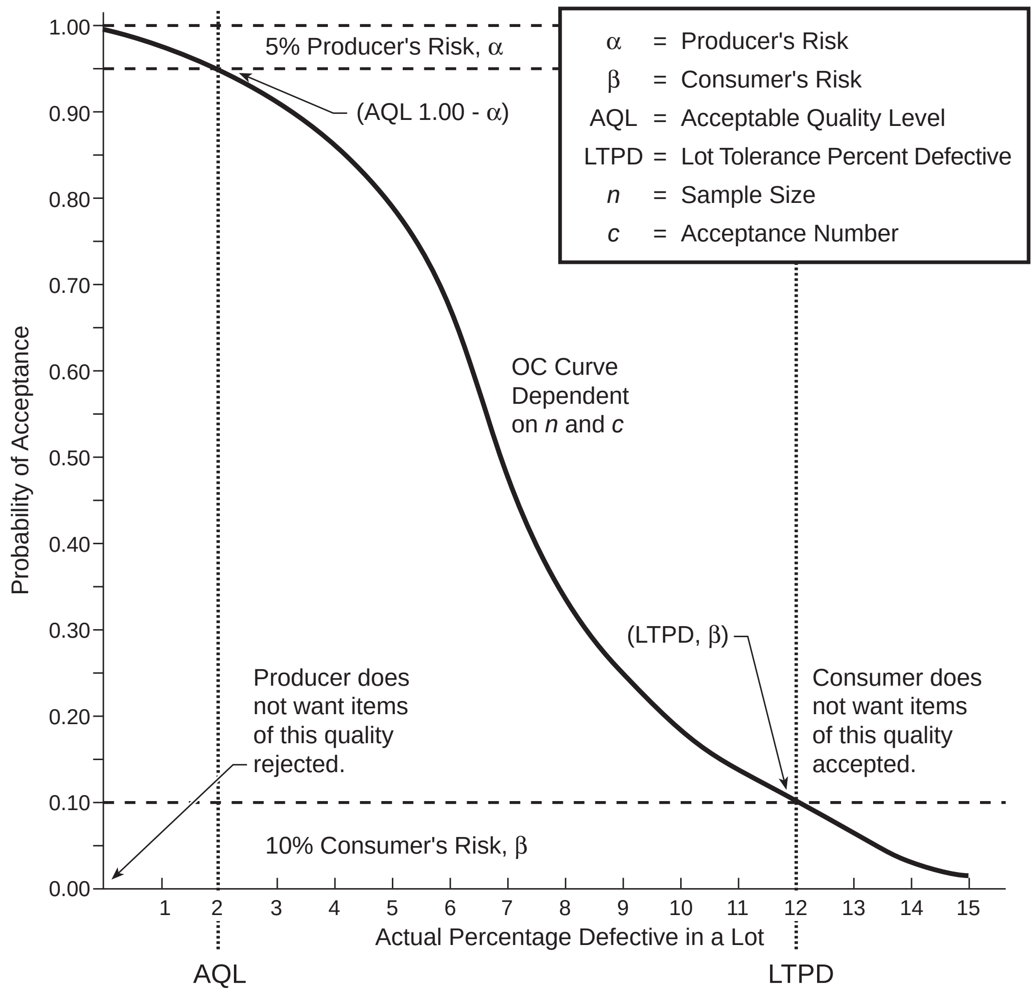


Figure 2.2 Operating Characteristics Curve (OC Curve)

In reality, the OC curve shows the probability of a type I (α) and type II (β) errors. It can help the highway engineer differentiate between what are defined as acceptable materials and what are defined as unacceptable materials. Furthermore, the OC curve will indicate the degree of a given sampling plan's discrimination between acceptable and non-acceptable lots.

2.1.4.3 Lot Size and Sample Size

One method often used in acceptance sampling is the lot-by-lot sampling technique. Anglade described this method as follows: "One considers each submitted lot of product separately and bases the decision to accept or reject the lot on the evidence of one or more samples chosen at random from the lot" [Anglade 98]. When the proper sampling plans are implemented, a large proportion of the high quality lot will be accepted and a large proportion of the low quality lot will be rejected.

The lot size is very important in acceptance sampling. Only by establishing the size of the lot can the proper sampling locations and testing frequencies (sample size) be selected for either quality control purposes or to estimate the quantity of the material characteristics.

In the lot-by-lot method, the whole highway project is considered to be a succession of lots. In the acceptance plan, the lots are presented separately to the engineer for acceptance or rejection. Each lot is made up of sublots. With sublots, the highway engineer can conduct stratified sampling or cluster sampling rather than random sampling. In some cases, stratified sampling and cluster sampling can reduce the sampling variance.

If the lot size is too small, the acceptance plan will need an excessive amount of costly testing. On the other hand, if the lot size is too large, a very large quantity of material may be rejected when, in fact, sublots may be acceptable.

A fundamental issue in acceptance sampling is defining an appropriate lot size and corresponding sample size to estimate the properties of the lot. In many cases, the sample size drives development of the lot size. Determining a lot size for tonnage is found by multiplying the number of samples by the sampling frequency.

2.1.4.4 Tolerable Error and Confidence Level

Tolerable error and confidence level are primary factors in applications of acceptance sampling in the reliability and life-testing areas. Tolerable error specifies limits that both producer and customer will accept.

According to Mendenhall et al., an *interval estimator* is a rule that specifies a method for using the sample measurement to calculate two numbers forming the endpoints of the interval [Mendenhall 81]. One or both of the endpoints of the interval, being functions of the sample measurements, may vary in a random manner from sample to sample. Thus, the length and location of the interval are random quantities, and it cannot be certain that the target parameter θ will actually fall between the endpoints of any single interval calculated from a single sample. The objective of setting a confidence interval is to find an interval estimator that generates narrow intervals enclosing θ with a high degree of probability [Mendenhall 81].

Suppose that $\hat{\theta}_L$ and $\hat{\theta}_U$ are the lower and upper confidence limits, respectively, for a parameter θ, if $P\ (\hat{\theta}_L < \theta < \hat{\theta}_U) = (1-\alpha)$, the probability $(1-\alpha)$ is called the *confidence coefficient*, which is also defined as the confidence level. In other words, the confidence level is the probability that a confidence interval will enclose θ [Mendenhall 81].

The confidence level gives the fraction of the number of times, in repeated sampling, that the intervals constructed will contain the target parameter θ. If a confidence level associated with the estimator is high, one can be highly confident that the confidence interval will enclose θ.

2.1.4.5 Hypothesis Testing, Type I Error and Type II Error

Hypothesis testing and decision errors are crucial concepts in determining sample size. To test a hypothesis, a procedure is devised to take a random sample, compute an appropriate test statistic, and then reject or fail to reject the null hypothesis H_0 [Mendenhall 81]. Part of this procedure is specifying the set of values for the test statistic that leads to rejection of H_0. This set of values is called the *critical region* for the test.

Two kinds of errors may be committed when testing hypotheses. If the null hypothesis is rejected when it is true, then a type I error has occurred. If the null hypothesis is not rejected when it is false, then a type II error has been made. The probabilities of these two errors are given as follows [Mendenhall 81]:

$$\alpha = P\ (\text{type I error}) = P\ (\text{reject } H_0 \mid H_0 \text{ is true})$$
$$\beta = P\ (\text{type II error}) = P\ (\text{fail to reject } H_0 \mid H_0 \text{ is false})$$

The general procedure in hypothesis testing is to specify a value of the probability of type I error (α). In this situation, the probability of type II error (β) has a suitably small value. However, it is also important to determine the probability of type II errors in any hypothesis-testing situation. The following example illustrates how to determine the probability of a type II error for testing the hypothesis (with the variance σ^2 known):

H_0: $\mu = \mu_0$

H_a: $\mu \neq \mu_0$

To find the probability of a type II error, it is assumed that the null hypothesis H_o is false, which implies that the alternative hypothesis H_a is true. Under this assumption, the distribution of the test statistic Z_0 is

$$Z_0 \sim N\left(\frac{\delta\sqrt{n}}{\sigma}, 1\right)$$

The distribution of the test statistic under both hypotheses H_0 and H_a is shown in Figure 2.3. From this figure, it can be seen that the probability of type II error is the probability of Z_0 falling between $-Z_{\alpha/2}$ and $Z_{\alpha/2}$, (given that H_a is true). The probability, which is shown as the shaded portion of the figure, can be expressed as [Mendenhall 81]:

$$\beta = \Phi\left(Z_{\alpha/2} - \frac{\delta\sqrt{n}}{\sigma}\right) - \Phi\left(-Z_{\alpha/2} - \frac{\delta\sqrt{n}}{\sigma}\right) \quad (2.6)$$

where $\Phi(z)$ denotes the probability to the left of z on the standard normal distribution.

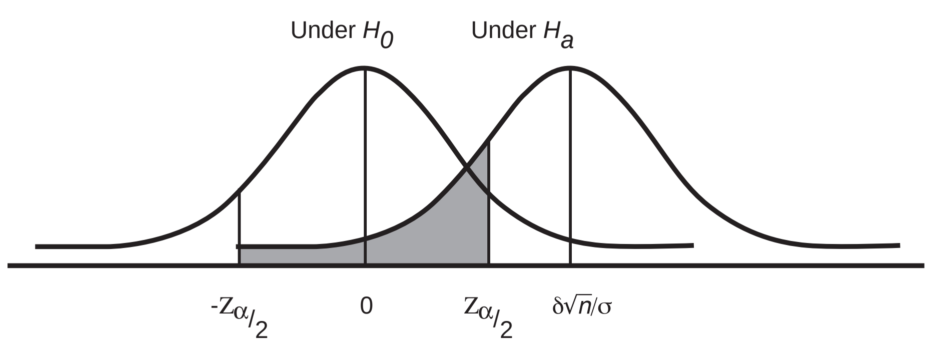


Figure 2.3 The Distribution of Z_0 under H_0 and H_a

In the case of pavement material acceptance sampling, whenever a decision is made based on the results of a small sample size, errors in judgment are possible. Acceptance sampling programs occasionally will authorize the acceptance of a lot with a relatively high percentage of defective items, but will also at some point reject a lot containing a relatively low percentage of defects.

A transportation agency, when making a decision about the acceptance of a lot, has two choices. It can either accept or reject the lot. These two choices have four consequences, as presented in Table 2.1.

Table 2.1 Decision Making and Type I Error/Type II Error

<table>
<tr><th colspan="2"></th><th>Ho is true</th><th>Ho is False</th></tr>
<tr><td rowspan="2">Decision</td><td>Reject Hypothesis (H_o)</td><td>Wrong Decision
Type I Error (α)</td><td>Correct Decision</td></tr>
<tr><td>Accept Hypothesis (H_o)</td><td>Correct Decision</td><td>Wrong Decision
Type II Error (β)</td></tr>
</table>

Table 2.1 shows that two of these consequences reflect correct decisions, the other two reflect wrong decisions. As discussed before, these two errors in judgment are named as type I error and type II error respectively. Therefore, these two errors can be defined as follows:

1. *Type I Error*: This type of error occurs whenever a hypothesis is rejected when it should have been accepted. It is also known as an alpha (α) error.
2. *Type II Error:* This type of error occurs whenever a hypothesis is accepted when it should have been rejected. This is also known as a beta (β) error.

From Table 2.1, it can be concluded that whenever a decision between two available alternatives is made, there is a possibility that the decision will be incorrect. This statement is always true unless one is completely certain about all of the factors that are involved in the decision.

When conducting hypothesis testing, the null hypothesis in acceptance is expressed in the form *there is no difference* between the sample average and the design target value. In the practice of highway engineering, acceptance is to begin with the interpretation of the situation by accepting the statement and then collecting data to determine whether or not the statement can be rejected. If the null hypothesis (H_o) can be rejected, then a type I error (α) can occur [Willenbrock 76].

It is also important to realize that, according the statistical concept, when an agency accepts the null hypothesis on the basis of the sample data, it is essentially saying that it does not have statistical evidence to reject it.

2.1.4.6 Risks and Levels.

As stated before, if a decision is made to reject a lot of material when the material is actually satisfactory, a type I error has been made. The risk or the probability of making such an error is generally symbolized by alpha (α) and, in the highway industry, is called the producer's risk.

On the other hand, if a decision is made to accept a material when the material is actually unsatisfactory, a type II error has occurred. The risk of making such an error is symbolized by beta (β) and is called the customer's risk. It is usually desirable to set up a sampling plan with both the producer's and the customer's risks in mind. These risks are illustrated in Table 2.2.

Table 2.2 Producer and Customer Interests

	Producer	Customer
Good lots rejected	Good product lost Producer's risk Type I Error (α)	Potential higher cost
Bad lots accepted	Potential customer dissatisfaction	Paid for bad product Customer's risk Type II Error (β)

When the producer's and customer's risks are fairly well defined in terms of good product rejected and bad product accepted, respectively, each has an interest in estimating and maintaining reasonable levels for the other.

Schilling [Schilling 82] introduced the following concepts and terminologies associated with this topic:

1. Producer's Quality Level (PQL): A level of quality that should be passed most of the time. It determines the maximum proportion of defectives allowed.
2. Producer's Risk (PR): The risk of having PQL material rejected by the plan, which is the type I error (α) in hypothesis.
3. Consumer's Quality Level (CQL): A level of quality that should be rejected most of the time.
4. Consumer's Risk (CR): The risk of having CQL material accepted by the plan, which is the type II error (β) in hypothesis.
5. Indifference Quality Level (IQL): The point where the producer and the consumer share a 50 percent probability of acceptance or rejection.

Different sample sizes have correspondingly different risk levels. During development of a sample size for a lot, risks to both the agency and contractor should be evaluated for different sample sizes. As stated before, both the agency and contractor share risk during the acceptance process, designated as the α and β risks. AASHTO has defined these risks as follows [AASHTO 96]:

1. Seller's Risk (α): The risk of rejecting "good" material. In highway construction this is associated with the risk of a contractor having good material rejected by the owner.
2. Buyer's Risk (β): The risk of accepting "bad" material at reduced or full payment. In highway construction, this risk is associated with the owner's risk of accepting what is actually bad material.

The α risk affects the contractor because it is probable that the agency may reject, what is in fact, acceptable work. The β risk affects the agency because it is probable that the agency may accept, what is in fact, unacceptable work. The true meaning of risk is how much one is willing to lose in terms of dollars if an action is taken.

A goal of developing statistically based methodology for determining the appropriate testing frequencies is to minimize (within practical limits) and balance the risks to both parties.

The choice of α and β depends on the consequences of a product's failure to perform its intended function. This failure is referred to as the *level of criticality* of the characteristic under consideration. If the failure of a product results in loss of life or in the complete uselessness of the unit in which the product is incorporated, it is a critical failure. In such cases, β is normally set to approximately zero. When the product's failure causes minor consequences, β can be made larger and α can be made smaller. AASHTO has provided guidelines for selecting both α and β risks, as shown in Table 2.3 [AASHTO 90]:

Table 2.3 AASHTO Suggested Risk Levels Based on Criticality

Criticality	Description	α %	β %
Critical	When the requirement is essential to preservation of life	5.0	0.5
Major	When the requirement is necessary for the prevention of substantial economic loss	1.0	5.0
Minor	When the requirement does not materially affect performance	0.5	10.0
Contractual	When the requirement is established only to provide uniform standards for bidding	0.1	20.0

For the purpose of this research, TxDOT has determined the maximum level of risk for both the contractor and the owner as 20% ($\beta \leq 20\%$ and $\alpha \leq 20\%$).

2.1.5 Sensitivity Analysis

Sensitivity analysis is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation.

A characteristic of a system is considered to be very sensitive with respect to an element of the system if the characteristic is greatly influenced by relatively small changes in the element. Sensitivity analysis aims to ascertain how the model depends upon the information fed into it, upon its structure, and upon the framing assumptions made to build it.

2.2 Determining the Variability of a Testing

As discussed previously, the required sample size and testing frequency are related to the variability of the material. Characterizing the variability of a material is a key issue in development of methodology in this research. Figure 2.4 illustrates three degrees of variability: 1) No variability; 2) Small variability; 3) Large variability.

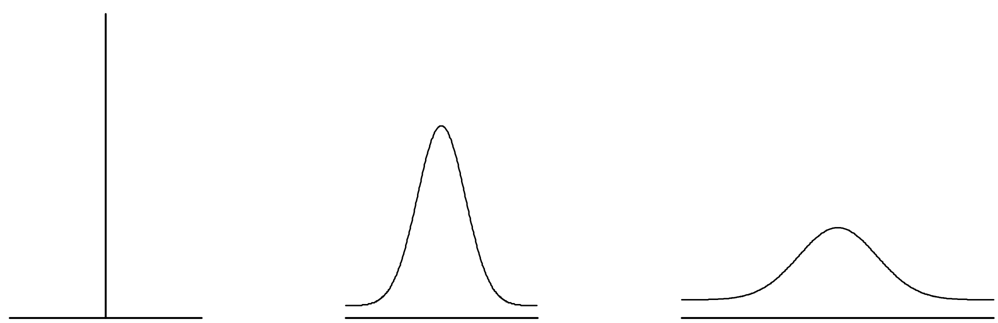


Figure 2.4 Three Degrees of Variability

Apparently, for situations where there is no variability at all, one test result would sufficiently represent the true characteristic of that material. However, such a situation rarely exists in the real world. For materials with larger variability, a bigger sample is required to properly characterize the material. A larger sample size also means more frequent testing.

The variability of a material for a specific test value can be determined by available historical data. By assuming the samples are random and the data conform to a normal distribution, the variability can be represented by the standard deviation (σ).

2.3 Determining Sample Size

It is a generally recognized statistical rule that the accuracy of the estimated mean value of a population increases as the number of samples taken from the population measured also increases. The accuracy of the estimate for variability or standard deviation from the mean also increases with the increase in sample size. It follows, then, that the greater the number of material tests conducted, the higher the confidence level that the mean will be identified with sufficient accuracy, that the variability will be better defined, and that substandard materials will be identified. This logic leads to the question of how many tests should be conducted in order to identify satisfactorily the characteristics of the material.

The objective of this section is to establish sample size relationships as a function of material variability and desired reliability. As described in the previous section, reliability of testing is defined by the probabilities of type I and type II errors. A type I error is made if H_0 is rejected when H_0 is true. The probability of type I error is denoted by α ; a type II error is made if H_0 is accepted when H_0 is not true. The probability of type II error is denoted by β .

Generally, there are two methods for determining an adequate statistical sample size. One considers only type I error; the other considers both type I and type II errors.

These two methodologies are illustrated in the following sub-sections.

2.3.1 Controlling Type I Error

The method of estimating the sample size to control the type I error only is described in this section. Once the standard deviation is determined from the historical data, three steps are recommended by Lohr to determine the sample size [Lohr 99].

1. Specify the tolerable error.

The engineer must determine the level of precision needed. The desired precision is often expressed by probability in absolute terms, as

$$P(|\bar{y}-\bar{y}_u| \le e) = 1-\alpha \tag{2.7}$$

where:

$\bar{y}$ = sample mean

$\bar{y}_u$ = population mean

α = type I error

e = tolerable error

The engineer must select a reasonable value for α (type I error or producer's risk) and e, which is called the margin of error or tolerable error.

To achieve the desired relative precision, the precision may be expressed as

$$P\left(\left|\frac{\bar{y}-\bar{y}_u}{\bar{y}_u}\right| \le e\right) = 1-\alpha \qquad (2.8)$$

2. Find an equation relating the sample size n.

The simplest equation relating the precision and sample size comes from the confidence interval. To obtain absolute precision, find a value of n that satisfies

$$e = \frac{Z_{\alpha/2}\sigma}{\sqrt{n}} \qquad (2.9)$$

Solving for n, it has

$$n = \frac{Z_{\alpha/2}^2 \sigma^2}{e^2} \qquad (2.10)$$

where :

n	=	sample size
$Z_{\alpha/2}$	=	the $(1-\alpha/2)$th percentile of the standard normal distribution
σ	=	standard deviation
e	=	tolerable error

3. Adjust the sample size n.

The equations presented before are based on asymptotic theory (as the sample size goes to infinity), therefore, the sample size n should be adjusted.

$$n_a = \frac{n}{1+\frac{n}{N}} \qquad (2.11)$$

where:

n_a = adjusted sample size

n = the sample size which ignores the finite population correction (FPC)

N = population size

Figures 2.5 through 2.7 illustrate the relationships between sample size and the parameters used to control the type I error: confidence level, standard deviation and tolerable error. These figures illustrate how the sample size changes with the parameters involved when considering only type I error.

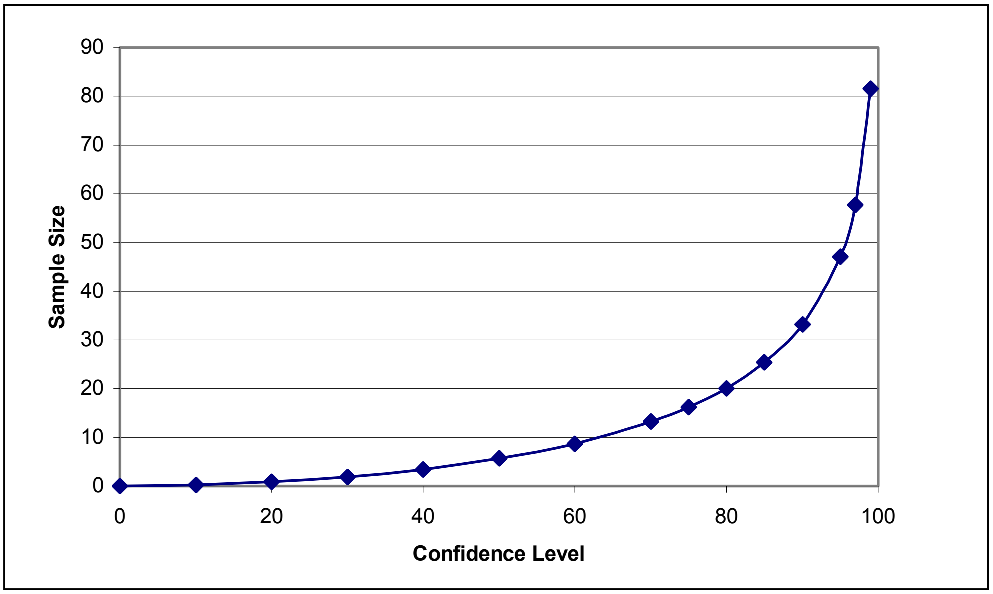


Figure 2.5 Relationship Between Sample Size and Confidence Level

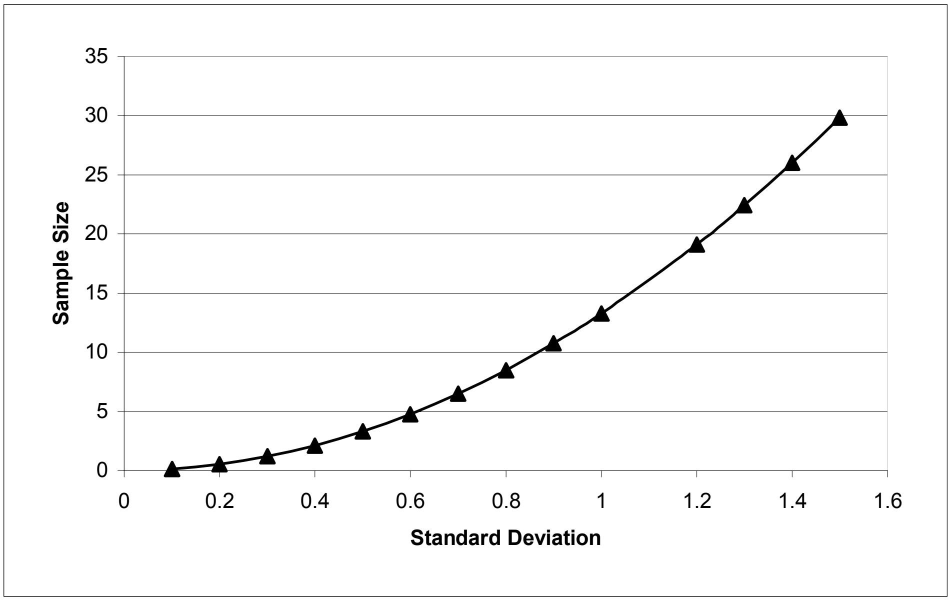


Figure 2.6 Relationship Between Sample Size and Standard Deviation

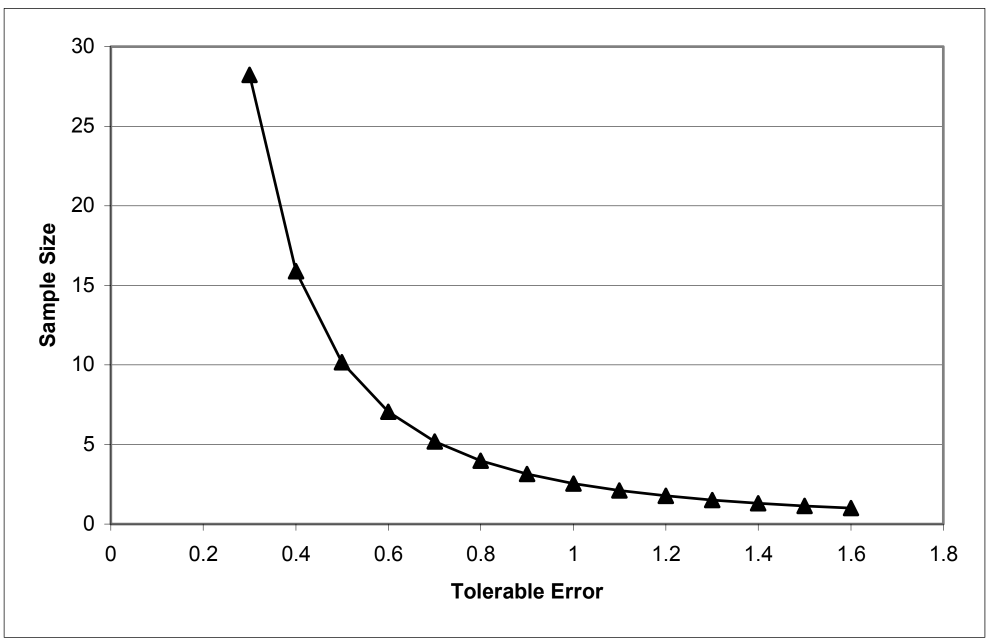


Figure 2.7 Relationship Between Sample Size and Tolerable Error

Figure 2.5 shows that the higher the confidence level, the larger the sample size will be. Sample size *n* is proportional to $Z_{\alpha/2}$.

Figure 2.6 indicates that as variability increases, a larger sample size is required. Sample size is proportional to σ^2.

Figure 2.7 gives the relationship between sample size and tolerable error. The required sample size decreases as the tolerable error increases. The sample size *n* is inversely proportional to e^2.

2.3.2 Controlling Both Type I Error and Type II Error

1. Calculating type II error probability.

Calculating β can be very difficult for some statistical tests, but the *Z* test can be used to demonstrate both the calculation of β and the logic employed in selecting the sample size for a test [Walpole 91].

For the test of H_0: $\mu = \mu_0$ against H_0: $\mu < \mu_0$, it is only possible to calculate type II error probabilities for any specific point in H_a. Suppose that the experimenter has a specific alternative, say, $\mu = \mu_0 - e$. The power of this test can be expressed as

$$1-\beta = P(\overline{X} < a, \text{when } \mu = \mu_0 - e)$$

The probability of a type II error, β, is

$$\beta = P(\overline{X} > a, \text{when } \mu_a = \mu_0 - e)$$

$$\beta = P\left(\frac{\overline{X}-(\mu_0 - e)}{\sigma/\sqrt{n}} > \frac{a-(\mu_0 - e)}{\sigma/\sqrt{n}}, \text{when } \mu_a = \mu_0 - e\right) \tag{2.12}$$

$$\textit{where,} \quad \frac{\overline{X}-(\mu_0 - e)}{\sigma/\sqrt{n}} = Z$$

Therefore, μ_a has an approximately standard normal distribution and the probability β can be determined by finding an area under a standard normal curve, as shown in Figure 2.8.

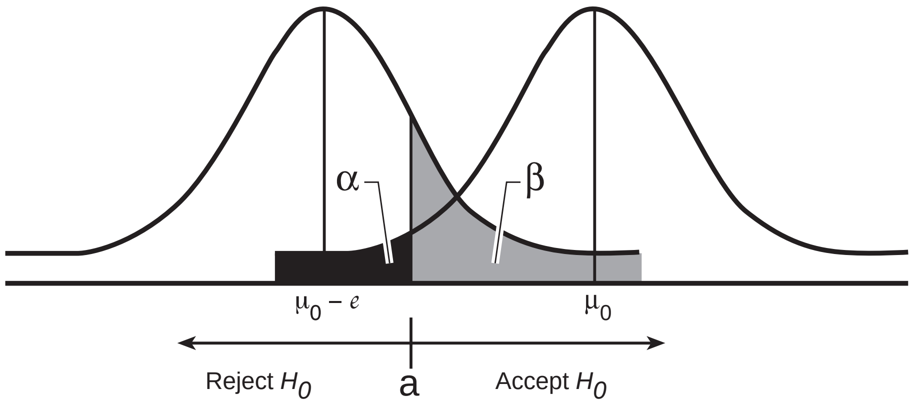


Figure 2.8 Type I Error and Type II Error

2. Find an equation relating the sample size n.

Suppose the test is H_0: $\mu = \mu_0$ against H_a: $\mu < \mu_0$. If the desired value of α and β is specified, the test depends upon two remaining quantities that must be determined. These are *n*, the sample size, and *a*, the point at which the rejection region begins (Figure 2.8). Since α and β can be written as probabilities involving *n* and *k*, there are two unknowns in two equations, which can be solved simultaneously for *n*. From the previous step,

$$\beta = P\left(Z > \frac{a - (\mu_0 - e)}{\sigma/\sqrt{n}} \right) \tag{2.13}$$

$$\beta = P\left(Z > \frac{a - \mu_0}{\sigma/\sqrt{n}} + \frac{e}{\sigma/\sqrt{n}} \right)$$

$$\beta = P\left(Z > -Z_\alpha + \frac{e}{\sigma/\sqrt{n}} \right) \tag{2.14}$$

$$Z_\beta = -Z_\alpha + \frac{e}{\sigma/\sqrt{n}} \tag{2.15}$$

The sample size for controlling both type I error and type II error can be expressed as

$$n = \frac{\left(Z_{\alpha} + Z_{\beta}\right)^{2}\sigma^{2}}{e^{2}} \tag{2.16}$$

where

n = sample size

α = type I error

β = type II error

Z_{α} = the $(1-\alpha)$th percentile of the standard normal distribution

Z_{β} = the $(1-\beta)$th percentile of the standard normal distribution

σ = standard deviation

e = tolerable error

In particular, when $\beta = 0.5$ (i.e., $z_{\beta} = 0$), Equation 2.16 would be the same as Equation 2.10, which controls only type I error.

Sometimes it is necessary to consider a failure whenever a test result is above the mean value. For example, when testing for air voids in asphalt pavement, very high values are considered unacceptable. In these cases, Equation 2.17 is used.

$$n = \frac{\left(Z_{\alpha/2} + Z_{\beta}\right)^{2}\sigma^{2}}{e^{2}} \tag{2.17}$$

3. Relationship between sample size and parameters.

Figures 2.9 through 2.11 illustrate how sample size changes with the parameters involved by considering both type I and type II errors.

Figure 2.9 shows the relationship between sample size and confidence level. The required sample size increases as the confidence level goes up. Holding the other parameters constant, the larger the type II error, (β), the smaller the required sample size. Specifically, when β =

0.5, $z_\beta = 0$, the resulting sample size is exactly the same as the one determined by the method that controls only type I error.

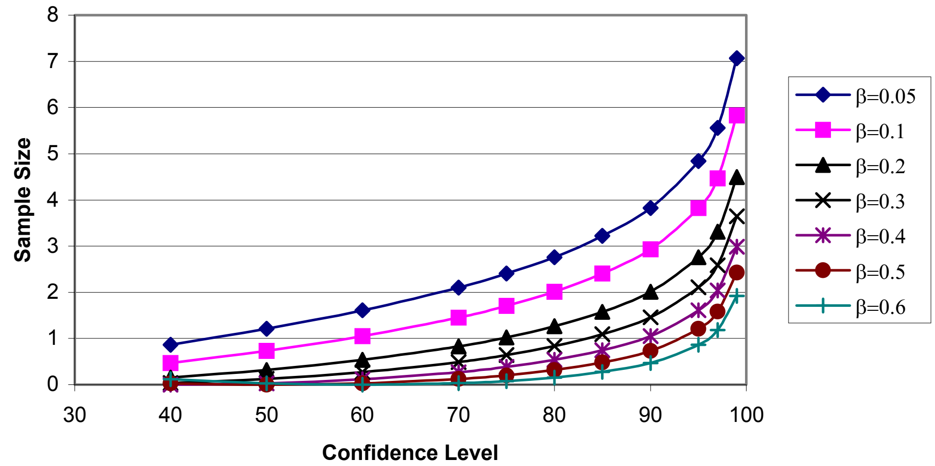


Figure 2.9 Relationship Between Sample Size and Confidence Level for Different Levels of β.

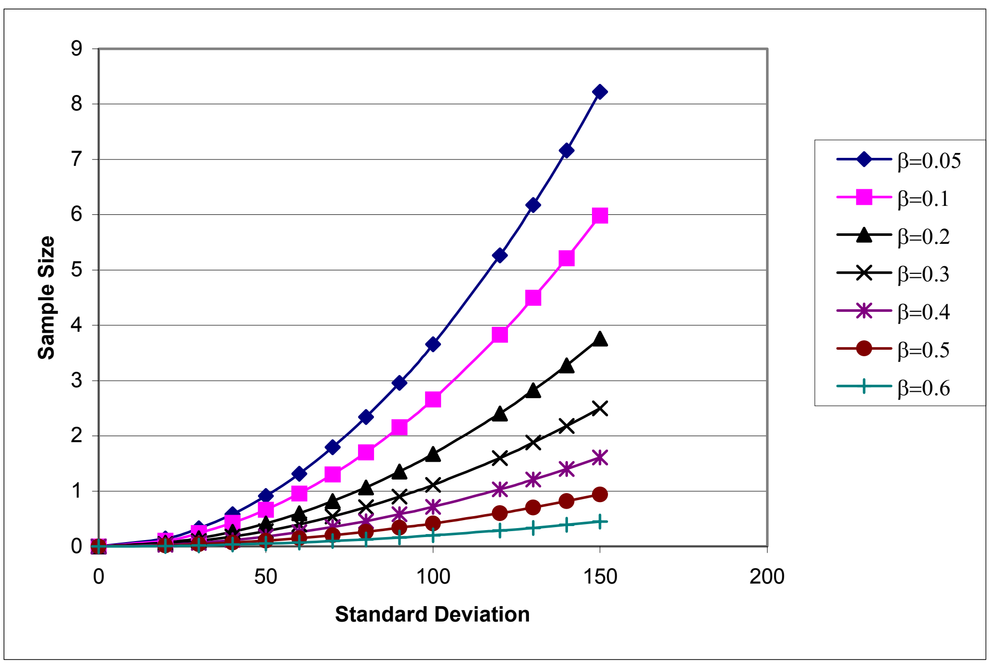


Figure 2.10 Relationship Between Sample Size and Standard Deviation for Different Levels of β

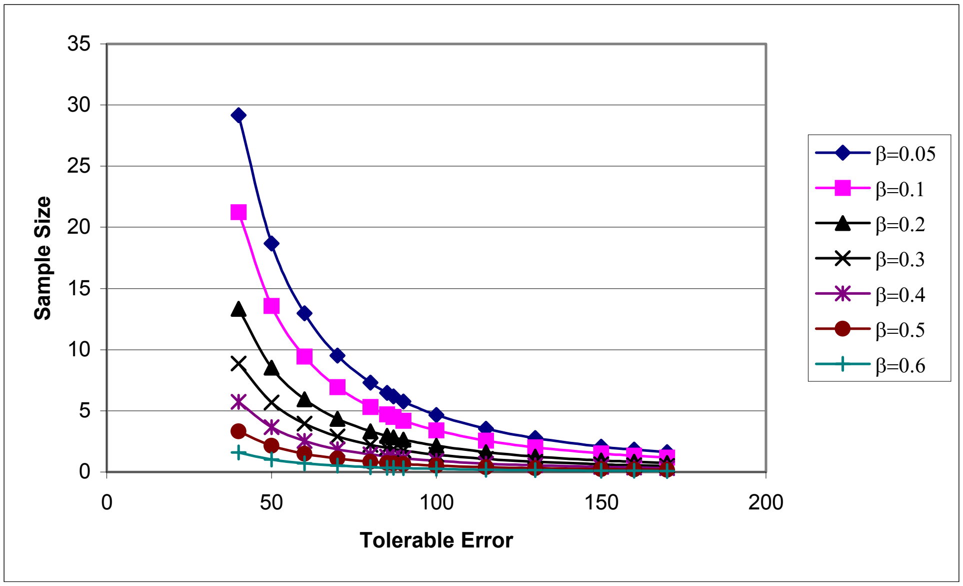


Figure 2.11 Relationship Between Sample Size and Tolerable Error for Different Levels of β

Figure 2.10 illustrates that, for a material with larger variability, a larger sample size is required. The required sample size *n* is proportional to the square of standard deviation σ . The change of sample size based on the type II error is similar to the one in Figure 2.10.

Figure 2.11 shows that, as tolerable error increases, the required sample size decreases. The required sample size *n* is inversely proportional to the square of tolerable error *e*. Again with the other parameters constant, the change of sample size affected by type II error is similar to the ones in the previous figures. When β equals 0.5, the result is exactly the same as in the situation that controls only type I error.

2.4 Determining Testing Frequencies

Testing frequencies can be specified as either time-based testing frequency or quantity-based testing frequency. Time-based testing frequency is expressed as "one for each day's production," "one for each 10 days' production," etc., while quantity-based testing frequency is described as "one per 1,000 tons," "one per sublot," or "one per ten lots," etc.

Once the required sample size is estimated, the testing frequency (TF) can be determined by using the following equations:

1. Time-based testing frequency:

$$TF = \text{daily production} / \text{sample size} \quad (2.17)$$

For example, if the estimated sample size is two and the samples are taken every day, then the testing frequency is "two for each day's production." If the estimated sample size is one, and the samples are taken every 10 days, the testing frequency is "one for each 10 days' production."

2. Quantity-based testing frequency:

$$TF = \text{batch quantity} / \text{sample size} \quad (2.18)$$

For example, if the required sample size is two, assuming the batch quantity is 3000 tons, then the testing frequency is "one per 1,500 tons." If the required sample size is two and the batch quantity is defined as one sublot, then the testing frequency is "two per sublot."

Sample size and testing frequency are interrelated to each other. Once the sample size is estimated by using Equation 2.21, testing frequency can be determined by Equation 2.22 or by Equation 2.23. Inversely, if the testing frequency is known, sample size can also be determined.

3. Data Collection

There were two types of data collected by the research team for this project: information on material testing frequencies used by other agencies and tests sample data for different materials and tests.

A survey was conducted in 1999 to determine the current QC/QA sampling practices used by state DOTs and other transportation agencies. This survey focused primarily on material testing frequency issues. The survey was sent by mail to 50 state DOTs and 12 other highway agencies such as the Federal Highway Administration and foreign transportation agencies. Twenty-six completed surveys were returned. Appendix C summarizes the methodologies reported by the surveyed agencies and the specific documents provided by them.

Appendix C also shows that most state DOTs use historical methods for determining material testing frequencies. Only six of the surveyed agencies suggested that they employ a statistically based acceptance sampling plan in some material areas. However, according to the documents these agencies provided, statistical theory is used only for analyzing data, not for determining sample size. Methodologies for determining the material testing frequency are generally based on historical experience. Detailed information on statistical methods was not provided by any of the agencies.

The other data collected were the actual results of laboratory tests and field tests from over 200 projects in the state of Texas. These test reports were obtained from the TxDOT districts of Austin, Dallas, El Paso, Fort Worth, Odessa, San Antonio and Yoakum, and from the Center for Transportation Research (CTR). The reports were, in fact, hard copies of the original documents; less than 10 percent were in a database format. The data had to be selected from over 15,000 files, organized, and entered onto a spreadsheet file in order to proceed with the statistical analysis.

TxDOT selected the materials and tests to be included in the research. These are described in the next section.

3.1 Highway Materials

The properties and behavior of highway materials are assumed to be normally distributed for large samples. These properties have been widely studied and their behavior can always be represented by a normal distribution.

TxDOT determined which construction materials needed to be included in this research project. Table 3.1 shows a list of all the materials and tests that were included in the research.

Table 3.1 Materials and Tests Analyzed for Optimum Sample Size/Test Frequency

Material	Test
Asphalt Concrete	• Lab Density • Air Void
Concrete for Pavements	• Air Entrainment • Strength • Slump
Concrete for Structures	• Air Entrainment • Strength • Slump
Subbase and Base Courses	• Gradation • Liquid Limit • Plasticity Index • Wet Ball Mill • Compaction
Treated Subbase and Base Courses	• In-Place Density

The materials and tests were grouped by characteristics and by project type. For example, concrete for structures was divided into concrete Class C and concrete Class S because of its specified flexural strength after 28 days; gradation test reports for subbase and base aggregates were classified by material group according to the AASHTO Soil Classification System.

Some of the projects were very well documented and had a large set of data available. Only a few reports were received from other projects, but the team considered these reports valuable as well in order to obtain the population of results for each material and test. The research team determined that combining the test results from all the projects from which data were received could approximate the properties of these populations.

During the analysis, the research team determined that retesting was permitted and the values from test results that failed to meet the specifications were included as part of the population. The researchers also concluded that the retests always yielded a value above the specifications and therefore were also included in the population data.

Table 3.2 shows the complete set of tests studied during the research. It also shows the sample size and coefficient of variance obtained from the data. By comparing the results of material variability with the results found on previous studies about the subject it can be concluded that the samples used have a variability that is consistent with those standards previously determined by a National Cooperative Highway Research Program (NCHRP) study [Hughes 96].

Table 3.2 Tests Studied, Population Data, and Coefficient of Variance

MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	n	CV
SUBBASE AND BASE COURSES	MATERIAL GROUP A1	Gradation	Tex-110-E	247	20.9%
		Liquid Limit	Tex-104-E	237	8.8%
		Plasticity Index	Tex-106-E	237	31.4%
		Wet Ball Mill	Tex-116-E	99	5.4%
	MATERIAL GROUP A2	Gradation	Tex-110-E	873	6.2%
		Liquid Limit	Tex-104-E	847	9.1%
		Plasticity Index	Tex-106-E	847	41.3%
		Wet Ball Mill	Tex-116-E	351	10.0%
	MATERIAL GROUP A4	Gradation	Tex-110-E	1837	21.8%
		Liquid Limit	Tex-104-E	1784	10.3%
		Plasticity Index	Tex-106-E	1779	46.1%
		Wet Ball Mill	Tex-116-E	746	9.7%
	MATERIAL GROUP D6	Gradation	Tex-110-E	131	27.0%
		Liquid Limit	Tex-104-E	83	13.7%
		Plasticity Index	Tex-106-E	133	46.7%
		Wet Ball Mill	Tex-116-E	23	11.9%
TREATED SUBBASE AND BASE COURSES		In-Place Density	Tex-115-E	417	4.8%
SUBBASE AND BASE COURSES		Compaction	Tex-115-E	417	2.2%
CONCRETE FOR STRUCTURES 'CLASS S'		Flexural Strength (Age: 28 days)	Tex-448-A	197	11.4%
		Slump	Tex-415-A	396	26.1%
		Slump (Plant)	Tex-415-A	112	27.6%
		Entrained Air	Tex-416-A or Tex-414-A	383	16.7%
CONCRETE FOR STRUCTURES 'CLASS C & S'		Flexural Strength	Tex-448-A	885	14.2%
		Compressive Strength (Age: 7 days)	Tex-418-A	122	14.4%
		Compressive Strength (Age: 28 days)	Tex-418-A	20	11.9%
		Slump	Tex-415-A	310	42.8%
		Entrained Air	Tex-416-A or Tex-414-A	223	18.1%
		Slump Plant	Tex-415-A	66	36.6%

Table 3.2 (continued)

MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	n	CV
CONCRETE FOR PAVEMENTS	Flexural Strength (Age: 7 days)	Tex-448-A	334	10.5%
	Flexural Strength (Age: 28days)	Tex-448-A	258	9.2%
	Flexural Strength (Age: 90 days)	Tex-448-A	71	4.2%
	Compressive Strength (Age: 7 days)	Tex-418-A	538	13.0%
	Compressive Strength (Age: 28 days)	Tex-418-A	489	11.9%
	Compressive Strength (Age: 90 days)	Tex-418-A	92	6.1%
	Compressive Strength (Age: 7 days) Cores	Tex-418-A	338	15.4%
	Compressive Strength (Age: 28 days) Cores	Tex-418-A	379	15.4%
	Compressive Strength (Age: 90 days) Cores	Tex-418-A	199	14.9%
	Splitting Tensile Strength (Age: 7 days)	Tex-421-A	452	11.0%
	Splitting Tensile Strength (Age: 28days)	Tex-421-A	373	12.3%
	Splitting Tensile Strength (Age:90 days)	Tex-421-A	162	9.7%
	Splitting Tensile Strength (Age: 7 days) Cores	Tex-421-A	272	15.5%
	Splitting Tensile Strength (Age: 28 days) Cores	Tex-421-A	355	14.8%
	Splitting Tensile Strength (Age: 90 days) Cores	Tex-421-A	244	19.5%
	Slump	Tex-415-A	126	46.8%
	Entrained Air	Tex-416-A or Tex-414-A	125	27.7%
ASPHALT CONCRETE	Lab Density	Tex-207-F	TxDOT 1997-1998	0.36%
	Air Voids	Tex-207-F		16.89%

4. Data Analysis and Calculations

The final goal of organizing and entering all the data from the different tests was to perform a much-needed statistical analysis on these populations. A "true" knowledge of the population had to be determined before any type of analysis could be done. In reality, this "true" knowledge could only be exact if sampling had occurred at all locations in the material e.g., when testing in-place density. For concrete, the number of samples taken from a lot would have to be large enough to show the normal distribution. The proximity to the normal distribution for a mean ($\overline{X}$) is precise if the sample size (*n*) is greater than or equal to 30 [Walpole et al. 92].

4.1 Determining Sample Size and Testing Frequencies

To explain the calculations and data analysis of the population data, the research team referred to the data collected for the test, "Tex-448-A, Flexural Strength of Concrete Using Simple Beam Third-Point Loading" using concrete for structures 'Class C and S' (age: 28 days). The design of concrete for structures 'Class C and S', specifies a minimum value for the Modulus of Rupture of 470 psi after 28 days.

4.1.1 Descriptive Statistics

The first step of the methodology is to create a descriptive statistics table for each test. Table 4.1 shows the descriptive statistics that characterize the material and test previously described. This table includes important information such as the population mean (μ), the standard deviation (σ), the coefficient of variance, the range, and the population size, among others.

A histogram defines a set of intervals and shows how many values in a sample fall into each interval. It shows the shape of the density of the population. The histograms developed with the population data for the different tests and materials confirmed the assumption of normality of the distribution, which was more noticeable in populations with a larger number of samples. Other graphs were used to prove the normality of the distribution or simply to show different characteristics of the data. Figure 4.1 shows the three types of graphs used during the research to characterize the data.

Table 4.1 Descriptive Statistics Table: Concrete for Structures "Class C & S" – Flexural Strength Test

Concrete for Structures "Class C & S" - Flexural Strength (spec. 470psi)	
Mean	613.17
Median	610.00
Mode	670.00
Standard Deviation	86.94
Sample Variance	7557.89
Range	550.00
Minimum	320.00
Maximum	870.00
Population Size	885.00
CV	14.18%

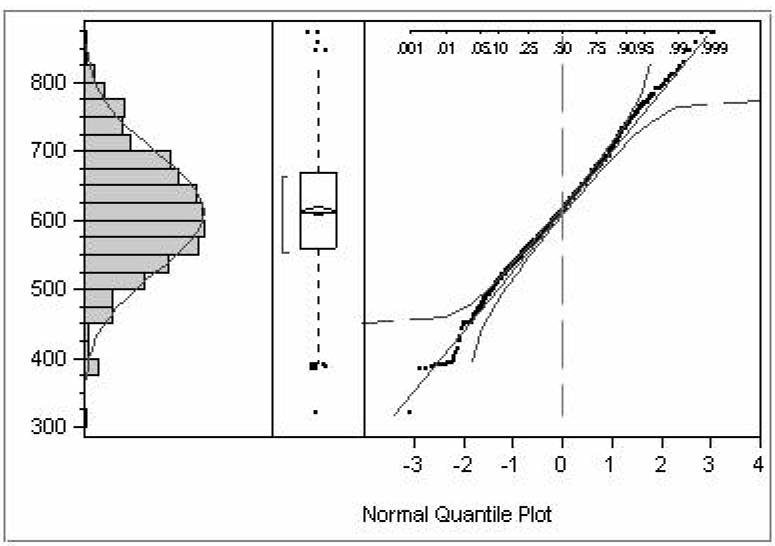


Figure 4.1 Histogram, Outlier Box Plot, and Normal Quantile Plot, Representing the Population Data of Flexural Strength Test for Concrete "Class C & S"

The Outlier Box Plot illustrates how the data are distributed. The box part within each plot surrounds the middle half of the data. The lower edge of the rectangle represents the lower quartile, the higher edge represents the upper quartile, and the line in the middle of the rectangle is the median. The lines extending from the box show the tails of the distribution extending to the farthest point that is still within 1.5 interquartile ranges from the quartiles. Points farther away are shown individually as outliers. The diamond inside the box shows the mean of the data and its 95 percent confidence interval.

The other plot used is the Normal Quantile Plot, which draws all the values of the data as points in a plot. If the data are normal, the points tend to follow a straight line, as it is revealed in Figure 4.1.

4.1.2 Sensitivity Analysis

To continue with the analysis of the data, the research team performed a study of sensitivity analysis to understand the effect of each variable in Equation 2.16 (sample size equation) to the sample size value, and to finally determine the statistically appropriate testing frequency of the tests. As described previously, sensitivity analysis is the study of how the variation in the output of a model can be apportioned, qualitatively or quantitatively, to different sources of variation. Sensitivity analysis is an important issue in determining appropriate testing frequencies and optimizing sample size.

In this research, the required sample size is considered to be highly sensitive with respect to one of the factors of the sample size equation (such as material variability, confidence level, or tolerable error), if the required sample size is greatly influenced by a relatively small change in the factor. This section will show the relationships between the dependent variable, sample size, and independent variables, such as material variability, confidence level, TxDOT's risk, and tolerable error for the flexural strength test of concrete for structures "Class C & S". Tables 4.2 to 4.4 and Figures 4.2 to 4.4, illustrate these relationships.

Table 4.2 along with Figure 4.2 illustrate the relationship between sample size and confidence level for the flexural strength test. As it was stated in Chapter 2, the confidence level is equal to $1-\alpha$. and that is where the produce's risk is considered. Based on the descriptive statistics table for this material and test (Table 4.1), the research team used a standard deviation of 86.9 psi and an assumed tolerable error of 130 psi (130 psi $\approx 1.5\ \sigma$).

Table 4.2 Relationship Sample Size vs. Confidence Level: Concrete for Structures "Class C & S" – Flexural Strength Test

Conf. Level	Other Factors		Sample Size (n)						
	μ	613	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	86.9	7	6	4	4	3	2	2
97	*e*	130	6	4	3	3	2	2	1
95			5	4	3	2	2	1	1
90			4	3	2	1	1	1	0
85			3	2	2	1	1	0	
80			3	2	1	1	1	0	
75			2	2	1	1	0		
70			2	1	1	0			
60			2	1	1	0			
50			1	1	0				
40			1	0					

Current Specs. TXDOT
(2 Beams for each 3000 S.Y.)

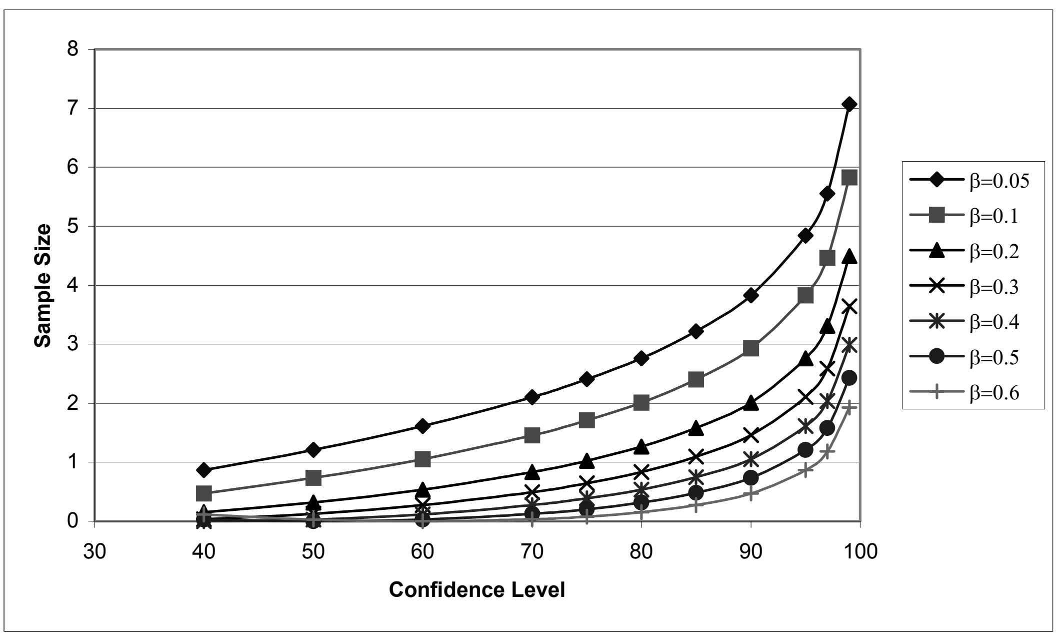


Figure 4.2 Sample Size vs. Confidence Level: Concrete for Structures "Class C & S" – Flexural Strength Test

The sample size values were then obtained based on Equation 2.16, considering several levels of risk for TxDOT. For each level of risk of the parties involved, an optimum sample size was obtained. The shaded cells represent the current testing frequencies used by TxDOT for this test. Appendix A describes the frequency and sample size of concrete for structures when tested for flexural strength as: "*one test (2 beams) for each 60 C.Y. or fraction thereof*."

Considering a maximum risk of 20 percent (suggested by TxDOT) for both TxDOT (β) and the contractor (α), Table 4.2 shows that the required sample size, based on the population data, its variability, and assuming a tolerable error of 130 psi, should be one (1) beam. In the same manner, if the desired risk is only 5 percent for TxDOT but keeping the confidence level on the material at 80 percent (α = 20%) the sample size should be increased to three (3) beams. Thus, the results of Table 4.2 show that, when considering a 20 percent risk for TxDOT and the contractor, the number of beams should be decreased from two (2) to one (1) for each 60 C.Y. or fraction thereof.

From this table and figure, the research team concluded that, for a higher confidence level, a larger sample size is required. Also, at a given confidence level, the size of the sample increases when the owner's risk (β) decreases. In other words, the contractor's risk (α) and the owner's risk (β) will decrease with larger samples. If we refer back to Figure 2.1 in Chapter 2, larger samples will always minimize the risk of failure, but at the expense of higher costs.

A very important fact derived from the results shown in Table 4.2 is that the adequate sample size obtained can be related to a level of risk for the two parties involved. For some materials, it may indicate that the number of samples should be increased under the same testing frequency in order to decrease a high level of risk. For other materials, decreasing the sample size will not change the confidence on the good quality of the material and will even represent cost savings during testing. When compared with the current sample size and testing frequencies stated in the Guide Schedule (Appendix A), the risk of accepting poor materials by TxDOT can be defined.

Table 4.3 Relationship Sample Size vs. Tolerable Error: Concrete for Structures "Class C & S" – Flexural Strength Test

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
40	Z_{alpha}	0.84	29	21	13	9	6	3	2
50	μ	613	19	14	9	6	4	2	1
60	σ	86.9	13	9	6	4	3	1	1
70			10	7	4	3	2	1	1
80			7	5	3	2	1	1	0
85			6	5	3	2	1	1	0
87			6	4	3	2	1	1	0
90			6	4	3	2	1	1	0
100			5	3	2	1	1	1	0
115			4	3	2	1	1	0	0
130			3	2	1	1	1	0	0
150			2	2	1	1	0	0	0
160			2	1	1	1	0	0	0
170			2	1	1	0	0	0	0

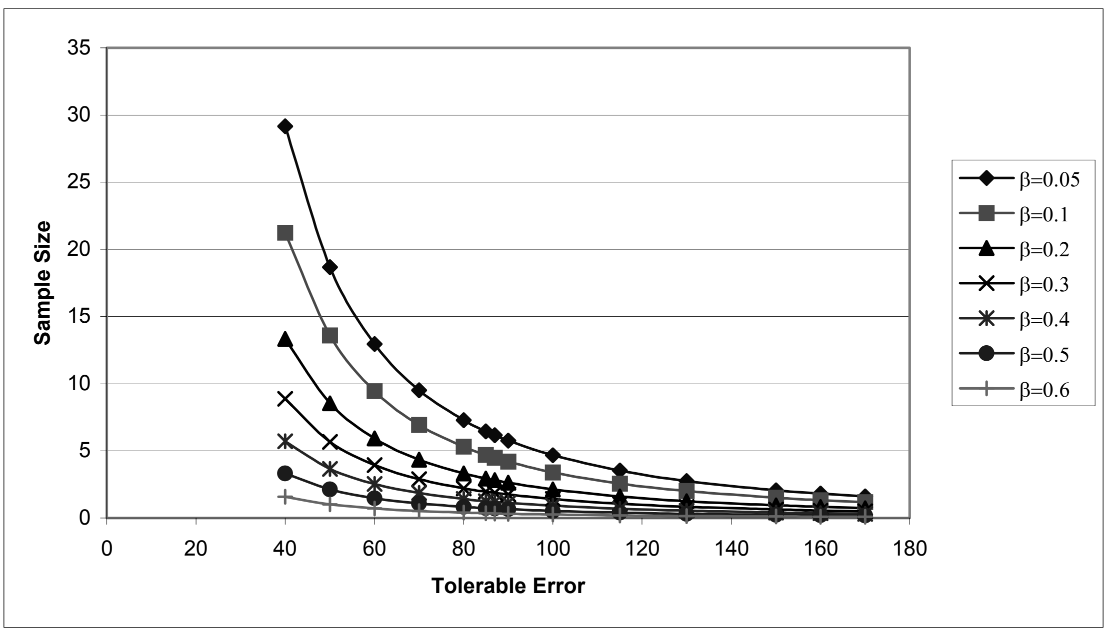


Figure 4.3 Sample Size vs. Tolerable Error: Concrete for Structures "Class C & S" – Flexural Strength Test

Table 4.3, along with Figure 4.3, illustrates the relationship between sample size and tolerable error for the flexural strength test. The confidence level is assumed to be 80 percent ($\alpha = 0.2$) and the standard deviation is 86.9 psi, as stated in Table 4.1. The required sample size decreases as the tolerable error increases, which indicates that the relationship is negative. The type II error, β, also has the same effect on sample size as in the previous relationship. As risk increases, the number of samples required will decrease.

The research team found that when the tolerable error (*e*) exceeds 100 psi ($\approx 1.25\ \sigma$) the change on the required sample size is not significantly evident. Figure 2.8 illustrates the distribution of the population (μ_0) and the distribution of a sample (μ_a). The difference between the means of these two distributions is the tolerable error. Thus, considering a tolerable error of 130 psi, the mean value of the sample (μ_a) is equal to 483 psi. This value is above the minimum value specified during design (470 psi), which gives some extra confidence on accepting the new specification.

Table 4.4, along with Figure 4.4, illustrates the relationship between sample size and standard deviation for the flexural strength test. It is assumed that the confidence level is 80 percent ($\alpha = 0.2$) and the tolerable error is 130 psi. It is evident that the required sample size increases as the standard deviation increases. In consideration of the type II error, when β increases from 5 percent to 60 percent, the sample size decreases with the other parameters held constant. In particular, when $\beta = 0.5$ (i.e., $Z_\beta = 0$), the results are exactly the same as those obtained from the method that controls only type I error. The relationship between sample size and type II error shows that the highway agency's risk (β) decreases as the sample size increases.

The sample size/test frequency analysis for the other tests studied during this research can be found in Appendix B. The tables in this appendix show the sensitivity analysis for every test. The tables should be interpreted in the same way as in this section for the test of flexural strength of concrete for structures.

Table 4.4 Relationship Sample Size vs. Standard Deviation. Concrete for Structures "Class C & S" – Flexural Strength (28 days)

σ	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
0	Z_{alpha}	0.84	0	0	0	0	0	0	0
20	μ	613	0	0	0	0	0	0	0
30	*e*	130	0	0	0	0	0	0	0
40			1	0	0	0	0	0	0
50			1	1	0	0	0	0	0
60			1	1	1	0	0	0	0
70			2	1	1	1	0	0	0
80			2	2	1	1	0	0	0
90			3	2	1	1	1	0	0
100			4	3	2	1	1	0	0
120			5	4	2	2	1	1	0
130			6	4	3	2	1	1	0
140			7	5	3	2	1	1	0
150			8	6	4	2	2	1	0

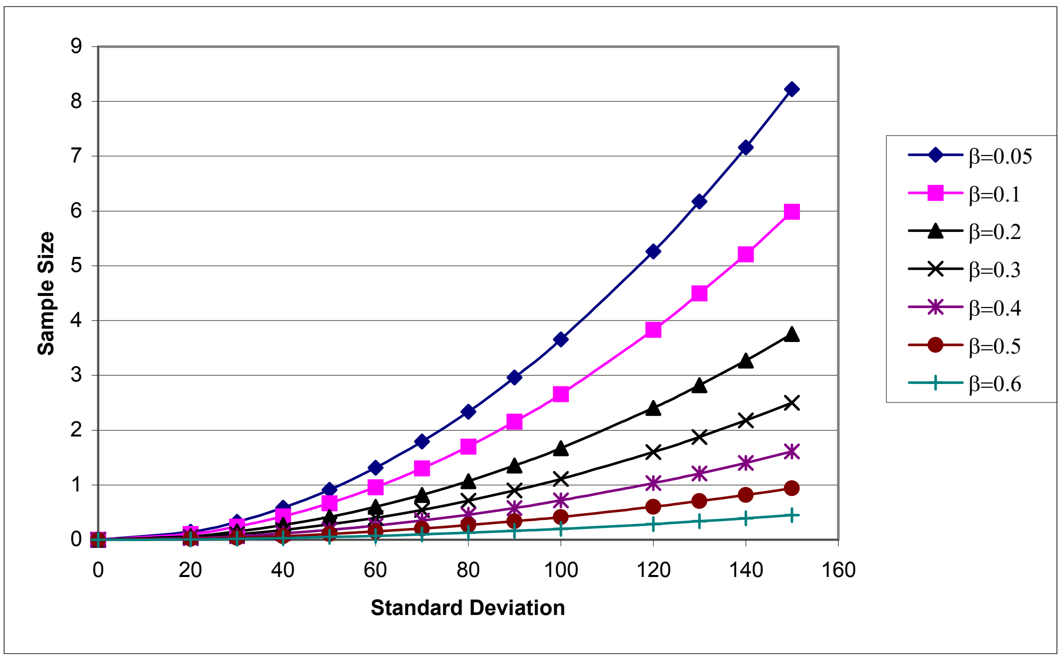


Figure 4.4 Sample Size vs. Standard Deviation. Concrete for Structures "Class C & S" – Flexural Strength Test

4.2 Descriptive Statistics of Pavement Materials

The following tables summarize all the statistical properties of the data collected for the pavement materials described in Chapter 3. It is important to recognize that the variability of the tests, represented by the standard deviation, is an approximation of the overall variability of the material. The overall variability considers inherent variations, variability given by the sampling and testing process, within-batch variability and batch-to-batch variability. The data of the different materials were organized by type of material, projects of similar characteristics, and design specifications.

With the information provided in these tables, the sample size/test frequency analysis was performed for all the tests. The results of this analysis is shown in Appendix B.

Table 4.5 Descriptive Statistics Table - Subbase and Base Courses

MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	Mean	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Count	CV
SUBBASE AND BASE COURSES	MATERIAL GROUP A1	Gradation	Tex-110-E	22	22.4	24.6	4.61	21.21	19	13.1	32.1	247	20.9%
		Liquid Limit	Tex-104-E	20	19	19	1.72	2.97	9	15	24	237	8.8%
		Plasticity Index	Tex-106-E	6	5	5	1.73	3.00	9	1	10	237	31.4%
		Wet Ball Mill	Tex-116-E	35	35	37	1.87	3.50	6	31	37	99	5.4%
	MATERIAL GROUP A2	Gradation	Tex-110-E	59	59.5	60	3.63	13.19	31.8	36.4	68.2	873	6.2%
		Liquid Limit	Tex-104-E	21	20	21	1.88	3.52	12	15	27	847	9.1%
		Plasticity Index	Tex-106-E	4	4	3	1.66	2.74	9	1	10	847	41.3%
		Wet Ball Mill	Tex-116-E	35	36	36	3.55	12.57	18	26	44	351	10.0%
	MATERIAL GROUP A4	Gradation	Tex-110-E	22	22.2	25.1	4.74	22.46	30	4.3	34.3	1837	21.8%
		Liquid Limit	Tex-104-E	21	21	20	2.18	4.76	13	15	28	1784	10.3%
		Plasticity Index	Tex-106-E	5	4	3	2.15	4.64	14	1	15	1779	46.1%
		Wet Ball Mill	Tex-116-E	36	37	36	3.54	12.53	22	22	44	746	9.7%
	MATERIAL GROUP D6	Gradation	Tex-110-E	20	20.6	17.1	5.48	30.01	29.3	4.6	33.9	131	27.0%
		Liquid Limit	Tex-104-E	20	20	19	2.81	7.91	14	16	30	83	13.7%
		Plasticity Index	Tex-106-E	6	5	5	2.74	7.52	13	2	15	133	46.7%
		Wet Ball Mill	Tex-116-E	36	34	32	4.25	18.06	12	31	43	23	11.9%
TREATED SUBBASE AND BASE COURSES		In-place Density	Tex-115-E	137	135.6	130.6	6.53	42.63	28.7	125	153.7	417	4.8%
SUBBASE AND BASE COURSES		Compaction	Tex-115-E	101	101	100	2.19	4.79	17	90	108	417	2.2%

Table 4.6 Descriptive Statistics Table - Concrete for Pavements

MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	Mean	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Count	CV
CONCRETE FOR PAVEMENTS	Flexural Strength (Age: 7 days)	Tex-448-A	592.6	595	605	62.45	3900.42	432	353	785	334	10.5%
	Flexural Strength (Age: 28days)	Tex-448-A	696.2	703	713	64.04	4101.61	336	510	846	258	9.2%
	Flexural Strength (Age: 90 days)	Tex-448-A	808.3	807	792	33.84	1145.26	200	702	902	71	4.2%
	Compressive Strength (Age: 7 days)	Tex-418-A	4378.2	4367	3870	569.05	323821.99	3980	1980	5960	538	13.0%
	Compressive Strength (Age: 28 days)	Tex-418-A	5289.3	5280	5200	628.66	395207.15	3895	3040	6935	489	11.9%
	Compressive Strength (Age: 90 days)	Tex-418-A	6111.2	6150	6180	372.81	138984.27	1740	5190	6930	92	6.1%
	Compressive Strength (Age: 7 days) Cores	Tex-418-A	4327.6	4338.5	3900	668.36	446699.72	4590	2310	6900	338	15.4%
	Compressive Strength (Age: 28 days) Cores	Tex-418-A	5031.3	5150	4455	773.32	598020.37	4335	2705	7040	379	15.4%
	Compressive Strength (Age: 90 days) Cores	Tex-418-A	5599.4	5670	5330	834.25	695973.02	4640	3260	7900	199	14.9%
	Splitting Tensile Strength (Age: 7 days)	Tex-421-A	441.6	442	460	48.71	2373.06	324	260	584	452	11.0%
	Splitting Tensile Strength (Age: 28days)	Tex-421-A	503.3	513	440	62.15	3862.18	617	55	672	373	12.3%
	Splitting Tensile Strength (Age:90 days)	Tex-421-A	592.6	590	590	57.50	3305.84	289	445	734	162	9.7%
	Splitting Tensile Strength (Age: 7 days) Cores	Tex-421-A	521.0	528.5	540	80.55	6487.81	579	280	859	272	15.5%
	Splitting Tensile Strength (Age: 28 days) Cores	Tex-421-A	589.2	585	500	87.34	7628.60	689	216	905	355	14.8%
	Splitting Tensile Strength (Age: 90 days) Cores	Tex-421-A	627.1	635	665	122.08	14904.73	575	355	930	244	19.5%
	Slump	Tex-415-A	1.9	1.75	1.75	0.90	0.80	4.5	0.5	5	126	46.8%
	Entrained Air	Tex-416-A or Tex-414-A	4.5	4.3	3.3	1.24	1.54	5.8	2.7	8.5	125	27.7%

Table 4.7 Descriptive Statistics Table: Concrete for Structures

MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	Mean	Median	Mode	Standard Deviation	Sample Variance	Range	Minimum	Maximum	Count	CV
CONCRETE FOR STRUCTURES 'CLASS S'	Flexural Strength (Age: 28 days)	Tex-448-A	632	640	700	72.00	5183.51	428	432	860	197	11.4%
	Slump	Tex-415-A	4	4.5	4	1.17	1.36	6.25	1	7.25	396	26.1%
	Slump (Plant)	Tex-415-A	5	5.5	5	1.48	2.19	8.5	1	9.5	112	27.6%
	Entrained Air	Tex-416-A or Tex-414-A	5	5	5	0.84	0.70	5.2	2	7.2	383	16.7%
CONCRETE FOR STRUCTURES 'CLASS C & S'	Flexural Strength	Tex-448-A	613	610	670	86.94	7557.89	550	320	870	885	14.2%
	Compressive Strength (Age: 7 days)	Tex-418-A	4682	4540	4170	675.14	455810.51	3220	3360	6580	122	14.4%
	Compressive Strength (Age: 28 days)	Tex-418-A	5951	5750	5590	706.42	499030.53	2050	5130	7180	20	11.9%
	Slump	Tex-415-A	4	4	4	1.70	2.89	7.75	0.75	8.5	310	42.8%
	Entrained Air	Tex-416-A or Tex-414-A	5	5.75	6	0.99	0.97	8	0	8	223	18.1%
	Slump Plant	Tex-415-A	5	5	4.5	1.94	3.75	8	1	9	66	36.6%

Table 4.8 Descriptive Statistics Table: Asphalt Concrete Pavements

MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	Mean	Standard Deviation	Count	CV
HMACP		Lab Density	Tex-207-F	96.2	0.35	TxDOT 1997-1998	0.4%
QA	HMACP	Lab Density	Tex-207-F				
QA	ROADWAY	Air Voids	Tex-207-F	7.4	1.25		16.9%

5. Sample Size and Testing Frequency

The purpose of this chapter is to present a set of summary tables defining the sample size and test frequency of the materials and tests included in the research, based on the analysis and calculations performed in the previous sections.

It is important to remember that the sample size values obtained are based on the variability of the population data, the maximum level of risk for the parties involved (TxDOT and contractors), and a tolerable error that realistically takes into consideration the specified design limits for each one of the materials and tests.

The assumed risk for TxDOT, (β), described before as the risk of accepting poor materials, will be set to a maximum of 20 percent. Similarly, the risk for the contractors (α) of getting good materials rejected will also be set to a maximum of 20 percent.

Because of the difficulties encountered by the research team during the data-gathering process, it was not possible to analyze the results of the statistically appropriate sample size with the rates of production and total quantities of materials delivered to the projects. This task could definitely reveal new and interesting findings about the testing frequencies being used because the sample could be related not only to the testing frequency used to gather it but also to the actual production rates and quantities involved.

The tables on the following pages provide the results for minimum sampling and testing frequencies according to the risk-based statistics analysis of the data collected from projects in the state of Texas. The tables will be divided by materials, and for some tests, the sample size will be given by class, type, or age. The "Table of Reference" column indicates the number of the table in Appendix B, from where these results were obtained. Chapter 4 describes how to interpret the results of the tables in Appendix B.

Table 5.1 Statistics Based Testing Frequencies for Subbase and Base Courses

MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	PROJECT ACCEPTANCE TESTS		
			LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	TABLE OF REFERENCE
SUBBASE AND BASE COURSES: MATERIAL GROUP A1	Gradation	Tex-110-E	During stockpiling oprs, from stockpile, or from windrow	Each 4,000 C.Y. or 6,000 tons	B.53
	Liquid Limit	Tex-104-E	During stockpiling oprs, from stockpile, or from windrow	Each 4,000 C.Y. or 6,000 tons	B.61
	Plasticity Index	Tex-106-E	During stockpiling oprs, from stockpile, or from windrow	Each 4,000 C.Y. or 6,000 tons	B.69
	Wet Ball Mill	Tex-116-E	During stockpiling oprs. from stockpile, or from windrow	Each 20,000 C.Y. or 25,000 tons	B.77
SUBBASE AND BASE COURSES: MATERIAL GROUP A2	Gradation	Tex-110-E	During stockpiling oprs, from stockpile, or from windrow	Each 4,000 C.Y. or 6,000 tons	B.55
	Liquid Limit	Tex-104-E	During stockpiling oprs, from stockpile, or from windrow	Each 4,000 C.Y. or 6,000 tons	B.63
	Plasticity Index	Tex-106-E	During stockpiling oprs, from stockpile, or from windrow	Each 4,000 C.Y. or 6,000 tons	B.71
	Wet Ball Mill	Tex-116-E	During stockpiling oprs. from stockpile, or from windrow	Two every 20,000 C.Y. or 25,000 tons	B.79
SUBBASE AND BASE COURSES: MATERIAL GROUP A4	Gradation	Tex-110-E	During stockpiling oprs, from stockpile, or from windrow	Two every 4,000 C.Y. or 6,000 tons	B.57
	Liquid Limit	Tex-104-E	During stockpiling oprs, from stockpile, or from windrow	Each 4,000 C.Y. or 6,000 tons	B.65
	Plasticity Index	Tex-106-E	During stockpiling oprs, from stockpile, or from windrow	Two every 4,000 C.Y. or 6,000 tons	B.73
	Wet Ball Mill	Tex-116-E	During stockpiling oprs. from stockpile, or from windrow	Three every 20,000 C.Y. or 25,000 tons	B.81
SUBBASE AND BASE COURSES: MATERIAL GROUP D6	Gradation	Tex-110-E	During stockpiling oprs, from stockpile, or from windrow	Two every 4,000 C.Y. or 6,000 tons	B.59
	Liquid Limit	Tex-104-E	During stockpiling oprs, from stockpile, or from windrow	Each 4,000 C.Y. or 6,000 tons	B.67
	Plasticity Index	Tex-106-E	During stockpiling oprs, from stockpile, or from windrow	Two every 4,000 C.Y. or 6,000 tons	B.75
	Wet Ball Mill	Tex-116-E	During stockpiling oprs. from stockpile, or from windrow	Two every 20,000 C.Y. or 25,000 tons	B.83
TREATED SUBBASE AND BASE COURSES	In-Place Density	Tex-115-E	As designated by the engineer	Each 3,000 lin. ft. per course per travel-way	B.87
SUBBASE AND BASE COURSES	Compaction	Tex-115-E	As designated by the engineer	Each 3,000 lin. ft. per course per travel-way	B.85

Table 5.2 Statistics-Based Testing Frequencies for Concrete for Pavements

MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	PROJECT ACCEPTANCE TESTS		
			LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	TABLE OF REFERENCE
CONCRETE FOR PAVEMENTS	Flexural Strength (Age: 7 days)	Tex-448-A	At point of concrete placement	One test (1 beam) for each 3,000 S.Y.	B.23
	Flexural Strength (Age: 28 days)	Tex-448-A	At point of concrete placement	One test (1 beam) for each 3,000 S.Y.	B.25
	Flexural Strength (Age: 90 days)	Tex-448-A	At point of concrete placement	One test (1 beam) for each 3,000 S.Y.	B.27
	Compressive Strength (Age: 7 days)	Tex-418-A	At point of concrete placement	One test (2 beams) for each 3,000 S.Y.	B.11
	Compressive Strength (Age: 28 days)	Tex-418-A	At point of concrete placement	One test (1 cylinder) for each 3,000 S.Y.	B.13
	Compressive Strength (Age: 90 days)	Tex-418-A	At point of concrete placement	One test (1 cylinder) for each 3,000 S.Y.	B.15
	Compressive Strength (Age: 7 days) Cores	Tex-418-A	At point of concrete placement	One test (2 beams) for each 3,000 S.Y.	B.17
	Compressive Strength (Age: 28 days) Cores	Tex-418-A	At point of concrete placement	One test (2 beams) for each 3,000 S.Y.	B.19
	Compressive Strength (Age: 90 days) Cores	Tex-418-A	At point of concrete placement	One test (1 cylinder) for each 3,000 S.Y.	B.21
	Splitting Tensile Strength (Age: 7 days)	Tex-421-A	At point of concrete placement	One test (1 beam) for each 3,000 S.Y.	B.29
	Splitting Tensile Strength (Age: 28 days)	Tex-421-A	At point of concrete placement	One test (1 beam) for each 3,000 S.Y.	B.31
	Splitting Tensile Strength (Age: 90 days)	Tex-421-A	At point of concrete placement	One test (1 beam) for each 3,000 S.Y.	B.33
	Splitting Tensile Strength (Age: 7 days) Cores	Tex-421-A	At point of concrete placement	One test (2 beams) for each 3,000 S.Y.	B.35
	Splitting Tensile Strength (Age: 28 days) Cores	Tex-421-A	At point of concrete placement	One test (2 beams) for each 3,000 S.Y.	B.37
	Splitting Tensile Strength (Age: 90 days) Cores	Tex-421-A	At point of concrete placement	One test (2 beams) for each 3,000 S.Y.	B.39
	Slump	Tex-415-A	At time and location strength specimens are made	Two tests per set of strength specimens	B.41
	Entrained Air	Tex-416-A or Tex-414-A	At time and location strength specimens are made	Three tests per set of strength specimens	B.43

Table 5.3 Statistics-Based Testing Frequencies for Concrete for Structures

MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	PROJECT ACCEPTANCE TESTS		
			LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	TABLE OF REFERENCE
CONCRETE FOR STRUCTURES 'CLASS S'	Flexural Strength (Age: 28 days)	Tex-448-A	At point of concrete placement	One test (1 beam) for each 60 C.Y. or fraction thereof	B.45
	Slump	Tex-415-A	At point of concrete placement	Three tests per set of strength specimens	B.49
	Slump (Plant)	Tex-415-A	Plant	Two tests per set of strength specimens	B.51
	Entrained Air	Tex-416-A or Tex-414-A	At point of concrete placement	One per placement	B.47
CONCRETE FOR STRUCTURES 'CLASS C & S'	Flexural Strength	Tex-448-A	At point of concrete placement	One test (1 beam) for each 60 C.Y. or fraction thereof	4.2
	Compressive Strength (Age: 7 days)	Tex-418-A	At point of concrete placement	One test (1 cylinder) for each 60 C.Y. or fraction thereof	B.1
	Compressive Strength (Age: 28 days)	Tex-418-A	At point of concrete placement	One test (1 cylinder) for each 60 C.Y. or fraction thereof	B.3
	Slump	Tex-415-A	At point of concrete placement	One test per set of strength specimens	B.5
	Slump (Plant)	Tex-415-A	Plant	Two tests per set of strength specimens	B.7
	Entrained Air	Tex-416-A or Tex-414-A	At point of concrete placement	Two per placement	B.9

Table 5.4 Statistics Based Testing Frequencies for Asphalt Concrete

MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	PROJECT ACCEPTANCE TESTS		
				LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	TABLE OF REFERENCE
QC/QA	HMACP	Lab Density	Tex-207-F	Split from QA test sample	1 per 12 quality assurance tests	B.91
QC/QA	HMACP	Air Voids	Tex-207-F	Selected from QA test	1 core per 24 QA tests	B.89

6. TxDOT's Guide Schedule Versus Statistic Sample Size

The following tables compare the results from this research with the current *Guide Schedule for Sampling and Testing* used by TxDOT. As in the previous chapter, the results of the research are based on a fixed level of risk. The assumed risk for TxDOT, (β), described before as the risk of accepting poor materials, will be set to a maximum of 20 percent. Similarly, the risk for the contractors (α) of getting good materials rejected will also be set to a maximum of 20 percent.

Again, these obtained sample size values are based on the variability of the population data, the maximum level of risk for the parties involved (TxDOT and contractors), and a tolerable error that realistically takes into consideration the specified design limits for each of the materials and tests.

It is important to remember that in the case of decreasing both or simply one of the assumed risks, α or β, the sample size and test frequency will increase. In the same way, if the tolerable error is smaller, a larger number of samples will be required.

The column "Sampling and Frequency (TxDOT)" describes the current specifications for testing by TxDOT. These specifications are intended to be the ones used during the sampling process of the materials. Therefore, the research team determined that the sample size obtained as a result of this research, considers the same testing frequency used throughout the sampling process during construction.

The "End Result" column indicates if the final sample size obtained by the research team is greater or lower than specified in the Guide Schedule at the given level of risk for both TxDOT and contractors (20% and 20% respectively). The column points out: 1) If the indicated test needs additional samples (+); 2) If the sample size could be reduced (−); and 3) If the sample size currently required by TxDOT is equal to the sample size obtained with the analysis of the variability of the samples in this research (*).

The overall impact of the methodology, based on the results shown in these tables, is that at the 20%/20% level of risk for both TxDOT and contractors, the sample size of the 70 percent of the test studied should be kept the same or decreased. This confirmation could not be made if the level of risk for any of the two parties is decreased. In this case the sample size required is most likely to increase if compared to the current specifications included in the Guide Schedule.

Table 6.1 Statistics-Based Testing Frequencies vs. Guide Schedule (TxDOT): Subbase and Base Courses

MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	PROJECT ACCEPTANCE TESTS		END RESULT
				SAMPLING AND FREQUENCY (0-1781)	SAMPLING AND FREQUENCY (TXDOT)	
SUBBASE AND BASE COURSES	MATERIAL GROUP A1	Gradation	Tex-110-E	Each 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	*
		Liquid Limit	Tex-104-E	Each 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	*
		Plasticity Index	Tex-106-E	Each 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	*
		Wet Ball Mill	Tex-116-E	Each 20,000 C.Y. or 25,000 tons	Each 20,000 C.Y. or 25,000 tons	*
	MATERIAL GROUP A2	Gradation	Tex-110-E	Each 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	*
		Liquid Limit	Tex-104-E	Each 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	*
		Plasticity Index	Tex-106-E	Each 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	*
		Wet Ball Mill	Tex-116-E	Two every 20,000 C.Y. or 25,000 tons	Each 20,000 C.Y. or 25,000 tons	+
	MATERIAL GROUP A4	Gradation	Tex-110-E	Two every 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	+
		Liquid Limit	Tex-104-E	Each 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	*
		Plasticity Index	Tex-106-E	Two every 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	+
		Wet Ball Mill	Tex-116-E	Three every 20,000 C.Y. or 25,000 tons	Each 20,000 C.Y. or 25,000 tons	+
	MATERIAL GROUP D6	Gradation	Tex-110-E	Two every 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	+
		Liquid Limit	Tex-104-E	Each 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	*
		Plasticity Index	Tex-106-E	Two every 4,000 C.Y. or 6,000 tons	Each 4,000 C.Y. or 6,000 tons	+
		Wet Ball Mill	Tex-116-E	Two every 20,000 C.Y. or 25,000 tons	Each 20,000 C.Y. or 25,000 tons	+
TREATED SUBBASE AND BASE COURSES		In-place Density	Tex-115-E	Each 3,000 lin. ft. per course per travel-way	Each 3,000 lin. ft. per course per travel-way	*
SUBBASE AND BASE COURSES		Compaction	Tex-115-E	Each 3,000 lin. ft. per course per travel-way	Each 3,000 lin. ft. per course per travel-way	*

Table 6.2 Statistics-Based Testing Frequencies vs. Guide Schedule (TxDOT): Concrete for Pavements

MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	PROJECT ACCEPTANCE TESTS		END RESULT
			SAMPLING AND FREQUENCY (0-1781)	SAMPLING AND FREQUENCY (TxDOT)	
CONCRETE FOR PAVEMENTS	Flexural Strength (Age: 7 days)	Tex-448-A	One test (1 beam) for each 3,000 S.Y.	One test (2 beams) for each 3,000 S.Y.	-
	Flexural Strength (Age: 28 days)	Tex-448-A	One test (1 beam) for each 3,000 S.Y.	One test (2 beams) for each 3,000 S.Y.	-
	Flexural Strength (Age: 90 days)	Tex-448-A	One test (1 beam) for each 3,000 S.Y.	One test (2 beams) for each 3,000 S.Y.	-
	Compressive Strength (Age: 7 days)	Tex-418-A	One test (2 cylinders) for each 3,000 S.Y.	One test (2 cylinders) for each 3,000 S.Y.	*
	Compressive Strength (Age: 28 days)	Tex-418-A	One test (1 cylinder) for each 3,000 S.Y.	One test (2 cylinders) for each 3,000 S.Y.	-
	Compressive Strength (Age: 90 days)	Tex-418-A	One test (1 cylinder) for each 3,000 S.Y.	One test (2 cylinders) for each 3,000 S.Y.	-
	Compressive Strength (Age: 7 days) Cores	Tex-418-A	One test (2 cylinders) for each 3,000 S.Y.	One test (2 cylinders) for each 3,000 S.Y.	*
	Compressive Strength (Age: 28 days) Cores	Tex-418-A	One test (2 cylinders) for each 3,000 S.Y.	One test (2 cylinders) for each 3,000 S.Y.	*
	Compressive Strength (Age: 90 days) Cores	Tex-418-A	One test (1 cylinder) for each 3,000 S.Y.	One test (2 cylinders) for each 3,000 S.Y.	-
	Splitting Tensile Strength (Age: 7 days)	Tex-421-A	One test (1 cylinder) for each 3,000 S.Y.	N/A	
	Splitting Tensile Strength (Age: 28 days)	Tex-421-A	One test (1 cylinder) for each 3,000 S.Y.	N/A	
	Splitting Tensile Strength (Age: 90 days)	Tex-421-A	One test (1 cylinder) for each 3,000 S.Y.	N/A	
	Splitting Tensile Strength (Age: 7 days) Cores	Tex-421-A	One test (2 cylinders) for each 3,000 S.Y.	N/A	
	Splitting Tensile Strength (Age: 28 days) Cores	Tex-421-A	One test (2 cylinders) for each 3,000 S.Y.	N/A	
	Splitting Tensile Strength (Age: 90 days) Cores	Tex-421-A	One test (2 cylinders) for each 3,000 S.Y.	N/A	
	Slump	Tex-415-A	Two tests per set of strength specimens	One test per set of strength specimens	+
	Entrained Air	Tex-416-A or Tex-414-A	Three tests per set of strength specimens	One test per set of strength specimens	+

Table 6.3 Statistics-Based Testing Frequencies vs. Guide Schedule (TxDOT): Concrete for Structures

MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	PROJECT ACCEPTANCE TESTS			END RESULT
			SAMPLING AND FREQUENCY (0-1781)		SAMPLING AND FREQUENCY (TXDOT)	
CONCRETE FOR STRUCTURES 'CLASS S'	Flexural Strength (Age: 28 days)	Tex-448-A	One test (1 beam) for each 60 C.Y. or fraction thereof		One test (2 beams) for each 60 C.Y. or fraction thereof	-
	Slump	Tex-415-A	Three tests per set of strength specimens		One test per set of strength specimens	+
	Slump (Plant)	Tex-415-A	Two tests per set of strength specimens		One test per set of strength specimens	+
	Entrained Air	Tex-416-A or Tex-414-A	One per placement		One per placement	*
CONCRETE FOR STRUCTURES 'CLASS C & S'	Flexural Strength	Tex-448-A	One test (1 beam) for each 60 C.Y. or fraction thereof		One test (2 beams) for each 60 C.Y. or fraction thereof	-
	Compressive Strength (Age: 7 days)	Tex-418-A	One test (1 cylinder) for each 60 C.Y. or fraction thereof		One test (2 cylinders) for each 60 C.Y. or fraction thereof	-
	Compressive Strength (Age: 28 days)	Tex-418-A	One test (1 cylinder) for each 60 C.Y. or fraction thereof		One test (2 cylinders) for each 60 C.Y. or fraction thereof	-
	Slump	Tex-415-A	One test per set of strength specimens		One test per set of strength specimens	*
	Entrained Air	Tex-416-A or Tex-414-A	Two per placement		One per placement	+

Table 6.4 Statistics-Based Testing Frequencies vs. Guide Schedule (TxDOT) Asphalt Concrete

MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	PROJECT ACCEPTANCE TESTS			END RESULT
				SAMPLING AND FREQUENCY (0-1781)		SAMPLING AND FREQUENCY (TxDOT)	
QC/QA	HMACP	Lab Density	Tex-207-F	1 per 12 quality assurance tests		1 per 12 quality assurance tests	*
	ROADWAY	Air Voids	Tex-207-F	1 core per 24 QA tests		2 cores per 24 QA tests	-

7. Implementation

Every time a new procedure is developed, its implementation represents putting into practice the results from the research. When the research objective is to improve a previous methodology or guideline, the implementation represents the coordination of every activity involved in the previous procedure and the activities proposed by the new one.

The implementation of the project results, which will be presented as a Testing Frequency Guideline, will have to be divided into several steps. Any testing frequency guideline modification will be directed primarily toward the specifications on the Guide Schedule, which serves as the basis for the testing frequencies of materials for projects in Texas.

An implementation process will have to consider several factors. These factors, described in terms of "actions to be taken," are noted below:

- Collect project level data to continue compiling a database for the estimation of the variabilities associated with the testing.
- Develop implementation plan for pilot projects where QC/QA specifications are a concern.
- Report on lessons learned from the pilot projects.
- Measure the potential impact of implementing the methodology on the pilot projects.
- Monitor the future performance of the pilot projects.
- Identify barriers if the same results are to be implemented in every TxDOT district.
- Extend the use of the methodology to contractors and producers.
- Update database and testing frequency results with findings of the implementation process.

Three potential areas of implementation of the research are briefly discussed in the following sections.

7.1 Pilot Projects

Implementation of trial testing frequencies for selected materials in a pilot project or projects is a good and effective method. It is extremely useful because, with pilot projects, the results of the new methodology can be proven to the parties interested. Modifications to the methodology could also be made with minimum level of risk to the success of the project and minimal economic consequences.

7.2 Quality Control / Quality Assurance Tool

The statistically appropriate testing frequencies developed in this research could be used to enhance the current QC/QA programs implemented for asphalt concrete pavements. It could also be part of future QC/QA programs developed for other materials.

7.3 Updating Design Procedures

The results of this research could also be used in the pavement design process to better control the reliability of the design. In particular, with the known testing frequencies of the materials used in the design and the corresponding risk level, the as-designed values of the design parameters can be well related to the expected as-built values. This would help reduce the overall costs of a project without compromising the quality of the project.

8. Conclusions and Recommendations

The objective of this research is to develop a methodology for determining appropriate testing frequencies for the construction materials used by TxDOT. This chapter presents the summary of the research results and recommendations for a future study.

8.1 Conclusions

The major research efforts and key findings from this study are summarized as follows:

1. A survey was conducted during the early stages of this research to collect information on current QC/QA practices among state DOTs and other agencies. The survey shows that most state DOTs use historical or experience-based methods to determine testing frequencies of materials.
2. A literature review was undertaken to identify, collect, and synthesize studies on the state-of-the-art of QC/QA practices. Different methods are used by different agencies in determining testing frequency. These methodologies can be grouped into three categories: 1) experience-based methods, 2) statistics-based methods, and 3) economics-based methods. Statistics-based methods have long been the accepted standard in the practice of acceptance sampling. In particular, the risk-based statistical method that controls both type I error and type II error proves to be the most promising approach for determining appropriate testing frequencies.
3. A methodology was developed to estimate required sample size and testing frequency based on statistical theory, reliability concepts, and economic principles.
4. Statistically appropriate testing frequencies or required sample sizes are based on primarily four factors: 1) the variability of the quality characteristic being measured, 2) the risks that a state DOT or contractor is willing to take, 3) the tolerable errors each is willing to accept, and 4) the cost of the testing to be performed. The required sample size can be determined by Equation 2.16.

Once the required sample size is estimated, the testing frequency (TF) can be determined by using the following calculations:

a. Time-based testing frequency:

TF = daily production / sample size

b. Quantity-based testing frequency:

TF = batch quantity / sample size

5. Type I errors and type II errors are critical to the determination of sample sizes. The producer's risk (type I error) affects the contractor, because it is probable that the agency may reject what is, in fact, an acceptable work. The customer's risk (type II error) affects the agency, because it is probable that the agency may accept what is in fact an unacceptable work. The true meaning of risk is how much one is willing to lose in terms of dollars if an action is taken. The goal of developing statistically based methodology for determining the appropriate testing frequencies is to minimize (within practical limits) and/or balance the risks of both parties.

6. The sensitivity analysis shows that the statistical model for determining the sample size presented in Chapter 2 (Equation 2.16) is sensitive to the change of material variability, confidence level (type I error), type II error, and the range of acceptability (tolerable error). According to the equation, the sample size is proportional to the variability (square of standard deviation). That is, for materials with larger variability, a larger sample size will be required in order to achieve the same reliability of material testing for a test with a smaller variability. The required sample size is inversely proportional to the square of the tolerable error. The larger the tolerable error, the smaller the required sample size. As for the confidence level, the contractor's risk (α) and the agency's risk (β) will decrease if the sample size increases.

8.2 Recommendations

The issues deserving additional research in the future are recommended as follows:

1. The statistics-based methodology developed in this research can be used not only for evaluating current QC/QA practice used at TxDOT, but also for determining appropriate testing frequencies for QC/QA programs.

2. Collection of project level data to continue compiling the developed database will increase the reliability of the methodology. Furthermore, by gathering data at the beginning of the construction activities on new projects, the rates of production can be taken into consideration to enhance the developed methodology.

3. As for continuing this research, it is recommended that a computer program be developed to speed up the calculation of the required sample size and ensure higher accuracy.

Appendices

Appendix A

The "Guide Schedule of Sampling and Testing," which applies to all the contracts under construction, is presented in the following tables.

Table I
Guide Schedule of Sampling and Testing
(Per Contract)
Embankments, Subbases, and Base Courses

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.			PROJECT TESTS		INDEPENDENT ASSURANCE TESTS		English Units
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY of SAMPLING	REMARKS
EMBANKMENT	In-place Density (H)	Tex-115-E	As designated by the Engineer	Each 5,000 C.Y. (F)	Same as Project Test	Each 50,000 C.Y. or fraction thereof (B)	Tex-115-E or other approved method
UNTREATED SUBBASE AND BASE COURSES	Gradation (H)	Tex-110-E	During stockpiling oprs, from stockpile, or from windrow (1)	Each 4,000 C.Y. or 6,000 tons	Same as Project Test	One out of 10 Project Tests or fraction thereof (C)	(1) Engineer will select any one of these three locations or any combinations thereof with the provision that at least one of 10 tests will be sampled from the windrow for Gradation, Liquid Limit and Plasticity Index.
	Liquid Limit	Tex-104-E	During stockpiling oprs, from stockpile, or from windrow (1)	Each 4,000 C.Y. or 6,000 tons	Same as Project Test	One out of 20 Project Tests or fraction thereof (C)	
	Plasticity Index	Tex-106-E	During stockpiling oprs, from stockpile, or from windrow (1)	Each 4,000 C.Y. or 6,000 tons	Same as Project Test	One out of 20 Project Tests or fraction thereof (C)	
	Wet Ball Mill	Tex-116-E	During stockpiling oprs. from stockpile, or from windrow	Each 20,000 C.Y. or 25,000 tons			When a stockpile is to be sampled that has not been built in horizontal layers, sampling will be one test for each 4,500 C.Y. or 6,000 tons.
	Triaxial	Tex-117-E	During stockpiling oprs. from stockpile, or from windrow	Each 20,000 C.Y. or 25,000 tons (D)			Triaxial tests are not a field laboratory function. When a stockpile is to be sampled that was not built in horizontal layers, sampling will be one test for each 12,000 C.Y. or 16,000 tons.
	Compaction (H)	Tex-115-E	As designated by the Engineer	Each 3,000 lin. ft. per course per travel-way (A)	Same as Project Test	One out of 10 Project Tests or fraction thereof (C)	Tex-115-E or other approved method
	Thickness (H)		As designated by the Engineer	One depth per 3,000 lin. ft. per travel-way (A) (E)	Same as Project Test	One total depth per travel-way per two miles or fraction thereof (A)(C)	If payment is by the S.Y. frequency shall be as called for in the governing specification.

(continued…)

Table I (continued)
Guide Schedule of Sampling and Testing
(Per Contract)
Embankments, Subbases, and Base Courses

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

				PROJECT TESTS		INDEPENDENT ASSURANCE TESTS		English Units
MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	REMARKS
TREATED SUBBASE AND BASE COURSES	Base Material	As shown above for untreated base (H)		As designated by the Engineer prior to the addition of a stabilizer	As shown above for untreated base	Same as Project Test	As shown above for untreated base	When central mix site or plant is used, windrow sampling may be waived.
	Lime	Compliance with Item 264 (I)	Tex-600-J	During delivery to project	TY A; 1 Per Project (I) TY B ea., 200 tons or fraction thereof TY C; 1 Per Project (I)			On projects requiring less than 50 tons, material from CSTM approved sources may be accepted on the basis of Producer's Certification without sampling.
	Cement	Compliance with the Std. Specifications & Spl. Provisions	AASHTO M 85	Railroad car, truck or cement bins	Each 2,000 bbls. for each type and brand			Each brand and each type to be sampled and tested separately. Sampling will be waived when source is certified by CSTM.
	Asphalt	Compliance with Item 300	Tex-500-C etc.	Sampled, tested and approved by CSTM				
	Fly Ash	Compliance with Dept. Matl. Spec. D9-8900	Tex-733-I	Sampled, tested and approved by CSTM				
	Complete Mixture	Pulverization	Tex-101-E Part III	Roadway; after pulverization	As necessary for control (G)			Where required to control degree of pulverization
		In-place Density (H)	Tex-115-E	As designated by the Engineer	Each 3,000 lin. ft. per course per travel-way (A)	Same as Project Test	One out of 10 Project Tests or fraction thereof (C)	Tex-115-E or other approved method
		Thickness (H)		As designated by the Engineer	Each 3,000 lin. ft. per course per travel-way (A) (E)	Same as Project Test	One total depth per travel-way per two miles or fraction thereof (A)(C)	When base is measured by the square yard the frequency will be as called for in the governing specification.

(A) Travel-way is defined, for sampling & testing only, as total width of a travel facility that is not separated from other parallel travel facilities by a median, ditch, etc.
(B) Independent Assurance Tests are not required for a contract quantity of less than 25,000 C.Y.
(C) Independent Assurance Tests are not required for a contract
quantity resulting in less than 6 acceptance tests.
(D) When base material is from a source where the District has a record of satisfactory triaxial results, the frequency of testing may be reduced to one per 30,000 C.Y. or 40,000 tons. If any one test falls below the minimum value required, the frequency of testing will return to that required by this guide.
(E) Not required where survey grade control documents compliance.
(F) Or approximately one foot compacted depth per lift as approved and directed by the Engineer
(G) At the beginning of the project, one test will be made for each 4,000 C.Y. or 6,000 tons until such time as the Engineer is satisfied that acceptable pulverization results are being obtained.
(H) When a non-exempt federal-aid project test fails but the product is accepted, the reasons for acceptance should be documented on the Letter of Certification of Materials Used.
(I) For Types A and C lime, sources not on the TxDOT Quality Monitoring Program will be sampled each 200 and 150 tons respectively.

Table IA
Asphalt Stabilized Base
(Plant Mix)

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

			PROJECT TESTS		**INDEPENDENT ASSURANCE TESTS**		**English Units**
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	REMARKS
AGGREGATE	Gradation (H)	Tex-200-F	During stockpiling oprs. from stockpile, or prior to mixing	Each 4,000 C.Y. or 6,000 tons	Same as Project Test	One out of 10 Project Tests or fraction thereof (A) (D)	
	Liquid Limit	Tex-104-E	During stockpiling oprs. from stockpile, or prior to mixing	Each 4,000 C.Y. or 6,000 tons	Same as Project Test	One out of 20 Project Tests or fraction thereof (A) (D)	
	Plasticity Index	Tex-106-E	During stockpiling oprs. from stockpile, or prior to mixing	Each 4,000 C.Y. or 6,000 tons	Same as Project Test	One out of 20 Project Tests or fraction thereof (A) (D)	
	Wet Ball Mill or L. A. Abrasion	Tex-116-E or 410-A	During stockpiling oprs. from stockpile, or prior to mixing	Each 20,000 C.Y. or 25,000 tons			When L. A. Abrasion is specified, tests are not required if aggregate is on CSTM Quality Monitoring Program. When a stockpile is to be sampled that was not built in horizontal layers, sampling will be one test for each 4,500 C.Y. or 6,000 tons.
	Sand Equivalent	Tex-203-F	Hot aggregate bins, feeder belt or stockpile	One each 10 days' production			
LIME	Compliance with Item 264 (G)	Tex-600-J	During delivery	TY A; 1 Per Project (G) TY B ea., 200 tons or fraction thereof TY C; 1 Per Project(G)			On projects requiring less than 50 tons, material from CSTM approved sources may be accepted on the basis of Producer's Certification without sampling.

Asphalt Stabilized Base
(Plant Mix)

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

			PROJECT TESTS		INDEPENDENT ASSURANCE TESTS		English Units
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	REMARKS
ASPHALT	Compliance with Item 300	Tex-500-C etc.	Sampled, tested and approved by CSTM				
COMPLETE MIXTURE	Laboratory Density and/or Strength	Tex-126-E or Tex-204-F	Plant or road	Each 12,000 C.Y. or 16,000 tons			When shown on the plans
	Percent Asphalt (H)	Tex-126-E, Tex-210-F, Tex-228-F, Tex-229-F (F)	Plant or road	One for each day's production (C)	Same as Project Test	One for each 10 days' production (A)	
	In-Place Density (H)	Tex-207-F	As designated by the Engineer	Each 3,000 lin. ft. per course per travel-way (B)	Same as Project Test	One out of 10 Project Tests or fraction thereof (D)	
	Dimensions (H)		As designated by the Engineer	One depth per 3,000 lin. ft. per travel-way (B) (E)	Same as Project Test	One total depth per travel-way per two miles or fraction thereof (B)	

(A) Not required when CSTM provides inspection at plant.
(B) Travel-way is defined, for sampling and testing only, as total width of a travel facility that is not separated from other parallel travel facilities by a median, ditch, etc.
(C) Not required when plant produces less than 1/2 day due to weather, breakdown, etc.
(D) Independent Assurance Tests are not required for a contract quantity resulting in less than 10 Project Tests.
(E) Not required for level-up courses over existing pavement surfaces.
(F) Test Methods Tex-228-F/229-F must be correlated with Tex-126-E or Tex-210-F every ten days.
(G) For Types A and C lime, sources not on the TxDOT Quality Monitoring Program will be sampled each 200 and 150 tons respectively.
(H) When a non-exempt federal-aid project test fails but the product is accepted, the reasons for acceptance should be documented on the Letter of Certification of Materials Used.

Table II
Surface Treatments

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.			**PROJECT TESTS**		**INDEPENDENT ASSURANCE TESTS**		**English Units**
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	REMARKS
AGGREGATE	Gradation (H)	Tex-200-F (Dry)	At source or at point of delivery	One each 300 C.Y.	Same as project test	One out of 10 project tests or fraction thereof (I)	Independent assurance testing not required when CSTM provides testing
ASPHALT	Compliance with Item 300	Tex-500-C etc.	Sampled, tested and approved by CSTM				

(H) When a non-exempt federal-aid project test fails but the product is accepted, the reasons for acceptance should be documented on the Letter of Certification of Materials Used.

(I) Independent Assurance Tests are not required for a contract quantity resulting in less than 6 Project Tests.

Table III
Portland Cement Concrete; Structural & Miscellaneous

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

				PROJECT TESTS		**INDEPENDENT ASSURANCE TESTS**		**English Units**
MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING (B)	REMARKS
MINERAL AGGREGATES	COARSE AGGREGATE	Decantation (A) (C) (H)	Tex-406-A	From stockpile at concrete plant	Two, each source			
		Sieve Analysis (A) (C) (H) (L)	Tex-401-A	From stockpile at concrete plant	One, each 500 C.Y. or fraction thereof	Same as Project Test	One each 5,000 C.Y. or fraction thereof	
	FINE AGGREGATE	Sand Equivalent (A) (C) (L)	Tex-203-F	From stockpile at concrete plant	One per week (Each source or combination of sources) (F)	Same as Project Test	One per project (Each source or combination of sources)	
		Organic Impurities (A) (C)	Tex-408-A	From stockpile at concrete plant	Two, each source			
		Sieve Analysis (A) (C) (H) (L)	Tex-401-A	From stockpile at concrete plant	One, each 500 C.Y. or fraction thereof	Same as Project Test	One each 5,000 C.Y. or fraction thereof	
		Fineness Modulus (A) (C) (L)	Tex-402-A	From stockpile at concrete plant	One, each 500 C.Y. or fraction thereof	Same as Project Test	One each 5,000 C.Y. or fraction thereof	

(Continued…)

Portland Cement Concrete; Structural & Miscellaneous

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

			PROJECT TESTS		INDEPENDENT ASSURANCE TESTS		English Units
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING (B)	REMARKS
CEMENT	Compliance with the Std. Specifications & Spl. Provisions (A) (C)	AASHTO M 85	Railroad car, truck or cement bins	Each 1,000 bbls. (For each type and brand)			Each brand and each type to be sampled and tested separately. Sampling will be waived when source is certified by CSTM.
FLY ASH	Compliance with Dept. Matl. Spec. D-9 8900	Tex-733-I	Sampled, tested and approved by CSTM				
WATER	Compliance with the Std. Specifications (A) (C)	AASHTO T-26	At source (If not approved)	One test (Each source)			Municipal supply approved by State Health Department will not require testing.
CONCRETE	Flexural Strength (C) (G) (H) (K)	Tex-448-A	At point of concrete placement	One test (2 beams) for each 60 C.Y. or fraction thereof (E)	Same as Project Test	One each 600 C.Y. or fraction thereof (M)	
	or Compressive Strength (C) (G) (H) (K)	Tex-418-A	At point of concrete placement	One test (2 cylinders) for each 60 C.Y. or fraction thereof (E)	Same as Project Test	One each 600 C.Y. or fraction thereof (M)	Independent Assurance Testing not required where CSTM provides inspection at source.
	Slump (C) (G) (J)	Tex-415-A	At point of concrete placement	One test per set of strength specimens (D)	Same as Project Test	One each 600 C.Y. or fraction thereof (M)	
	Entrained Air (C) (G) (H)	Tex-416-A or Tex-414-A	At point of concrete placement	One per placement (D)	Same as Project Test	One each 600 C.Y. or fraction thereof (M)	Required when used.
	Average Texture Depth	Tex-436-A	After concrete has hardened	One per placement			For bridge decks and top slab of direct traffic culverts.
	Temperature of Slab Concrete		At point of concrete placement	One per truckload			

(Continued…)

Portland Cement Concrete; Structural & Miscellaneous

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.			**PROJECT TESTS**		**INDEPENDENT ASSURANCE TESTS**		**English Units**
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING (B)	REMARKS
ADMIXTURE	Compliance with the Std. Specifications Item 437	As specified	Sampled, tested and approved by CSTM				Contractor shall furnish AE one copy of invoice for the admixture to be used on the project.
JOINT MATERIAL	Compliance with the Std. Specifications & Spec. Provisions	As specified	Sampled at jobsite if not sampled at source by CSTM; tested by CSTM	One per batch or shipment			
CURING COMPOUND	Compliance with the Std. Specifications & Spec. Provisions	Tex-718-I	Sampled at jobsite if not sampled at source by CSTM; tested by CSTM	One per batch of shipment			
REIN-FORCING STEEL	Compliance with the Std. Specifications & Spec. Provisions	As Specified	Sampled, tested and approved by CSTM				
	Depth of reinforcement		During finishing	One per 50 S.Y.; Min. 4, Max. 20 per placement			Record locations & dimensions for bridge and top slab of direct traffic culverts.

(A) Coordination of inspection should be utilized to avoid duplication of sampling and testing. These Project Tests may be used for one or more projects being furnished concrete from the same plant during the same period. Also applicable to Independent Assurance Tests.

(B) Independent Assurance Tests are not necessary when the amount of concrete placed is less than 600 C.Y.

(C) Miscellaneous concrete is defined as concrete with less critical structural use, such as culverts (except top slabs of direct traffic structures), pipe headwalls, inlets, manholes, riprap, concrete in compaction wings and thrust beams, curb, curb and gutter, and other concrete so designated in the plans. Concrete used in bridges (including foundations), top slabs of direct traffic structures, retaining walls, pump stations, paving and other concrete that may be designated on the plans is not included in this category of miscellaneous concrete.

(C) Normally, the tests marked (C) will not be required for miscellaneous concrete which may be accepted on the basis of strength test (2 cylinders for each 50 C.Y. or 2 beams for each 50 C.Y. with a minimum of one test per project). Where deemed necessary by the Engineer, plant inspection on tests marked (C) and (E) may be required and used to determine specification compliance.

(D) For Class S, F and H ready mix concrete for bridge slab only, both air and slump will be checked on the first few loads of concrete as necessary to obtain a desired consistency. Thereafter, each third load will be tested for both slump and air content. Slump and air content tests should be performed on the same load from which strength tests specimens are made.

(E) Not less than one set of beams or cylinders will be required for each day's placement except for miscellaneous concrete.

(F) Where the fine aggregate is from a source with a history of sand equivalent values greater than 85 or the specified sand equivalent value of +5 more, the frequency of testing may be reduced to one per month during production. If any individual test fails below 85 or the specified sand equivalent value of +5 or more, the test frequency should be one per week during production until the value is 85 or the specified sand equivalent value of +5 more, or higher for four consecutive weeks.

(G) Sampling shall be in accordance with Test Method Tex-407-A.

(H) When a non-exempt federal-aid project test fails but the product is accepted, the reasons for acceptance should be documented on the Letter of Certification of Materials Used.

(I) Not required for extruded or slip form items.

(J) Not required for extruded curb.

(L) Test combined aggregate when used.

(M) When the project site is an extreme distance from the district laboratory, district or independent laboratory personnel may witness making and breaking the beams. The contractor or area engineer personnel should do the 7-day and 28-day breaks on district or independent laboratory equipment.

Table IV
Portland Cement Concrete Pavements

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

				PROJECT TESTS		INDEPENDENT ASSURANCE TESTS		English Units
MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING (A)	REMARKS
MINERAL AGGREGATES	COARSE AGGREGATE	Decantation	Tex-406-A	From stockpile at concrete plant	Two, each source			
		Sieve Analysis (H)	Tex-401-A	From stockpile at concrete plant	Each 3,000 C.Y.	Same as Project Test	Each 9,000 C.Y. or fraction thereof	Test combined aggregate when used.
	FINE AGGREGATE	Sand Equivalent	Tex-203-F	From stockpile at concrete plant	One each week during production (Each source or combination of sources) (D)	Same as Project Test	One each source or combination of sources	Test combined aggregate when used.
		Organic Impurities	Tex-408-A	From stockpile at concrete plant	Two, each source			
		Sieve Analysis (H)	Tex-401-A	From stockpile at concrete plant	Each 1,500 C.Y.	Same as Project Test	Each 4,500 C.Y. or fraction thereof.	Test combined aggregate when used.
MINERAL FILLER		Sieve Analysis (H)	Tex-401-A	From stockpile at concrete plant	Each 1,500 C.Y.	Same as Project Test	Each 4,500 C.Y. or fraction thereof.	
CEMENT		Compliance with the Std. Specifications &Spl. Provision	AASHTO M 85	Railroad car, truck or cement bins	Each 1,000 bbls. (For each type and brand)			Each brand and each type to be sampled and tested separately. Sampling will be waived when source is certified by CSTM.
FLY ASH		Compliance with Dept. Matl. Spec. D-9 8900	Tex-733-I	Sampled, tested and approved by CSTM				
WATER		Compliance with the Std. Specifications	AASHTO T-26	At source (If not approved)	One test (Each source)			Municipal supply approved by State Health Department will not require testing.

(*Continued…*)

Portland Cement Concrete Pavements

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

			PROJECT TESTS		INDEPENDENT ASSURANCE TESTS		English Units
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING (A)	REMARKS
CONCRETE	Strength (B) (H)	Tex-448-A or Tex-418-A	At point of concrete placement	One test (2 beams) for each 3,000 S.Y.		One each 30,000 S.Y. or fraction thereof (F)	Minimum of one per day
	Slump (B) (C)	Tex-415-A	At time and location strength specimens are made	One test per set of strength specimens		Witness one test	
	Entrained Air (B) (H)	Tex-416-A or Tex-414-A	At time and location strength specimens are made	One test per set of strength specimens		One each 30,000 S.Y. or fraction thereof (F)	When entrained air is required by specifications.
	Average Texture Depth (E)	Tex-436-A	After concrete has hardened	Three for each day's production			Number of tests may be reduced to one each day after a satisfactory finishing procedure has been established and approved by the Engineer.
	Thickness (H)	Tex-424-A	After 14 days' placement or as called for in the specification	One core per 1,000 lin. ft. per traffic lane when payment is by the S.Y. or one core per 2,000 lin. Ft. per traffic lane when payment is by the C.Y.			Contractor will core if called for in the governing specification.

(Continued…)

Portland Cement Concrete Pavements

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

			PROJECT TESTS		INDEPENDENT ASSURANCE TESTS		English Units
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OF TIME OF SAMPLING	FREQUENCY OF SAMPLING (A)	REMARKS
ADMIXTURE	Compliance with Specification Item 437	As specified	Sampled, tested and approved by CSTM				Contractor shall furnish area engineer one copy of invoice for the admixture to be used on the project.
JOINT MATERIAL	Compliance with the Std. Specifications & Spl. Provisions	As specified	Sampled at job site if not sampled at source by CSTM; tested by CSTM	One per batch or shipment			
CURING COMPOUND	Compliance with the Std. Specifications & Spl. Provision	Tex-718-I	Sampled at job site if not sampled at source by CSTM; tested by CSTM	One per batch or shipment			
REINFORCING STEEL	Compliance with the Std. Specifications & Spl. Provisions	As Specified	Sampled, tested and approved by CSTM				

(A) No Independent Assurance Tests will be required if the contract quantity is less than 600 C.Y. or equivalent sq. yards.
(B) Sampling shall be in accordance with Test Method Tex-407-A.
(C) Not required for slip-formed pavement.
(D) Or one per approved stockpile.
(E) Not required when a carpet drag and transverse metal tine finish device is called for in the Specifications.
(F) When the project site is an extreme distance from District laboratory, District or Independent laboratory personnel may witness making and breaking the beams. The contractor or engineer personnel may strip the specimen from the forms and place the specimen for curing.
(H) When a non-exempt federal-aid project test fails but the product is accepted, the reasons for acceptance should be documented on the letter of certification of materials used.

Table V
Asphaltic Concrete Pavements

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

			PROJECT TESTS		INDEPENDENT ASSURANCE TESTS		English Units
MATERIAL OR PRODUCT	TEST FOR	TEST NUMBER	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING	LOCATION OR TIME OF SAMPLING	FREQUENCY OF SAMPLING (E)	REMARKS
COARSE AGGREGATE	Gradation (H) (J)	Tex-200-F (Dry)	During delivery to plant or from stockpile	Each 3,000 tons or fraction thereof (D) (G)	Same as project test	Each 60,000 tons or fraction thereof (A) (D)	
	Deleterious Material and Decantation	Tex-217-F	As designated by district engineer or as specified	Each 12,000 tons or fraction thereof (D)	Same as Project Test	(A) (D)	When the fine aggregate in a coarse aggregate stockpile exceeds 15%, it shall be tested for Linear Shrinkage.
FINE AGGREGATE	Gradation (H) (J)	Tex-200-F (Dry)	During delivery to plant or from stockpile	Each 6,000 tons or fraction thereof (D) (G)	Same as Project Test	Each 60,000 tons or each fraction thereof (A) (D)	
	Linear Shrinkage (J)	Tex-107-E	Stockpile	1 per 6,000 Tons or fraction thereof			Required only when 15 percent or more passes the No. 10 sieve.
MINERAL FILLER	Gradation (H)	Tex-200-F (DRY)	During delivery to plant or from stockpile	Each 6,000 tons or fraction thereof	Same as Project Test	Each 60,000 tons or each fraction thereof (A)	
COMBINED AGGREGATES	Gradation (H)	Tex-200-F (Dry)	Hot aggregate bins	Three for each day's production	Same as Project Test	One for each ten days production (A) (D)	Applies to weigh batch plants only. Reduce the required number of tests proportionately when plant produces fractional part of day.
	Sand Equivalent	Tex-203-F	Stockpiles, hot aggregate bins, or feeder belt	One per 10 days of production			Sample prior to addition of additives to materials, i.e., lime, mineral filler, etc.
ASPHALT, OILS & EMULSIONS	Compliance with Item 300	Tex-500-C, etc.	Sampled, tested and approved by CSTM				

(Continued…)

Asphaltic Concrete Pavements

This is a guide for minimum sampling and testing. When necessary for quality control, additional sampling and testing will be required.

MATERIAL OR PRODUCT		TEST FOR	TEST NUMBER	PROJECT TESTS: LOCATION OR TIME OF SAMPLING	PROJECT TESTS: FREQUENCY OF SAMPLING	INDEPENDENT ASSURANCE TESTS: LOCATION OR TIME OF SAMPLING	INDEPENDENT ASSURANCE TESTS: FREQUENCY OF SAMPLING (E)	English Units: REMARKS
COMPLETE MIXTURE	HOT MIX ACP & HOT MIX-COLD LAID ACP	Laboratory Density	Tex-207-F	Plant or road	One for each day's production (K)	Same as Project Test	One for each 10 days production or fraction thereof (A)	
		Stability	Tex-208-F	Plant or road	One for each day's production (K)	Same as Project Test	One for each 10 days production or fraction thereof (A)	
		Percent Asphalt and/or Gradation (H)	Tex-210-F Tex-228-F Tex-229-F, Tex-236-F (I)	Plant or road	One for each days production (F) (I) (K)	Same as Project Test	One for each 10 days production or fraction thereof (A)	
		In Place Density (H)	Tex-207-F	Per course	(K) One for each day's production	Same as Project Test	One for each 10 days production or fraction thereof	When required
		Moisture Content	Tex-212-F	Plant or road	(K) One for each day's production			
		Hydrocarbon Volatile Content	Tex-213-F	Plant or road	One for each day's production (K)	Same as Project Test	One for each 10 days production or fraction thereof (A)	Required for Hot-Mix-Cold Laid ACP only
	LIMESTONE ROCK ASPHALT (LRA) PAVEMENT	Compliance with Item 330 or 332	As specified	Sampled, tested and approved by CSTM				
		Moisture Content	Tex-212-F	When weighing for payment	Each 200 tons or fraction thereof per day			
		Dimensions (H)		Completed pavement	As necessary for control		One total depth per travel-way per 2 miles or fraction thereof (B) (C)	

(A) Not required when CSTM provides inspection at plant.
(B) Travel-way is defined, for sampling and testing only, as total width of a travel facility that is not separated from other parallel travel facilities by a median, ditch, etc.
(C) Not required for level-ups and overlays.
(D) When synthetic aggregate is used in lieu of natural aggregate, reduce the quantity under Frequency of Sampling by 50%.
(E) Independent Assurance Tests are not required for a contract quantity of less than 3,000 tons.
(F) When producing from drum mixer, modified weigh batch, or specialized recycling plants, one test per 1,000 tons or fraction thereof not to exceed three (3) per day.
(G) When production is by weigh batch plant, frequency shall be 6,000 tons or fraction thereof.
(H) When a non-exempt federal-aid project test fails but the product is accepted, the reasons for acceptance should be documented on the Letter of Certification of Materials Used.
(I) Test Methods Tex-228-F/229-F must be correlated with Tex-210-F every five days.
(J) Test each aggregate.
(K) Not required when production falls below 200 tons per day.

Table VI
QC/QA Asphaltic Concrete Pavement (Items 3063, 3007)

This is a guide for minimum sampling and testing for department-performed tests.

			MONITOR OR VERIFICATION TESTS		INDEPENDENT ASSURANCE TESTS (A)		English Units
MATERIAL	TEST FOR	TEST NUMBER	LOCATION	FREQUENCY	LOCATION	FREQUENCY	REMARKS
COARSE AGGREGATE	L. A. Abrasion	Tex-410-A	Stockpile	1 per 25,000 tons or fraction thereof			Required only when source is not on TxDOT QM Program.
	Magnesium Soundness	Tex-411-A	Stockpile	1 per 25,000 tons or fraction thereof			Required only when source is not on TxDOT QM Program.
	Pressure Slake	Tex-431-A	Stockpile	1 per 10,000 tons or fraction thereof			Same as above. Required only for lightweight aggregate
	Polish Value	Tex-438-A	Stockpile	1 per 25,000 tons or fraction thereof			Same as above. Required only for lightweight aggregate
	Unit Weight	Tex-404-A	Stockpile	1 per 10,000 tons or fraction thereof			Test lightweight aggregate only.
	Crushed Face Count	Tex-460-A	Stockpile	1 per 25,000 tons or fraction thereof			Test gravel only.
	Linear Shrinkage	Tex-107-E	Stockpile	1 per 10,000 tons or fraction thereof			Required only when 15 percent or more passes the No. 10 sieve.
	Deleterious Material and Decantation	Tex-217-F	Stockpile	1 per 10,000 tons or fraction thereof			
FINE AGGREGATE	Linear Shrinkage	Tex-107-E	Stockpile	1 per 2,500 tons or fraction thereof	Stockpile	One per project	
COMBINED AGGREGATE	Sand Equivalent	Tex-203-F	Stockpiles, hot bins or feeder belts	1 per 10 days production			Sample prior to addition of additives, e.g., lime, filler
	Gradation	Tex-229-F	Combined Cold Feed belt	1 per 12 quality assurance tests	Combined Cold Feed belt	1 per 10 verification or fraction thereof	
COMPLETE MIXTURE	Percent Asphalt	Tex-228-F or Tex-236-F	Split from QA test sample	1 per 12 quality assurance tests	Truck	1 per 10 verification or fraction thereof	
	Voids in Mineral Aggregates (VMA)	Tex-207-F	Design	1 per design			
	Moisture Susceptibility (B)	Tex-531-C	Design	1 per design			If determined to be needed by the Engineer
	Gradation	Tex-210-F or Tex-236-F	Split from QA test sample	1 per 12 quality assurance tests	Truck	1 per 10 verification or fraction thereof	Required only when combined cold feed gradation is not performed.

(*Continued…*)

QC/QA Asphaltic Concrete Pavement (Items 3063, 3007)

This is a guide for minimum sampling and testing for department-performed tests.			MONITOR OR VERIFICATION TESTS		INDEPENDENT ASSURANCE TESTS (A)		English Units
MATERIAL	TEST FOR	TEST NUMBER	LOCATION	FREQUENCY	LOCATION	FREQUENCY	REMARKS
COMPLETE MIXTURE (cont.)	Maximum Theoretical Gravity	Tex-227-F	Split from QA test sample	1 per 12 quality assurance tests		1 per 10 verification or fraction thereof	Randomly selected within the lot.
	Lab Molded Density	Tex-207-F	Split from QA test sample	1 per 12 quality assurance tests	Truck	1 per 10 verification or fraction thereof	
	Hveem Stability	Tex-208-F	Lab molded density from QA test	1 per 12 quality assurance tests			Each set of 3 lab molded specimens per lot are verification tested for stability.
ROADWAY	Air Voids	Tex-207-F	Selected from QA test	2 cores per 24 QA tests		1 per 10 verification or fraction thereof (C)	Two cores taken per sublot and averaged.
	Profile Index	Tex-1000-S	Review Chart from QA tests	Each day			

(A) Not required when CSTM provides inspection at plant, or when contract quantities are less than 3,000 tons.
(B) Production verification using Tex-530-C is required when anti-stripping additives are used unless otherwise shown in the plans. The Engineer will determine the location and frequency of testing and will perform the test.
(C) Independent Assurance Test may consist of witnessing the verification testing.

(Continued…)

QC/QA Asphaltic Concrete Pavement (Item 3116, 3146)

This is a guide for minimum sampling and testing for department-performed tests.

			QUALITY ASSURANCE TESTS		INDEPENDENT ASSURANCE TESTS (A)		English Units
MATERIAL	TEST FOR	TEST NUMBER	LOCATION	FREQUENCY	LOCATION	FREQUENCY	REMARKS
COARSE AGGREGATE	L. A. Abrasion	Tex-410-A	Stockpile (H)	1 per 25,000 Tons or fraction thereof			Required only when source is not on TxDOT QM Program.
	Magnesium Soundness	Tex-411-A	Stockpile(H)	1 per 25,000 Tons or fraction thereof			
	Pressure Slake	Tex-431-A	Stockpile (H)	1 per 10,000 Tons or fraction thereof			Same as above. Required only for lightweight aggregate.
	Polish Value	Tex-438-A	Stockpile (H)	1 per 25,000 Tons or fraction thereof			Same as above. Required only for lightweight aggregate.
	Unit Weight	Tex-404-A	Stockpile (H)	1 per 10,000 Tons or fraction thereof			Test lightweight aggregate only.
	Crushed Face Count	Tex-460-A	Stockpile (H)	1 per 25,000 Tons or fraction thereof			Test gravel only. Each Source.
	Linear Shrinkage	Tex-107-E	Stockpile (H)	1 per 10,000 Tons or fraction thereof			Required only when 15 percent or more passes the No. 10 sieve.
	Deleterious Material and Decantation	Tex-217-F	Stockpile (H)	1 per 10,000 Mg or fraction thereof			
FINE AGGREGATE	Linear Shrinkage	Tex-107-E	Stockpile	1 per 2,500 Mg or fraction thereof	Stockpile	One per project	
COMBINED AGGREGATE	Sand Equivalent	Tex-203-F	Stockpiles, hot bins or feeder belts	1 per 10 days production	Same as QA tests	One per project	Sample prior to addition of additives, e.g., lime, filler.
	Gradation (D)	Tex-229-F	Combined Cold Feed belt	Minimum of 1 per 12 Sublots	Combined Cold Feed belt	1 per 10 Lots	
ASPHALT	Compliance with Item 300 (G)	Tex-500-C series	Sampled, Tested and Approved by CSTM				
COMPLETE MIXTURE	Percent Asphalt	Tex-228-F or Tex 236-F	Engineer Truck Sample	Minimum of 1 per 4 Sublots	Truck	1 per 10 Lots	Contractor sample may be tested for compliance with operational controls.
	Voids in Mineral Aggregates (VMA)	Tex-207-F	Design	1 per design			
	Moisture Susceptibility (B)	Tex-531-C	Design	1 per design			If determined to be needed by the Engineer.

(Continued…)

QC/QA Asphaltic Concrete Pavement (Item 3116, 3146) (Continued)

THIS IS A GUIDE FOR MINIMUM SAMPLING AND TESTING FOR DEPARTMENT-PERFORMED TESTS.			QUALITY ASSURANCE TESTS		INDEPENDENT ASSURANCE TESTS (A)		English Units
MATERIAL	TEST FOR	TEST NUMBER	LOCATION	FREQUENCY	LOCATION	FREQUENCY	REMARKS
COMPLETE MIXTURE (cont.)	Gradation (I) (F)	Tex-210-F or Tex-236-F	Engineer Truck Sample	Minimum 1 per 12 Sublots (I)	Truck	1 per 10 Lots	Minimum. Required only when combined cold feed gradation is not performed.
	Maximum Theoretical Gravity	Tex-227-F	Engineer/Contractor Truck Sample	1 per Sublot		1 per 10 Lots	Randomly selected within the lot.
	Lab Molded Density	Tex-207-F	Engineer/Contractor Truck Sample	1 per Sublot	Truck	1 per 10 Lots (E)	Use contractor split only for sublots not sampled by the Engineer
	Hveem Stability	Tex-208-F	Lab Density Molds	1 per Lot			Each set of 3 lab molded specimens per lot are tested for stability.
	Creep	Tex-231-F	Lab Density Molds	1 per Design			CMHB mixtures only
ROADWAY	Air Voids	Tex-207-F	Contractor Random Sample	2 cores per Sublot		1 per 10 Lots (C)	Two cores taken per sublot and averaged.
	Profile Index	Tex-1000-S	Review Chart from QC Tests	Each day			Only required when called for in plans.

(A) Not required when CSTM provides inspection at plant, or when contract quantities are less than 3,000 Tons.
(B) If production verification using Tex-530-C is required, the Engineer will determine the location and frequency of testing and will perform the test.
(C) Independent Assurance Test may consist of witnessing the quality assurance test.
(D) Correlation factors must be verified by the contractor and approved by the Engineer every 5 days.
(E) The Independent Assurance test should be performed as early in the project as possible so that any inaccuracies due to equipment or technique can be detected as soon as possible.
(F) Aggregate may be obtained using extraction or ignition oven.
(G) Or as called for in the Specifications.
(H) Sampling may be performed at the plant or quarry or both. Aggregate properties may be re-tested at any time during the project. Correlation is to be verified by the contractor and approved by the engineer once every 5 production days.

Appendix B

The following the tables are the sensitivity analysis of all the tests included in the research.

Table B.1 Relationship Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Compressive Strength 7 Days

Conf. Level	Other Factors		Sample Size (n)						
	μ	4682	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	675.1	4	4	3	2	2	1	1
97	*e*	1300	3	3	2	2	1	1	1
95			3	2	2	1	1	1	1
90			2	2	1	1	1	0	0
85			2	1	1	1	0	0	0
80			2	1	1	1	0	0	0
75			1	1	1	0	0	0	0
70			1	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	0	0	0	0	0	0
40			1	0	0	0	0	0	0

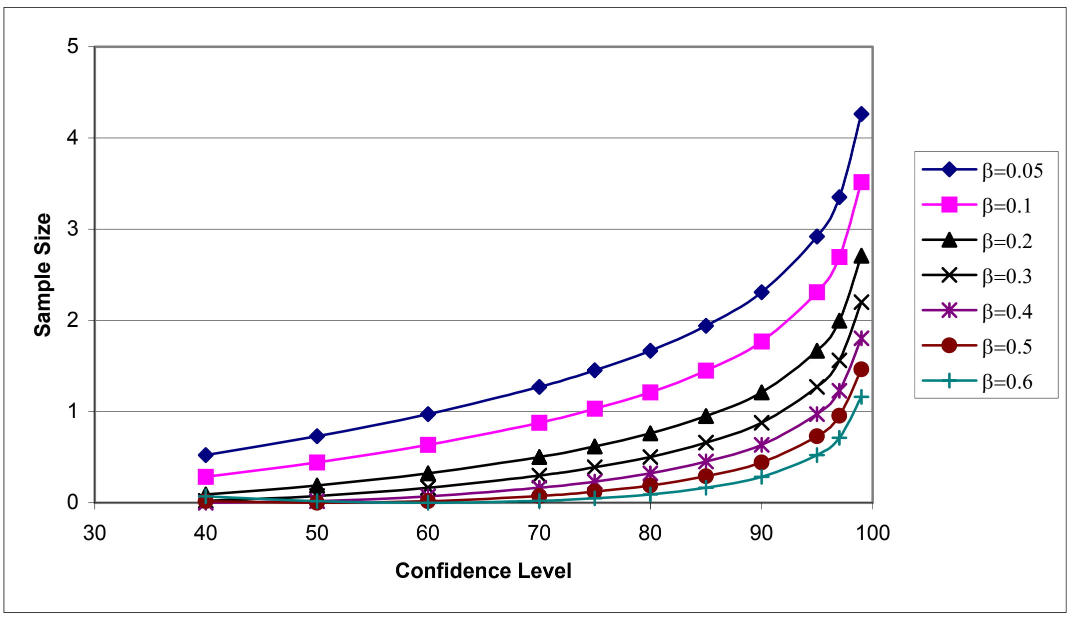


Figure B.1 Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Compressive Strength 7 Days

Table B.2 Relationship Sample Size vs. Tolerable Error.
Concrete for Structures 'Class C & S' – Compressive Strength 7 Days

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
300	Z_α	0.84	31	23	14	10	6	4	2
350	μ	4682	23	17	11	7	5	3	1
400	σ	675.1	18	13	8	5	3	2	1
500			11	8	5	3	2	1	1
600			8	6	4	2	2	1	0
650			7	5	3	2	1	1	0
680			6	4	3	2	1	1	0
700			6	4	3	2	1	1	0
800			4	3	2	1	1	1	0
900			3	3	2	1	1	0	0
1000			3	2	1	1	1	0	0
1100			2	2	1	1	0	0	0
1300			2	1	1	1	0	0	0
1500			1	1	1	0	0	0	0

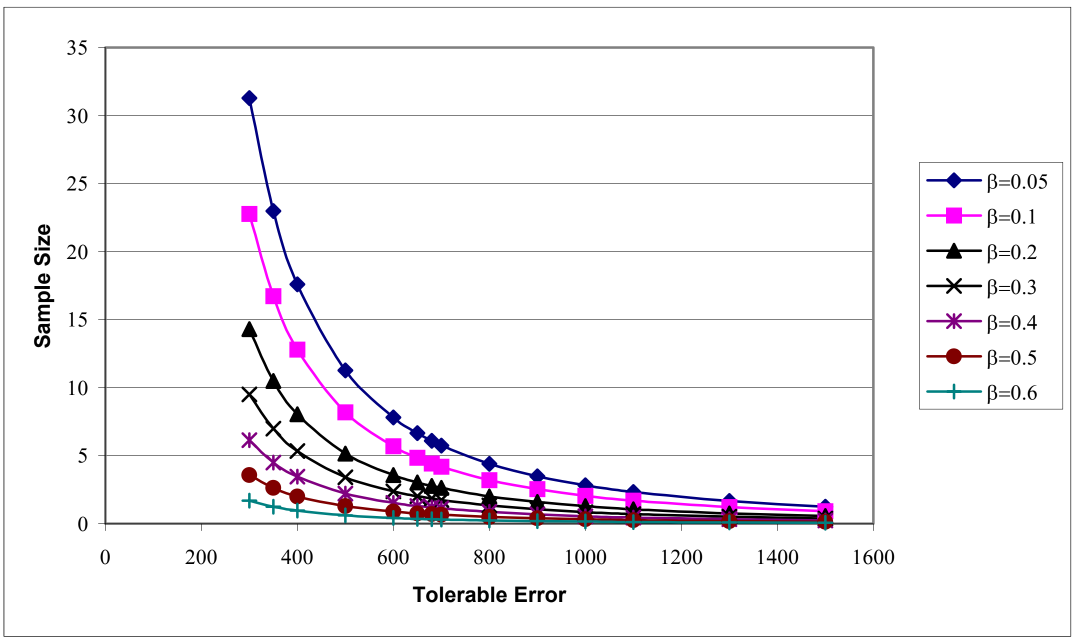


Figure B.2 Relationship Sample Size vs. Tolerable Error.
Concrete for Structures 'Class C & S' – Compressive Strength 7 Days

Table B.3 Relationship Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Compressive Strength 28 Days.

Conf. Level	Other Factors		Sample Size (n)						
	μ	5951	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	706.4	4	3	2	2	1	1	1
97	*e*	1500	3	2	2	1	1	1	1
95			2	2	1	1	1	1	0
90			2	1	1	1	1	0	0
85			2	1	1	1	0	0	0
80			1	1	1	0	0	0	0
75			1	1	1	0	0	0	0
70			1	1	0	0	0	0	0
60			1	1	0	0	0	0	0
50			1	0	0	0	0	0	0
40			0	0	0	0	0	0	0

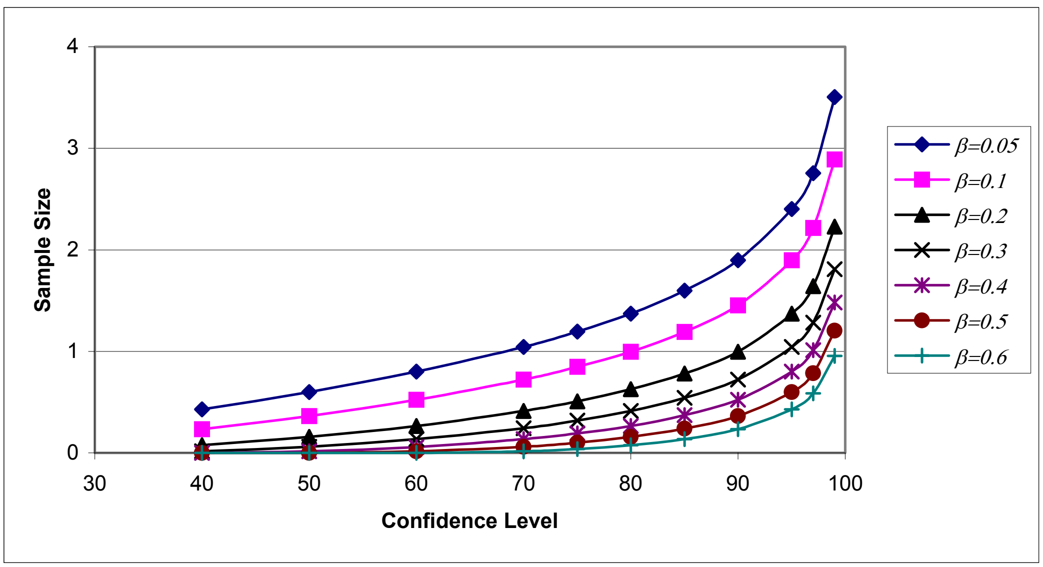


Table B.3 Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Compressive Strength 28 Days

Table B.4 Relationship Sample Size vs. Tolerable Error.
Concrete for Structures 'Class C & S' – Compressive Strength 28 Days.

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
300	Z_α	0.84	34	25	16	10	7	4	2
400	μ	5951	19	14	9	6	4	2	1
500	σ	706.42	12	9	6	4	2	1	1
600			9	6	4	3	2	1	0
700			6	5	3	2	1	1	0
800			5	4	2	1	1	1	0
900			4	3	2	1	1	0	0
1100			3	2	1	1	0	0	0
1300			2	1	1	1	0	0	0
1500			1	1	1	0	0	0	0
1700			1	1	0	0	0	0	0
1900			1	1	0	0	0	0	0
2000			1	1	0	0	0	0	0
2100			1	1	0	0	0	0	0

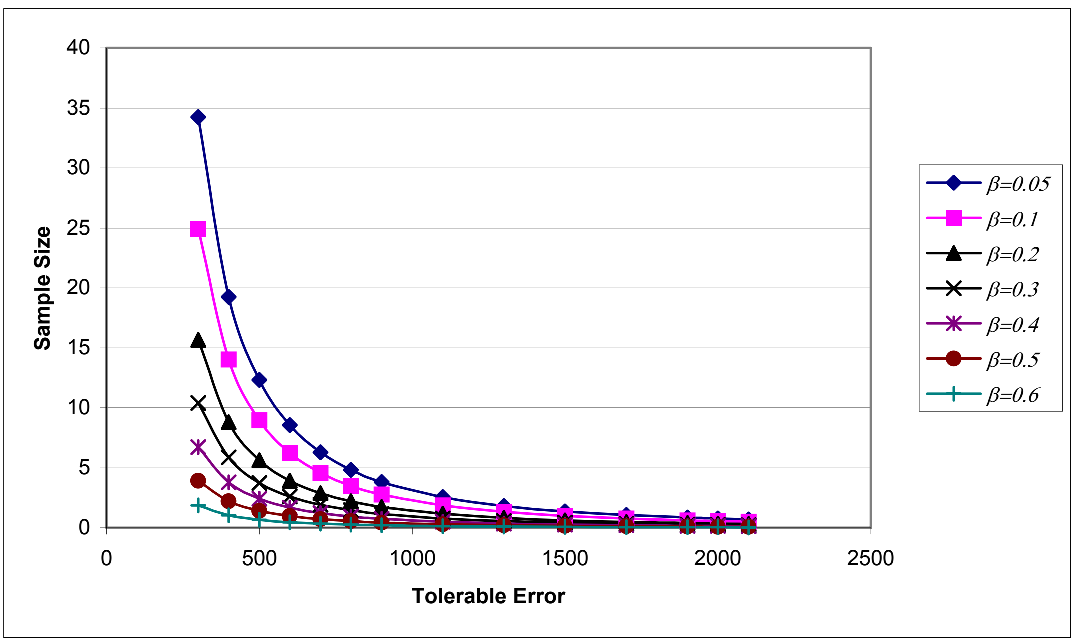


Figure B.4 Sample Size vs. Tolerable Error.
Concrete for Structures 'Class C & S' – Compressive Strength 28 Days.

Table B.5 Relationship Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Slump

Conf. Level	Other Factors		Sample Size (n)						
	μ	4.0	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.7	6	5	4	3	3	2	2
97	*e*	3	5	4	3	2	2	2	1
95			4	3	3	2	2	1	1
90			3	3	2	2	1	1	1
85			3	2	2	1	1	1	0
80			3	2	1	1	1	1	0
75			3	2	1	1	1	0	0
70			2	2	1	1	1	0	0
60			2	1	1	1	0	0	0
50			2	1	1	0	0	0	0
40			2	1	1	0	0	0	0
30			1	1	0	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

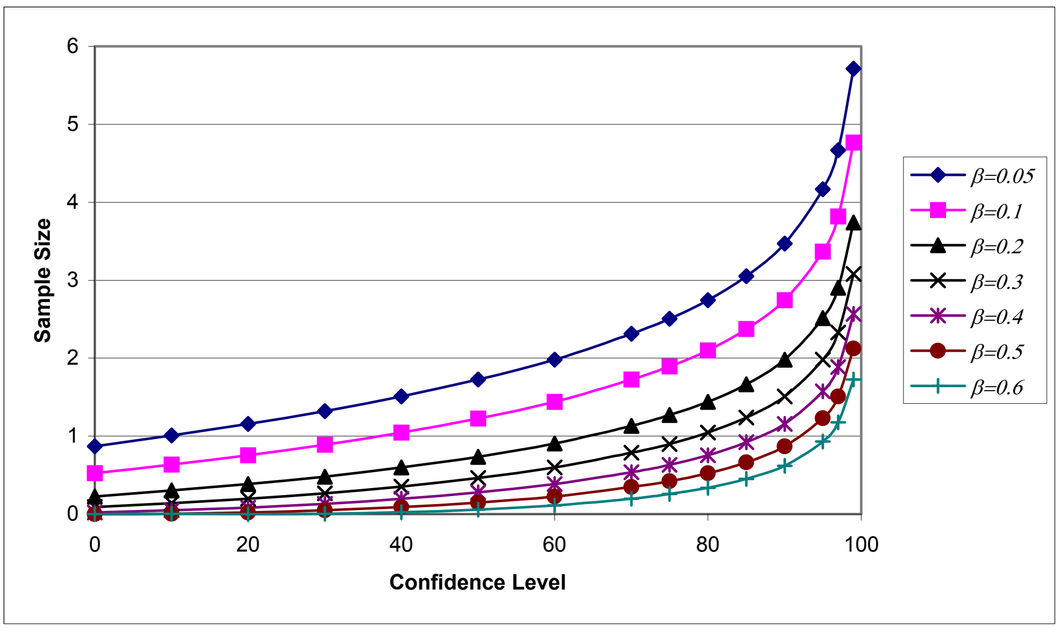


Figure B.5 Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Slump

**Table B.6 Relationship Sample Size vs. Tolerable Error.
Concrete for Structures 'Class C & S' – Slump**

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
0.8	$Z_{\alpha/2}$	1.28	39	30	20	15	11	7	5
1	μ	4.0	25	19	13	9	7	5	3
1.2	σ	1.70	17	13	9	7	5	3	2
1.5			11	8	6	4	3	2	1
1.6			10	7	5	4	3	2	1
1.7			9	7	4	3	2	2	1
1.8			8	6	4	3	2	1	1
1.9			7	5	4	3	2	1	1
2			6	5	3	2	2	1	1
2.2			5	4	3	2	1	1	1
2.5			4	3	2	2	1	1	0
2.8			3	2	2	1	1	1	0
3			3	2	1	1	1	1	0
3.5			2	2	1	1	1	0	0

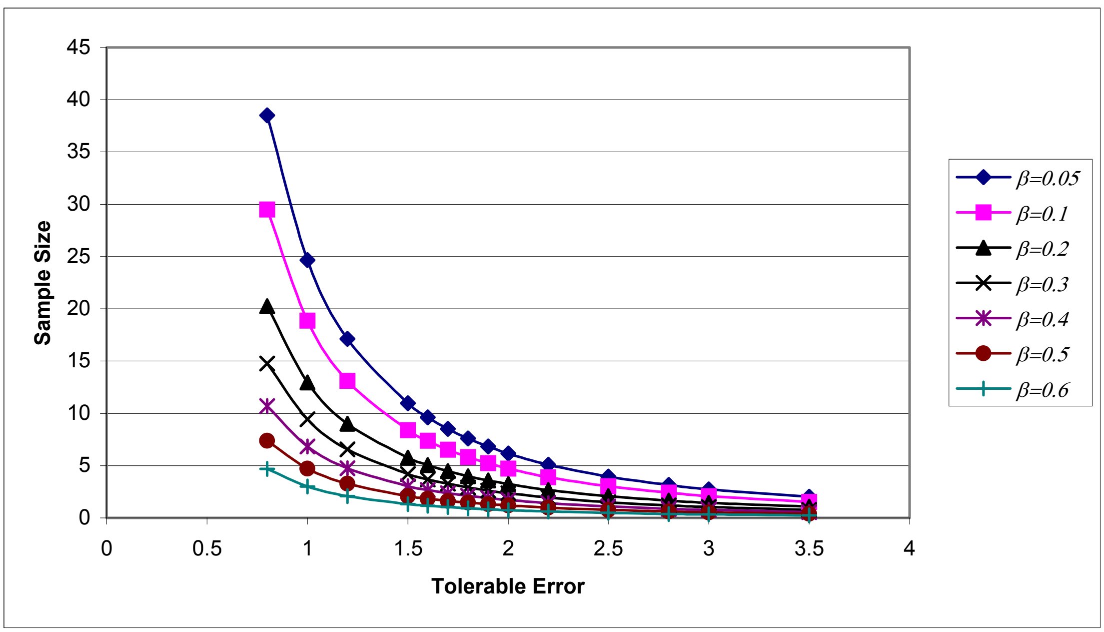


Figure B.6 Sample Size vs. Tolerable Error. Concrete for Structures 'Class C & S' – Slump

Table B.7 Relationship Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Slump Plant

Conf. Level	Other Factors		Sample Size (n)						
	μ	5.3	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.9	7	6	5	4	3	3	2
97	e	3	6	5	4	3	2	2	2
95			5	4	3	3	2	2	1
90			5	4	3	2	2	1	1
85			4	3	2	2	1	1	1
80			4	3	2	1	1	1	0
75			3	2	2	1	1	1	0
70			3	2	1	1	1	0	0
60			3	2	1	1	0	0	0
50			2	2	1	1	0	0	0
40			2	1	1	0	0	0	0
30			2	1	1	0	0	0	0
20			2	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

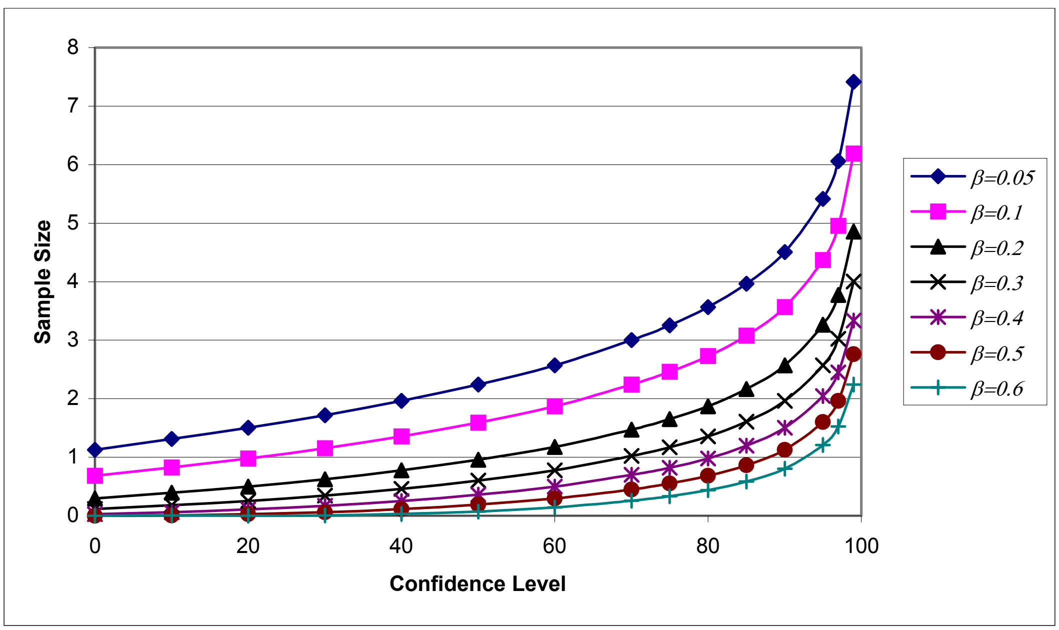


Figure B.7 Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Slump Plant

Table B.8 Relationship Sample Size vs. Tolerable Error.
Concrete for Structures 'Class C & S' – Slump Plant

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
0.8	$Z_{\alpha/2}$	1.28	50	38	26	19	14	10	6
1	μ	5.3	32	25	17	12	9	6	4
1.2	σ	1.94	22	17	12	9	6	4	3
1.5			14	11	7	5	4	3	2
1.6			13	10	7	5	3	2	2
1.7			11	9	6	4	3	2	1
1.8			10	8	5	4	3	2	1
1.9			9	7	5	3	2	2	1
2			8	6	4	3	2	2	1
2.2			7	5	3	3	2	1	1
2.5			5	4	3	2	1	1	1
2.8			4	3	2	2	1	1	0
3			4	3	2	1	1	1	0
3.5			3	2	1	1	1	1	0

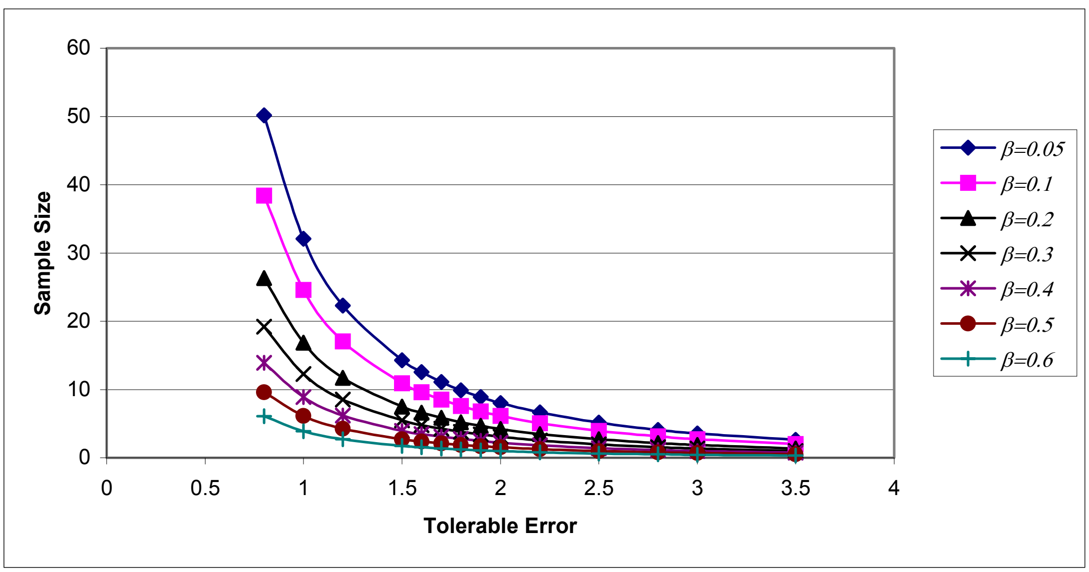


Figure B.8 Sample Size vs. Tolerable Error. Concrete for Structures 'Class C & S' – Slump

Table B.9 Relationship Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Air content.

Conf. Level	Other Factors		Sample Size (n)						
	μ	5.4	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.0	8	6	5	4	3	3	2
97	*e*	1.5	6	5	4	3	3	2	2
95			6	5	3	3	2	2	1
90			5	4	3	2	2	1	1
85			4	3	2	2	1	1	1
80			4	3	2	1	1	1	0
75			3	3	2	1	1	1	0
70			3	2	2	1	1	0	0
60			3	2	1	1	1	0	0
50			2	2	1	1	0	0	0
40			2	1	1	0	0	0	0
30			2	1	1	0	0	0	0
20			2	1	1	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

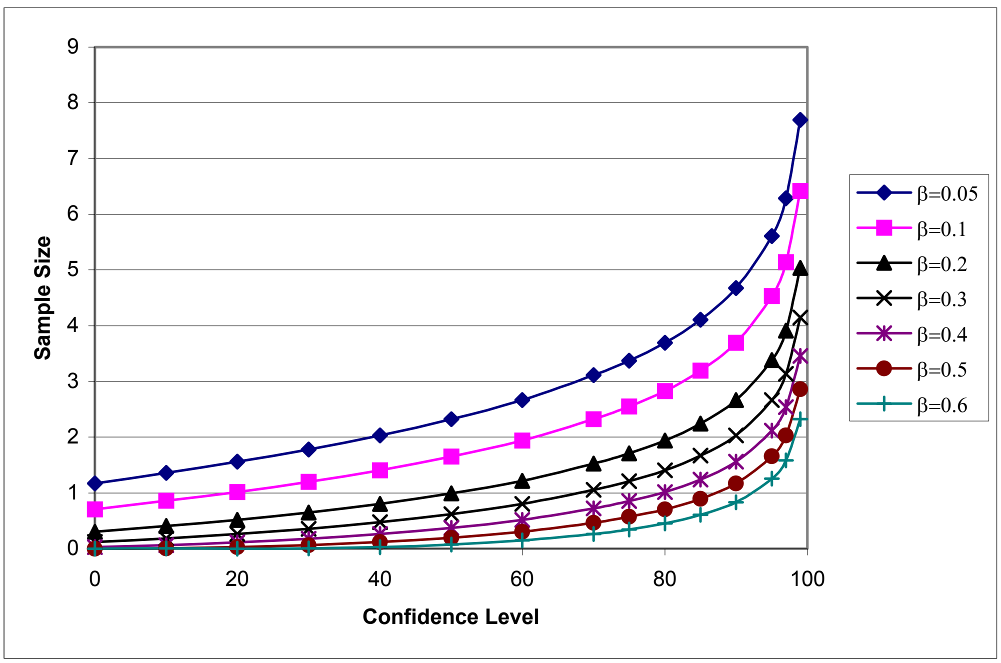


Figure B.9 Sample Size vs. Confidence Level.
Concrete for Structures 'Class C & S' – Air content.

Table B.10 Relationship Sample Size vs. Tolerable Error.
Concrete for Structures 'Class C & S' – Air Content.

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
0.5	$Z_{\alpha/2}$	1.28	33	25	17	13	9	6	4
0.6	μ	5.4	23	18	12	9	6	4	3
0.7	σ	1.0	17	13	9	6	5	3	2
0.8			13	10	7	5	4	2	2
0.9			10	8	5	4	3	2	1
1			8	6	4	3	2	2	1
1.1			7	5	4	3	2	1	1
1.2			6	4	3	2	2	1	1
1.3			5	4	3	2	1	1	1
1.4			4	3	2	2	1	1	1
1.5			4	3	2	1	1	1	0
2			2	2	1	1	1	0	0
2.5			1	1	1	1	0	0	0
3			1	1	0	0	0	0	0

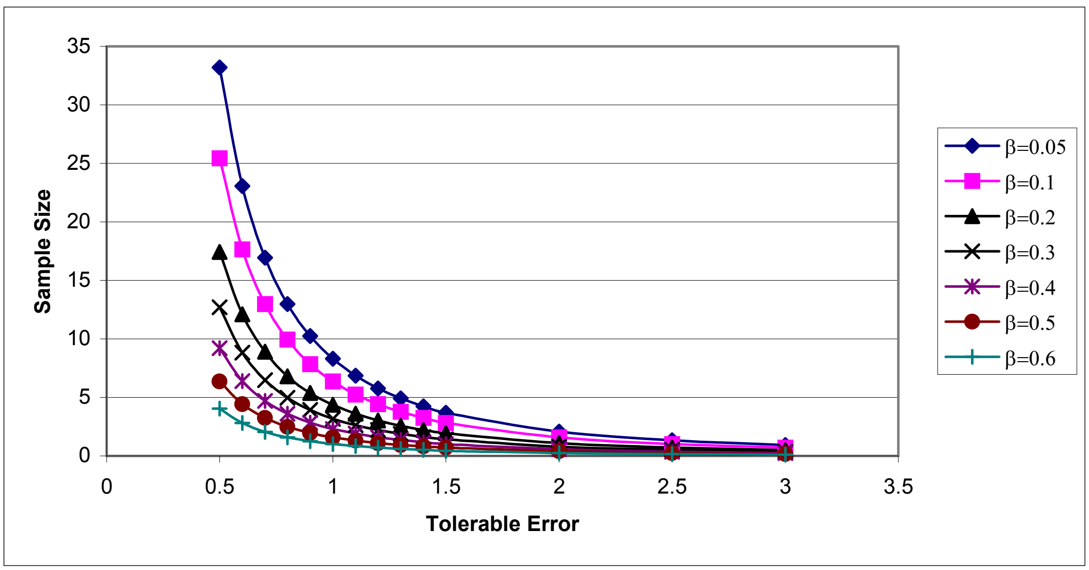


Figure B.10 Sample Size vs. Tolerable Error.
Concrete for Structures 'Class C & S' – Air Content

Table B.11 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 7 Days

Conf. Level	Other Factors		Sample Size (n)						
	μ	4378	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	569.1	9	8	6	5	4	3	3
97	*e*	800	7	6	5	4	3	2	2
95			7	5	4	3	2	2	1
90			5	4	3	2	2	1	1
85			5	4	3	2	1	1	1
80			4	3	2	2	1	1	1
75			4	3	2	1	1	1	0
70			4	3	2	1	1	1	0
60			3	2	1	1	1	0	0
50			3	2	1	1	0	0	0
40			2	2	1	1	0	0	0

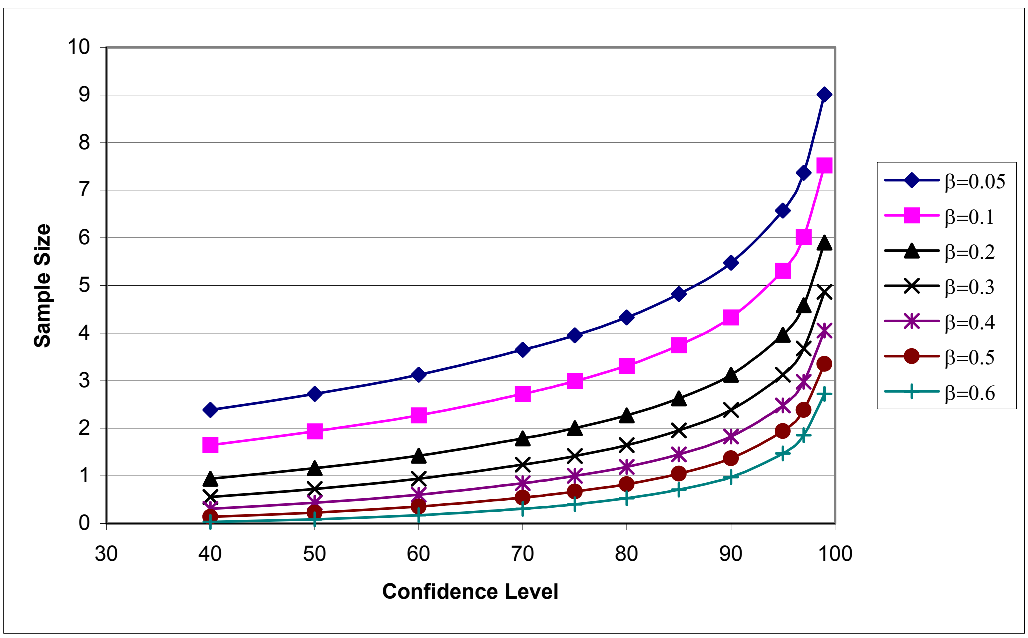


Figure B.11 Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 7 Days

Table B.12 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 7 Days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
300	Z_α	0.84	22	16	10	7	4	3	1
400	μ	4378	12	9	6	4	2	1	1
500	σ	569.1	8	6	4	2	2	1	0
600			6	4	3	2	1	1	0
700			4	3	2	1	1	0	0
800			3	2	1	1	1	0	0
900			2	2	1	1	0	0	0
1000			2	1	1	1	0	0	0
1100			2	1	1	1	0	0	0
1200			1	1	1	0	0	0	0
1300			1	1	1	0	0	0	0
1400			1	1	0	0	0	0	0
1500			1	1	0	0	0	0	0
1600			1	1	0	0	0	0	0

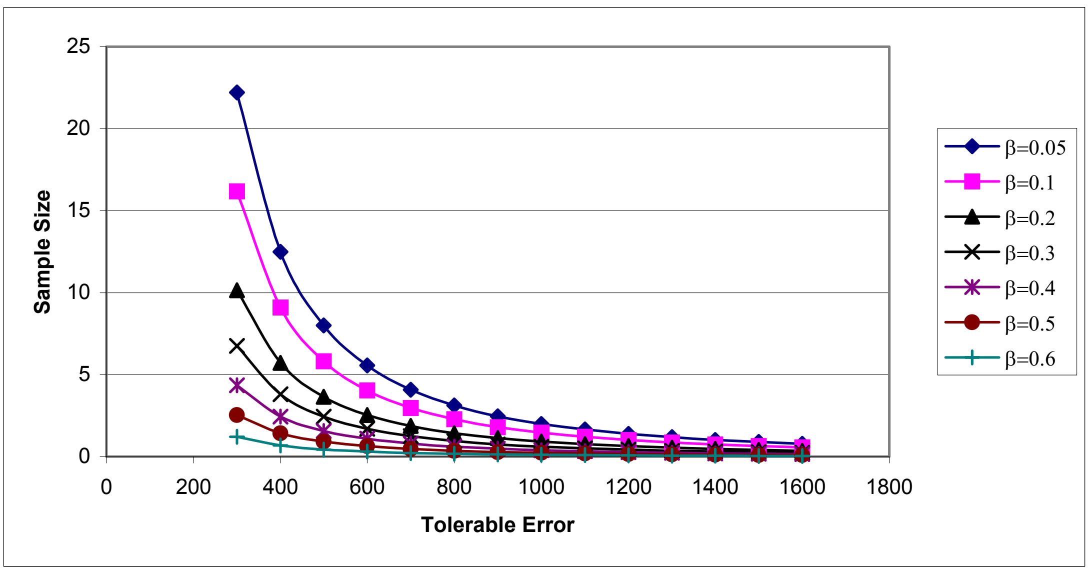


Figure B.12 Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 7 Days

Table B.13 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 28 Days

Conf. Level	Other Factors		Sample Size (n)						
	μ	5289	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	628.7	6	5	4	3	3	2	2
97	*e*	1000	5	4	3	2	2	1	1
95			4	3	2	2	1	1	1
90			3	3	2	1	1	1	0
85			3	2	1	1	1	0	0
80			2	2	1	1	0	0	0
75			2	2	1	1	0	0	0
70			2	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0

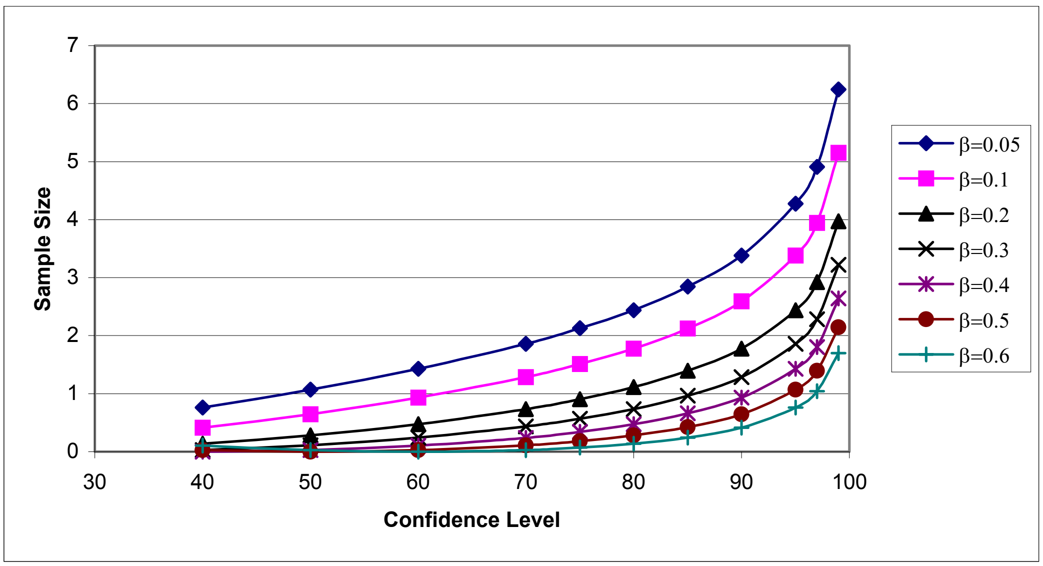


Figure B.13 Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 28 Days

Table B.14 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 28 Days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
300	Z_α	0.84	27	20	12	8	5	3	1
400	μ	5289	15	11	7	5	3	2	1
500	σ	628.7	10	7	4	3	2	1	1
600			7	5	3	2	1	1	0
700			5	4	2	2	1	1	0
800			4	3	2	1	1	0	0
900			3	2	1	1	1	0	0
1000			2	2	1	1	0	0	0
1100			2	1	1	1	0	0	0
1200			2	1	1	1	0	0	0
1300			1	1	1	0	0	0	0
1400			1	1	1	0	0	0	0
1500			1	1	0	0	0	0	0
1600			1	1	0	0	0	0	0

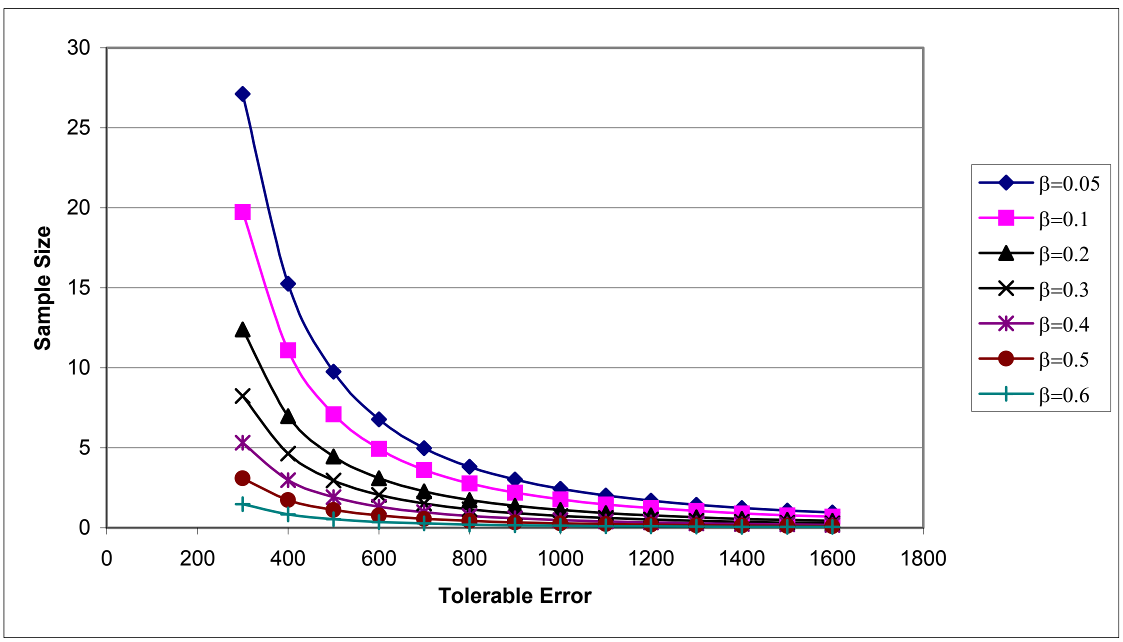


Figure B.14 Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 28 Days

Table B.15 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 90 Days

Conf. Level	Other Factors		Sample Size (n)						
	μ	6111	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	372.8	2	2	1	1	1	1	1
97	*e*	1000	2	1	1	1	1	0	0
95			2	1	1	1	1	0	0
90			1	1	1	0	0	0	0
85			1	1	0	0	0	0	0
80			1	1	0	0	0	0	0
75			1	1	0	0	0	0	0
70			1	0	0	0	0	0	0
60			1	0	0	0	0	0	0
50			0	0	0	0	0	0	0
40			0	0	0	0	0	0	0

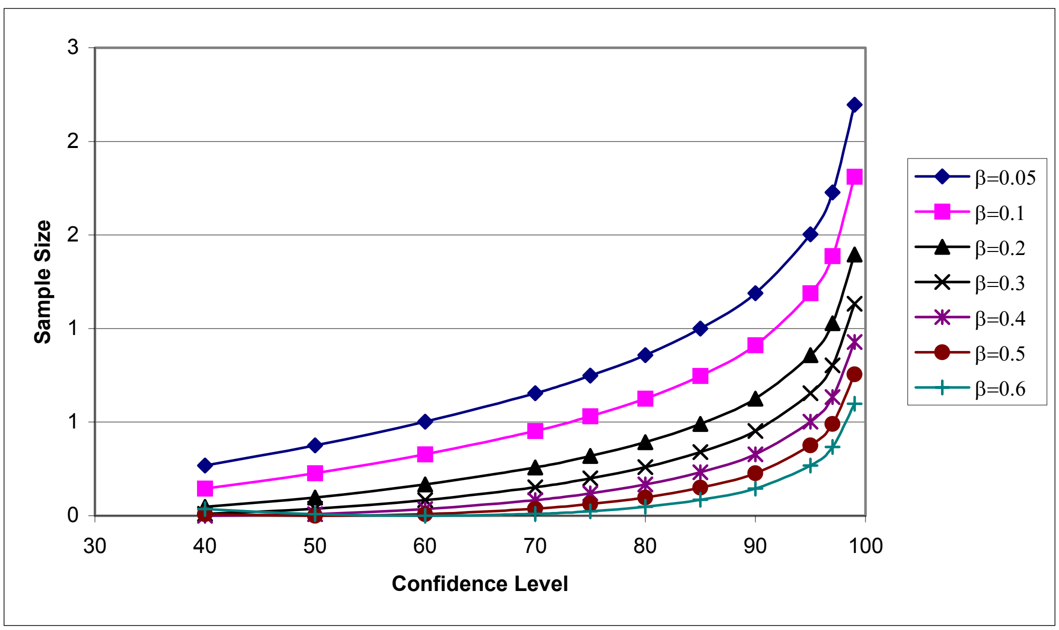


Figure B.15 Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 90 Days

Table B.16 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 90 Days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta=0.05$	$\beta=0.10$	$\beta=0.20$	$\beta=0.30$	$\beta=0.40$	$\beta=0.50$	$\beta=0.60$
200	Z_α	0.84	21	16	10	7	4	2	1
300	μ	6111	10	7	4	3	2	1	1
350	σ	372.8	7	5	3	2	1	1	0
400			5	4	2	2	1	1	0
500			3	2	2	1	1	0	0
600			2	2	1	1	0	0	0
700			2	1	1	1	0	0	0
800			1	1	1	0	0	0	0
900			1	1	0	0	0	0	0
1000			1	1	0	0	0	0	0
1100			1	1	0	0	0	0	0
1200			1	0	0	0	0	0	0
1500			0	0	0	0	0	0	0
2000			0	0	0	0	0	0	0

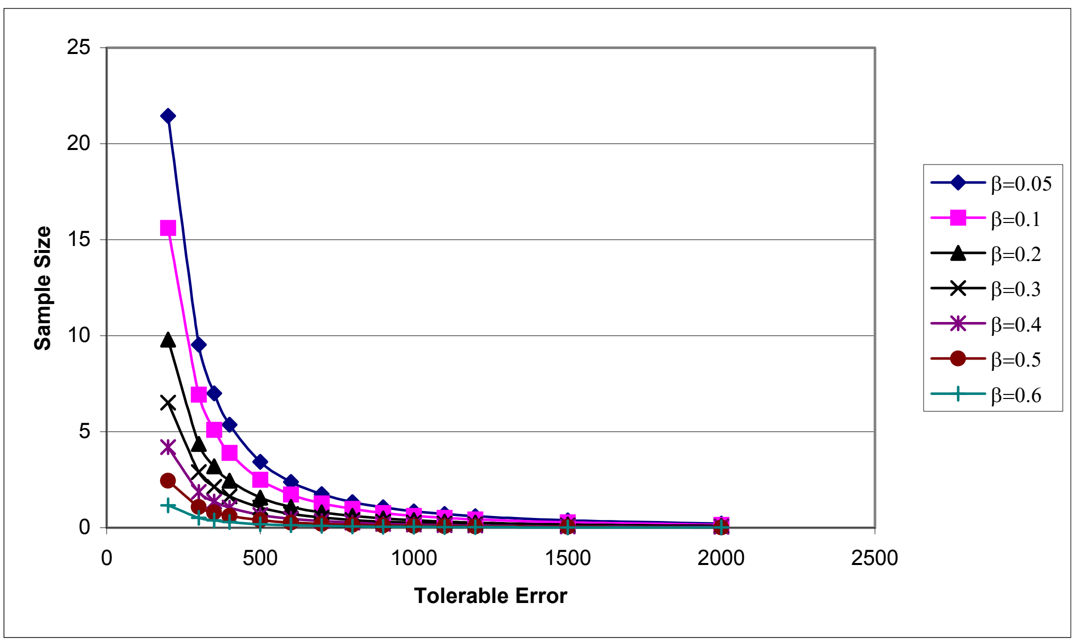


Figure B.16 Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 90 Days

Table B.17 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 7 Days (Cores)

Conf. Level	Other Factors		Sample Size (n)						
	μ	4328	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	668.4	11	9	7	6	5	4	3
97	*e*	800	9	7	5	4	3	2	2
95			8	6	4	3	3	2	1
90			6	5	3	2	2	1	1
85			5	4	2	2	1	1	0
80			4	3	2	1	1	0	0
75			4	3	2	1	1	0	0
70			3	2	1	1	0	0	0
60			3	2	1	0	0	0	0
50			2	1	0	0	0	0	0
40			1	1	0	0	0	0	0

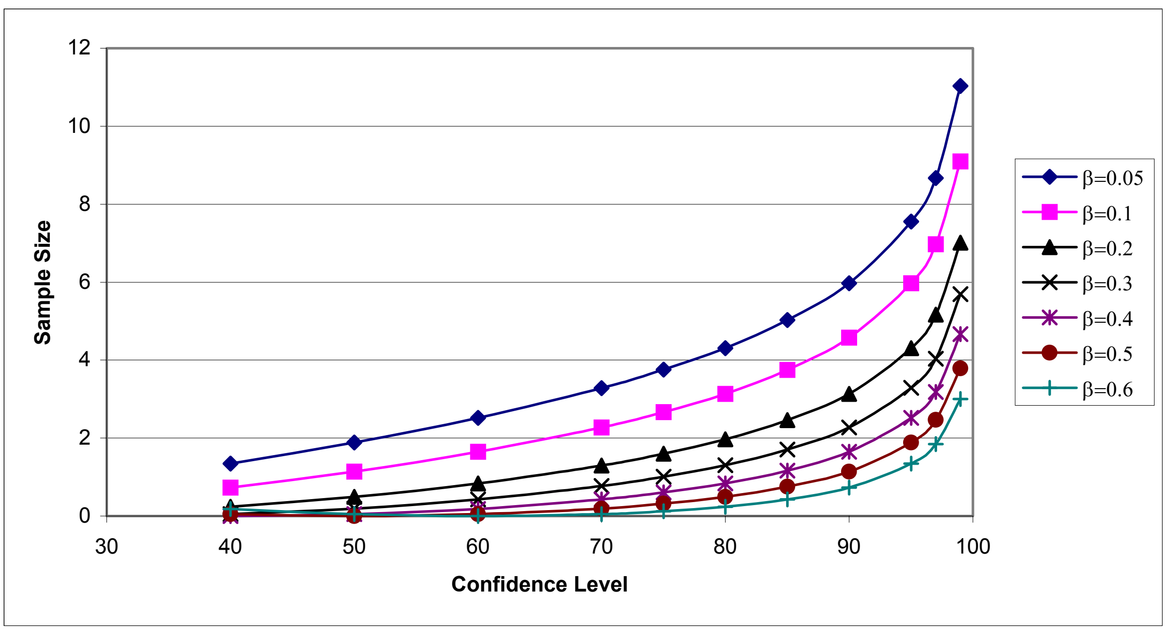


Figure B.17 Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 7 Days (Cores

**Table B.18 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 7 Days (Cores)**

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
300	Z_α	0.84	31	22	14	9	6	4	2
400	μ	4328	17	13	8	5	3	2	1
500	σ	668.36	11	8	5	3	2	1	1
550			9	7	4	3	2	1	0
600			8	6	4	2	2	1	0
650			7	5	3	2	1	1	0
700			6	4	3	2	1	1	0
750			5	4	2	1	1	1	0
800			4	3	2	1	1	0	0
850			4	3	2	1	1	0	0
900			3	2	2	1	1	0	0
950			3	2	1	1	1	0	0
1000			3	2	1	1	1	0	0
1100			2	2	1	1	0	0	0

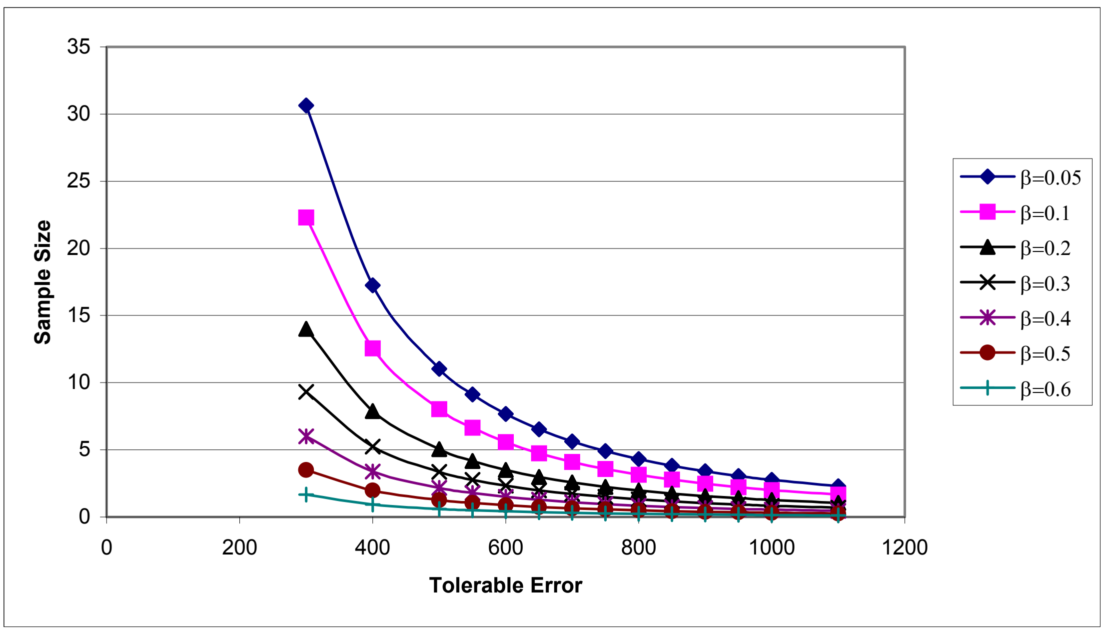


**Figure B.18 Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 7 Days (Cores)**

Table B.19 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 28 Days (Cores)

Conf. Level	Other Factors		Sample Size (n)						
	μ	5031	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	773.3	9	8	6	5	4	3	3
97	*e*	1000	7	6	4	3	3	2	2
95			6	5	4	3	2	2	1
90			5	4	3	2	1	1	1
85			4	3	2	1	1	1	0
80			4	3	2	1	1	0	0
75			3	2	1	1	1	0	0
70			3	2	1	1	0	0	0
60			2	1	1	0	0	0	0
50			2	1	0	0	0	0	0
40			1	1	0	0	0	0	0

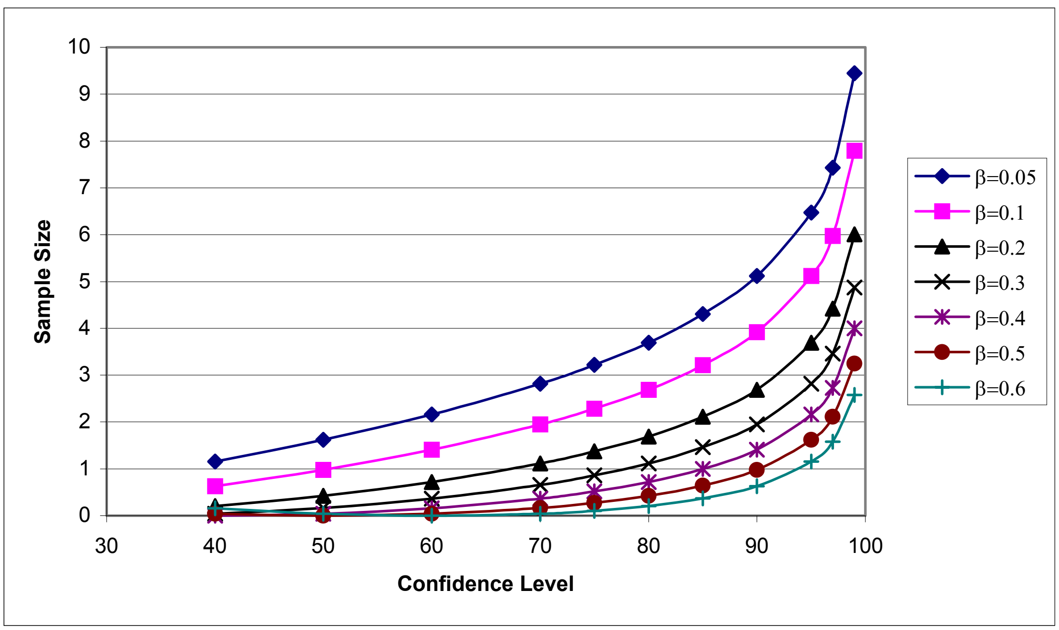


Figure B.19 Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 28 Days (Cores)

Table B.20 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 28 Days (Cores)

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
350	Z_{α}	0.84	30	22	14	9	6	3	2
400	μ	5031	23	17	11	7	5	3	1
500	σ	773.3	15	11	7	4	3	2	1
600			10	7	5	3	2	1	1
700			8	5	3	2	1	1	0
750			7	5	3	2	1	1	0
780			6	4	3	2	1	1	0
800			6	4	3	2	1	1	0
900			5	3	2	1	1	1	0
1100			3	2	1	1	1	0	0
1300			2	2	1	1	0	0	0
1400			2	1	1	1	0	0	0
1500			2	1	1	0	0	0	0
1600			1	1	1	0	0	0	0

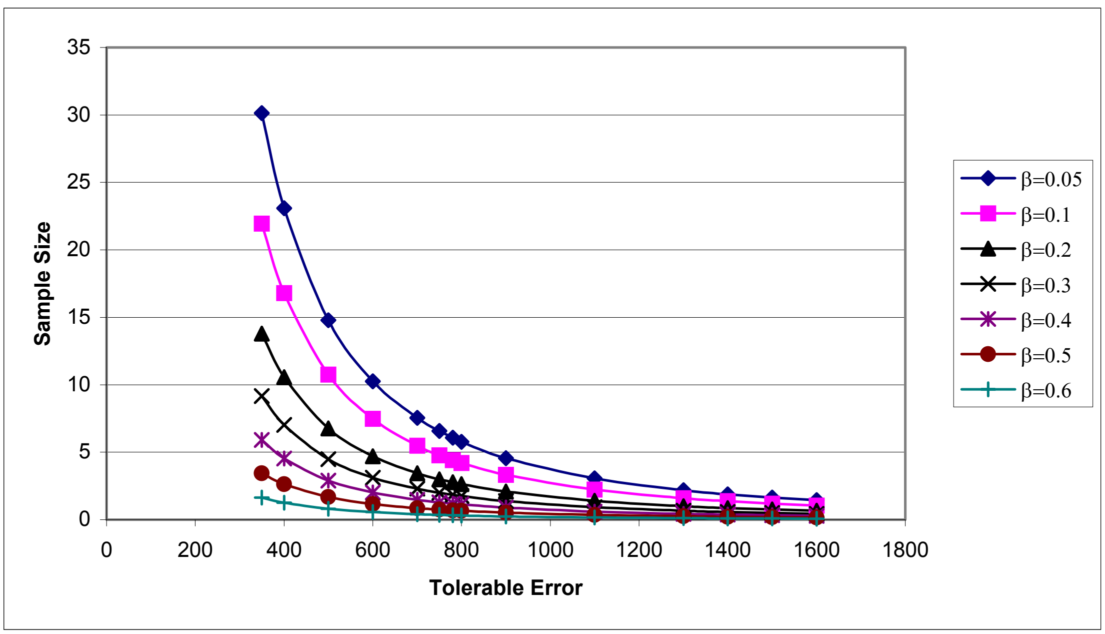


Figure B.20 Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 28 Days (Cores

Table B.21 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 90 Days (Cores)

Conf. Level	Other Factors		Sample Size (n)						
	μ	5599	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	834.2	5	4	3	3	2	2	1
97	*e*	1500	4	3	2	2	1	1	1
95			3	3	2	1	1	1	1
90			3	2	1	1	1	1	0
85			2	2	1	1	1	0	0
80			2	1	1	1	0	0	0
75			2	1	1	0	0	0	0
70			1	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0

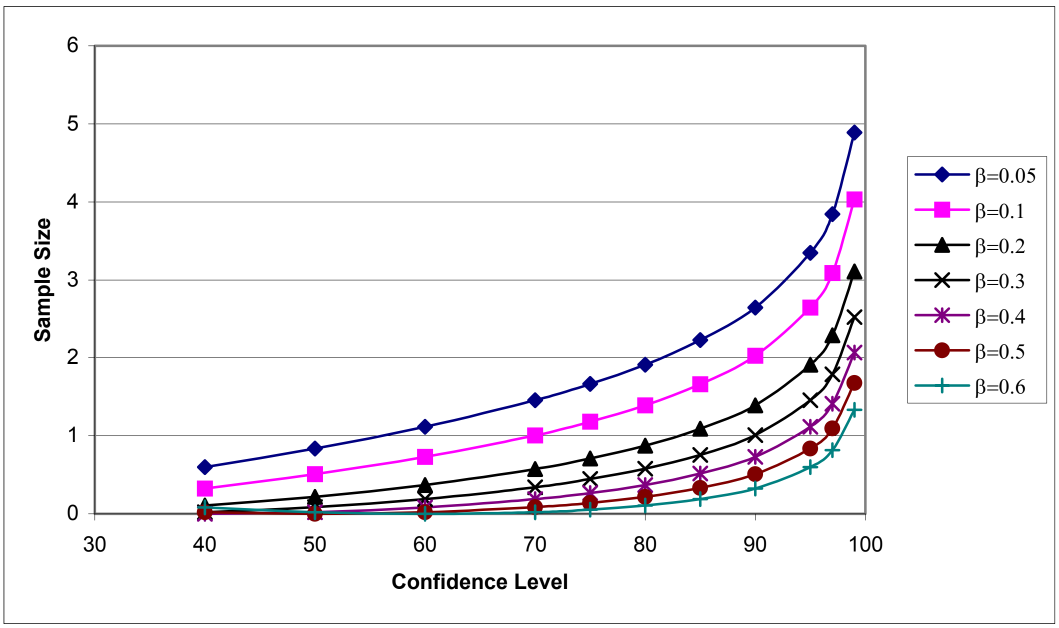


Figure B.21 Sample Size vs. Confidence Level.
Concrete for Pavements – Compressive Strength 90 Days (Cores)

Table B.22 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 90 Days (Cores)

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
300	Z_α	0.84	48	35	22	15	9	5	3
400	μ	5599	27	20	12	8	5	3	1
500	σ	834.2	17	13	8	5	3	2	1
700			9	6	4	3	2	1	0
750			8	6	3	2	1	1	0
800			7	5	3	2	1	1	0
850			6	4	3	2	1	1	0
900			5	4	2	2	1	1	0
950			5	3	2	1	1	1	0
1000			4	3	2	1	1	0	0
1100			4	3	2	1	1	0	0
1200			3	2	1	1	1	0	0
1400			2	2	1	1	0	0	0
1600			2	1	1	1	0	0	0

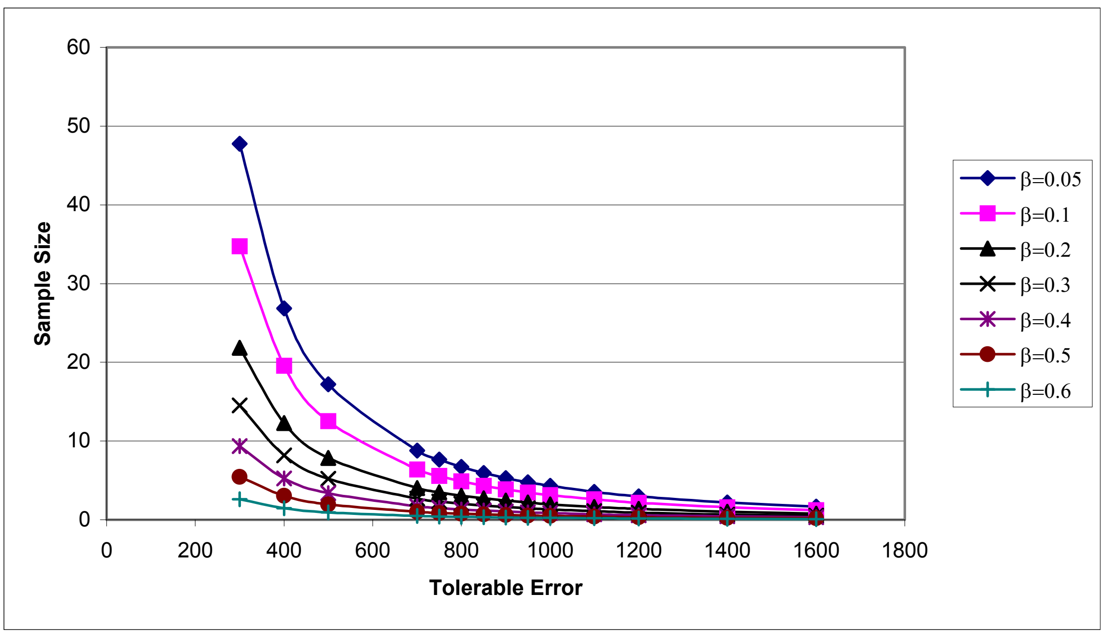


Figure B.22 Sample Size vs. Tolerable Error.
Concrete for Pavements – Compressive Strength 90 Days (Cores)

Table B.23 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Flexural Strength 7 Days

Conf. Level	Other Factors		Sample Size (n)						
	μ	593	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	62.5	6	5	4	3	3	2	2
97	*e*	100	5	4	3	2	2	1	1
95			4	3	2	2	1	1	1
90			3	3	2	1	1	1	0
85			3	2	1	1	1	0	0
80			2	2	1	1	0	0	0
75			2	1	1	1	0	0	0
70			2	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0

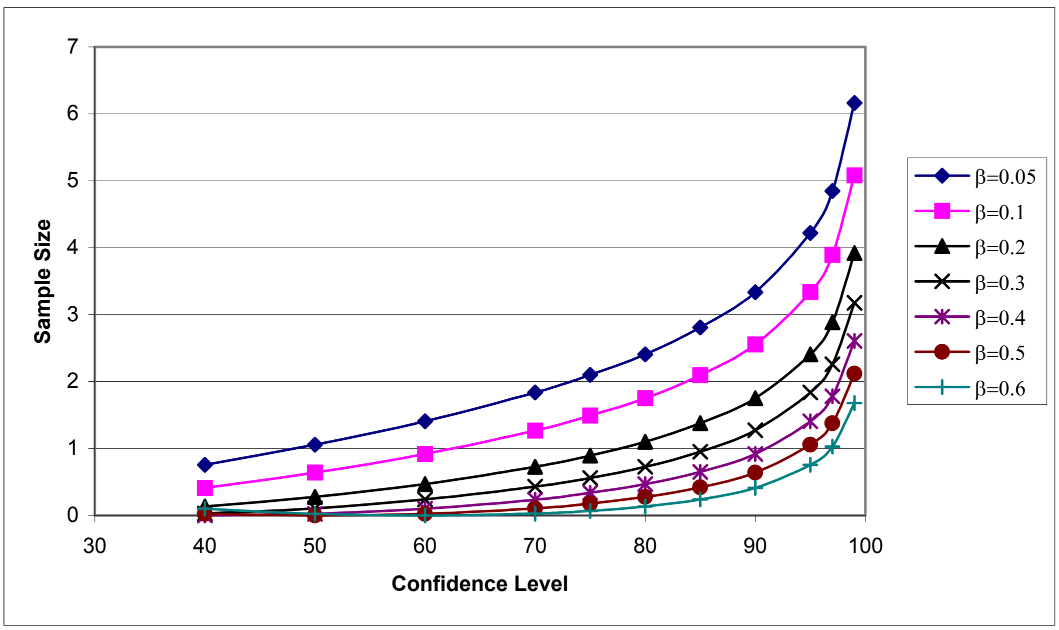


Figure B.23 Sample Size vs. Confidence Level.
Concrete for Pavements – Flexural Strength 7 Days

Table B.24 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Flexural Strength 7 Days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
30	Z_α	0.84	27	19	12	8	5	3	1
40	μ	593	15	11	7	5	3	2	1
50	σ	62.5	10	7	4	3	2	1	1
60			7	5	3	2	1	1	0
70			5	4	2	1	1	1	0
80			4	3	2	1	1	0	0
100			2	2	1	1	0	0	0
120			2	1	1	1	0	0	0
130			1	1	1	0	0	0	0
150			1	1	0	0	0	0	0
160			1	1	0	0	0	0	0
180			1	1	0	0	0	0	0
200			1	0	0	0	0	0	0
220			0	0	0	0	0	0	0

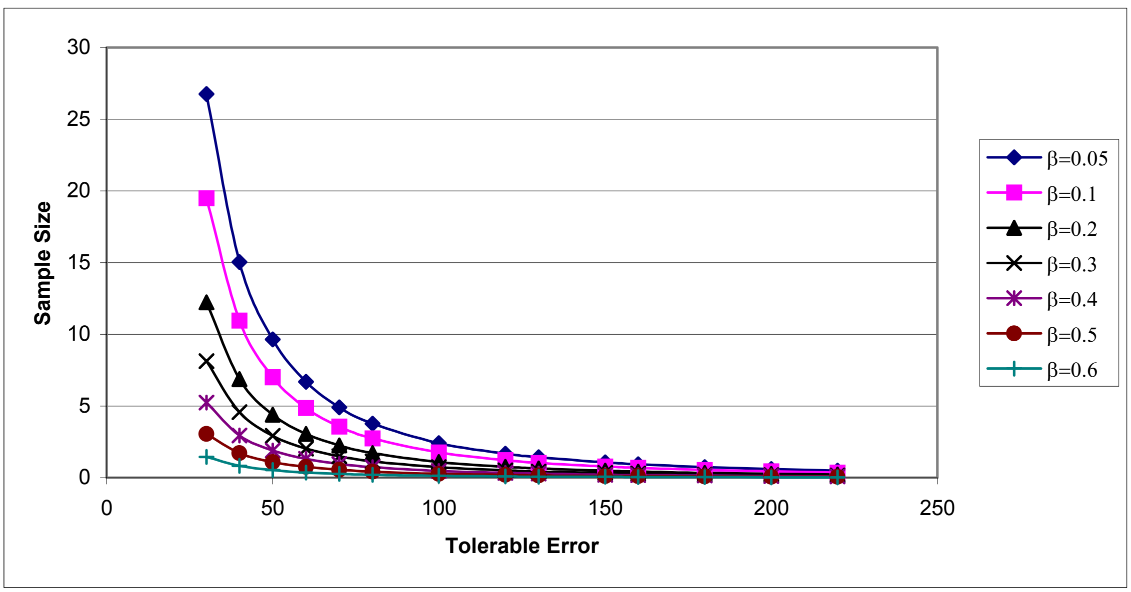


Figure B.24 Sample Size vs. Tolerable Error.
Concrete for Pavements – Flexural Strength 7 Days.

Table B.25 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Flexural Strength 28 Days

Conf. Level	Other Factors		Sample Size (n)						
	μ	690	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	62.3	6	5	4	3	3	2	2
97	*e*	100	5	4	3	2	2	1	1
95			4	3	2	2	1	1	1
90			3	3	2	1	1	1	0
85			3	2	1	1	1	0	0
80			2	2	1	1	0	0	0
75			2	1	1	1	0	0	0
70			2	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0

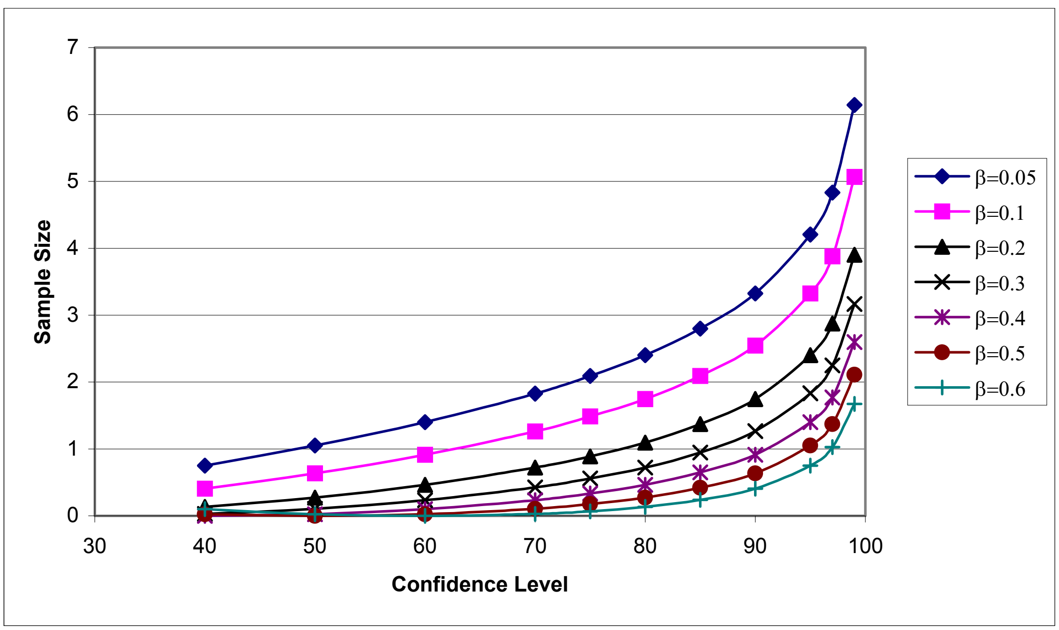


Figure B.25 Sample Size vs. Confidence Level.
Concrete for Pavements – Flexural Strength 28 Days

Table B.26 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Flexural Strength 28 Days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
30	Z_α	0.84	27	19	12	8	5	3	1
40	μ	690	15	11	7	5	3	2	1
50	σ	62.3	10	7	4	3	2	1	1
60			7	5	3	2	1	1	0
70			5	4	2	1	1	1	0
80			4	3	2	1	1	0	0
100			2	2	1	1	0	0	0
120			2	1	1	1	0	0	0
130			1	1	1	0	0	0	0
150			1	1	0	0	0	0	0
160			1	1	0	0	0	0	0
180			1	1	0	0	0	0	0
200			1	0	0	0	0	0	0
220			0	0	0	0	0	0	0

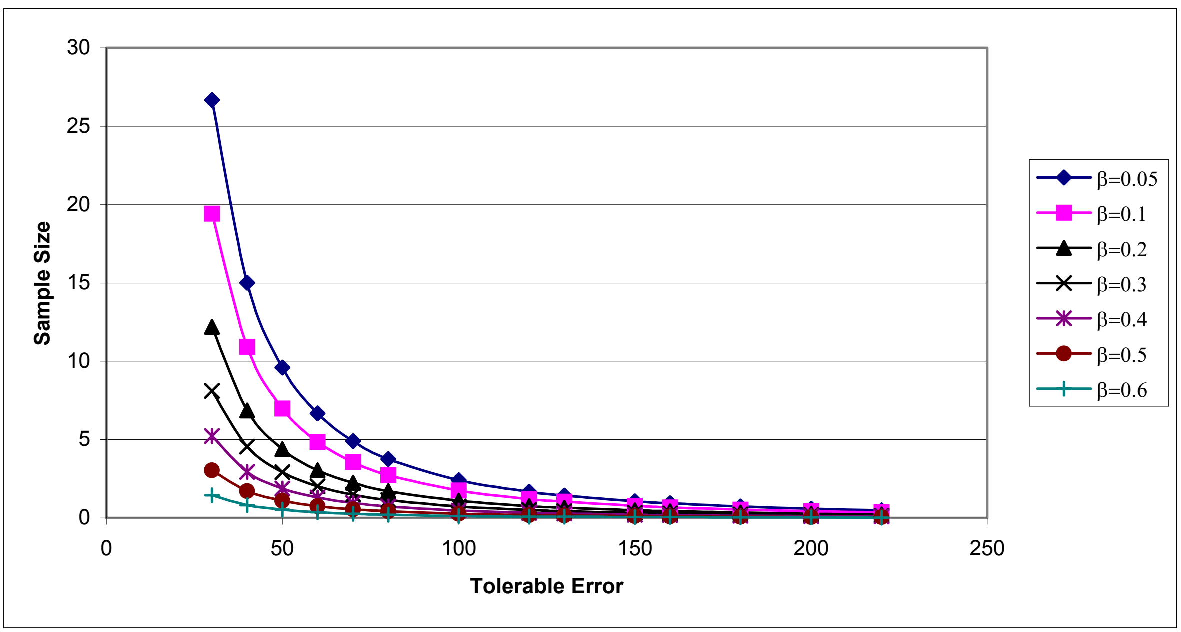


Figure B.26 Sample Size vs. Tolerable Error.
Concrete for Pavements – Flexural Strength 28 Days

Table B.27 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Flexural Strength 90 Days

Conf. Level	Other Factors		Sample Size (n)						
	μ	808	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	33.8	2	1	1	1	1	1	0
97	*e*	100	1	1	1	1	1	0	0
95			1	1	1	1	0	0	0
90			1	1	1	0	0	0	0
85			1	1	0	0	0	0	0
80			1	1	0	0	0	0	0
75			1	0	0	0	0	0	0
70			1	0	0	0	0	0	0
60			0	0	0	0	0	0	0
50			0	0	0	0	0	0	0
40			0	0	0	0	0	0	0

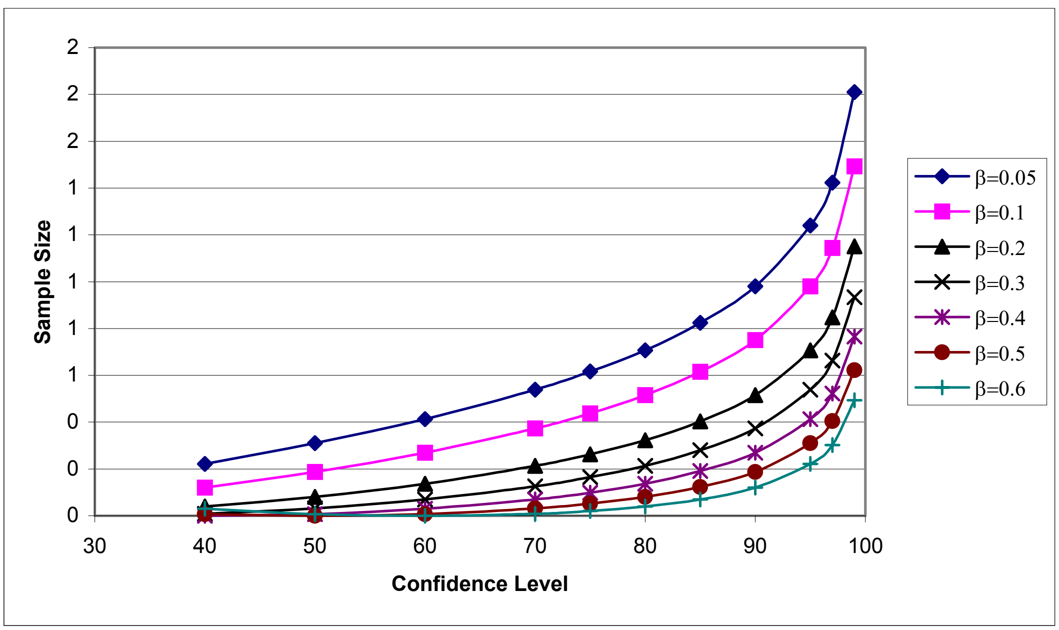


Figure B.27 Sample Size vs. Confidence Level.
Concrete for Pavements – Flexural Strength 90 Days

Table B.28 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Flexural Strength 90 Days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
20	Z_α	0.84	18	13	8	5	3	2	1
25	μ	808	11	8	5	3	2	1	1
30	σ	33.8	8	6	4	2	2	1	0
40			4	3	2	1	1	1	0
50			3	2	1	1	1	0	0
60			2	1	1	1	0	0	0
70			1	1	1	0	0	0	0
80			1	1	1	0	0	0	0
90			1	1	0	0	0	0	0
100			1	1	0	0	0	0	0
110			1	0	0	0	0	0	0
120			0	0	0	0	0	0	0
150			0	0	0	0	0	0	0
200			0	0	0	0	0	0	0

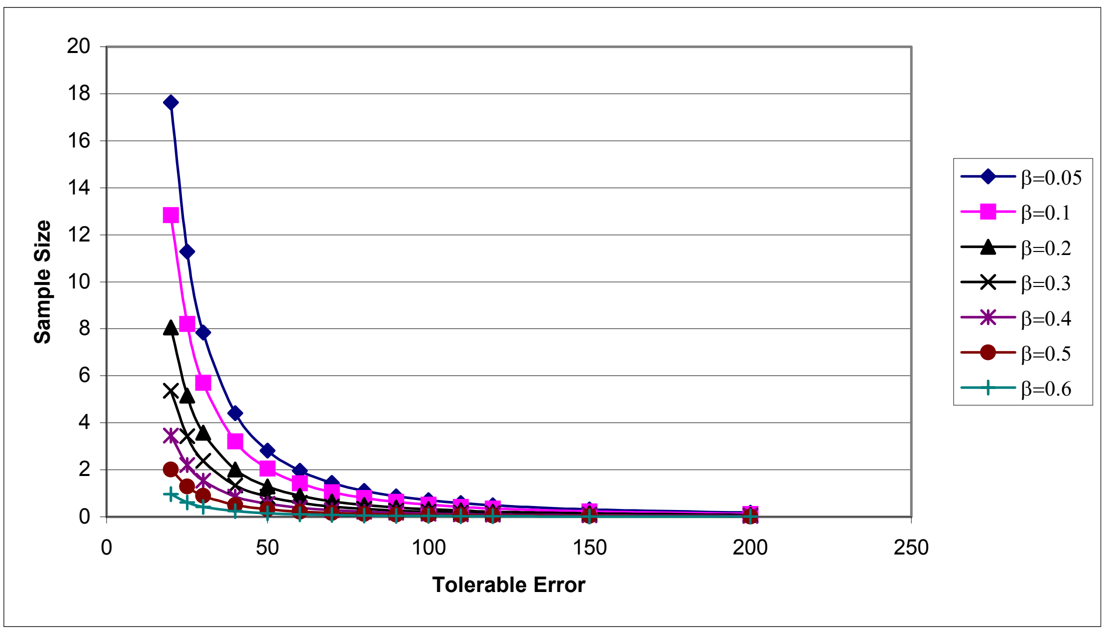


Figure B.28 Sample Size vs. Tolerable Error.
Concrete for Pavements – Flexural Strength 90 Days

Table B.29 Relationship Sample Size vs. Confidence Level. Concrete for Pavements – Splitting tensile strength 7 days

Conf. Level	Other Factors		Sample Size (n)						
	μ	442	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	48.7	6	5	4	3	2	2	2
97	*e*	80	5	4	3	2	2	1	1
95			4	3	2	2	1	1	1
90			3	2	2	1	1	1	0
85			3	2	1	1	1	0	0
80			2	2	1	1	0	0	0
75			2	1	1	1	0	0	0
70			2	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0

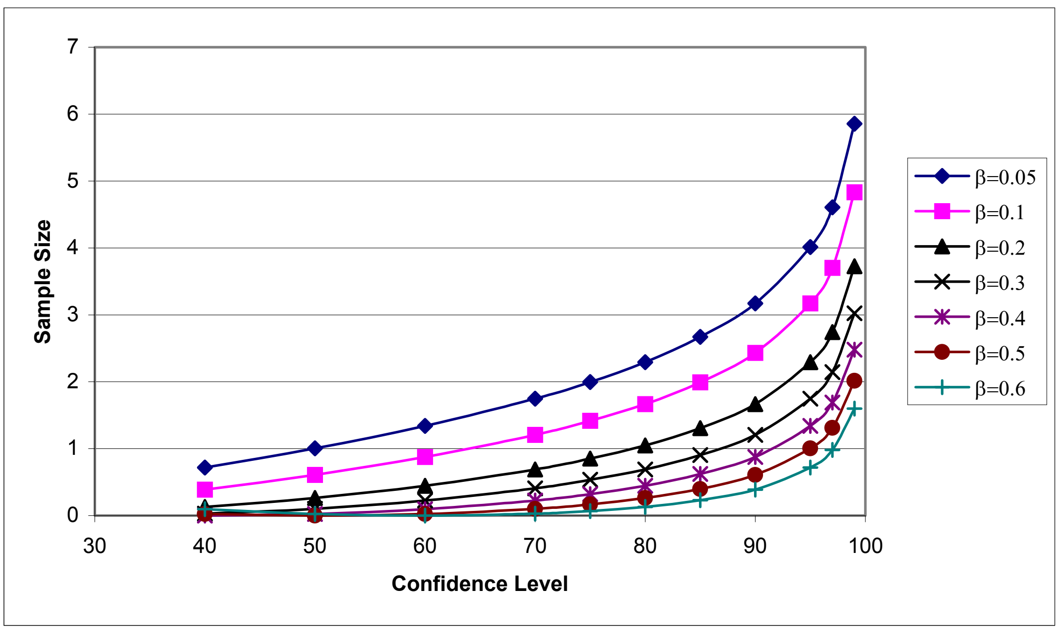


Figure B.29 Sample Size vs. Confidence Level. Concrete for Pavements – Splitting tensile strength 7 days

Table B.30 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 7 days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
30	Z_α	0.84	16	12	7	5	3	2	1
40	μ	442	9	7	4	3	2	1	0
50	σ	48.7	6	4	3	2	1	1	0
60			4	3	2	1	1	0	0
80			2	2	1	1	0	0	0
100			1	1	1	0	0	0	0
110			1	1	1	0	0	0	0
120			1	1	0	0	0	0	0
130			1	1	0	0	0	0	0
140			1	1	0	0	0	0	0
150			1	0	0	0	0	0	0
160			1	0	0	0	0	0	0
170			1	0	0	0	0	0	0
200			0	0	0	0	0	0	0

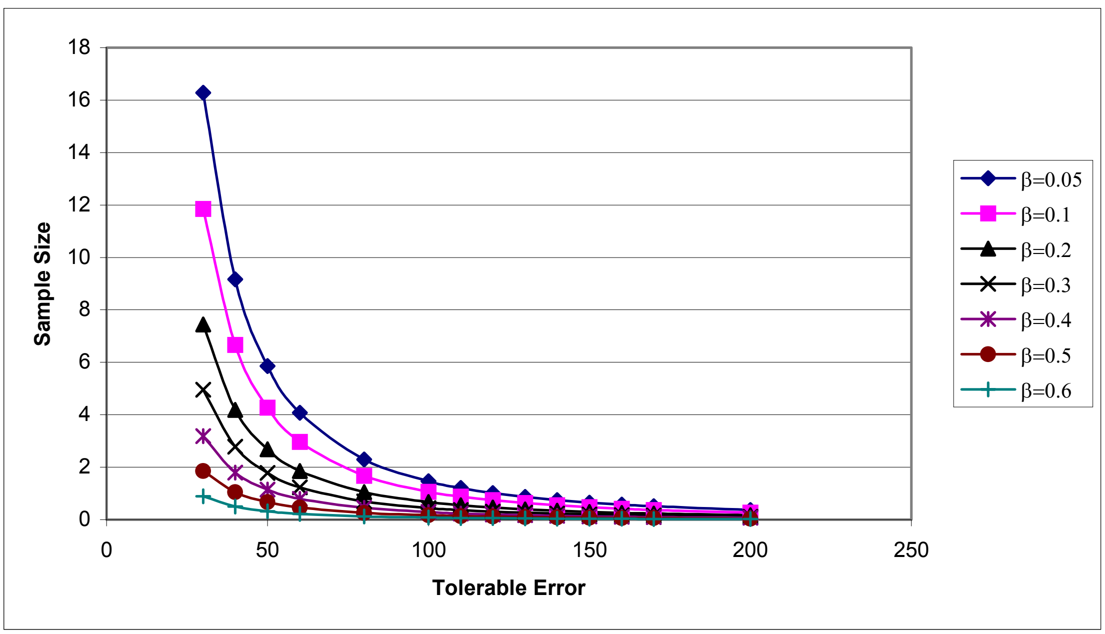


Figure B.30 Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 7 days

Table B.31 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Splitting tensile strength 28 days

Conf. Level	Other Factors		Sample Size (n)						
	μ	503	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	62.1	6	5	4	3	3	2	2
97	*e*	100	5	4	3	2	2	1	1
95			4	3	2	2	1	1	1
90			3	3	2	1	1	1	0
85			3	2	1	1	1	0	0
80			2	2	1	1	0	0	0
75			2	1	1	1	0	0	0
70			2	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0

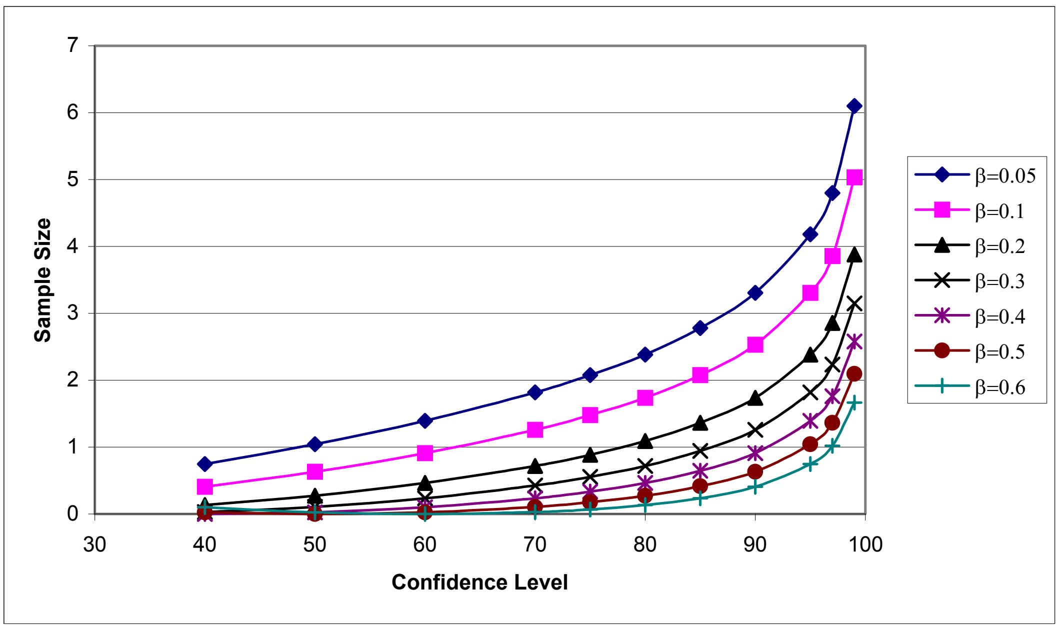


Figure B.31 Sample Size vs. Confidence Level.
Concrete for Pavements – Splitting tensile strength 28 days

Table B.32 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 28 days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
30	Z_α	0.84	26	19	12	8	5	3	1
40	μ	503	15	11	7	5	3	2	1
50	σ	62.1	10	7	4	3	2	1	1
60			7	5	3	2	1	1	0
80			4	3	2	1	1	0	0
100			2	2	1	1	0	0	0
110			2	1	1	1	0	0	0
120			2	1	1	1	0	0	0
130			1	1	1	0	0	0	0
140			1	1	1	0	0	0	0
150			1	1	0	0	0	0	0
160			1	1	0	0	0	0	0
170			1	1	0	0	0	0	0
200			1	0	0	0	0	0	0

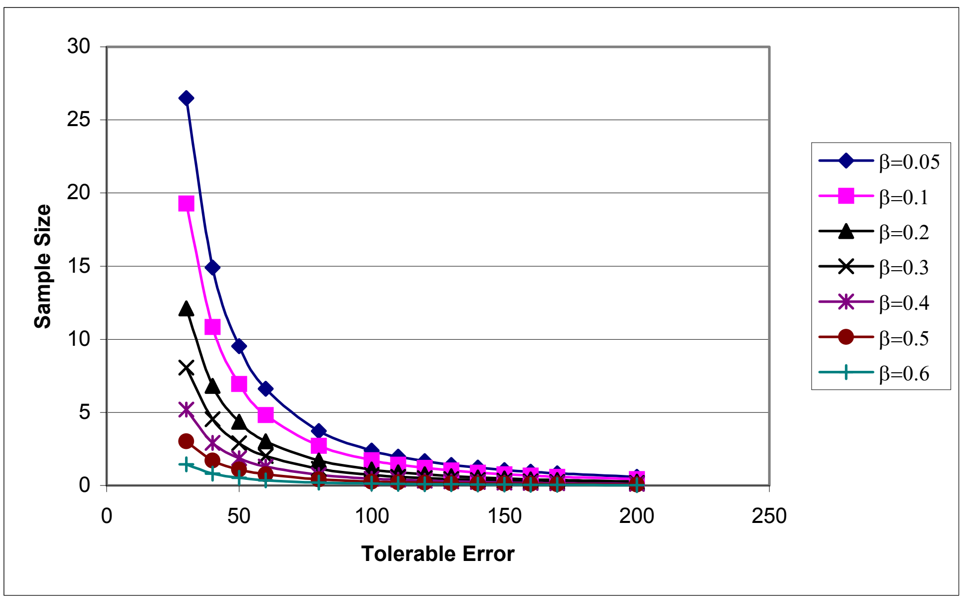


Figure B.32 Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 28 days

Table B.33 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Splitting tensile strength 90 days

Conf. Level	Other Factors		Sample Size (n)						
	μ	593	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	57.5	5	4	3	3	2	2	1
97	*e*	100	4	3	2	2	2	1	1
95			4	3	2	2	1	1	1
90			3	2	1	1	1	1	0
85			2	2	1	1	1	0	0
80			2	1	1	1	0	0	0
75			2	1	1	0	0	0	0
70			2	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0

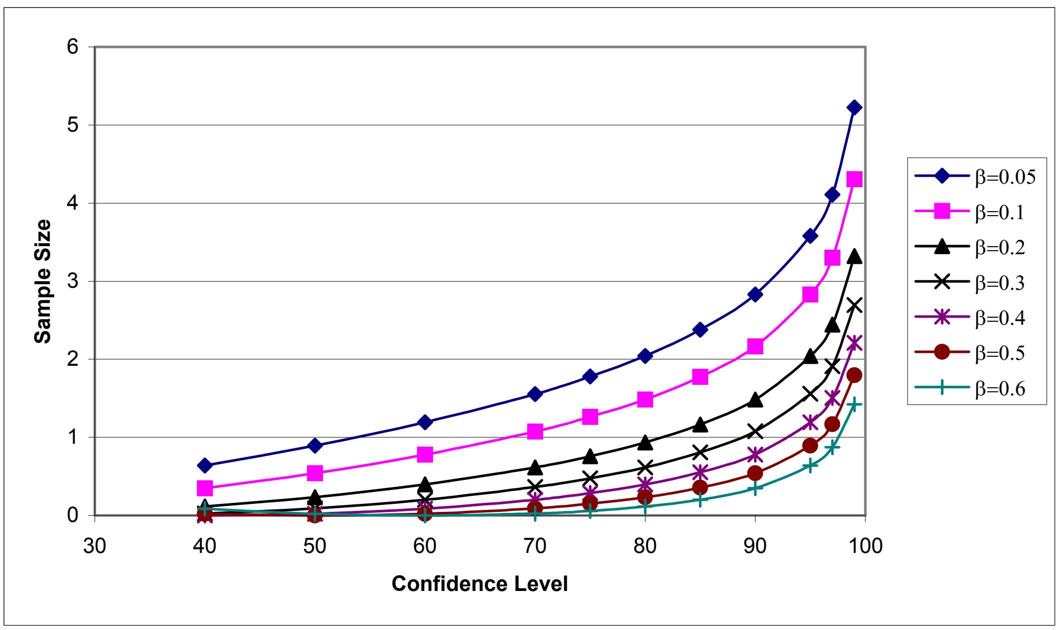


Figure B.33 Sample Size vs. Confidence Level.
Concrete for Pavements – Splitting tensile strength 90 days

Table B.34 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 90 days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
30	Z_α	0.84	23	17	10	7	4	3	1
40	μ	593	13	9	6	4	3	1	1
50	σ	57.5	8	6	4	2	2	1	0
60			6	4	3	2	1	1	0
80			3	2	1	1	1	0	0
100			2	1	1	1	0	0	0
110			2	1	1	1	0	0	0
120			1	1	1	0	0	0	0
130			1	1	1	0	0	0	0
140			1	1	0	0	0	0	0
150			1	1	0	0	0	0	0
160			1	1	0	0	0	0	0
170			1	1	0	0	0	0	0
200			1	0	0	0	0	0	0

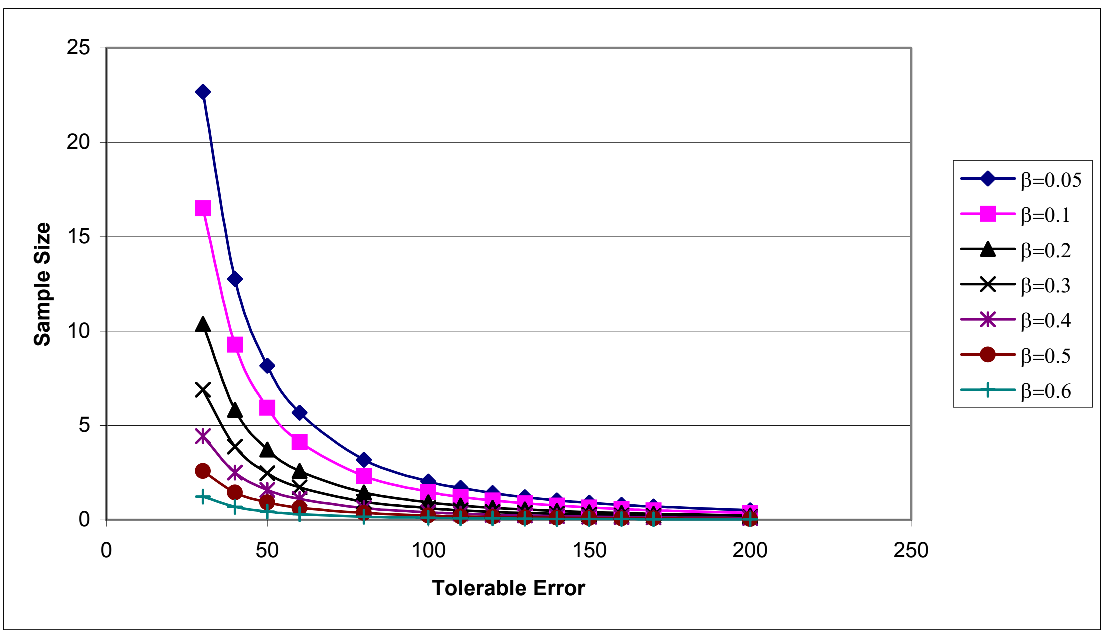


Table B.34 Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 90 days

Table B.35 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 7 days (Cores)

Conf. Level	Other Factors		Sample Size (n)						
	μ	521	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	80.5	10	8	7	5	4	4	3
97	*e*	100	8	6	5	4	3	2	2
95			7	6	4	3	2	2	1
90			6	4	3	2	2	1	1
85			5	3	2	2	1	1	0
80			4	3	2	1	1	0	0
75			3	2	1	1	1	0	0
70			3	2	1	1	0	0	0
60			2	2	1	0	0	0	0
50			2	1	0	0	0	0	0
40			1	1	0	0	0	0	0

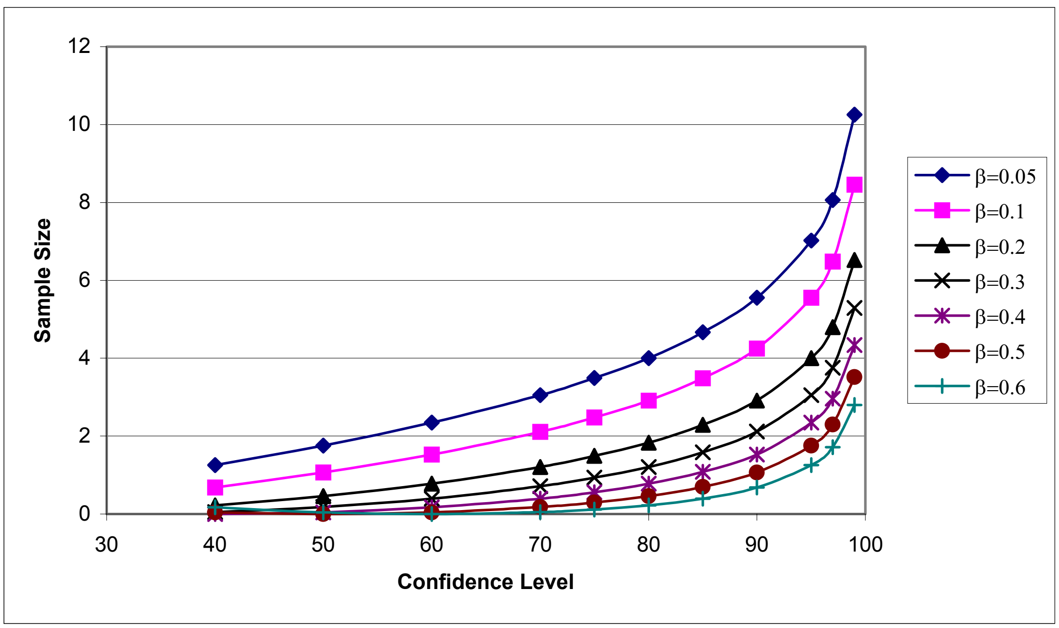


Figure B.35 Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 7 days (Cores)

Table B.36 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 7 days (Cores)

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
30	Z_α	0.84	16	12	7	5	3	2	1
40	μ	442	9	7	4	3	2	1	0
50	σ	48.7	6	4	3	2	1	1	0
60			4	3	2	1	1	0	0
80			2	2	1	1	0	0	0
100			1	1	1	0	0	0	0
110			1	1	1	0	0	0	0
120			1	1	0	0	0	0	0
130			1	1	0	0	0	0	0
140			1	1	0	0	0	0	0
150			1	0	0	0	0	0	0
160			1	0	0	0	0	0	0
170			1	0	0	0	0	0	0
200			0	0	0	0	0	0	0

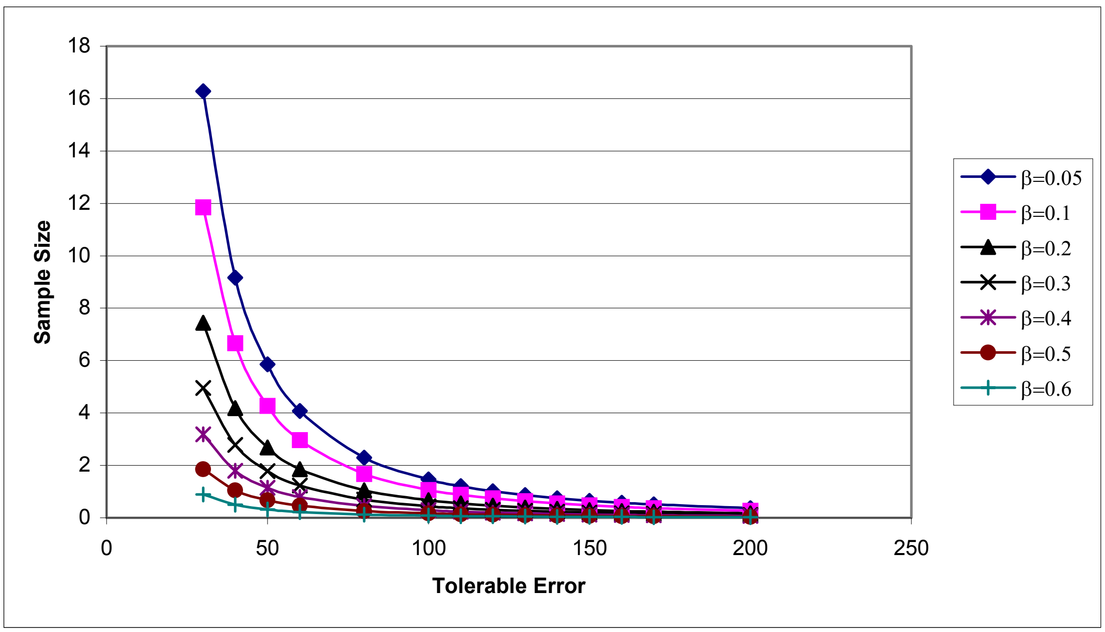


Figure B.36 Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 7 days (Cores)

Table B.37 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Splitting tensile strength 28 days (Cores)

Conf. Level	Other Factors		Sample Size (n)						
	μ	589	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	87.3	12	10	8	6	5	4	3
97	*e*	100	9	8	6	4	3	3	2
95			8	7	5	4	3	2	1
90			7	5	3	2	2	1	1
85			5	4	3	2	1	1	0
80			5	3	2	1	1	1	0
75			4	3	2	1	1	0	0
70			4	2	1	1	0	0	0
60			3	2	1	0	0	0	0
50			2	1	1	0	0	0	0
40			1	1	0	0	0	0	0

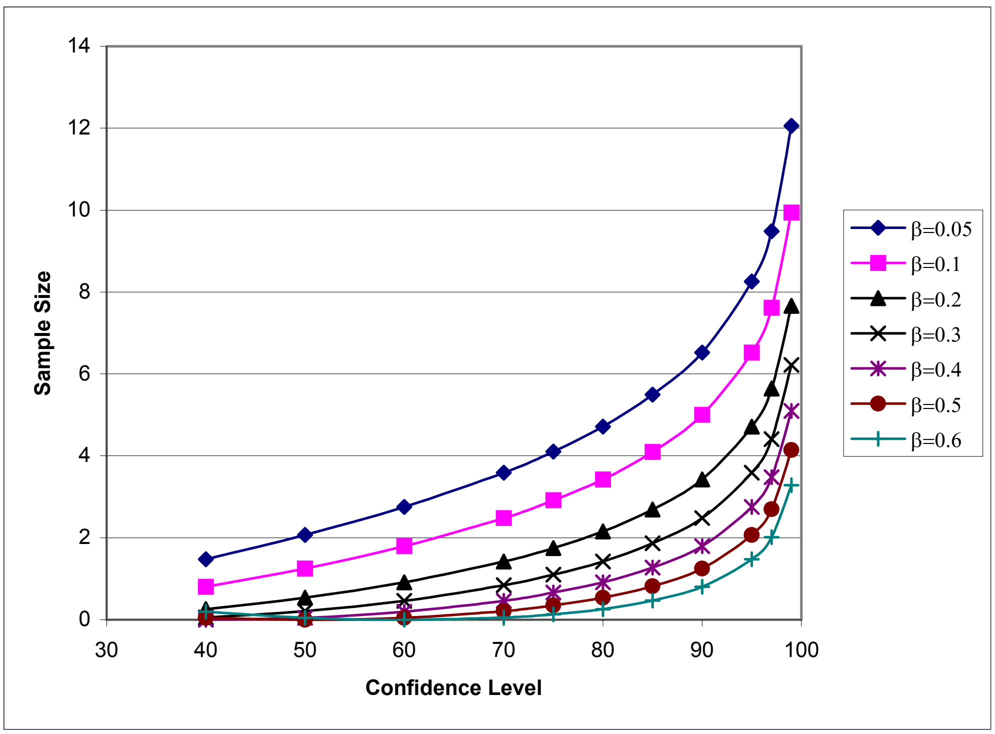


Figure B.37 Sample Size vs. Confidence Level.
Concrete for Pavements – Splitting tensile strength 28 days (Cores)

Table B.38 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 28 days (Cores)

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
50	Z_α	0.84	19	14	9	6	4	2	1
60	μ	589	13	10	6	4	3	1	1
70	σ	87.3	10	7	4	3	2	1	1
80			7	5	3	2	1	1	0
90			6	4	3	2	1	1	0
100			5	3	2	1	1	1	0
110			4	3	2	1	1	0	0
120			3	2	1	1	1	0	0
130			3	2	1	1	1	0	0
140			2	2	1	1	0	0	0
150			2	2	1	1	0	0	0
160			2	1	1	1	0	0	0
170			2	1	1	0	0	0	0
200			1	1	1	0	0	0	0

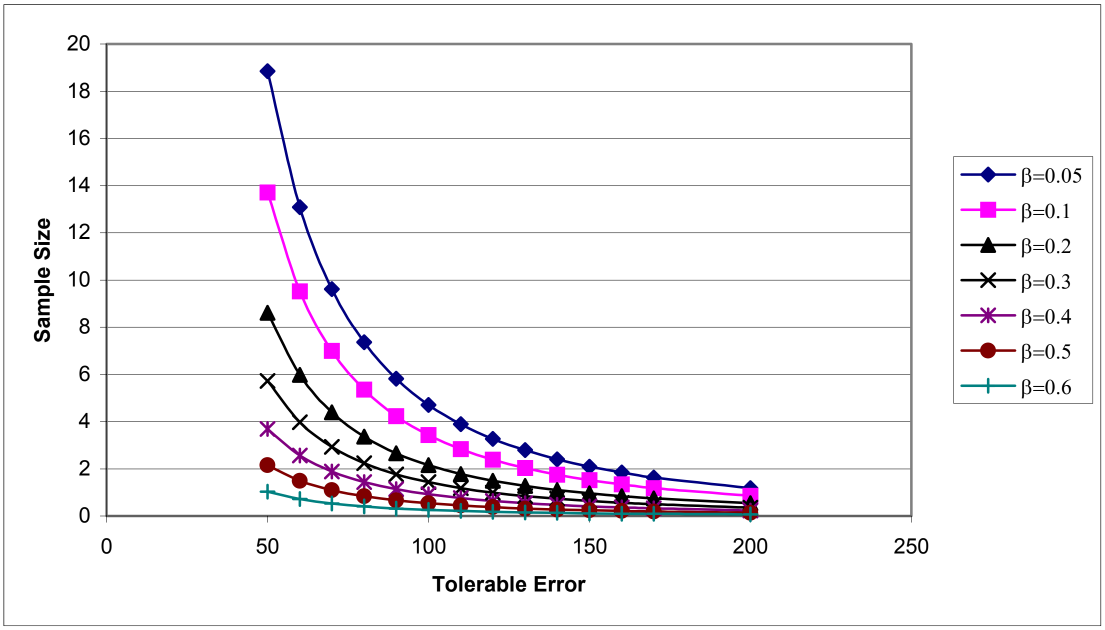
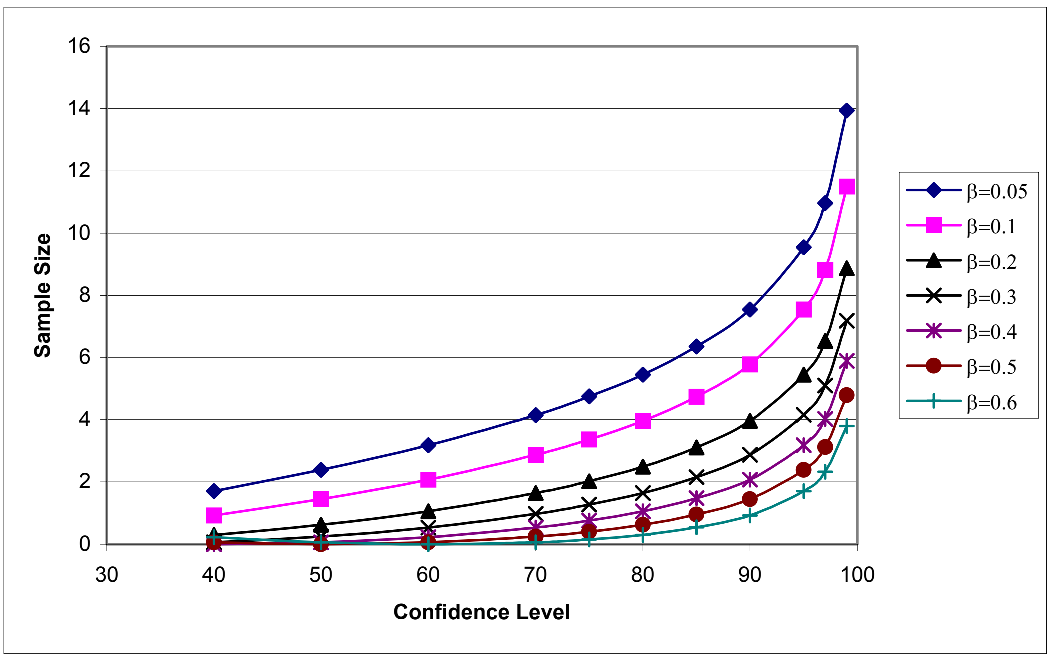


Figure B.38 Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 28 days (Cores)

Table B.39 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Splitting tensile strength 90 days (Cores)

Conf. Level	Other Factors		Sample Size (n)						
	μ	627	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	122.1	14	11	9	7	6	5	4
97	*e*	130	11	9	7	5	4	3	2
95			10	8	5	4	3	2	2
90			8	6	4	3	2	1	1
85			6	5	3	2	1	1	1
80			5	4	2	2	1	1	0
75			5	3	2	1	1	0	0
70			4	3	2	1	1	0	0
60			3	2	1	1	0	0	0
50			2	1	1	0	0	0	0
40			2	1	0	0	0	0	0



FigureB.39 Sample Size vs. Confidence Level.
Concrete for Pavements – Splitting tensile strength 90 days (Cores)

Table B.40 Relationship Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 90 days (Cores)

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
50	Z_α	0.84	37	27	17	11	7	4	2
60	μ	627	26	19	12	8	5	3	1
70	σ	122.1	19	14	9	6	4	2	1
80			14	10	7	4	3	2	1
90			11	8	5	3	2	1	1
100			9	7	4	3	2	1	1
110			8	6	3	2	1	1	0
120			6	5	3	2	1	1	0
130			5	4	2	2	1	1	0
140			5	3	2	1	1	1	0
150			4	3	2	1	1	0	0
160			4	3	2	1	1	0	0
170			3	2	1	1	1	0	0
200			2	2	1	1	0	0	0

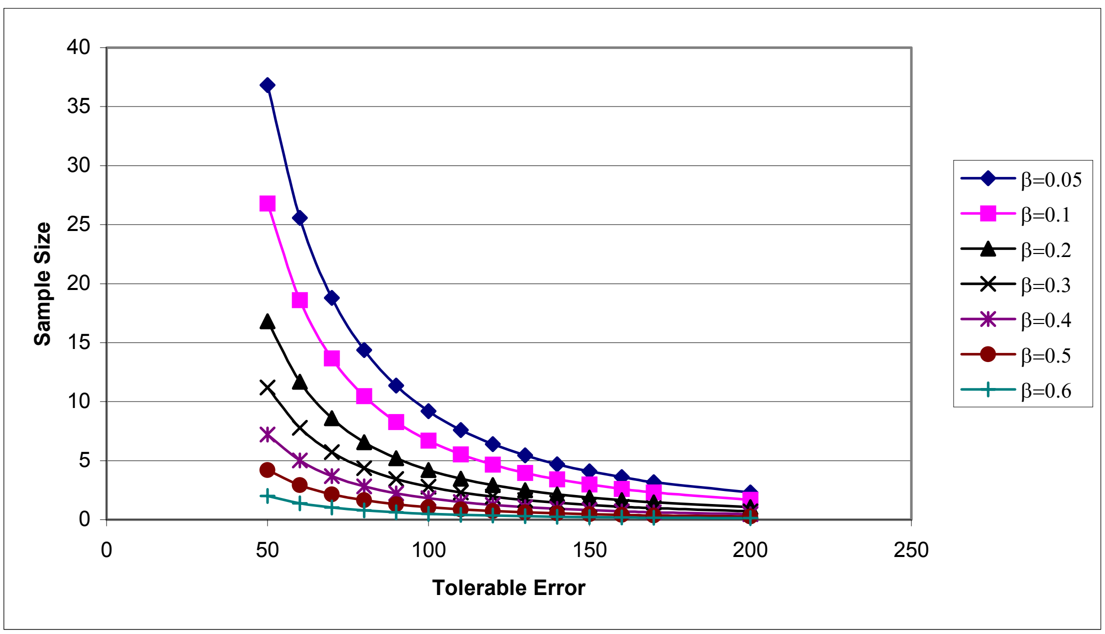


Figure B.40 Sample Size vs. Tolerable Error.
Concrete for Pavements – Splitting tensile strength 90 days (Cores)

Table B.41 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Slump

Conf. Level	Other Factors		Sample Size (n)						
	μ	1.9	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	0.896	6	5	4	3	3	2	2
97	*e*	1.5	5	4	3	3	2	2	1
95			5	4	3	2	2	1	1
90			4	3	2	2	1	1	1
85			3	3	2	1	1	1	1
80			3	2	2	1	1	1	0
75			3	2	1	1	1	0	0
70			3	2	1	1	1	0	0
60			2	2	1	1	0	0	0
50			2	1	1	1	0	0	0
40			2	1	1	0	0	0	0
30			1	1	1	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

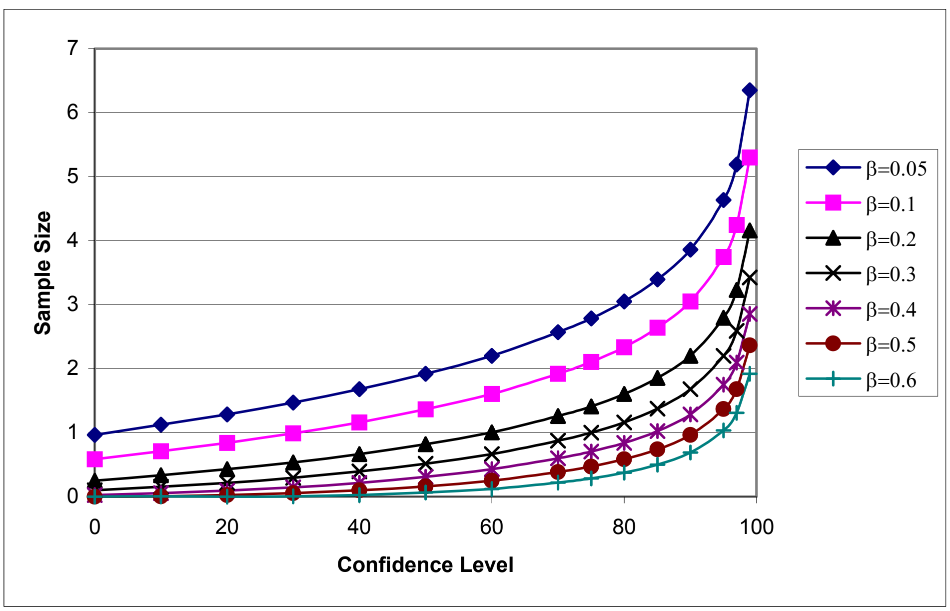


Figure B.41 Sample Size vs. Confidence Level.
Concrete for Pavements – Slump

Table B.42 Relationship Sample Size vs. Tolerable Error. Concrete for Pavements – Slump

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
0.4	$Z_{\alpha/2}$	1.28	43	33	23	16	12	8	5
0.45	μ	1.9152	34	26	18	13	9	6	4
0.5	σ	0.8957	27	21	14	11	8	5	3
0.75			12	9	6	5	3	2	1
0.8			11	8	6	4	3	2	1
1			7	5	4	3	2	1	1
1.1			6	4	3	2	2	1	1
1.2			5	4	3	2	1	1	1
1.3			4	3	2	2	1	1	0
1.4			4	3	2	1	1	1	0
1.5			3	2	2	1	1	1	0
1.7			2	2	1	1	1	0	0
1.8			2	2	1	1	1	0	0
1.9			2	1	1	1	1	0	0

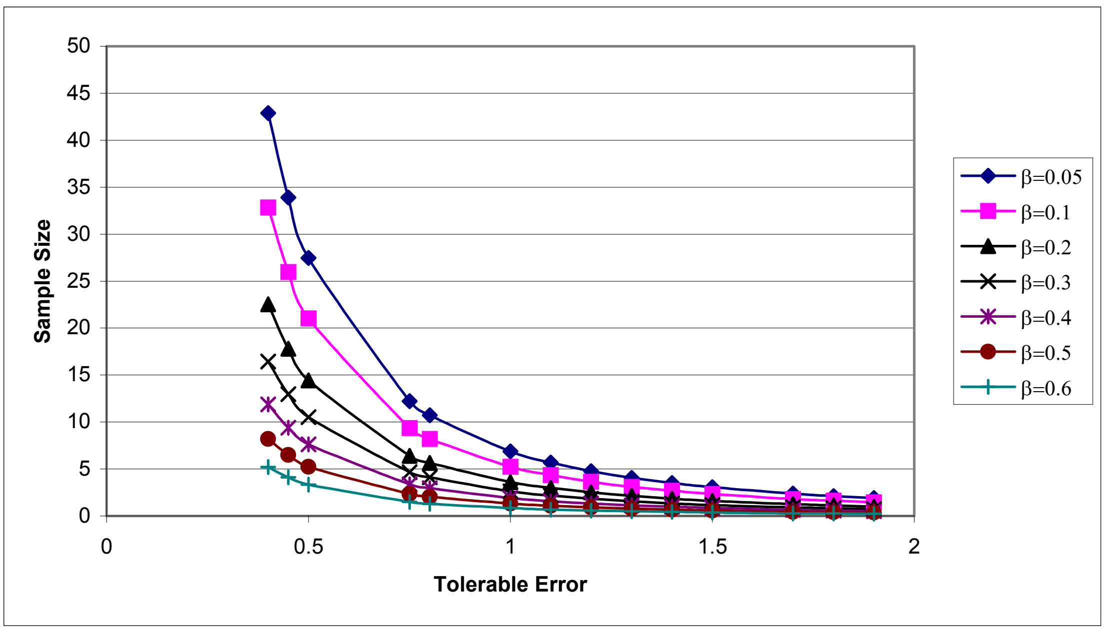


Figure B.42 Sample Size vs. Tolerable Error. Concrete for Pavements – Slump

Table B.43 Relationship Sample Size vs. Confidence Level.
Concrete for Pavements – Air Content

Conf. Level	Other Factors		Sample Size (n)						
	μ	4.5	$\beta=0.05$	$\beta=0.10$	$\beta=0.20$	$\beta=0.30$	$\beta=0.40$	$\beta=0.50$	$\beta=0.60$
99	σ	1.2	12	10	8	7	5	5	4
97	*e*	1.5	10	8	6	5	4	3	3
95			9	7	5	4	3	3	2
90			7	6	4	3	2	2	1
85			6	5	4	3	2	1	1
80			6	4	3	2	2	1	1
75			5	4	3	2	1	1	1
70			5	4	2	2	1	1	0
60			4	3	2	1	1	0	0
50			4	3	2	1	1	0	0
40			3	2	1	1	0	0	0
30			3	2	1	1	0	0	0
20			2	2	1	0	0	0	0
10			2	1	1	0	0	0	0
0			2	1	0	0	0	0	0

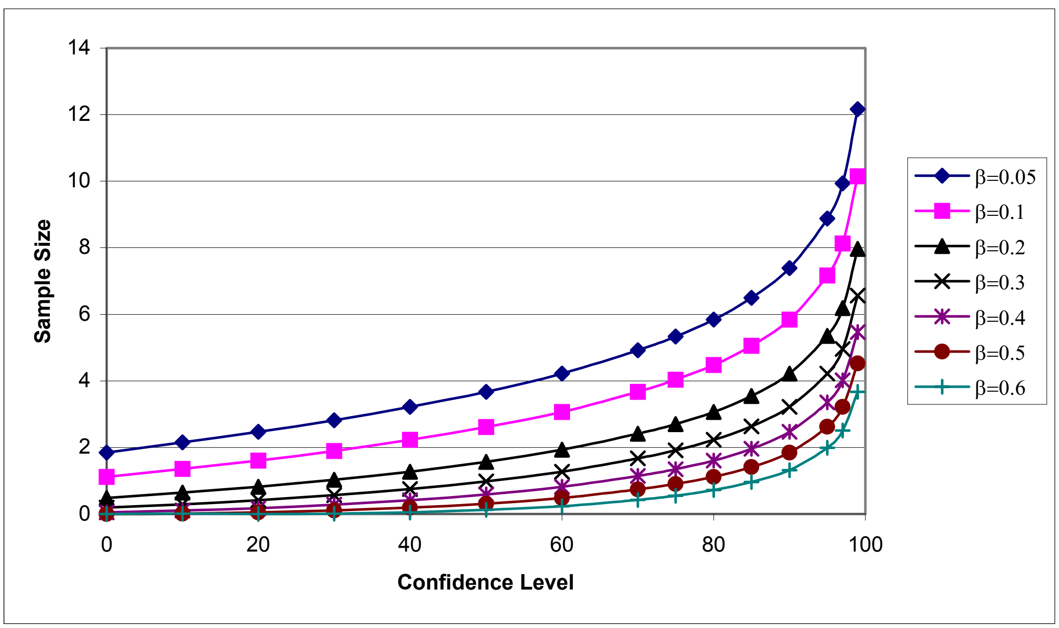


Figure B.43 Sample Size vs. Confidence Level.
Concrete for Pavements – Air Content

Table B.44 Relationship Sample Size vs. Tolerable Error. Concrete for Pavements – Air Content

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
0.5	$Z_{\alpha/2}$	1.28	53	40	28	20	15	10	6
0.6	μ	4.5	37	28	19	14	10	7	4
0.7	σ	1.2	27	21	14	10	7	5	3
0.8			21	16	11	8	6	4	2
0.9			16	12	9	6	4	3	2
1			13	10	7	5	4	3	2
1.1			11	8	6	4	3	2	1
1.2			9	7	5	3	3	2	1
1.3			8	6	4	3	2	1	1
1.4			7	5	4	3	2	1	1
1.5			6	4	3	2	2	1	1
2			3	3	2	1	1	1	0
2.5			2	2	1	1	1	0	0
3			1	1	1	1	0	0	0

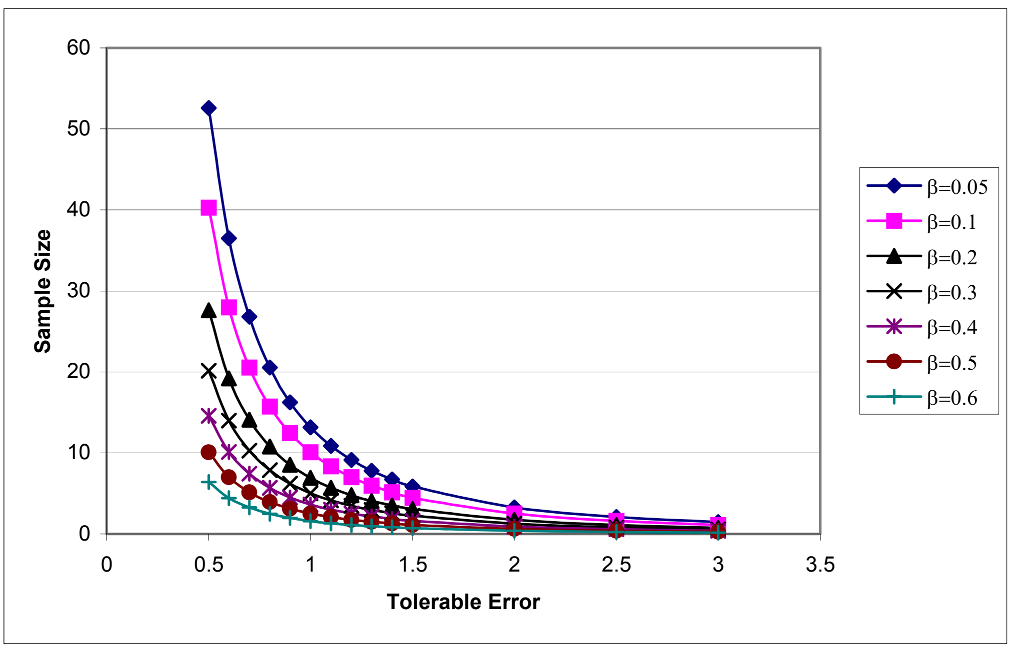


Figure B.44 Sample Size vs. Tolerable Error. Concrete for Pavements – Air Content.

Table B.45 Relationship Sample Size vs. Confidence Level.
Concrete for Structures 'Class S' -Flexural Strength 28 Days

Conf. Level	Other Factors		Sample Size (n)						
	μ	632	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	72.0	8	7	5	4	3	3	2
97	*e*	100	6	5	4	3	2	2	1
95			6	4	3	2	2	1	1
90			4	3	2	2	1	1	1
85			4	3	2	1	1	1	0
80			3	2	1	1	1	0	0
75			3	2	1	1	0	0	0
70			2	2	1	1	0	0	0
60			2	1	1	0	0	0	0
50			1	1	0	0	0	0	0
40			1	1	0	0	0	0	0

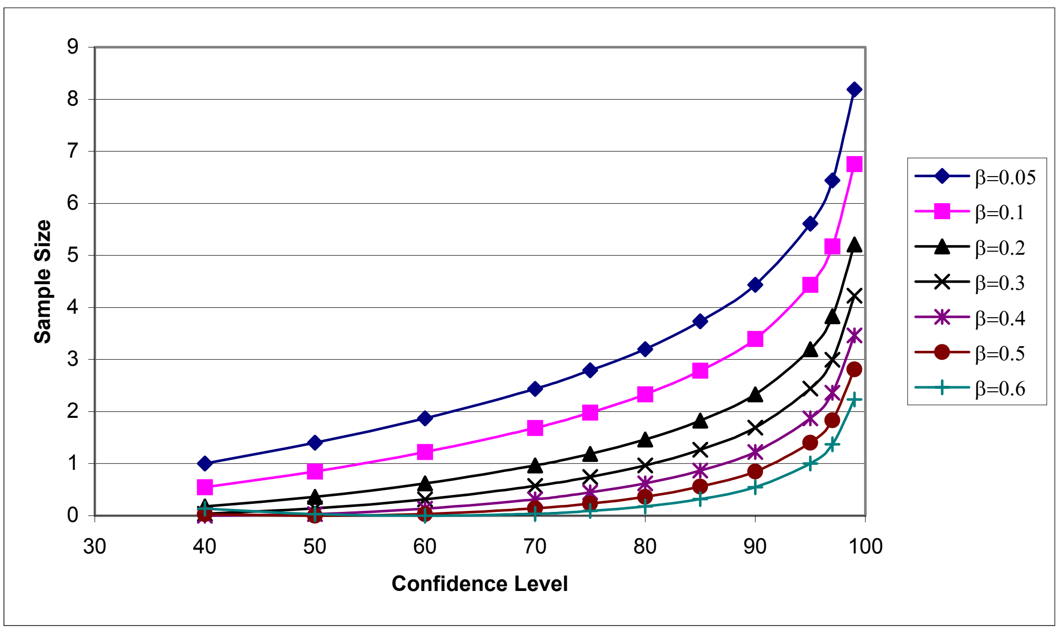


Figure B.45 Sample Size vs. Confidence Level.
Concrete for Structures 'Class S' -Flexural Strength 28 Days

Table B.46 Relationship Sample Size vs. Tolerable Error. Concrete for Structures 'Class S' - Flexural Strength 28 Days

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
30	Z_{α}	0.84	36	26	16	11	7	4	2
40	μ	632	20	15	9	6	4	2	1
50	σ	72.0	13	9	6	4	3	1	1
60			9	6	4	3	2	1	0
70			7	5	3	2	1	1	0
80			5	4	2	2	1	1	0
100			3	2	1	1	1	0	0
120			2	2	1	1	0	0	0
130			2	1	1	1	0	0	0
150			1	1	1	0	0	0	0
160			1	1	1	0	0	0	0
180			1	1	0	0	0	0	0
200			1	1	0	0	0	0	0
220			1	0	0	0	0	0	0

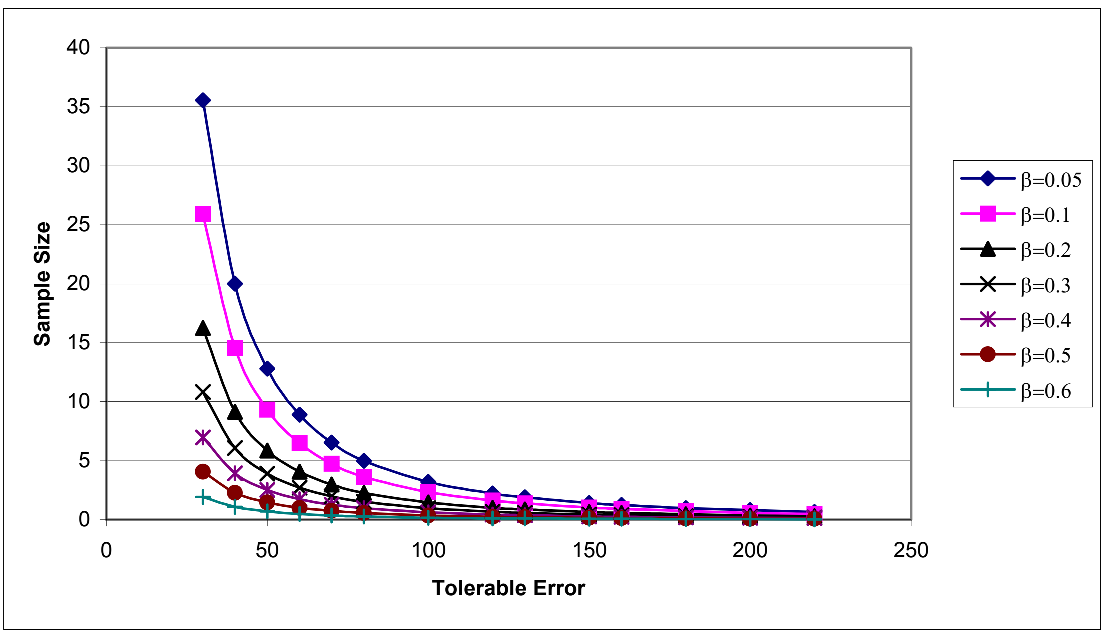


Figure B.46 Sample Size vs. Tolerable Error.
Concrete for Structures 'Class S' -Flexural Strength 28 Days

Table B.47 Relationship Sample Size vs. Confidence Level. Concrete for Structures 'Class S' –Air Content

Conf. Level	Other Factors		Sample Size (n)						
	μ	5.0	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	0.84	6	5	4	3	2	2	2
97	*e*	1.5	5	4	3	2	2	1	1
95			4	3	2	2	2	1	1
90			3	3	2	1	1	1	1
85			3	2	2	1	1	1	0
80			3	2	1	1	1	1	0
75			2	2	1	1	1	0	0
70			2	2	1	1	1	0	0
60			2	1	1	1	0	0	0
50			2	1	1	0	0	0	0
40			1	1	1	0	0	0	0
30			1	1	0	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

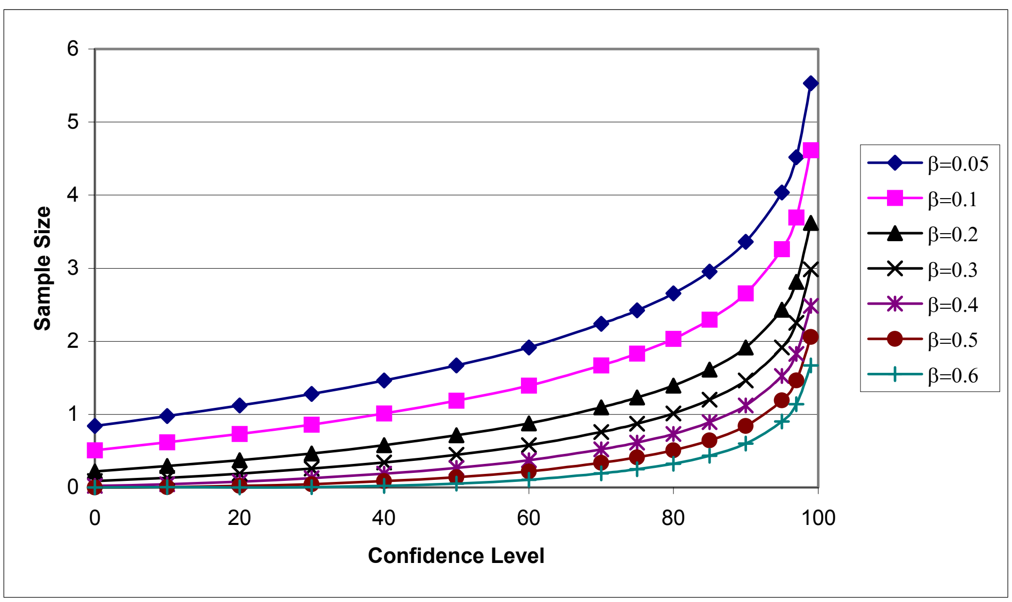


Figure B.47 Sample Size vs. Confidence Level. Concrete for Structures 'Class S' –Air Content

Table B.48 Relationship Sample Size vs. Tolerable Error.
Concrete for Structures 'Class S' – Air Content

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
0.5	$Z\ \alpha_{/2}$	1.28	24	18	13	9	7	5	3
0.6	μ	5.0	17	13	9	6	5	3	2
0.7	σ	0.8	12	9	6	5	3	2	1
0.8			9	7	5	4	3	2	1
0.9			7	6	4	3	2	1	1
1			6	5	3	2	2	1	1
1.1			5	4	3	2	1	1	1
1.2			4	3	2	2	1	1	1
1.3			4	3	2	1	1	1	0
1.4			3	2	2	1	1	1	0
1.5			3	2	1	1	1	1	0
2			1	1	1	1	0	0	0
2.5			1	1	1	0	0	0	0
3			1	1	0	0	0	0	0

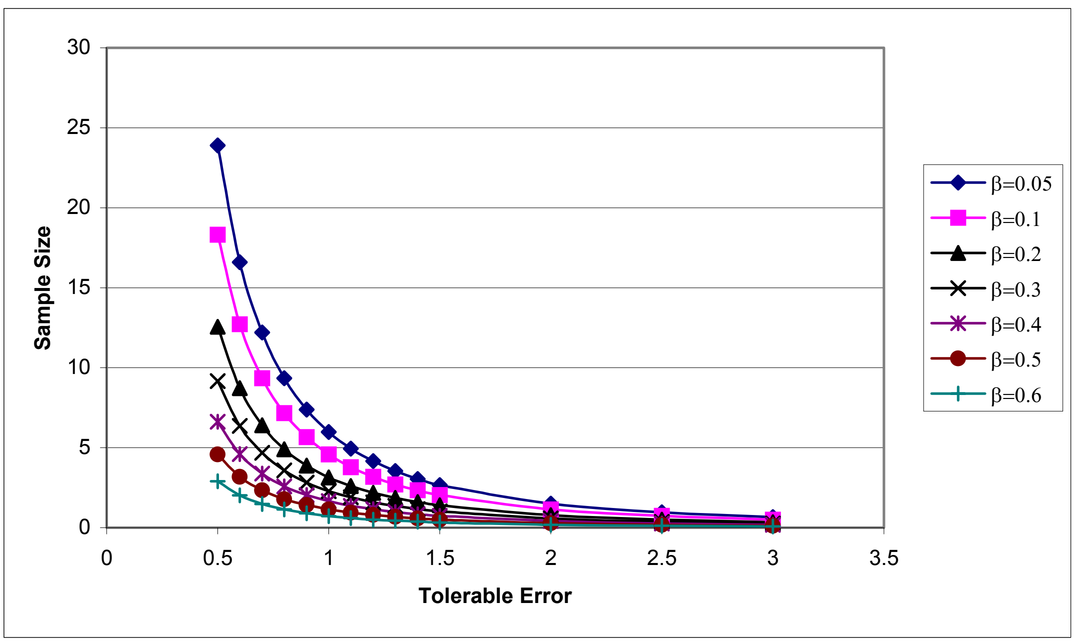


Figure B.48 Sample Size vs. Tolerable Error.
Concrete for Structures 'Class S' – Air Content

Table B.49 Relationship Sample Size vs. Confidence Level. Concrete for Structures "Class S"' - Slump

Conf. Level	Other Factors		Sample Size (n)						
	μ	4.5	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.166	11	9	7	6	5	4	3
97	*e*	1.5	9	7	5	4	4	3	2
95			8	6	5	4	3	2	2
90			7	5	4	3	2	2	1
85			6	4	3	2	2	1	1
80			5	4	3	2	1	1	1
75			5	4	2	2	1	1	0
70			4	3	2	1	1	1	0
60			4	3	2	1	1	0	0
50			3	2	1	1	1	0	0
40			3	2	1	1	0	0	0
30			2	2	1	1	0	0	0
20			2	1	1	0	0	0	0
10			2	1	1	0	0	0	0
0			2	1	0	0	0	0	0

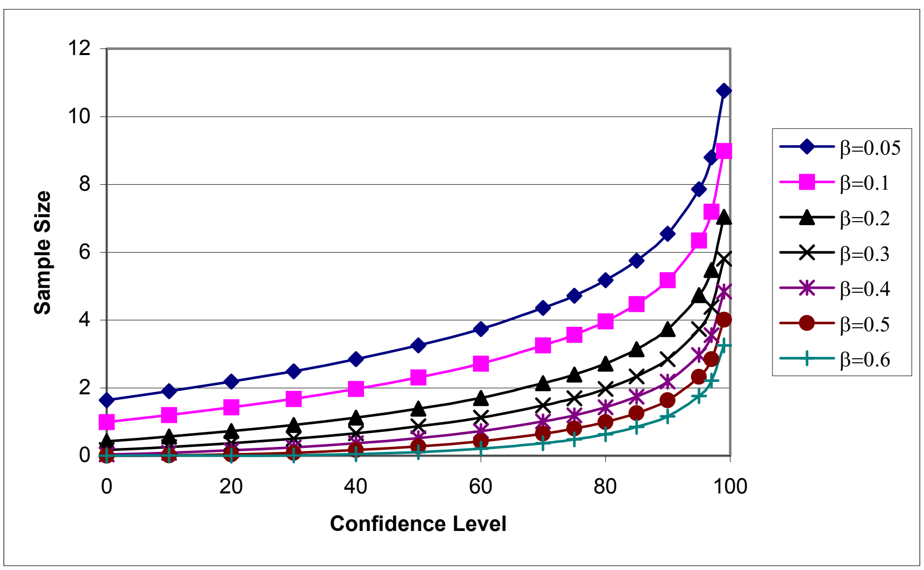


Figure B.49 Sample Size vs. Confidence Level. Concrete for Structures "Class S"' - Slump

Table B.50 Relationship Sample Size vs. Tolerable Error.
Concrete for Structures 'Class S' - Slump

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
0.4	$Z_{\alpha/2}$	1.28	73	56	38	28	20	14	9
0.45	μ	4.46	57	44	30	22	16	11	7
0.5	σ	1.17	47	36	24	18	13	9	6
0.75			21	16	11	8	6	4	3
0.8			18	14	10	7	5	3	2
1			12	9	6	4	3	2	1
1.1			10	7	5	4	3	2	1
1.2			8	6	4	3	2	2	1
1.3			7	5	4	3	2	1	1
1.4			6	5	3	2	2	1	1
1.5			5	4	3	2	1	1	1
1.7			4	3	2	2	1	1	0
1.8			4	3	2	1	1	1	0
1.9			3	2	2	1	1	1	0

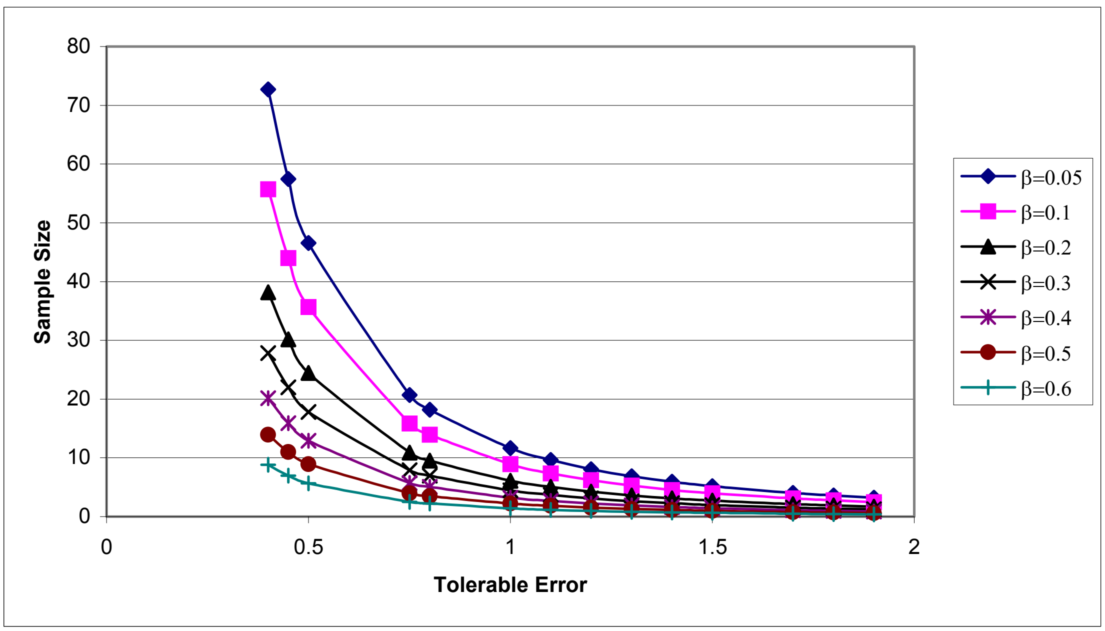


Figure B.50 Sample Size vs. Tolerable Error. Concrete for Structures 'Class S' - Slump

Table B.51 Relationship Sample Size vs. Confidence Level.
Concrete for Structures 'Class S' -Slump (Plant)

Conf. Level	Other Factors		Sample Size (n)						
	μ	5.4	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.48	10	8	6	5	4	4	3
97	*e*	2	8	7	5	4	3	3	2
95			7	6	4	3	3	2	2
90			6	5	3	3	2	1	1
85			5	4	3	2	2	1	1
80			5	4	2	2	1	1	1
75			4	3	2	2	1	1	0
70			4	3	2	1	1	1	0
60			3	2	2	1	1	0	0
50			3	2	1	1	0	0	0
40			3	2	1	1	0	0	0
30			2	2	1	0	0	0	0
20			2	1	1	0	0	0	0
10			2	1	1	0	0	0	0
0			1	1	0	0	0	0	0

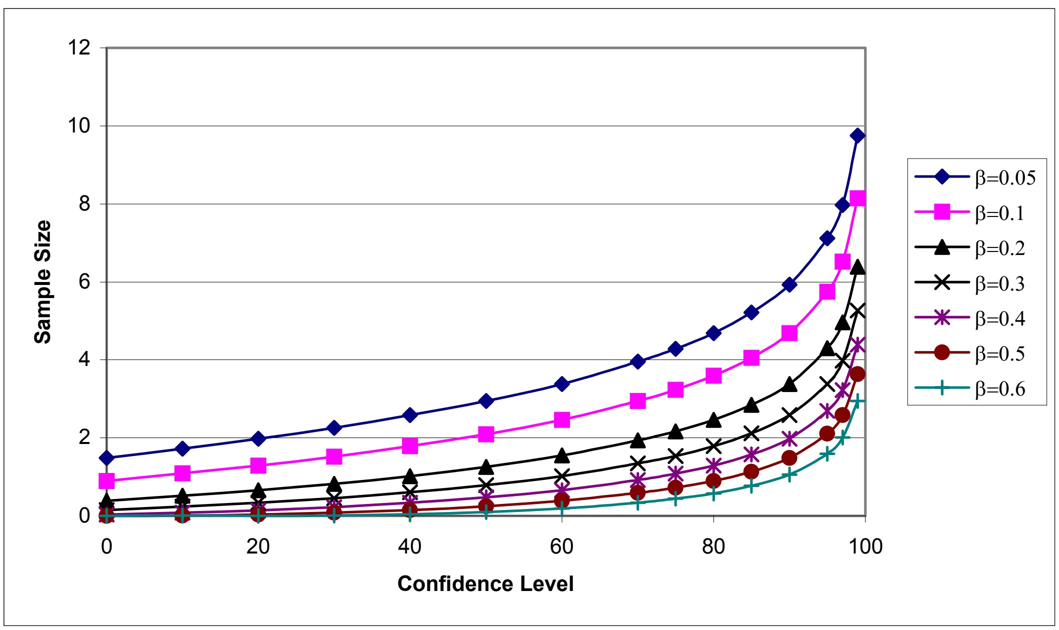


Figure B.51 Sample Size vs. Confidence Level. Concrete for Structures 'Class S' -Slump (Plant)

Table B.52 Relationship Sample Size vs. Tolerable Error.
Structures 'Class S' - Slump (Plant)

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
0.8	$Z_{\alpha/2}$	1.28	29	22	15	11	8	6	4
0.9	μ	5.36	23	18	12	9	6	4	3
1	σ	1.48	19	14	10	7	5	4	2
1.1			15	12	8	6	4	3	2
1.2			13	10	7	5	4	2	2
1.4			10	7	5	4	3	2	1
1.5			8	6	4	3	2	2	1
1.6			7	6	4	3	2	1	1
1.7			6	5	3	2	2	1	1
1.8			6	4	3	2	2	1	1
2			5	4	2	2	1	1	1
2.2			4	3	2	1	1	1	0
2.4			3	2	2	1	1	1	0
2.6			3	2	1	1	1	1	0

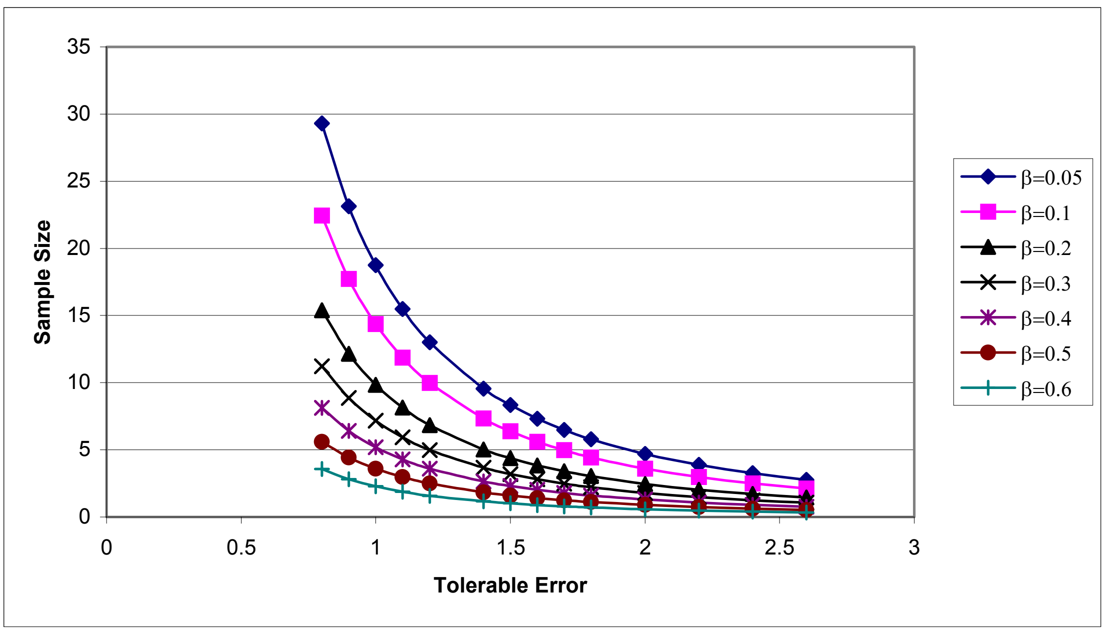


Figure B.52 Sample Size vs. Tolerable Error.
Structures 'Class S' - Slump (Plant)

Table B.53 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A1 - Gradation

Conf. Level	Other Factors		Sample Size (n)						
	μ	22	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	4.6	6	5	4	3	3	2	2
97	*e*	8	5	4	3	2	2	2	1
95			4	3	3	2	2	1	1
90			4	3	2	2	1	1	1
85			3	2	2	1	1	1	0
80			3	2	1	1	1	1	0
75			3	2	1	1	1	0	0
70			2	2	1	1	1	0	0
60			2	1	1	1	0	0	0
50			2	1	1	0	0	0	0
40			2	1	1	0	0	0	0
30			1	1	0	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

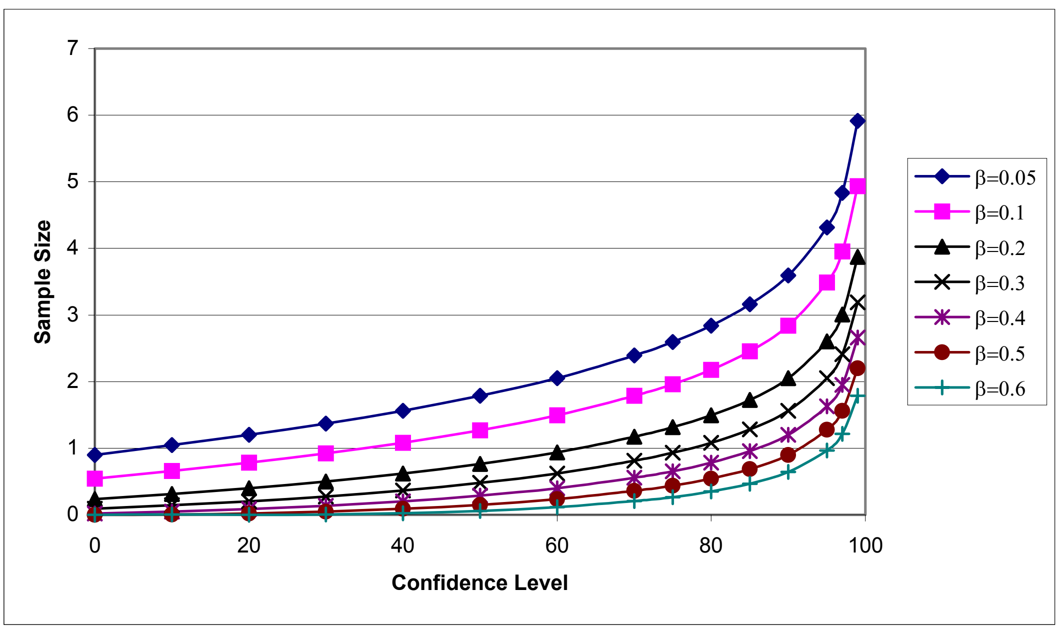


Figure B.53 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A1 - Gradation

Table B.54 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A1 - Gradation

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
3	$Z_{\alpha/2}$	1.28	20	15	11	8	6	4	2
3.5	μ	22	15	11	8	6	4	3	2
4	σ	4.61	11	9	6	4	3	2	1
4.5			9	7	5	3	2	2	1
4.75			8	6	4	3	2	2	1
5			7	6	4	3	2	1	1
5.25			7	5	3	3	2	1	1
5.5			6	5	3	2	2	1	1
6			5	4	3	2	1	1	1
6.5			4	3	2	2	1	1	1
7			4	3	2	1	1	1	0
7.5			3	2	2	1	1	1	0
8			3	2	1	1	1	1	0
9			2	2	1	1	1	0	0

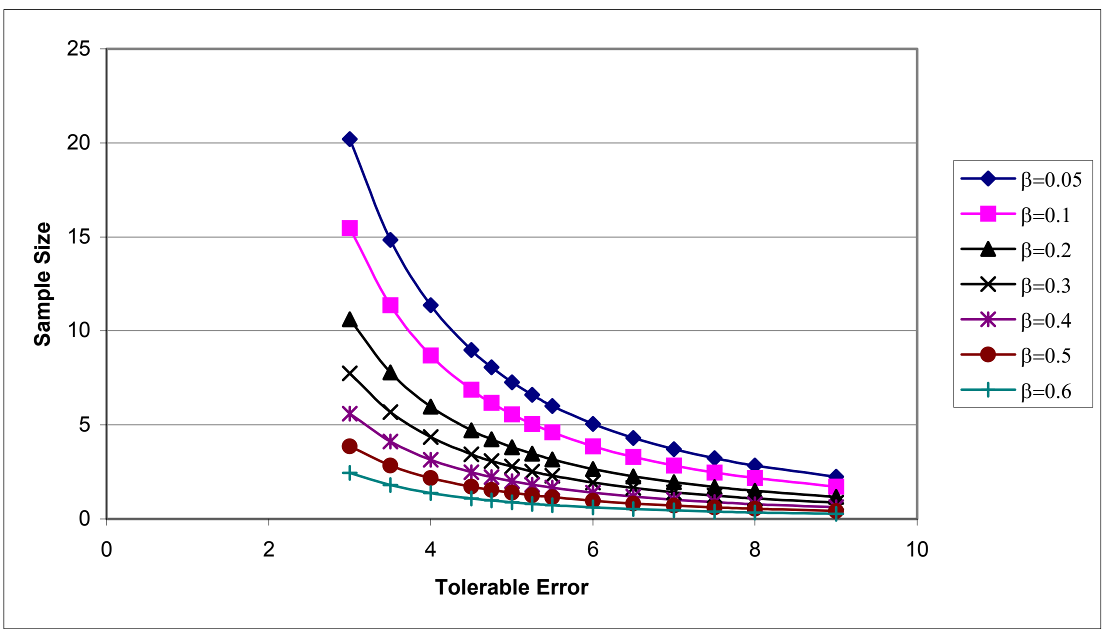


Figure B.54 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A1 - Gradation

Table B.55 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A2 - Gradation

Conf. Level	Other Factors		Sample Size (n)						
	μ	59	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	3.6	3	2	2	2	1	1	1
97	*e*	9	2	2	1	1	1	1	1
95			2	2	1	1	1	1	0
90			2	1	1	1	1	0	0
85			2	1	1	1	0	0	0
80			1	1	1	1	0	0	0
75			1	1	1	0	0	0	0
70			1	1	1	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	1	0	0	0	0	0
30			1	0	0	0	0	0	0
20			1	0	0	0	0	0	0
10			1	0	0	0	0	0	0
0			0	0	0	0	0	0	0

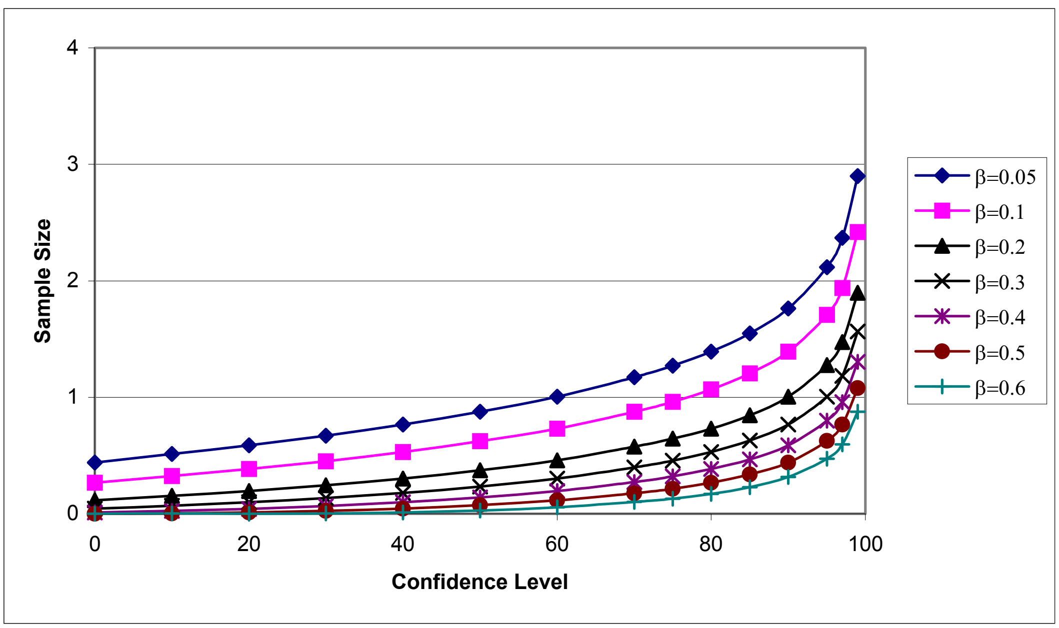


Figure B.55 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A2 - Gradation

Table B.56 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A2 - Gradation

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
3	$Z_{\alpha/2}$	1.28	13	10	7	5	3	2	2
3.5	μ	59	9	7	5	4	3	2	1
4	σ	3.63	7	5	4	3	2	1	1
4.5			6	4	3	2	2	1	1
5			5	3	2	2	1	1	1
5.5			4	3	2	1	1	1	0
6			3	2	2	1	1	1	0
6.5			3	2	1	1	1	1	0
7			2	2	1	1	1	0	0
7.5			2	2	1	1	1	0	0
8			2	1	1	1	0	0	0
8.5			2	1	1	1	0	0	0
9			1	1	1	1	0	0	0
10			1	1	1	0	0	0	0

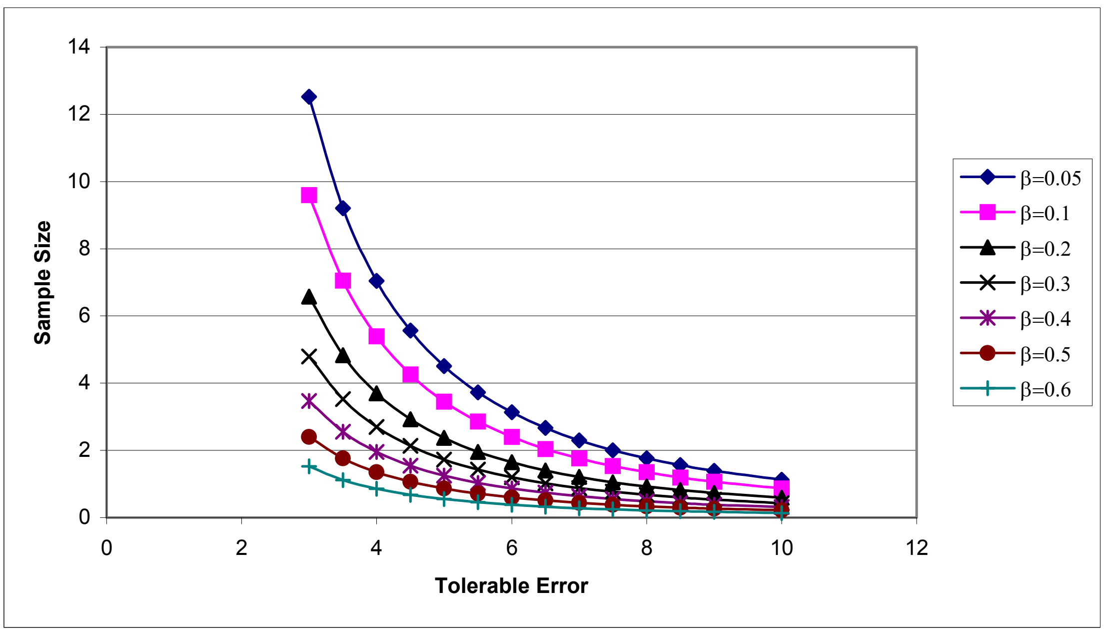


Figure B.56 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A2 - Gradation

Table B.57 Relationship Sample Size vs. Confidence Level. Sub-base and base courses. Material Group A4 - Gradation

Conf. Level	Other Factors		Sample Size (n)						
	μ	22	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	4.7	6	5	4	3	3	2	2
97	*e*	8	5	4	3	3	2	2	1
95			5	4	3	2	2	1	1
90			4	3	2	2	1	1	1
85			3	3	2	1	1	1	0
80			3	2	2	1	1	1	0
75			3	2	1	1	1	0	0
70			3	2	1	1	1	0	0
60			2	2	1	1	0	0	0
50			2	1	1	1	0	0	0
40			2	1	1	0	0	0	0
30			1	1	1	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

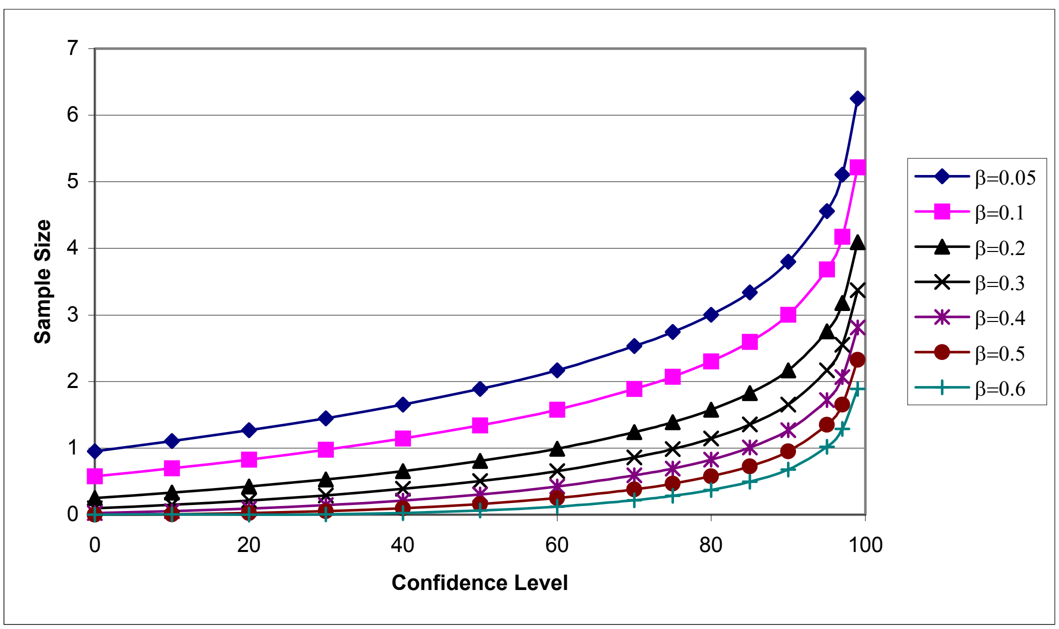


Figure B.57 Sample Size vs. Confidence Level. Sub-base and base courses. Material Group A4 - Gradation

Table B.58 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A4 – Gradation

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
3	$Z_{\alpha/2}$	1.28	21	16	11	8	6	4	3
3.5	μ	22	16	12	8	6	4	3	2
4	σ	4.74	12	9	6	5	3	2	1
4.5			9	7	5	4	3	2	1
5			8	6	4	3	2	1	1
5.5			6	5	3	2	2	1	1
6			5	4	3	2	1	1	1
6.5			5	3	2	2	1	1	1
7			4	3	2	2	1	1	0
7.5			3	3	2	1	1	1	0
8			3	2	2	1	1	1	0
8.5			3	2	1	1	1	1	0
9			2	2	1	1	1	0	0
10			2	1	1	1	1	0	0

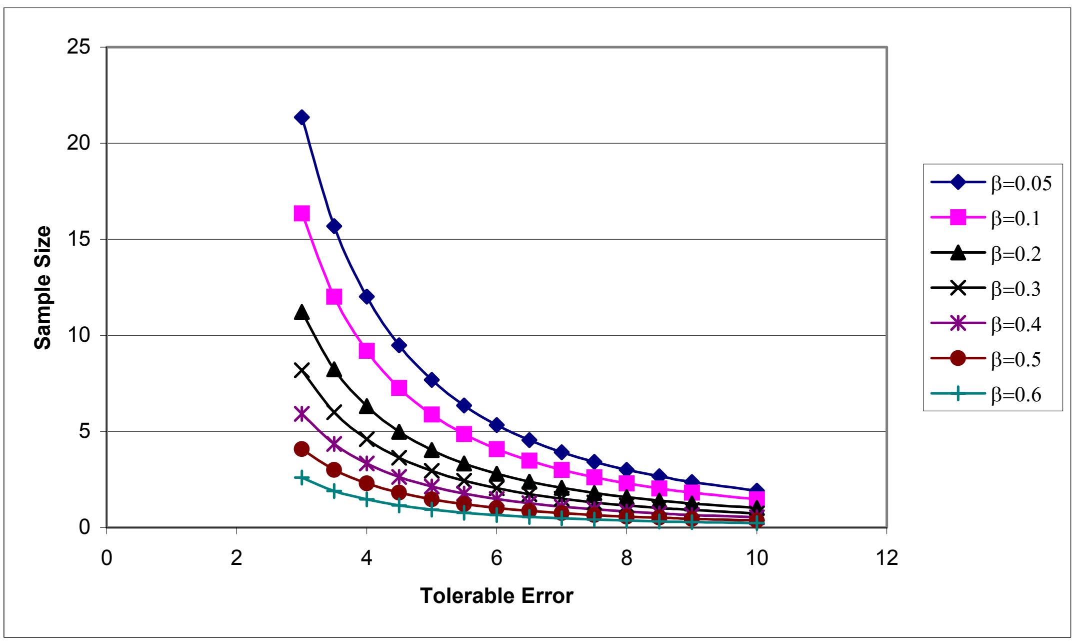


Figure B.58 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A4 – Gradation

Table B.59 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group D6 - Gradation

Conf. Level	Other Factors		Sample Size (n)						
	μ	20	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	5.5	7	6	4	4	3	2	2
97	*e*	9	5	4	3	3	2	2	1
95			5	4	3	2	2	1	1
90			4	3	2	2	1	1	1
85			4	3	2	1	1	1	1
80			3	2	2	1	1	1	0
75			3	2	1	1	1	0	0
70			3	2	1	1	1	0	0
60			2	2	1	1	0	0	0
50			2	1	1	1	0	0	0
40			2	1	1	0	0	0	0
30			2	1	1	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

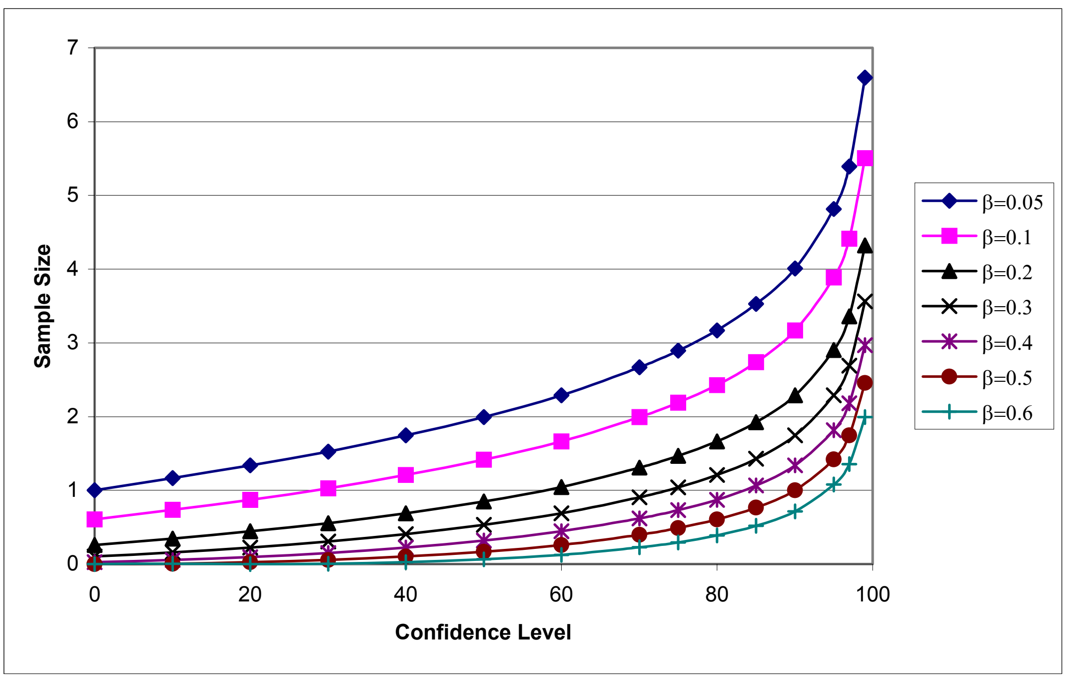
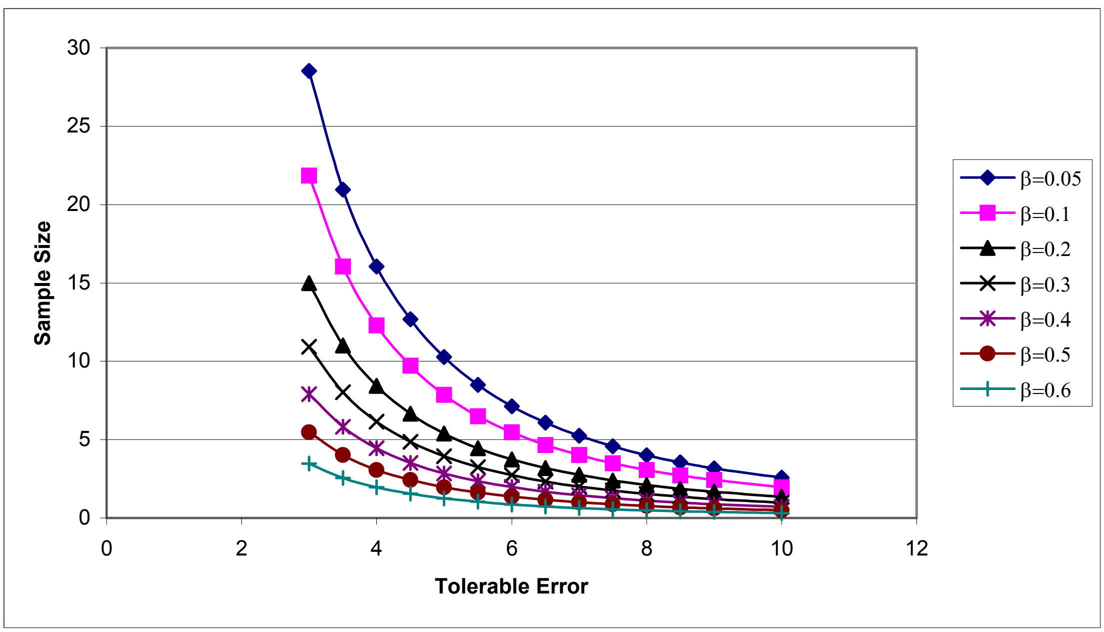


Figure B.59 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group D6 - Gradation

Table B.60 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group D6 – Gradation

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
3	$Z_{\alpha/2}$	1.28	29	22	15	11	8	5	3
3.5	μ	20	21	16	11	8	6	4	3
4	σ	5.48	16	12	8	6	4	3	2
4.5			13	10	7	5	4	2	2
5			10	8	5	4	3	2	1
5.5			8	7	4	3	2	2	1
6			7	5	4	3	2	1	1
6.5			6	5	3	2	2	1	1
7			5	4	3	2	1	1	1
7.5			5	3	2	2	1	1	1
8			4	3	2	2	1	1	0
8.5			4	3	2	1	1	1	0
9			3	2	2	1	1	1	0
10			3	2	1	1	1	0	0



FigureB.60 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group D6 – Gradation

Table B.61 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A1 –Liquid Limit

Conf. Level	Other Factors		Sample Size (n)						
	μ	20	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.7	2	2	1	1	1	1	1
97	*e*	5	2	1	1	1	1	1	0
95			2	1	1	1	1	0	0
90			1	1	1	1	0	0	0
85			1	1	1	0	0	0	0
80			1	1	1	0	0	0	0
75			1	1	0	0	0	0	0
70			1	1	0	0	0	0	0
60			1	1	0	0	0	0	0
50			1	0	0	0	0	0	0
40			1	0	0	0	0	0	0
30			0	0	0	0	0	0	0
20			0	0	0	0	0	0	0
10			0	0	0	0	0	0	0
0			0	0	0	0	0	0	0

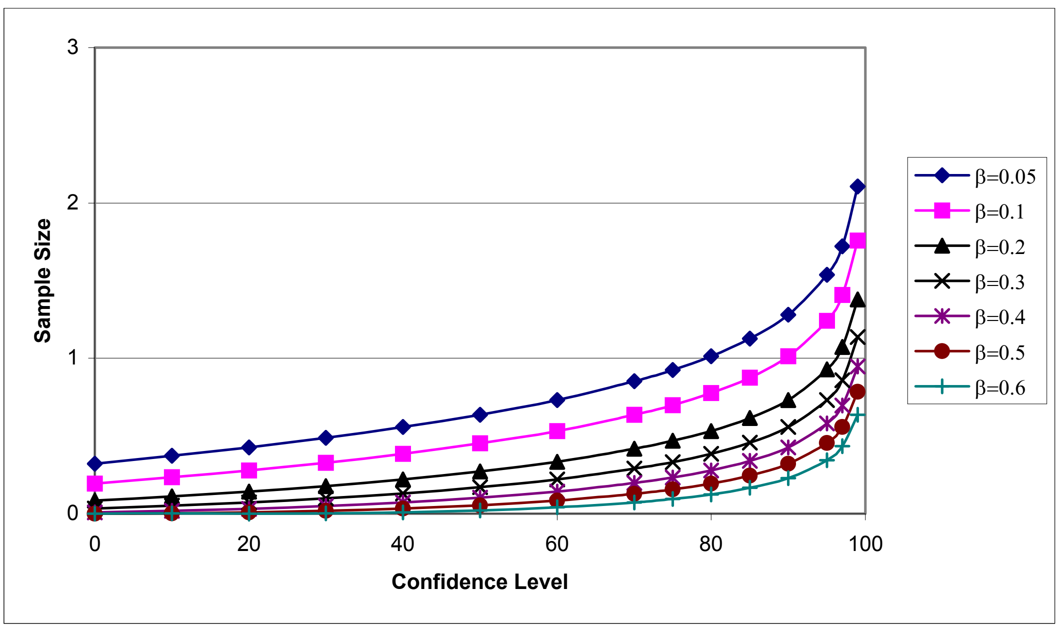


Figure B.61 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A1 –Liquid Limit

**Table B.62 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A1 –Liquid Limit**

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
1	$Z_{\alpha/2}$	1.28	25	19	13	10	7	5	3
1.5	μ	20	11	9	6	4	3	2	1
2	σ	1.72	6	5	3	2	2	1	1
2.5			4	3	2	2	1	1	0
3			3	2	1	1	1	1	0
3.5			2	2	1	1	1	0	0
4			2	1	1	1	0	0	0
4.5			1	1	1	0	0	0	0
5			1	1	1	0	0	0	0
5.5			1	1	0	0	0	0	0
6			1	1	0	0	0	0	0
6.5			1	0	0	0	0	0	0
7			1	0	0	0	0	0	0
7.5			0	0	0	0	0	0	0

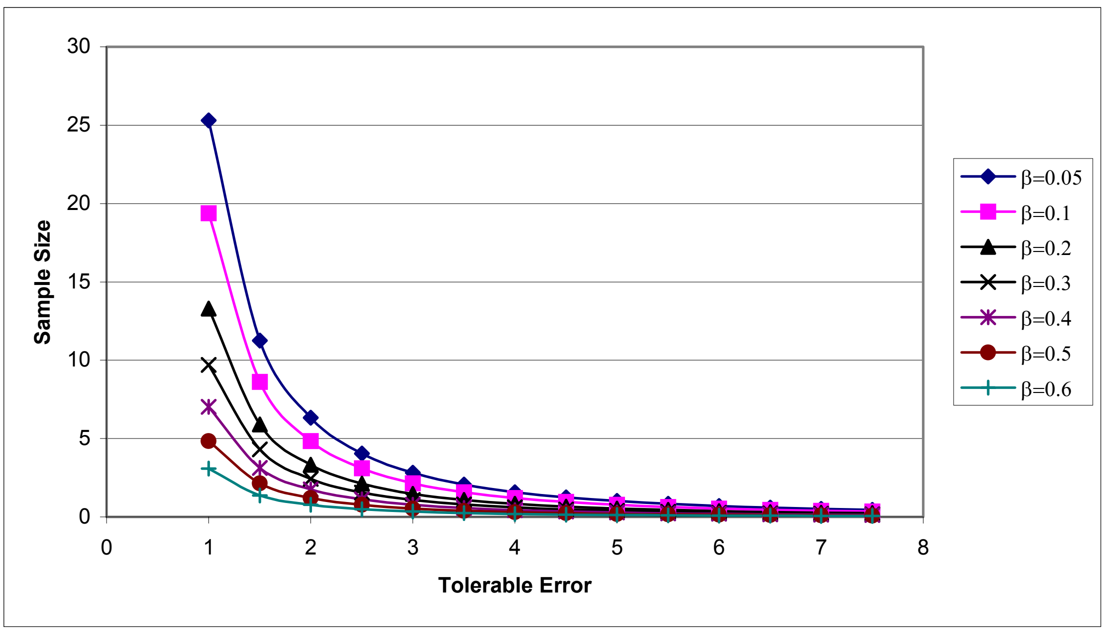


**Figure B.62 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A1 –Liquid Limit**

Table B.63 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A2 –Liquid Limit

Conf. Level	Other Factors		Sample Size (n)						
	μ	21	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.9	3	2	2	1	1	1	1
97	*e*	5	2	2	1	1	1	1	1
95			2	1	1	1	1	1	0
90			2	1	1	1	1	0	0
85			1	1	1	1	0	0	0
80			1	1	1	0	0	0	0
75			1	1	1	0	0	0	0
70			1	1	0	0	0	0	0
60			1	1	0	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0
30			1	0	0	0	0	0	0
20			1	0	0	0	0	0	0
10			0	0	0	0	0	0	0
0			0	0	0	0	0	0	0

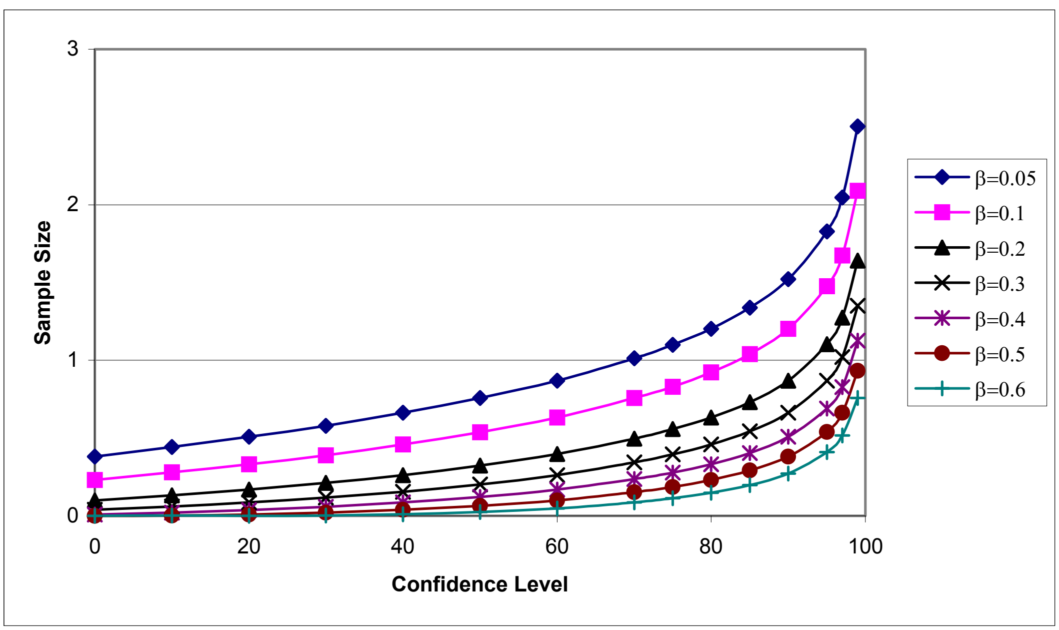


Figure B.63 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A2 –Liquid Limit

Table B.64 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A2 –Liquid Limit

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
1	$Z_{\alpha/2}$	1.28	30	23	16	12	8	6	4
1.5	μ	21	13	10	7	5	4	3	2
2	σ	1.88	8	6	4	3	2	1	1
2.5			5	4	3	2	1	1	1
3			3	3	2	1	1	1	0
3.5			2	2	1	1	1	0	0
4			2	1	1	1	1	0	0
4.5			1	1	1	1	0	0	0
5			1	1	1	0	0	0	0
5.5			1	1	1	0	0	0	0
6			1	1	0	0	0	0	0
6.5			1	1	0	0	0	0	0
7			1	0	0	0	0	0	0
7.5			1	0	0	0	0	0	0

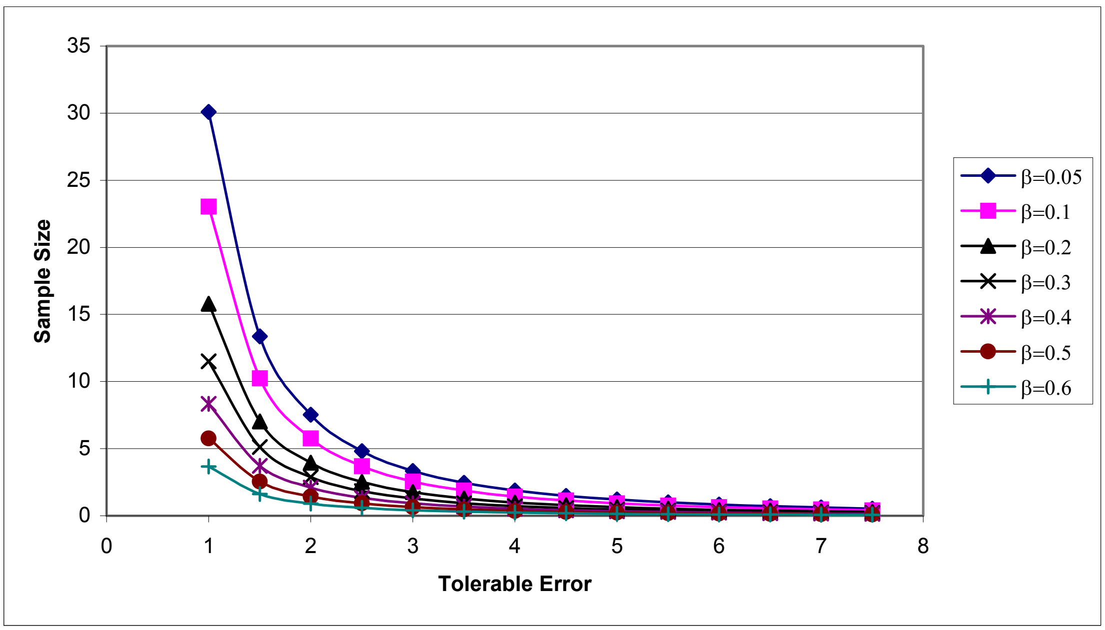


Figure B.64 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A2 –Liquid Limit

Table B.65 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A4 –Liquid Limit

Conf. Level	Other Factors		Sample Size (n)						
	μ	21	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	2.2	3	3	2	2	2	1	1
97	*e*	5	3	2	2	1	1	1	1
95			2	2	1	1	1	1	1
90			2	2	1	1	1	1	0
85			2	1	1	1	1	0	0
80			2	1	1	1	0	0	0
75			1	1	1	1	0	0	0
70			1	1	1	0	0	0	0
60			1	1	1	0	0	0	0
50			1	1	0	0	0	0	0
40			1	1	0	0	0	0	0
30			1	1	0	0	0	0	0
20			1	0	0	0	0	0	0
10			1	0	0	0	0	0	0
0			1	0	0	0	0	0	0

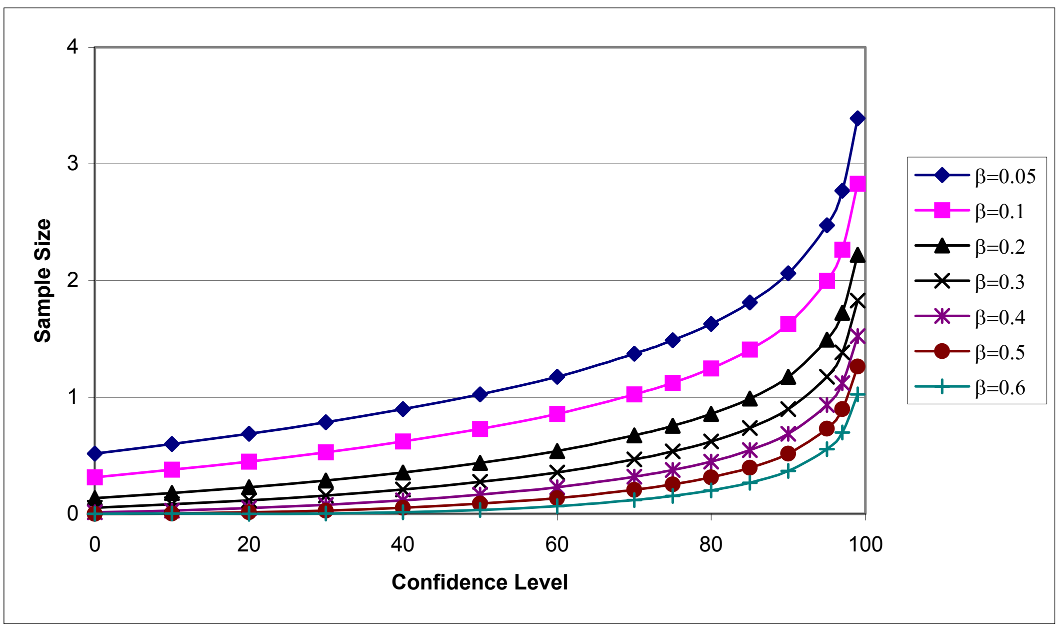


Figure B.65 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A4 –Liquid Limit

Table B.66 Relationship Sample Size vs. Tolerable Error. Sub-base and base courses. Material Group A4 –Liquid Limit

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
1	$Z_{\alpha/2}$	1.28	41	31	21	16	11	8	5
1.5	μ	21	18	14	10	7	5	3	2
2	σ	2.18	10	8	5	4	3	2	1
2.5			7	5	3	2	2	1	1
3			5	3	2	2	1	1	1
3.5			3	3	2	1	1	1	0
4			3	2	1	1	1	0	0
4.5			2	2	1	1	1	0	0
5			2	1	1	1	0	0	0
5.5			1	1	1	1	0	0	0
6			1	1	1	0	0	0	0
6.5			1	1	1	0	0	0	0
7			1	1	0	0	0	0	0
7.5			1	1	0	0	0	0	0

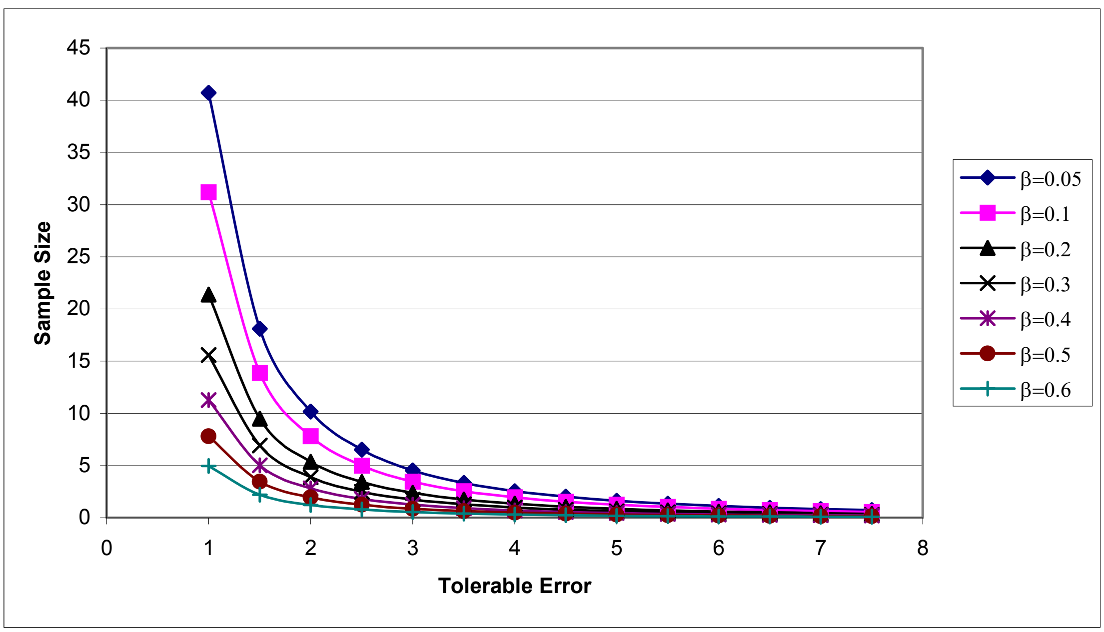


Figure B.66 Sample Size vs. Tolerable Error. Sub-base and base courses. Material Group A4 –Liquid Limit

Table B.67 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group D6 –Liquid Limit

Conf. Level	Other Factors		Sample Size (n)						
	μ	20	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	2.8	6	5	4	3	3	2	2
97	*e*	5	5	4	3	2	2	1	1
95			4	3	2	2	2	1	1
90			3	3	2	1	1	1	1
85			3	2	2	1	1	1	0
80			3	2	1	1	1	1	0
75			2	2	1	1	1	0	0
70			2	2	1	1	1	0	0
60			2	1	1	1	0	0	0
50			2	1	1	0	0	0	0
40			1	1	1	0	0	0	0
30			1	1	0	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

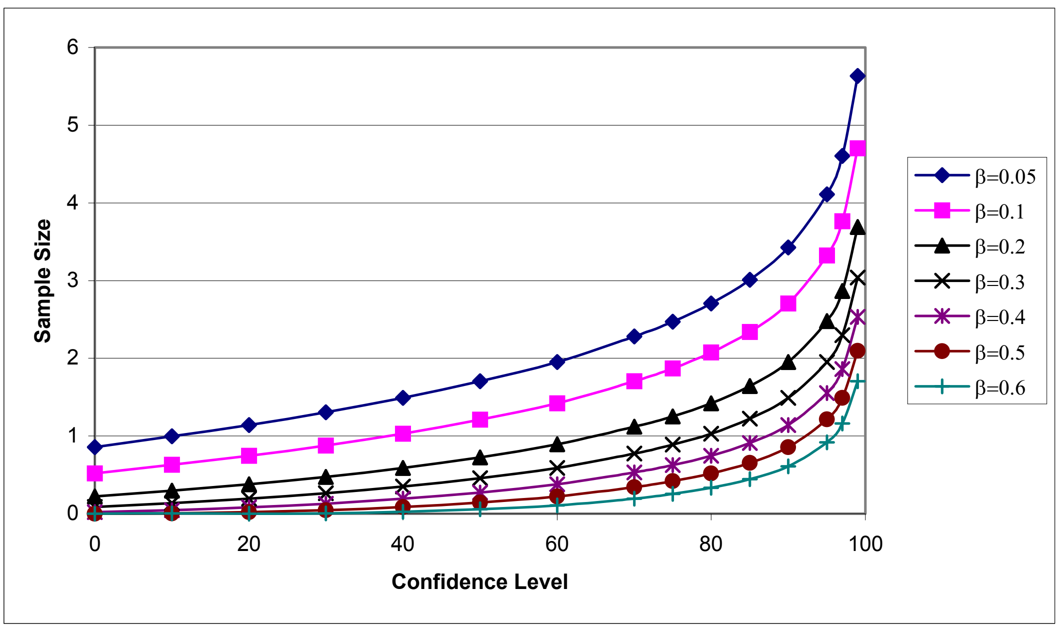


Figure B.67 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group D6 –Liquid Limit

Table B.68 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group D6 –Liquid Limit

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
1	$Z_{\alpha/2}$	1.28	68	52	36	26	19	13	8
1.5	μ	20	30	23	16	12	8	6	4
2	σ	2.81	17	13	9	6	5	3	2
2.5			11	8	6	4	3	2	1
3			8	6	4	3	2	1	1
3.5			6	4	3	2	2	1	1
4			4	3	2	2	1	1	1
4.5			3	3	2	1	1	1	0
5			3	2	1	1	1	1	0
5.5			2	2	1	1	1	0	0
6			2	1	1	1	1	0	0
6.5			2	1	1	1	0	0	0
7			1	1	1	1	0	0	0
7.5			1	1	1	0	0	0	0

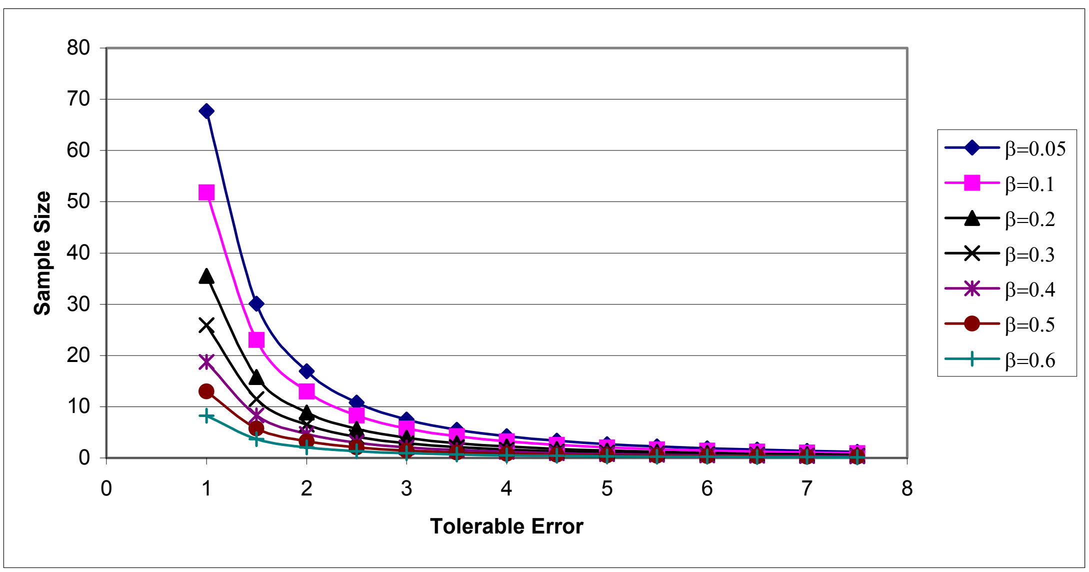


Figure B.68 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group D6 –Liquid Limit

**Table B.69 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A1 –Plasticity Index**

Conf. Level	Other Factors		Sample Size (n)						
	μ	6	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.7	2	2	1	1	1	1	1
97	*e*	5	2	1	1	1	1	1	0
95			2	1	1	1	1	0	0
90			1	1	1	1	0	0	0
85			1	1	1	0	0	0	0
80			1	1	1	0	0	0	0
75			1	1	0	0	0	0	0
70			1	1	0	0	0	0	0
60			1	1	0	0	0	0	0
50			1	0	0	0	0	0	0
40			1	0	0	0	0	0	0
30			0	0	0	0	0	0	0
20			0	0	0	0	0	0	0
10			0	0	0	0	0	0	0
0			0	0	0	0	0	0	0

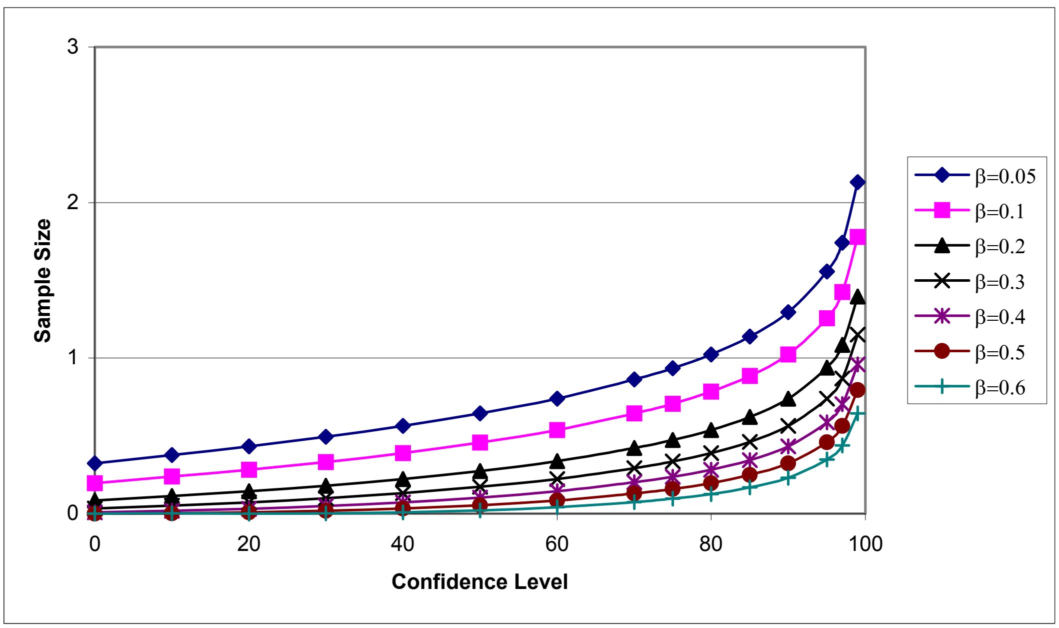


**Figure B.69 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A1 –Plasticity Index**

Table B.70 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A1 –Plasticity Index

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
1	$Z_{\alpha/2}$	1.28	26	20	13	10	7	5	3
1.5	μ	6	11	9	6	4	3	2	1
2	σ	1.73	6	5	3	2	2	1	1
2.5			4	3	2	2	1	1	0
3			3	2	1	1	1	1	0
3.5			2	2	1	1	1	0	0
4			2	1	1	1	0	0	0
4.5			1	1	1	0	0	0	0
5			1	1	1	0	0	0	0
5.5			1	1	0	0	0	0	0
6			1	1	0	0	0	0	0
6.5			1	0	0	0	0	0	0
7			1	0	0	0	0	0	0
7.5			0	0	0	0	0	0	0

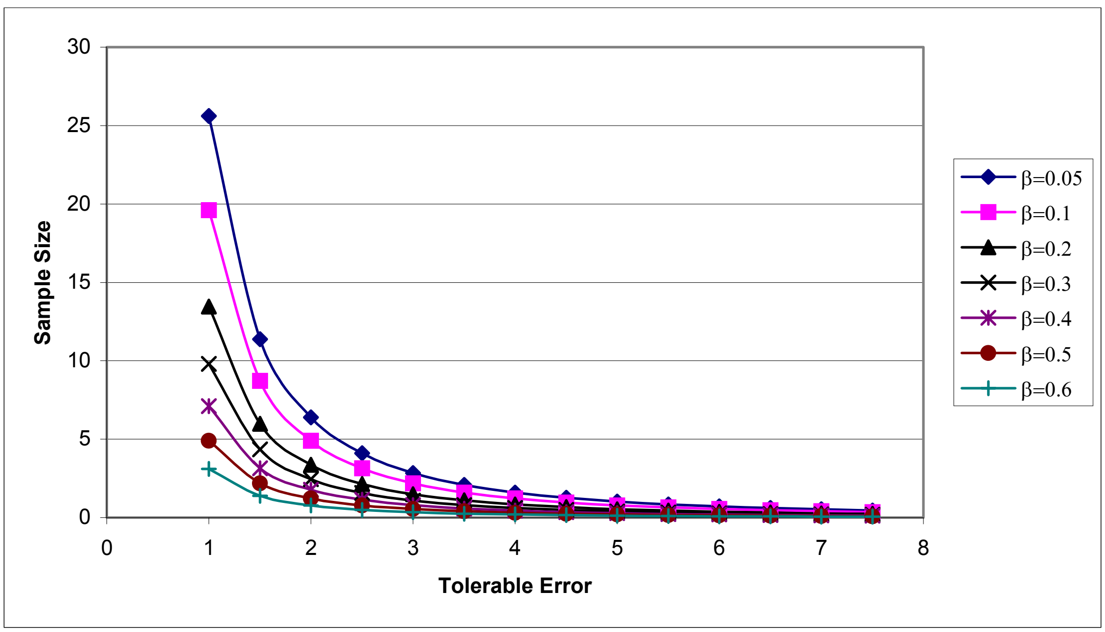


Figure B.70 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A1 –Plasticity Index

Table B.71 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A2 –Plasticity Index

Conf. Level	Other Factors		Sample Size (n)						
	μ	4	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
99	σ	1.7	4	3	3	2	2	1	1
97	*e*	3.5	3	3	2	2	1	1	1
95			3	2	2	1	1	1	1
90			2	2	1	1	1	1	0
85			2	2	1	1	1	0	0
80			2	1	1	1	1	0	0
75			2	1	1	1	0	0	0
70			2	1	1	1	0	0	0
60			1	1	1	0	0	0	0
50			1	1	1	0	0	0	0
40			1	1	0	0	0	0	0
30			1	1	0	0	0	0	0
20			1	1	0	0	0	0	0
10			1	0	0	0	0	0	0
0			1	0	0	0	0	0	0

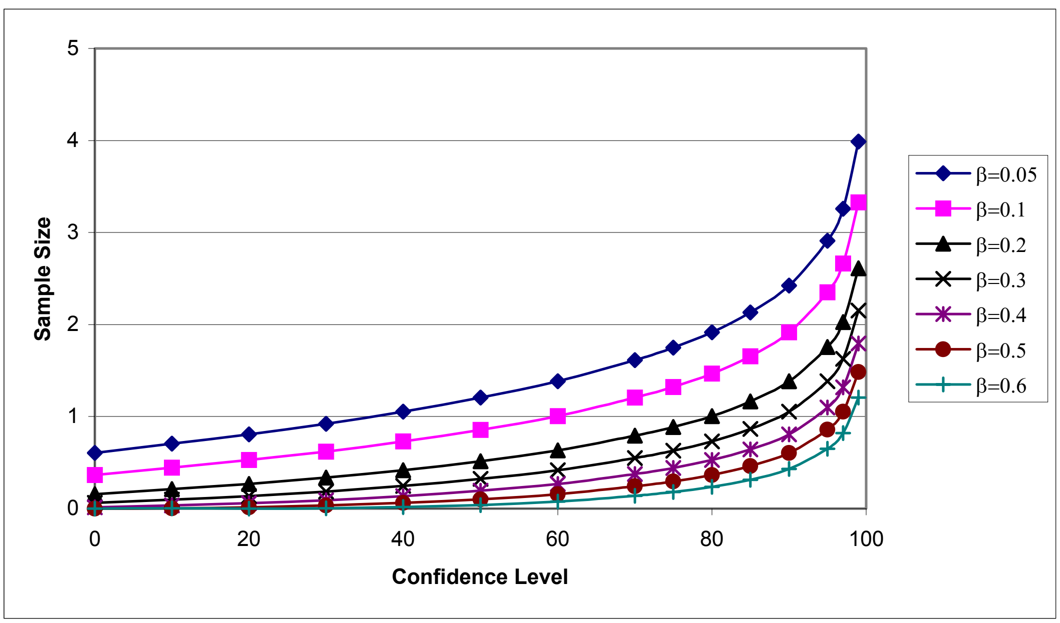


Figure B.71 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A2 –Plasticity Index

Table B.72 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A2 –Plasticity Index

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
1	$Z_{\alpha/2}$	1.28	23	18	12	9	7	4	3
1.5	μ	4	10	8	5	4	3	2	1
1.6	σ	1.66	9	7	5	4	3	2	1
1.7			8	6	4	3	2	2	1
1.8			7	6	4	3	2	1	1
1.9			6	5	3	2	2	1	1
2			6	4	3	2	2	1	1
2.1			5	4	3	2	1	1	1
2.2			5	4	3	2	1	1	1
2.3			4	3	2	2	1	1	1
2.5			4	3	2	1	1	1	0
3			3	2	1	1	1	0	0
3.5			2	1	1	1	1	0	0
4			1	1	1	1	0	0	0

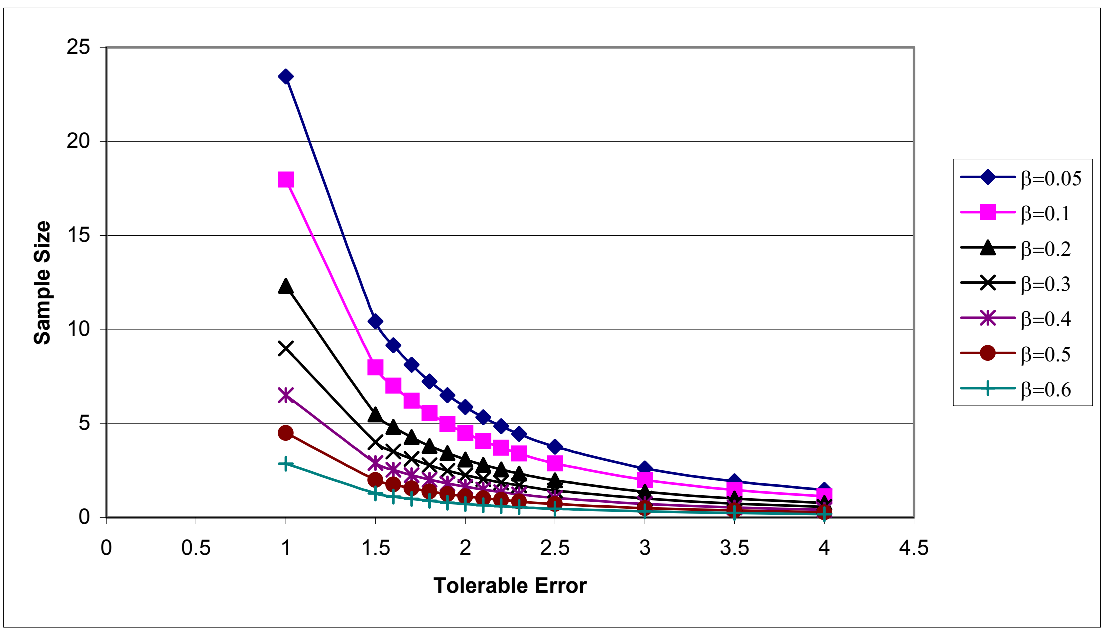


Figure B.72 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A2 –Plasticity Index

Table B.73 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A4 –Plasticity Index

Conf. Level	Other Factors		Sample Size (n)						
	μ	4.7	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	2.2	7	6	4	4	3	3	2
97	*e*	3.5	6	5	3	3	2	2	1
95			5	4	3	2	2	1	1
90			4	3	2	2	1	1	1
85			4	3	2	1	1	1	1
80			3	2	2	1	1	1	0
75			3	2	2	1	1	1	0
70			3	2	1	1	1	0	0
60			2	2	1	1	0	0	0
50			2	1	1	1	0	0	0
40			2	1	1	0	0	0	0
30			2	1	1	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

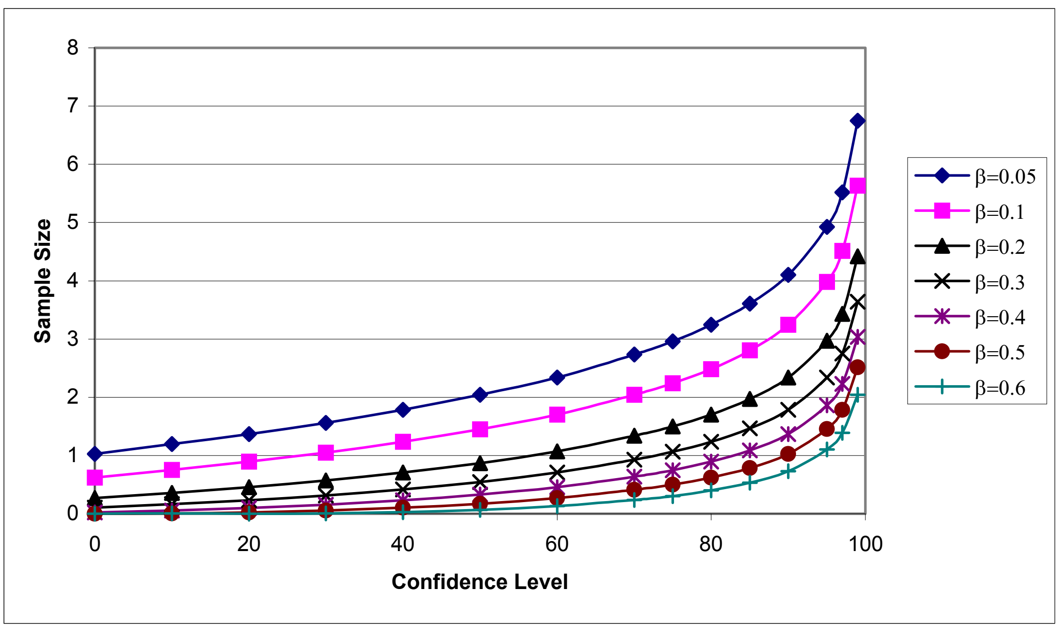


Figure B.73 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A4 –Plasticity Index

Table .B.74 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A4 –Plasticity Index

e	Other Factors		Sample Size (n)						
	α	0.2	$\beta = 0.05$	$\beta = 0.10$	$\beta = 0.20$	$\beta = 0.30$	$\beta = 0.40$	$\beta = 0.50$	$\beta = 0.60$
1	$Z_{\alpha/2}$	1.28	40	30	21	15	11	8	5
1.5	μ	4.7	18	14	9	7	5	3	2
1.8	σ	2.15	12	9	6	5	3	2	1
2			10	8	5	4	3	2	1
2.2			8	6	4	3	2	2	1
2.4			7	5	4	3	2	1	1
2.6			6	5	3	2	2	1	1
2.8			5	4	3	2	1	1	1
3			4	3	2	2	1	1	1
3.2			4	3	2	1	1	1	0
3.4			3	3	2	1	1	1	0
3.6			3	2	2	1	1	1	0
3.8			3	2	1	1	1	1	0
4			2	2	1	1	1	0	0

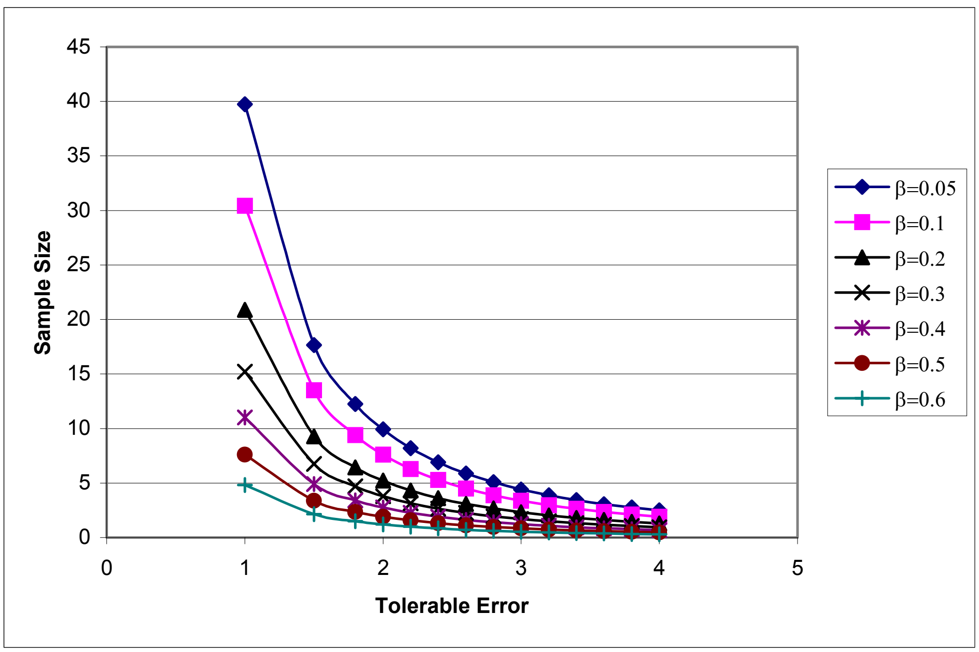


Figure.B.74 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A4 –Plasticity Index

Table B.75 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group D6 –Plasticity Index

Conf. Level	Other Factors		Sample Size (n)						
	μ	5.9	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	2.7	8	7	5	5	4	3	3
97	*e*	4	7	6	4	3	3	2	2
95			6	5	4	3	2	2	1
90			5	4	3	2	2	1	1
85			4	3	2	2	1	1	1
80			4	3	2	2	1	1	0
75			4	3	2	1	1	1	0
70			3	3	2	1	1	1	0
60			3	2	1	1	1	0	0
50			3	2	1	1	0	0	0
40			2	2	1	1	0	0	0
30			2	1	1	0	0	0	0
20			2	1	1	0	0	0	0
10			1	1	0	0	0	0	0
0			1	1	0	0	0	0	0

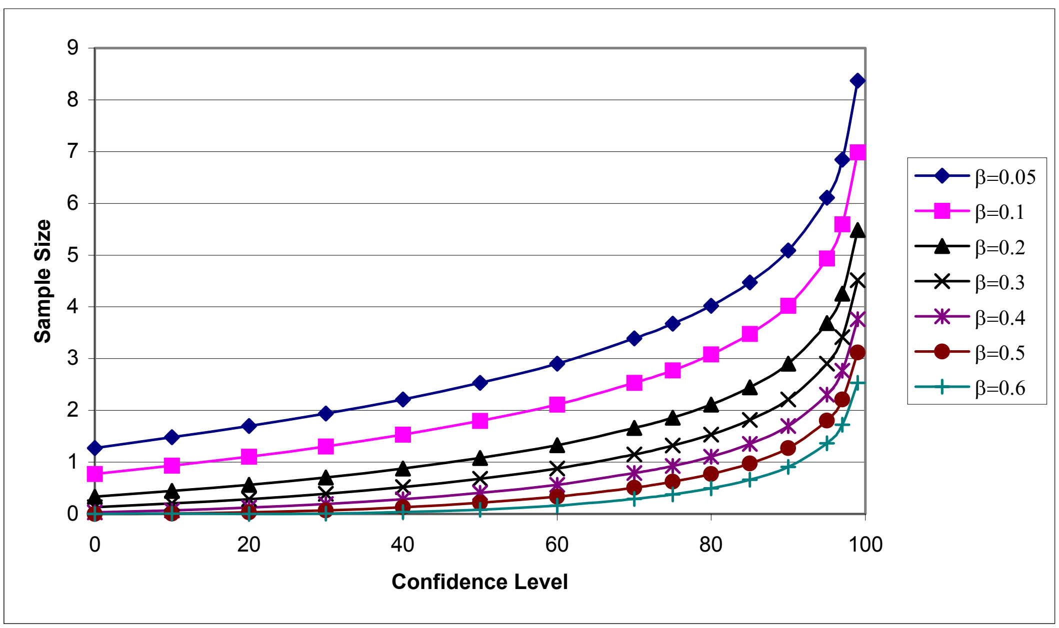


Table B.75 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group D6 –Plasticity Index

Table B.76 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group D6 –Plasticity Index

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
1.3	$Z_{\alpha/2}$	1.28	38	29	20	15	11	7	5
1.5	μ	5.9	29	22	15	11	8	5	3
1.8	σ	2.74	20	15	10	8	5	4	2
2			16	12	8	6	4	3	2
2.3			12	9	6	5	3	2	1
2.6			10	7	5	4	3	2	1
3			7	5	4	3	2	1	1
3.3			6	5	3	2	2	1	1
3.6			5	4	3	2	1	1	1
4			4	3	2	2	1	1	0
4.3			3	3	2	1	1	1	0
4.6			3	2	2	1	1	1	0
5			3	2	1	1	1	0	0
5.5			2	2	1	1	1	0	0

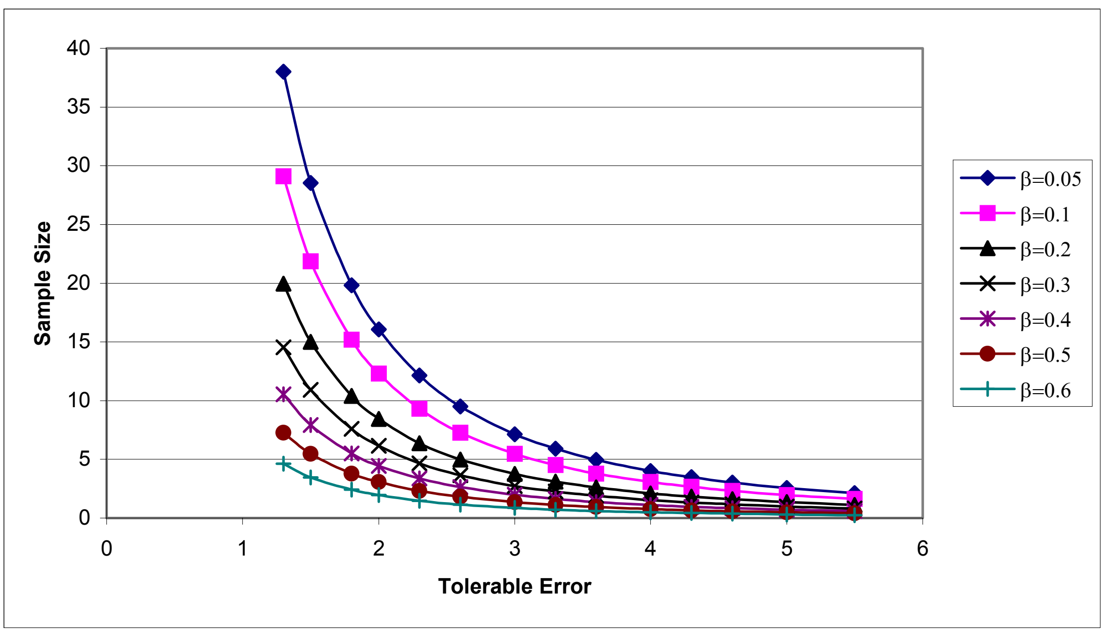


Figure B.76 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group D6 –Plasticity Index

Table B.77 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A1 –Wet Ball Mill

Conf. Level	Other Factors		Sample Size (n)						
	μ	35	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	1.9	5	4	3	3	2	2	2
97	*e*	3.5	4	3	3	2	2	1	1
95			4	3	2	2	1	1	1
90			3	2	2	1	1	1	1
85			3	2	1	1	1	1	0
80			2	2	1	1	1	0	0
75			2	2	1	1	1	0	0
70			2	2	1	1	0	0	0
60			2	1	1	1	0	0	0
50			2	1	1	0	0	0	0
40			1	1	1	0	0	0	0
30			1	1	0	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	0	0	0	0	0	0

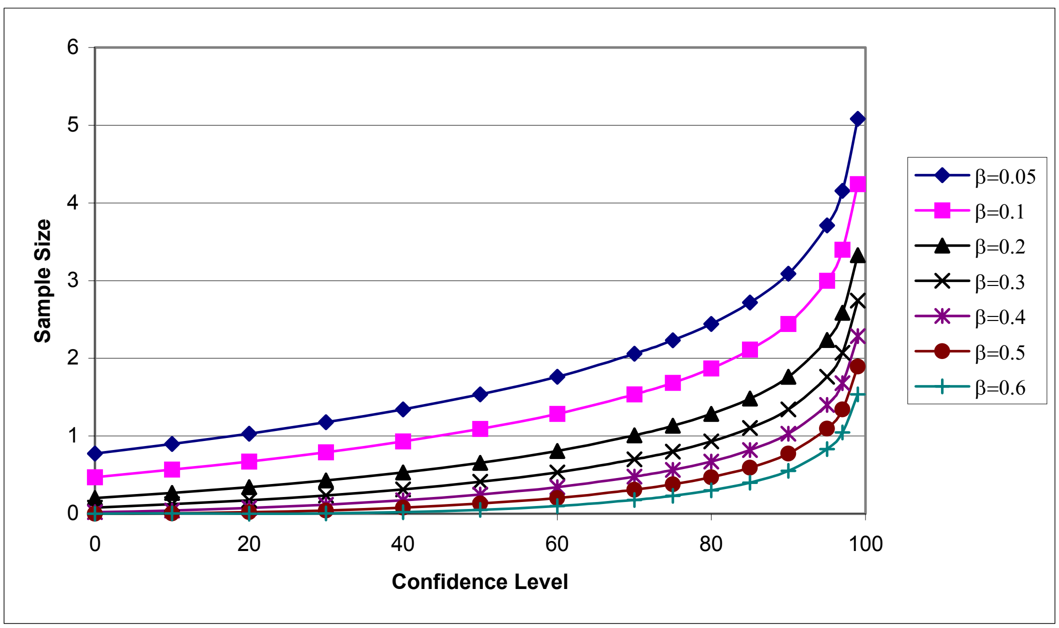


Figure B.77 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A1 –Wet Ball Mill

Table B.78 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A1 –Wet Ball Mill

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
1	$Z_{\alpha/2}$	1.28	30	23	16	11	8	6	4
1.5	μ	35	13	10	7	5	4	3	2
2	σ	1.87	7	6	4	3	2	1	1
2.5			5	4	3	2	1	1	1
3			3	3	2	1	1	1	0
3.5			2	2	1	1	1	0	0
4			2	1	1	1	1	0	0
4.5			1	1	1	1	0	0	0
5			1	1	1	0	0	0	0
5.5			1	1	1	0	0	0	0
6			1	1	0	0	0	0	0
6.5			1	1	0	0	0	0	0
7			1	0	0	0	0	0	0
7.5			1	0	0	0	0	0	0

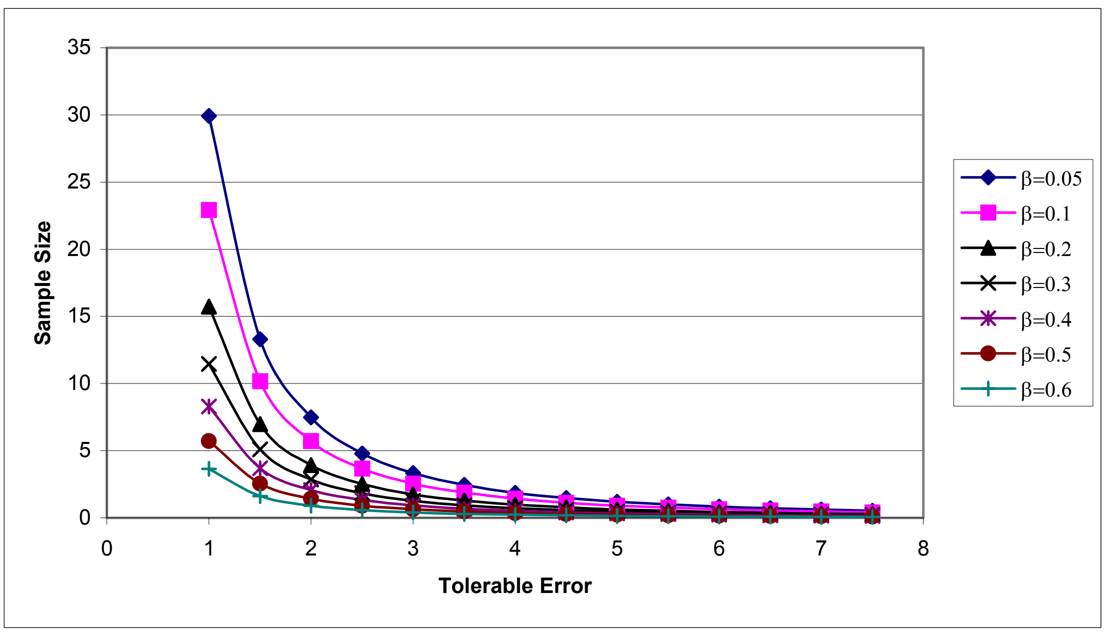


Figure B.78 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A1 –Wet Ball Mill

Table B.79 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A2 –Wet Ball Mill

Conf. Level	Other Factors		Sample Size (n)						
	μ	35	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	3.6	9	7	6	5	4	3	3
97	*e*	5	7	6	5	4	3	2	2
95			7	5	4	3	2	2	1
90			5	4	3	2	2	1	1
85			5	4	3	2	1	1	1
80			4	3	2	2	1	1	1
75			4	3	2	1	1	1	0
70			4	3	2	1	1	1	0
60			3	2	1	1	1	0	0
50			3	2	1	1	0	0	0
40			2	2	1	1	0	0	0
30			2	1	1	0	0	0	0
20			2	1	1	0	0	0	0
10			2	1	0	0	0	0	0
0			1	1	0	0	0	0	0

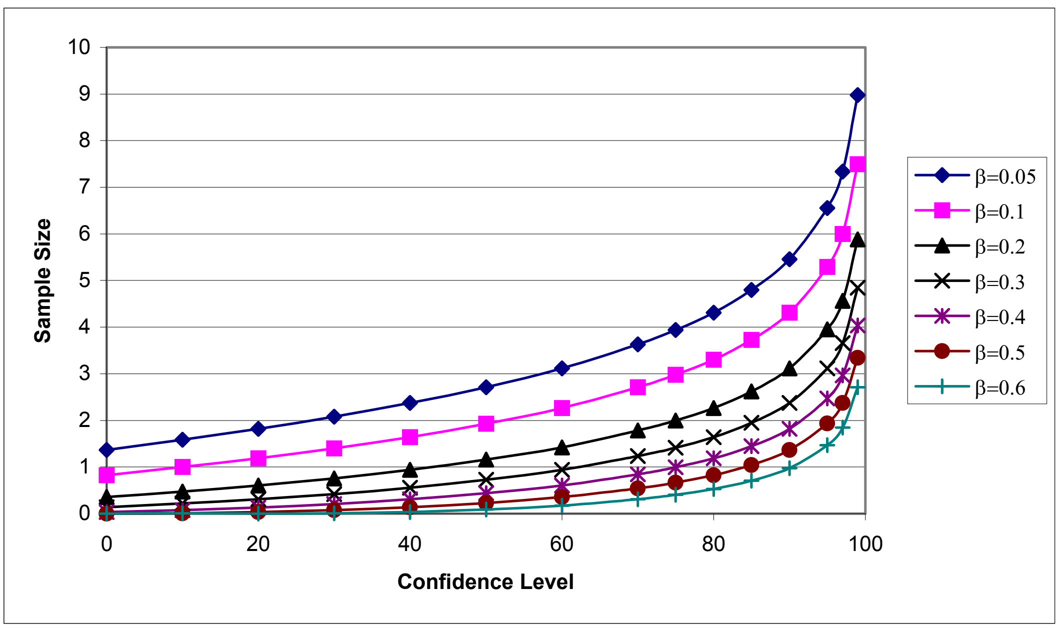


Figure B.79 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A2 –Wet Ball Mill

**Table B.80 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A2 –Wet Ball Mill**

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
2	$Z_{\alpha/2}$	1.28	27	21	14	10	7	5	3
2.5	μ	35	17	13	9	7	5	3	2
3	σ	3.55	12	9	6	5	3	2	1
3.25			10	8	5	4	3	2	1
3.5			9	7	5	3	2	2	1
3.75			8	6	4	3	2	1	1
4			7	5	4	3	2	1	1
4.5			5	4	3	2	1	1	1
5			4	3	2	2	1	1	1
5.5			4	3	2	1	1	1	0
6			3	2	2	1	1	1	0
6.5			3	2	1	1	1	0	0
7			2	2	1	1	1	0	0
7.5			2	1	1	1	1	0	0

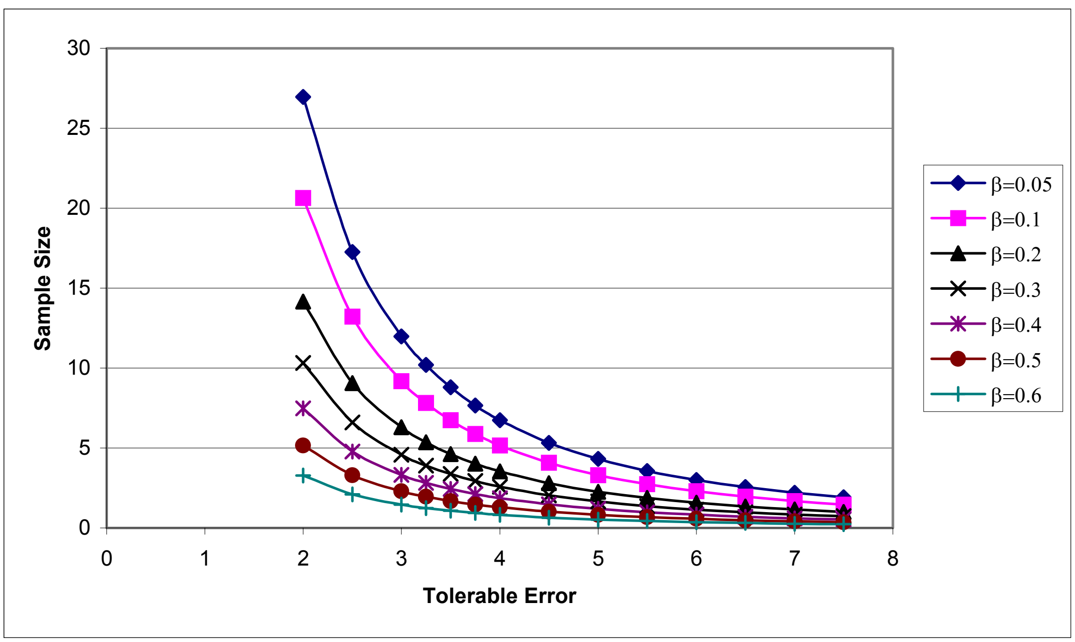


**Figure B.80 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A2 –Wet Ball Mill**

Table B.81 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A4 –Wet Ball Mill

Conf. Level	Other Factors		Sample Size (n)						
	μ	36	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	3.5	11	9	7	6	5	4	3
97	*e*	4.5	9	7	6	4	4	3	2
95			8	6	5	4	3	2	2
90			7	5	4	3	2	2	1
85			6	5	3	2	2	1	1
80			5	4	3	2	1	1	1
75			5	4	2	2	1	1	0
70			4	3	2	2	1	1	0
60			4	3	2	1	1	0	0
50			3	2	1	1	1	0	0
40			3	2	1	1	0	0	0
30			3	2	1	1	0	0	0
20			2	1	1	0	0	0	0
10			2	1	1	0	0	0	0
0			2	1	0	0	0	0	0

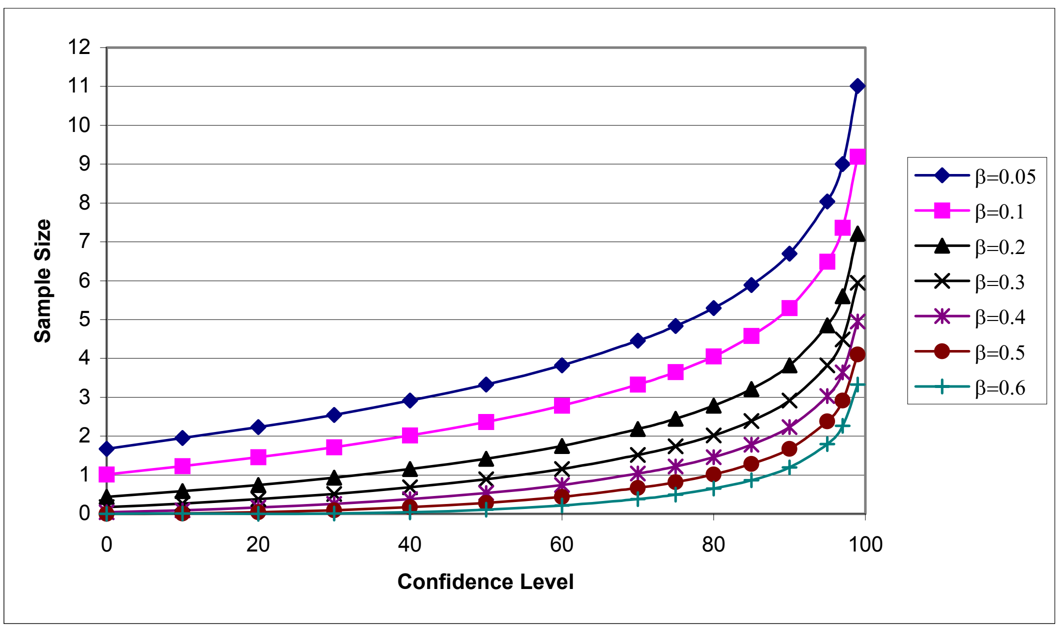


Figure B.81 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group A4 –Wet Ball Mill

Table B.82 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A4 –Wet Ball Mill

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
2	$Z_{\alpha/2}$	1.28	27	21	14	10	7	5	3
2.5	μ	36	17	13	9	7	5	3	2
3	σ	3.54	12	9	6	5	3	2	1
3.25			10	8	5	4	3	2	1
3.5			9	7	5	3	2	2	1
3.75			8	6	4	3	2	1	1
4			7	5	4	3	2	1	1
4.5			5	4	3	2	1	1	1
5			4	3	2	2	1	1	1
5.5			4	3	2	1	1	1	0
6			3	2	2	1	1	1	0
6.5			3	2	1	1	1	0	0
7			2	2	1	1	1	0	0
7.5			2	1	1	1	1	0	0

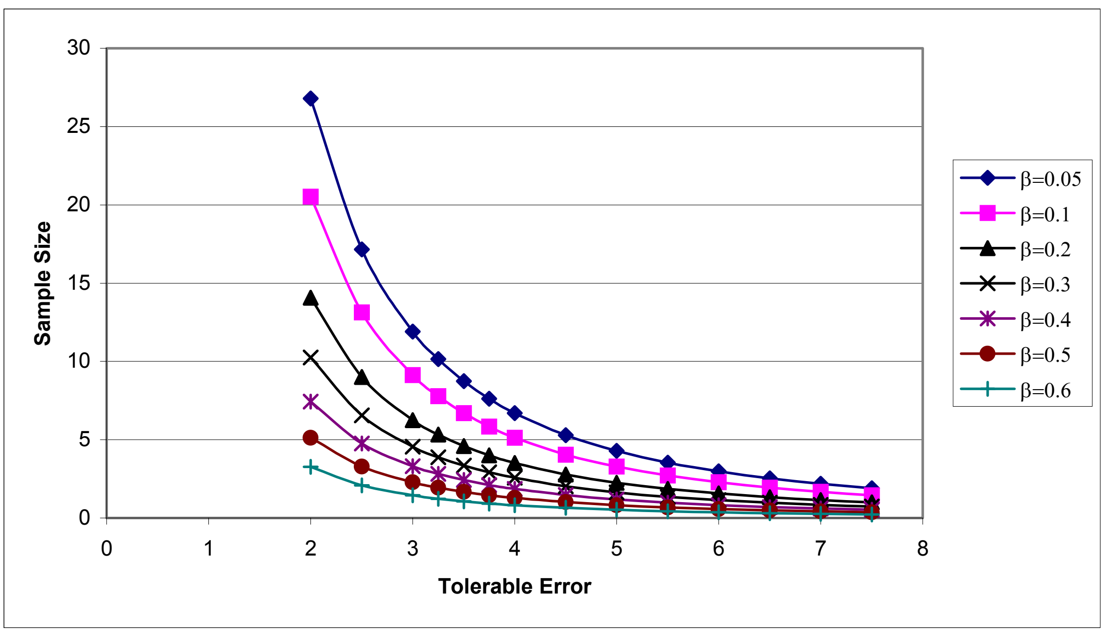


Figure B.82 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group A4 –Wet Ball Mill

Table B.83 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group D6 –Wet Ball Mill

Conf. Level	Other Factors		Sample Size (n)						
	μ	36	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	4.2	10	8	6	5	4	4	3
97	*e*	5.75	8	7	5	4	3	3	2
95			7	6	4	3	3	2	2
90			6	5	3	3	2	1	1
85			5	4	3	2	2	1	1
80			5	4	2	2	1	1	1
75			4	3	2	2	1	1	0
70			4	3	2	1	1	1	0
60			3	2	2	1	1	0	0
50			3	2	1	1	0	0	0
40			3	2	1	1	0	0	0
30			2	2	1	0	0	0	0
20			2	1	1	0	0	0	0
10			2	1	1	0	0	0	0
0			1	1	0	0	0	0	0

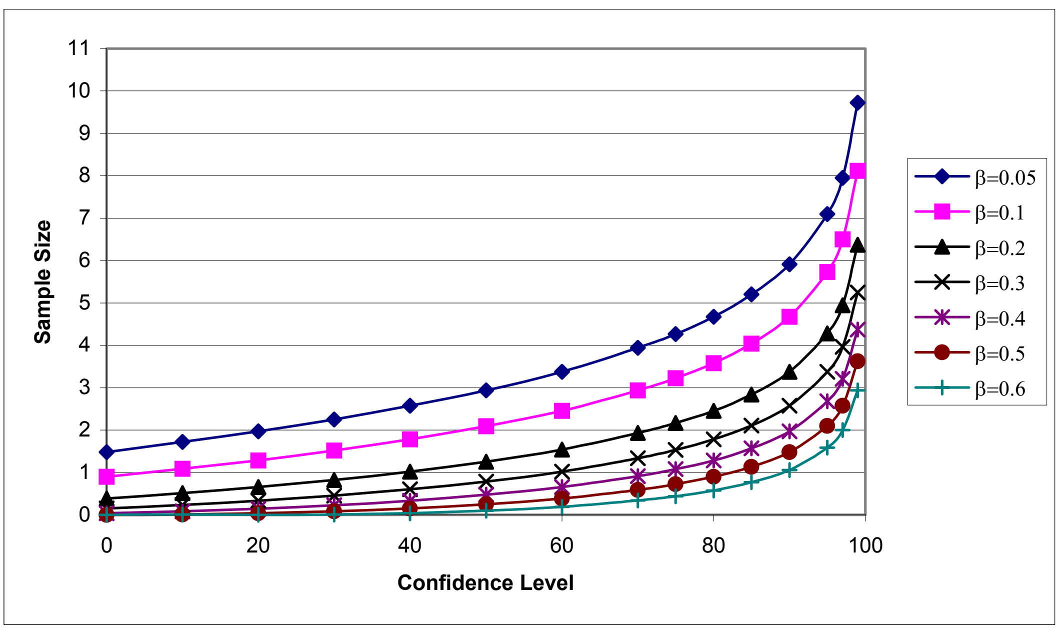


Figure B.83 Sample Size vs. Confidence Level.
Sub-base and base courses. Material Group D6 –Wet Ball Mill

Table B.84 Relationship Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group D6 –Wet Ball Mill

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
3	$Z_{\alpha/2}$	1.28	17	13	9	7	5	3	2
3.5	μ	36	13	10	7	5	3	2	2
4	σ	4.25	10	7	5	4	3	2	1
4.25			9	7	4	3	2	2	1
4.5			8	6	4	3	2	1	1
4.75			7	5	4	3	2	1	1
5			6	5	3	2	2	1	1
5.25			6	4	3	2	2	1	1
5.5			5	4	3	2	1	1	1
5.75			5	4	2	2	1	1	1
6			4	3	2	2	1	1	1
6.5			4	3	2	1	1	1	0
7			3	2	2	1	1	1	0
7.5			3	2	1	1	1	1	0

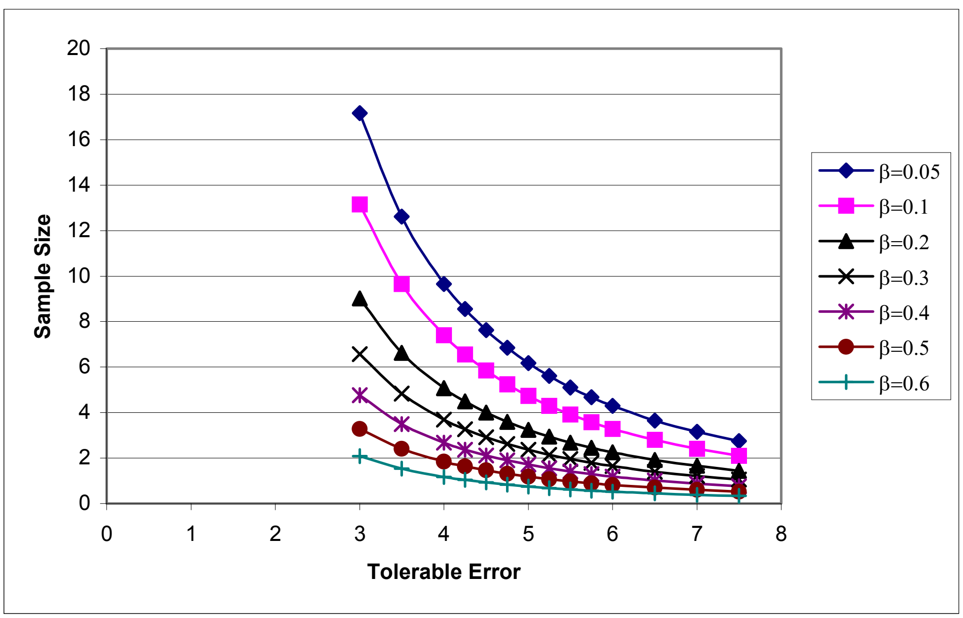


Figure B.84 Sample Size vs. Tolerable Error.
Sub-base and base courses. Material Group D6 –Wet Ball Mill

Table B.85 Relationship Sample Size vs. Confidence Level.
Sub-base and base courses. –Compaction

Conf. Level	Other Factors		Sample Size (n)						
	μ	101	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	2.2	3	3	2	2	1	1	1
97	*e*	5	2	2	1	1	1	1	1
95			2	2	1	1	1	1	0
90			2	1	1	1	0	0	0
85			1	1	1	0	0	0	0
80			1	1	1	0	0	0	0
75			1	1	0	0	0	0	0
70			1	1	0	0	0	0	0
60			1	0	0	0	0	0	0
50			1	0	0	0	0	0	0
40			0	0	0	0	0	0	0

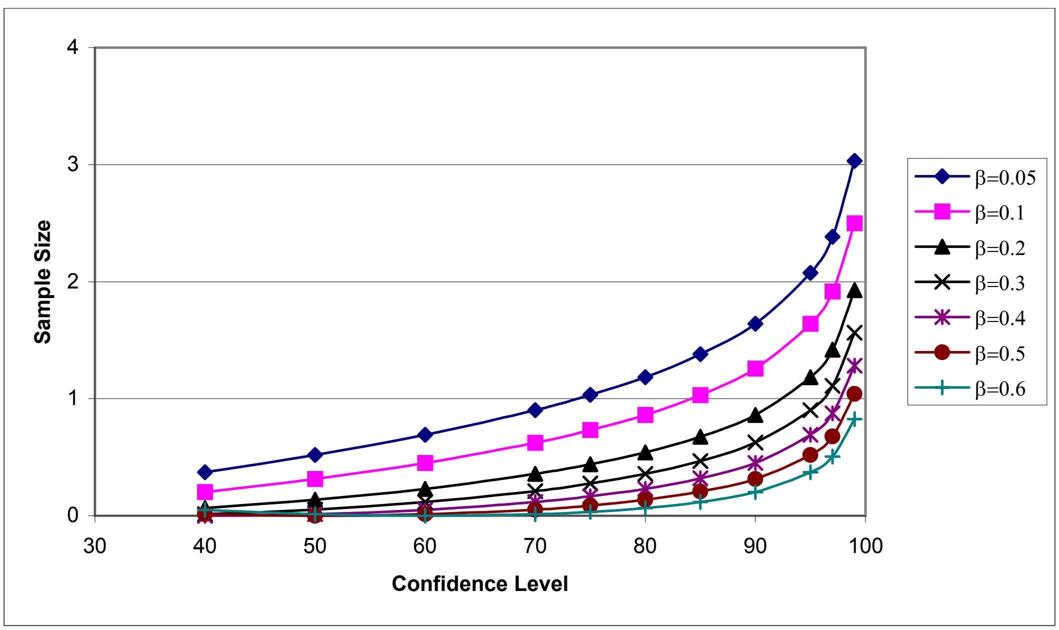


Figure B.85 Sample Size vs. Confidence Level. Sub-base and base courses. –Compaction

Table B.86 Relationship Sample Size vs. Tolerable Error. Sub-base and base courses. –Compaction

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
1	Z_α	0.84	30	22	14	9	6	3	2
1.3	μ	101	18	13	8	5	3	2	1
1.8	σ	2.2	9	7	4	3	2	1	0
2			7	5	3	2	1	1	0
2.3			6	4	3	2	1	1	0
2.8			4	3	2	1	1	0	0
3			3	2	2	1	1	0	0
3.3			3	2	1	1	1	0	0
3.8			2	1	1	1	0	0	0
4			2	1	1	1	0	0	0
4.5			1	1	1	0	0	0	0
5			1	1	1	0	0	0	0
5.5			1	1	0	0	0	0	0
6			1	1	0	0	0	0	0

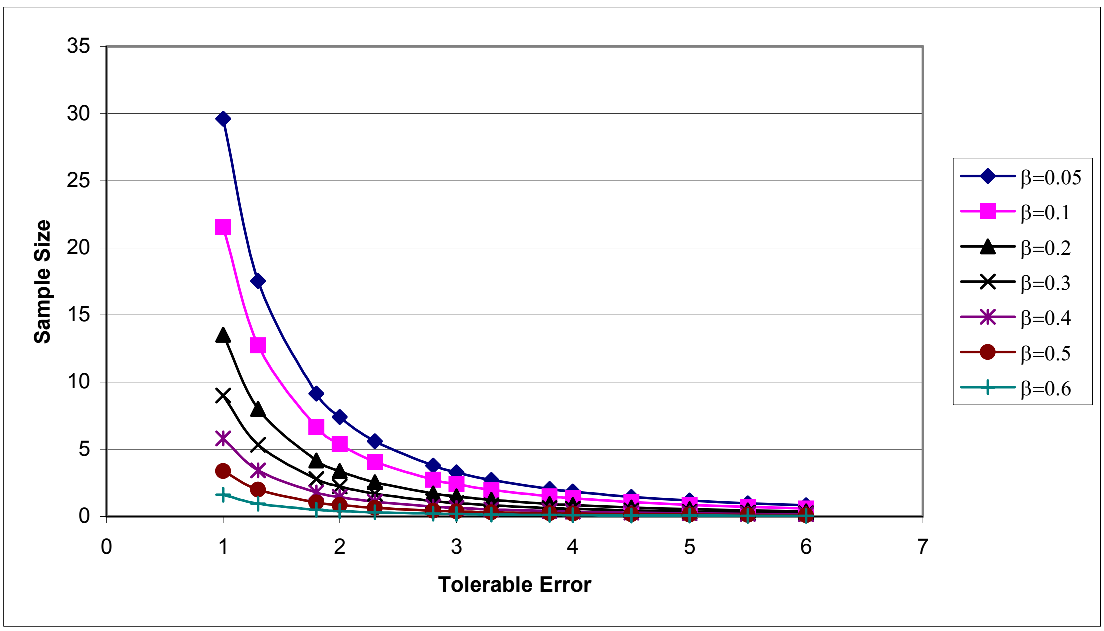


Figure B.86 Sample Size vs. Tolerable Error. Sub-base and base courses. –Compaction

Table B.87 Relationship Sample Size vs. Confidence Level.
Treated Sub-base and base courses. –In place density

Conf. Level	Other Factors		Sample Size (n)						
	μ	137	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	6.5	7	6	4	3	3	2	2
97	*e*	10	5	4	3	2	2	2	1
95			5	4	3	2	2	1	1
90			4	3	2	1	1	1	0
85			3	2	2	1	1	0	0
80			3	2	1	1	1	0	0
75			2	2	1	1	0	0	0
70			2	1	1	0	0	0	0
60			2	1	1	0	0	0	0
50			1	1	0	0	0	0	0
40			1	0	0	0	0	0	0

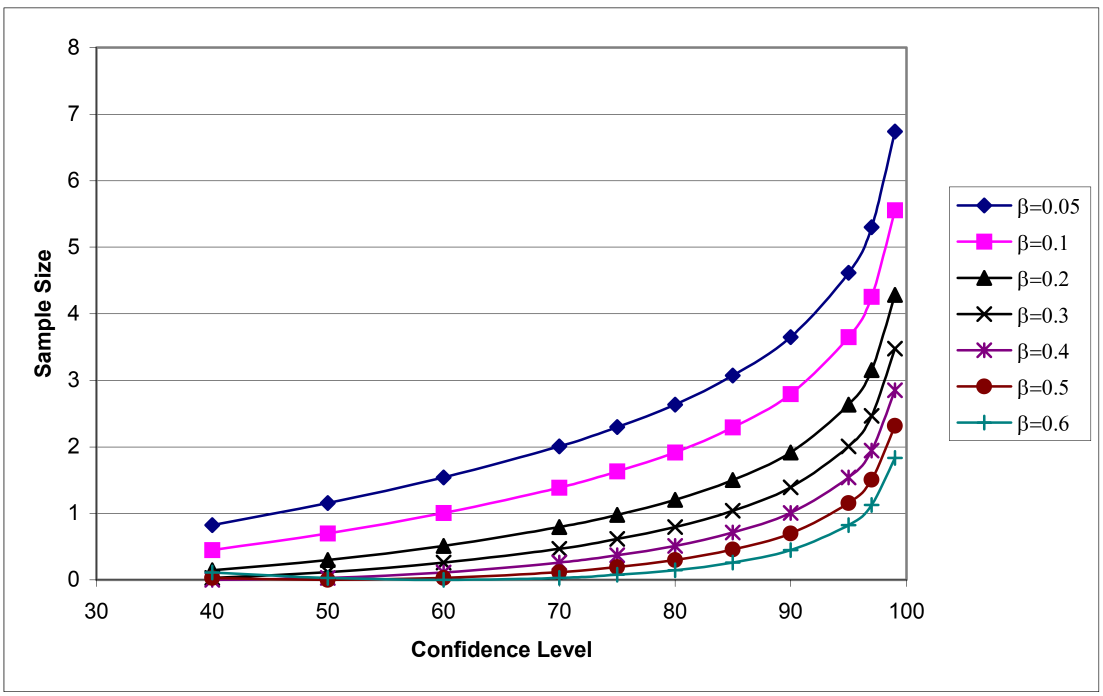


Figure B.87 Sample Size vs. Confidence Level.
Treated Sub-base and base courses. –In place density

Table B.88 Relationship Sample Size vs. Tolerable Error.
Treated Sub-base and base courses. –In place density

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
1	Z_α	0.84	263	192	120	80	52	30	14
2	μ	137	66	48	30	20	13	8	4
3	σ	6.5	29	21	13	9	6	3	2
4			16	12	8	5	3	2	1
5			11	8	5	3	2	1	1
6			7	5	3	2	1	1	0
6.5			6	5	3	2	1	1	0
7			5	4	2	2	1	1	0
8			4	3	2	1	1	0	0
9			3	2	1	1	1	0	0
10			3	2	1	1	1	0	0
11			2	2	1	1	0	0	0
12			2	1	1	1	0	0	0
13			2	1	1	0	0	0	0

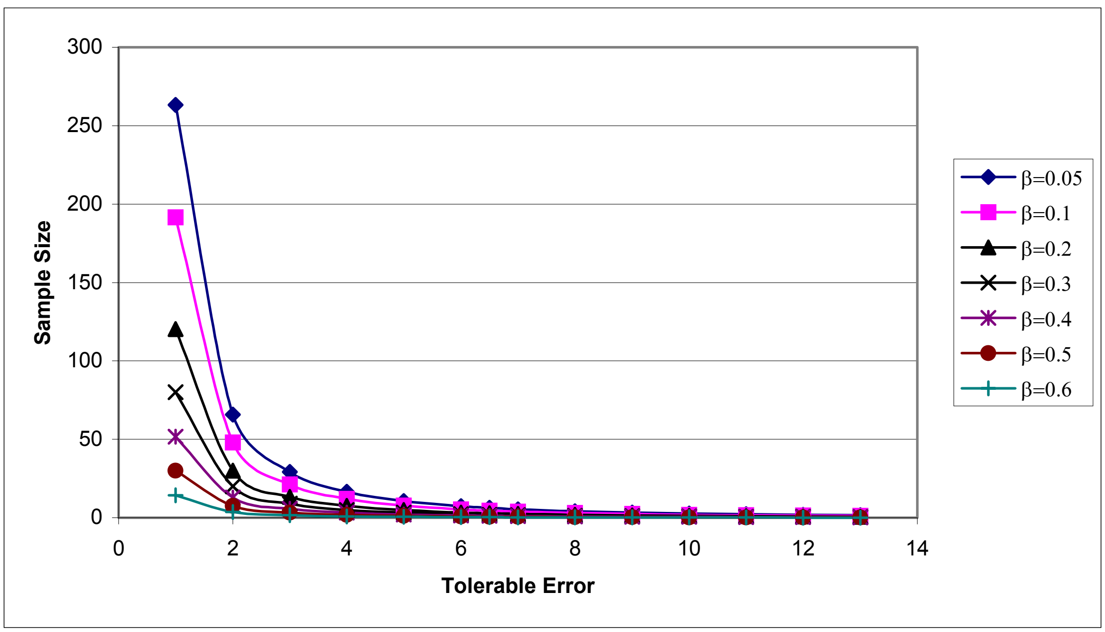


Figure B.88 Sample Size vs. Tolerable Error.
Treated Sub-base and base courses. –In place density

Table B.89 Relationship Sample Size vs. Confidence Level.
Asphalt Concrete Pavements -Air Voids

Conf. Level	Other Factors		Sample Size (n)						
	μ	7.4	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	1.25	5	4	3	3	2	2	1
97	*e*	2.4	4	3	2	2	2	1	1
95			4	3	2	2	1	1	1
90			3	2	2	1	1	1	1
85			3	2	1	1	1	1	0
80			2	2	1	1	1	0	0
75			2	2	1	1	1	0	0
70			2	1	1	1	0	0	0
60			2	1	1	1	0	0	0
50			1	1	1	0	0	0	0
40			1	1	1	0	0	0	0
30			1	1	0	0	0	0	0
20			1	1	0	0	0	0	0
10			1	1	0	0	0	0	0
0			1	0	0	0	0	0	0

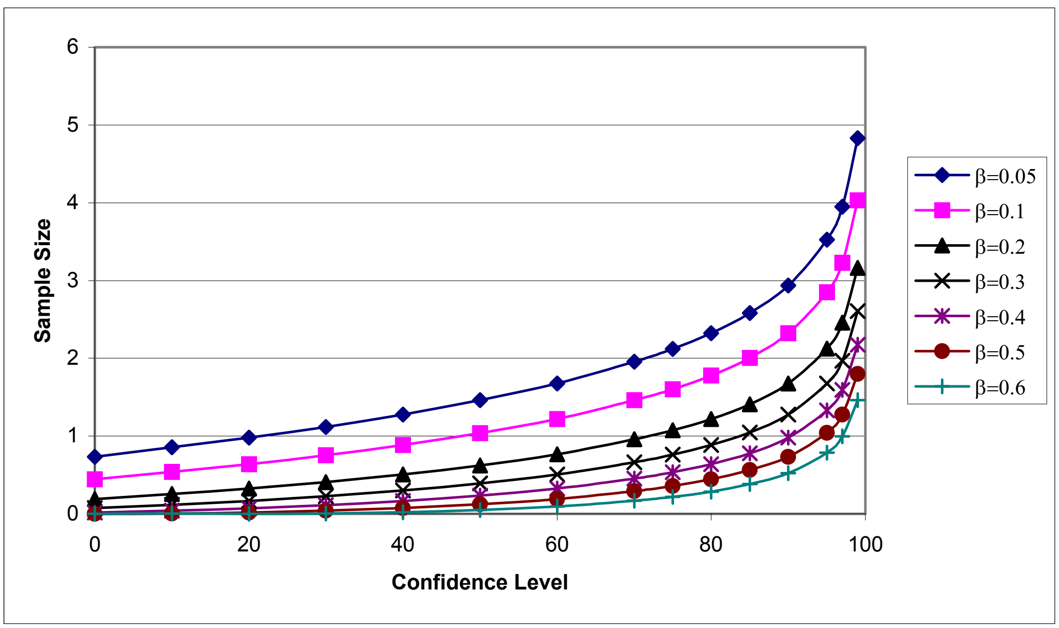


Figure B.89 Sample Size vs. Confidence Level. Asphalt Concrete Pavements -Air Voids

Table B.90 Relationship Sample Size vs. Tolerable Error. Asphalt Concrete Pavements -Air Voids

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
1	$Z_{\alpha/2}$	1.28	13	10	7	5	4	3	2
1.2	μ	7.4	9	7	5	4	3	2	1
1.3	σ	1.25	8	6	4	3	2	2	1
1.4			7	5	4	3	2	1	1
1.5			6	5	3	2	2	1	1
1.6			5	4	3	2	1	1	1
1.7			5	4	2	2	1	1	1
1.8			4	3	2	2	1	1	1
1.9			4	3	2	1	1	1	0
2			3	3	2	1	1	1	0
2.2			3	2	1	1	1	1	0
2.4			2	2	1	1	1	0	0
2.6			2	2	1	1	1	0	0
3			1	1	1	1	0	0	0

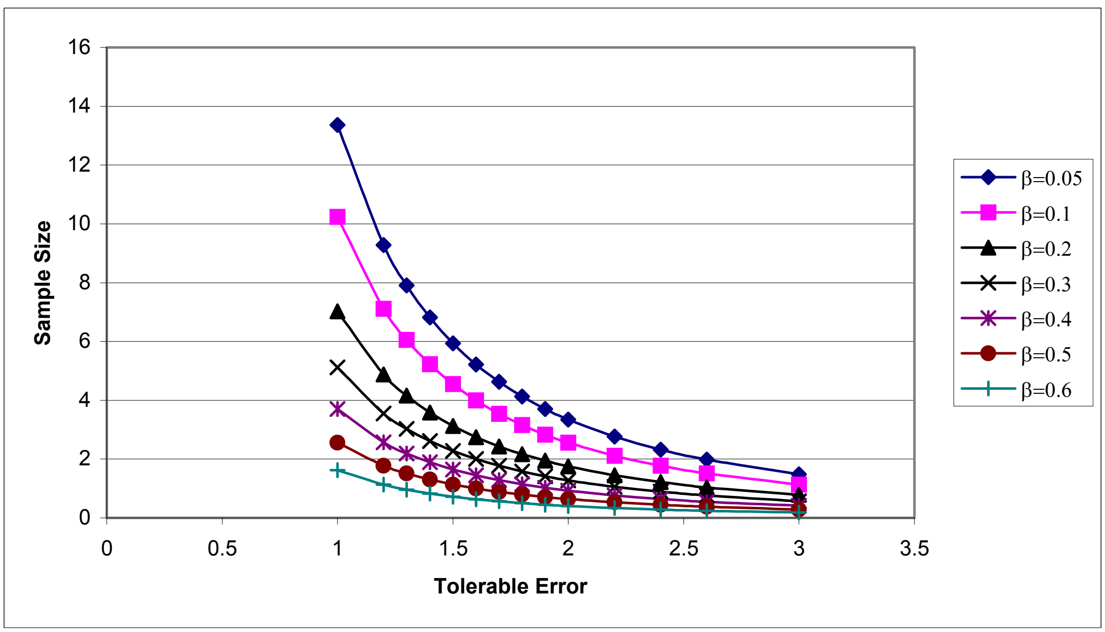


Figure B.90 Sample Size vs. Tolerable Error. Asphalt Concrete Pavements -Air Voids

Table B.91 Relationship Sample Size vs. Confidence Level. Asphalt Concrete Pavements -Lab density

Conf. Level	Other Factors		Sample Size (n)						
	μ	96.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
99	σ	0.35	2	1	1	1	1	1	0
97	*e*	1.20	1	1	1	1	1	0	0
95			1	1	1	1	0	0	0
90			1	1	1	0	0	0	0
85			1	1	0	0	0	0	0
80			1	1	0	0	0	0	0
75			1	1	0	0	0	0	0
70			1	0	0	0	0	0	0
60			1	0	0	0	0	0	0
50			0	0	0	0	0	0	0
40			0	0	0	0	0	0	0
30			0	0	0	0	0	0	0
20			0	0	0	0	0	0	0
10			0	0	0	0	0	0	0
0			0	0	0	0	0	0	0

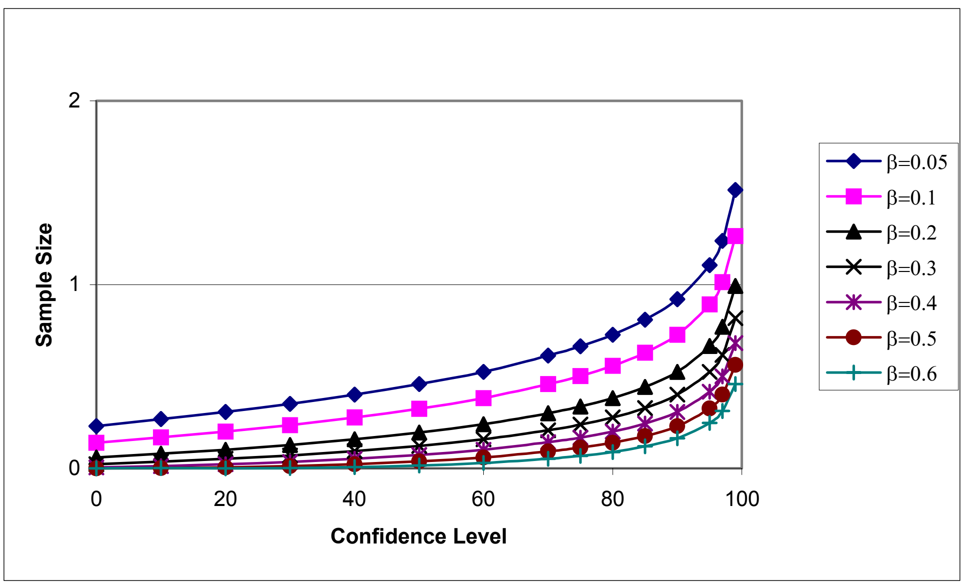


Figure B.91 Sample Size vs. Confidence Level. Asphalt Concrete Pavements -Lab density

Table B.92 Relationship Sample Size vs. Tolerable Error.
Asphalt Concrete Pavements -Lab density

e	Other Factors		Sample Size (n)						
	α	0.2	β = 0.05	β = 0.10	β = 0.20	β = 0.30	β = 0.40	β = 0.50	β = 0.60
0.2	$Z_{\alpha/2}$	1.28	26	20	14	10	7	5	3
0.3	μ	96	12	9	6	4	3	2	1
0.4	σ	0.35	7	5	3	3	2	1	1
0.5			4	3	2	2	1	1	1
0.6			3	2	2	1	1	1	0
0.7			2	2	1	1	1	0	0
0.8			2	1	1	1	0	0	0
0.9			1	1	1	0	0	0	0
1			1	1	1	0	0	0	0
1.1			1	1	0	0	0	0	0
1.2			1	1	0	0	0	0	0
1.3			1	0	0	0	0	0	0
1.4			1	0	0	0	0	0	0
1.5			0	0	0	0	0	0	0

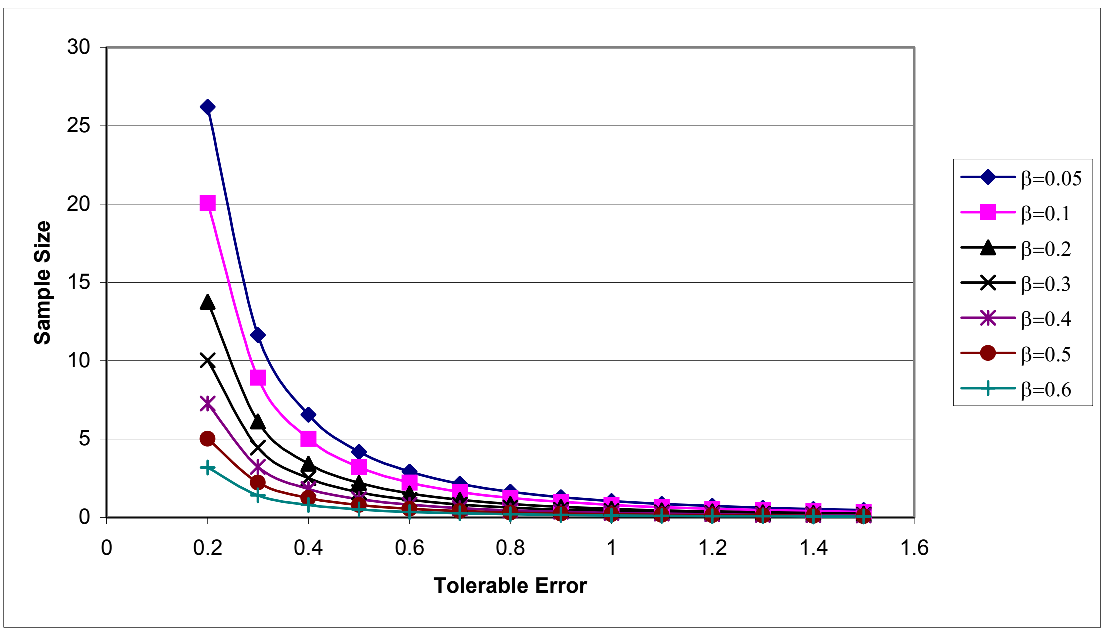


Figure B.92 Sample Size vs. Tolerable Error.
Asphalt Concrete Pavements -Lab density

Appendix C

Table C.1 Methods of Material Testing Frequency by States Departments of Transportation

Agency	Sampling Method		Notes
	Historical	Statistical	
Arizona Department of Transportation	**X**		
Arkansas State Highway and Transportation department		X (Data analysis)	Correlation Table to Verify Contractor Acceptance Test Result: This document provides the minimum sample size and testing frequency, but does not give any information on the statistical methodology. Development of an Acceptance Sampling Plan and Pay Adjustment Schedule: This document shows the use of a statistical method only for data analysis.
California Department of Transportation	X		
Connecticut Department of Transportation	X		
Federal Highway Administration HRDI-11		X (Data analysis)	Optimal Acceptance Procedures for Statistical Construction Specifications: Development of methodology for highway agencies to establish optimum acceptance plans for pavements. Cost effectiveness of current sampling and testing programs for pavement construction material.

Table C.1 (Continued)

Agency	Sampling Method		Notes
	Historical	Statistical	
Florida Department of Transportation	X	**X**	Sampling, Testing & Reporting Guide: The method described in this document is based on historical experience and historical data. Mineral Aggregate Manual & Rule of the Department of Transportation, Chapter 14-103: These documents provide some information on aggregate mines. The method is based on statistical analysis, but no detailed information about how to determine the testing frequency. System-Based Unit of Time: Earthwork Independent Assurance Inspection / Independent Assurance Inspection Frequency Tables; (No detailed document.) This program is not fully developed. Sampling Frequency Reduction for Structural Concrete: (No detailed document.) A statistics-based method for reducing the sampling frequency. The frequency will be reduced to 1/100 CY when the average strength becomes two standard deviations greater than the minimum required strength. No information on how to use the standard deviation to determine the frequency.

Table C.1 (Continued)

Agency	Sampling Method		Notes
	Historical	Statistical	
Georgia Department of Transportation	X	X (only in asphalt program)	Georgia DOT uses statistical sampling methods in their asphalt area. (No information available.) Sampling and Testing Guide: This document provides the sample size of some materials, but contains no detailed information about how to determine these sample sizes.
Hawaii Department of Transportation	X		
Idaho Department of Transportation	X		
Indiana Department of Transportation	X		
Kansas Department of Transportation	X		
Kentucky Department of Transportation	X		
Maine Department of Transportation	X		

Table C.1 (Continued)

Agency	Sampling Method		Notes
	Historical	Statistical	
Michigan Department of Transportation		X (Concrete program) Only for data analysis	Michigan DOT uses a statistically-based concrete quality assurance specification. Special Provision for Furnishing Portland Cement Concrete (Quality Assurance): Statistical evaluation of 28-day compressive strength test to estimate the percentage of defective material in the lot. The statistical theory is used only for data analysis, not for determining the testing frequency. Materials Sampling Guide, Bulletin 1999-1: Normal sampling frequency in some areas, but no information on statistical method. MDOT Office Memorandum - Materials Quality Assurance Procedures Manual Distribution No. 5: This document has no information on how to determine the material testing frequency.
Nebraska Department of Transportation	X		
Nevada Department of Transportation	X		
New Hampshire Department of Transportation	X		

Table C.1 (Continued)

Agency	Sampling Method		Notes
	Historical	Statistical	
New Jersey Department of Transportation	X	X	Bureau of Materials Sampling Criteria for the Majority of Material Sampled: This document gives only the testing frequency of some materials and products. It doesn't provide any methodology on how to determine the testing frequency or sample size.
New York Department of Transportation	X	X (only in Grade 60 Steel Reinforcing Bars)	Inspection, Sampling, and Testing of Guide 60 Steel Reinforcing Bars (1975): No statistical method on how to determine the sample size and testing frequency.
North Carolina Dept. of Transportation		X	Documents provided were QC/QA Program Manual, Solid Concrete Masonry Brick/Unit Quality Control, Superpave Hot Mix Asphalt Quality Management System Manual, and HDPE Pipe QC/QA Program Manual. These documents provided the minimum sample size and frequency of tests but did not give any information on how to determine the testing frequency based on statistical methodology. Statistical methods are used to analyze the results of material testing.

Table C.1 (Continued)

Agency	Sampling Method		Notes
	Historical	Statistical	
North Dakota Department of Transportation	X		
Nova Scotia Department of Transportation	X		
Ontario Ministry of Transportation	X		
South Carolina Department of Transportation	X		
Tennessee Department of Transportation	X		
Vermont Department of Transportation	X		

Appendix D

AASHTO Soil Classification System.

Table D.1 AASHTO Soil Classification System

General Classification	Granular Materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing No. 200)			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-a		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis, % passing:											
No. 10 (200 mm)	50 max	...	...	...	...	...	...	...	...	...	...
No. 40 (425 Åm)	30 max	50 max	51 min	...	...	...	...	...	...	...	...
No. 200 (75 Åm)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40 (425 Åm)											
Liquid limit	...		...	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min*
Usual types of significant constituent materials	Stone Fragments Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General rating as subgrade	Excellent to Good							Fair to Poor			

* Plasticity index of A-7-5 subgroup is equal to or less than *LL* minus 30. Plasticity index of A-7-6 subgroup is greater than *LL* minus 30.
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