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Comparison of Spacing Factors as Measured by the Air-Void Analyzer and ASTM C457

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Kansas Department of Transportation
Bureau of Research

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Final Report

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Abstract

The Kansas Department of Transportation (KDOT) began using the Air-Void Analyzer (AVA) in 2001 and first incorporated an AVA spacing factor requirement into paving specifications beginning in late 2002. In 2005, a statewide investigation to evaluate the AVA and specifications began with the collection of 4-inch diameter hardened concrete samples taken at or near locations where the spacing factor was determined with the AVA. The hardened concrete samples were tested to determine the spacing factor in accordance with ASTM C457 (2012), a well-established test method used to determine spacing factors in hardened concrete. A total of 270 data pairs were collected to evaluate KDOT's current use of the AVA and ASTM C457 tests and to determine if a correlation (either direct or pass-fail criteria) exists between spacing factors obtained with the two methods. Results of the study indicate that average spacing factors obtained with the AVA were 1.67 higher than average spacing factors determined using ASTM C457. A strong direct correlation was not identified between the two test methods, although pass-fail criterion that limits KDOT's risk of accepting concrete with an inadequate air-void system was identified.

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Chapter 1: Introduction

1.1 General

Freezing and thawing cycles will result in damage to concrete that is saturated unless the concrete is properly entrained with small and well-dispersed air voids. Durable concrete subject to cycles of freezing and thawing must have an air-void system (in the cement paste) with an adequate spacing factor, specific surface area, and air content. The spacing factor is defined as the average distance from any point in the paste to the edge of the nearest (air) void, or more simply, half of the average space between air voids, and is the most commonly used parameter to evaluate air void systems (Neville, 1995). A maximum spacing factor of 0.200 mm (0.0080 in.) measured in the hardened concrete is generally considered necessary to adequately protect paste from freezing and thawing (ACI Committee 201, 2008), although the Canadian Standards Association (CSA A23.2-09, 2009) recommends a slightly higher limit of 0.250 mm (0.0100 in.). Specific surface area is the surface area of air voids per unit volume of paste and air content is the volume of air per unit volume of concrete. In general, the size and distribution of the entrained air is thought to be of more importance than the volume of air (Ley, Felice, & Freeman, 2012). The Kansas Department of Transportation (KDOT) places limits on the air content and spacing factor, which is the focus of this report (KDOT, 2015).

Various test methods exist to evaluate air-void systems in plastic and hardened concrete. Evaluations of both the plastic and hardened concrete are used in Kansas to prequalify concrete paving mixtures and verify performance in the field. The air-void system in hardened concrete is determined in accordance with ASTM C457 (2012), which is the widely accepted method to determine the spacing factor based on work by Powers (1954). It is important to note that ASTM C457 spacing factor test results can vary by more than 50% and must be performed on hardened concrete, making quality control testing difficult. The Air Void Analyzer (AVA) was developed in the early 1990s as a relatively quick method (approximately 30 minutes) to determine the air content and spacing factor of plastic (unhardened) concrete (Germann Instruments, Inc., n.d.). Real-time determination of air-void characteristics provides a distinct advantage over ASTM C457; however, questions remain regarding the accuracy and effectiveness of the tool. Although both methods determine a spacing factor, they operate very differently and so it comes as no surprise that differences exist in the values obtained between each test.

KDOT currently uses the AVA for prequalification and field verification and has capabilities to run ASTM C457 at the Materials and Research Center in Topeka, KS. The goal of this work is twofold: first, evaluate KDOT's current use of the AVA and ASTM C457 in terms of the risk of accepting concrete with an inadequate air void system, and second, determine if a correlation (either direct or pass-fail criteria) exists between spacing factors obtained with ASTM C457 and the AVA.

1.2 Background

KDOT began using the AVA in 2001 and first incorporated a spacing factor requirement into the specifications beginning in late 2002. In 2005, a statewide investigation to evaluate the AVA began with the collection of 4-inch diameter hardened concrete samples taken at or near locations where the spacing factor was determined with the AVA. The spacing factor was determined for the hardened concrete samples in accordance with ASTM C457 (2012) utilizing Procedure A (linear traverse), and the results were compared with spacing factors measured with the AVA in an effort to determine the efficacy of the AVA system. There is concern that the original equipment (AVA-2000 model) is reaching its useful service life with limited options for computer software upgrades and replacement parts. A new version of the AVA equipment (AVA-3000 model) is available; however, acquiring new AVA equipment for KDOT labs across the state will cost well over $150,000, making this evaluation timely.

1.2.1 Units and Significant Figures

The AVA spacing factor data included in this report was measured and recorded to the nearest thousandth of a millimeter (0.001 mm), while the *calculated* ASTM C457 spacing factors were generally reported to the nearest ten-thousandth of a millimeter (0.0001 mm). KDOT now uses U.S. customary units and reports the AVA and ASTM C457 spacing factors to the nearest ten-thousandth of an inch (0.0001 in.). For this report, the primary units for the collected data (and any summary statistics) will remain in millimeters (nearest 0.001 mm) with inch equivalents (nearest 0.0001 in.) shown in parentheses or secondary axes and calculated by dividing the unrounded raw data by 25.4 mm/in. Spacing factor limits and previous specification requirements are also reported with dual units, however, a *soft* conversion factor of 25 mm/in. is used so that rounding is not required to interpret the specifications (*e.g.*, 0.250 mm equals 0.0100 in.). Recommended changes to the *current specification* presented in Chapters 3 and 4 will be based on data collected and analyzed in metric units and then converted to equivalent U.S. customary units. Finally, discussion of the spacing factor limits in the *current specification* in Section 1.2.3 will only be reported in inches in order to maintain consistency with the current specification style and to avoid potential confusion due to rounding.

1.2.2 Historical Development

KDOT first began using the AVA for research in 2001. Data was collected for two construction seasons before a spacing factor requirement was developed and incorporated into the specifications beginning with projects let after December 2002. The original requirements have undergone several revisions that have impacted spacing factors measured in the field, but the specifications have consistently required the AVA for mix design approval and field verification. Field verification for Quality Control/Quality Assurance (QC/QA) concrete projects is currently required for portland cement concrete pavement once every four weeks of production. The requirement is different for non-QC/QA projects and requires one test at the start of paving and one during the second week of production. Statewide average annual AVA spacing factors, as reported by each district, between 2001 and 2014 are shown in Figure 1.1 with key specification changes and target spacing factors identified.

The first AVA specification (December 2002) set a maximum spacing factor (as measured by the AVA) of 0.250 mm (0.0100 in.) and contained a remove-and-replace clause for concrete with spacing factors greater than 0.375 mm (0.0150 in.). The remove-and-replace limit represents a 50% increase over the maximum specified limit of 0.250 mm (0.0100 in.), which is similar to the acceptable range of results for ASTM C457. In 2006, KDOT agreed (with industry) to not enforce the removal clause if contractors would agree to continue working to improve the air-void characteristics through a reduction in spacing factors. This change in policy was reflected in the February 2006 specification. Up to this point, the average annual AVA spacing factor decreased from a high of 0.281 mm (0.0111 in.) in 2002 to 0.194 mm (0.0076 in.)

in 2005 (as shown in Figure 1.1). Average spacing factors immediately began to increase in 2006, and by 2009, the average spacing factor had risen to nearly the same level as when the program began in 2001—losing all the gains previously made with the 2002 specification. It should be noted that in April 2008, the remove-and-replace clause was reinstated for pavement with a spacing factor greater than 0.375 mm (0.0150 in.) although there is some question whether this penalty has been enforced, and there has not been a large subsequent impact on the average annual spacing factors.

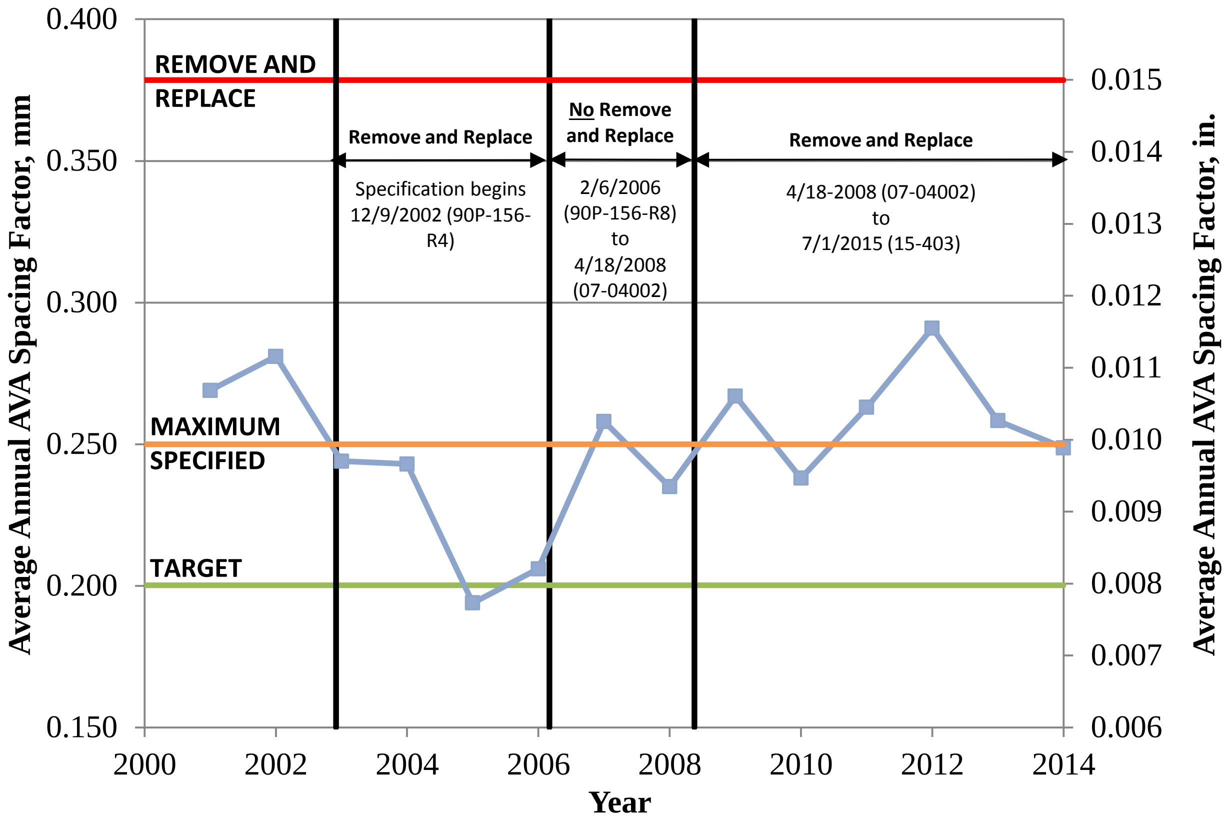


Figure 1.1: KDOT Average Annual Spacing Factor as Measured by AVA Testing

Average annual spacing factors oscillate above and below the maximum specified value of 0.250 mm (0.0100 in.) from 2007 to 2011 before increasing to 0.291 mm (0.0115 in.) in 2012—the highest average annual spacing factor to date, as shown in Figure 1.1. Average annual spacing factors decrease for 2013 and 2014 but are still at or above the maximum specified limit, which appears to be the target used in the field since the remove-and-replace clause was first removed in 2006. The specifications have recently been rewritten with an emphasis on field adjustments to the mix following verification testing. The current specification is described next.

1.2.3 Current Specification

Beginning with projects let in July 2015, the remove-and-replace clause based on the AVA spacing factor has been removed. A *design* AVA spacing factor of 0.0100 in.[1] is required for prequalification and mixes with AVA spacing factors larger than this value will not be approved. Several strategies to reduce the spacing factor are provided if the AVA spacing factor exceeds 0.0100 in. at any point during the course of the project (based on verification testing). These strategies include the following:

1. Compare AVA spacing factors taken before and after the paver to determine the loss of air and spacing factor due to the paving operation,
2. Verify calibration of the AVA,
3. Change the location of the AVA during testing,
4. Compare with results obtained from another machine,
5. Check the mix design for compliance with all relevant specifications,
6. Check aggregate gradations,
7. Check the total air content versus the target air content,
8. Check dosage rates of admixtures, and
9. Check for admixture compatibility using alternate sources.

If the preceding strategies do not decrease the spacing factor to an acceptable level (*i.e.*, less than 0.0125 in.), two cores will be taken from the affected area (*i.e.*, AVA sample location) and tested to determine the hardened air spacing factor in accordance with ASTM C457. For this report, the AVA spacing factor that prompts C457 testing (which ultimately is used for acceptance) is referred to as the AVA threshold. If the AVA spacing factor is greater than 0.0125 in. and the average hardened air spacing factor is greater than 0.0080 in., then suspend paving operations and submit (and prequalify) a new concrete mix design. The pavement will be accepted if the average hardened air spacing factor is less than 0.0080 in. Using the AVA as a

[1] Spacing factor limits in the *current specification* are only reported in inches in order to maintain consistency with the current specification style and to avoid potential confusion due to rounding.

screening tool that triggers additional air testing (ASTM C457) reemphasizes the importance of spacing factors and addresses some industry concerns with the accuracy and precision of the AVA by not relying solely on one test. The frequency of AVA field verification testing is specified as once for every four weeks of production for QC/QA projects, and once at the beginning of paving and once during the second week of paving for non-QC/QA projects. This testing frequency may not be enough for these requirements to have a significant effect on the actual spacing factors obtained over the course of a project.

Four testing outcomes are possible when the two tests are conducted on the same concrete as shown in Figure 1.2. Quadrants 1 and 3 (Q1 and Q3) indicate agreement in the test methods (*i.e.*, both tests identify passing or failing spacing factors). Quadrant 2 indicates samples with acceptable AVA spacing factors and unacceptable C457 spacing factors. Pavement falling into this quadrant, however, would not normally be tested using ASTM C457 as the AVA spacing factor is less than the threshold value that triggers the test. This quadrant represents a risk to KDOT by accepting potentially non-freeze-thaw durable concrete (*i.e.*, C457 spacing factor greater than 0.0080 in.). Quadrant 4 indicates pavement with a failing AVA spacing factor that, in fact, has a spacing factor less than 0.0080 in. and passes the KDOT requirements for ASTM C457. There is a need to establish an appropriate AVA threshold value that limits the risk of accepting non-durable concrete, balances the amount of ASTM C457 testing, and encourages contractors to produce concrete with spacing factors well below the limit. The objective of this study is to evaluate the current AVA threshold using data collected since 2001, determine if 0.0125 in. produces an acceptable level of risk while balancing the number of ASTM C457 evaluations required, and if needed, recommend changes to the standard specification.

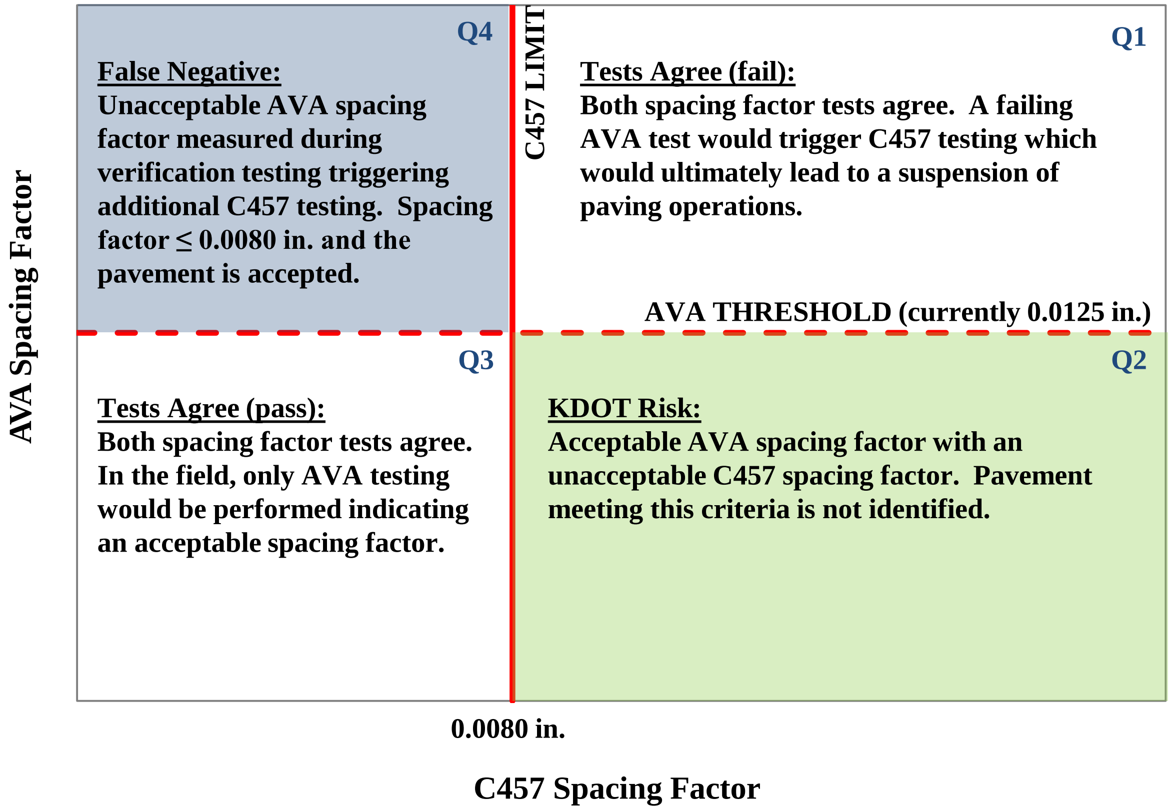
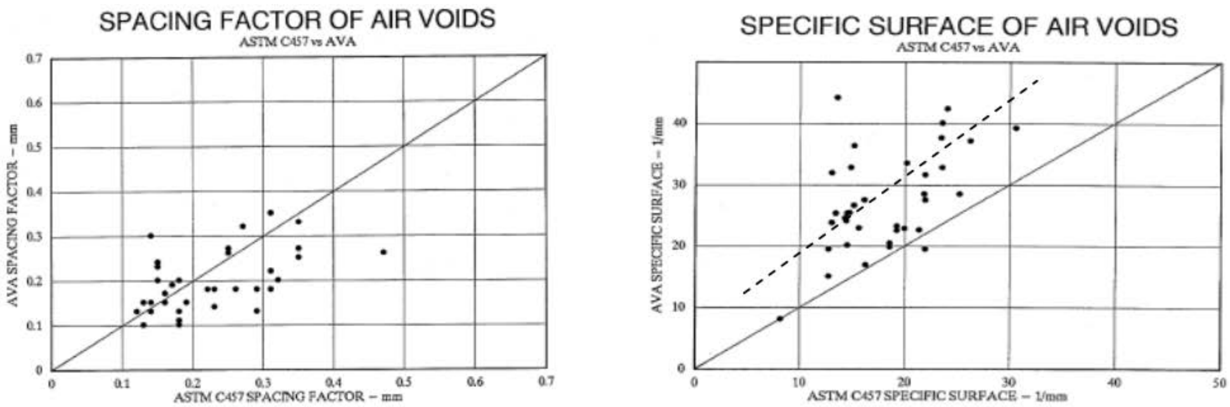


Figure 1.2: AVA and C457 Spacing Factor Outcome Matrix

1.3 Previous Work

A number of studies have been performed to evaluate the AVA in terms of test robustness, variability, and potential applications, although few comprehensive studies have been completed to compare and determine a correlation to the spacing factors obtained with ASTM C457 (2012). An investigation of the factors influencing AVA test results is provided by Wang, Mohamed-Metwally, Bektas, and Grove (2008).

The first comprehensive study in the United States was completed by the Federal Highway Administration (FHWA) in 1996 (Magura, 1996). A total of 33 concrete mixtures obtained in four states were evaluated for air content, AVA spacing factor and specific surface, and ASTM C457 spacing factor and specific surface. The AVA tended to measure a lower total air content (as compared to the air content measured using the pressure air meter [ASTM C231, 2014]). Weak correlations were observed between the spacing factors and specific surfaces measured by the AVA and C457 as shown in Figure 1.3. In general, C457 spacing factors were lower and specific surface values were higher as compared to the results obtained with the AVA.



(a) (b)

Figure 1.3: Correlation Between (a) AVA and ASTM C457 Spacing Factors, and (b) AVA and C457 Specific Surfaces
Note: 25.4 mm = 1 in.
Source: Magura (1996)

Wang et al. (2008) compiled AVA and ASTM C457 spacing factor data obtained from the Missouri Department of Transportation (MoDOT) for 38 data pairs obtained from 14 lab mixtures and 4 field mixtures and 32 data pairs from the FHWA mobile lab. The results of the comparison are shown in Figure 1.4. The correlation between AVA and C457 spacing factors is weak, although unlike the data presented by Magura (1996), the AVA spacing factors for the MoDOT data pairs are consistently higher than those determined using C457. For the MoDOT data, there is good agreement between the AVA and C457 data pairs when pass-fail criterion is used. With an AVA and C457 spacing factor limit of 0.200 mm (0.0080 in.)[2], the two test methods agree 55% of the time (*i.e.*, both pass or both fail). When the AVA spacing factor limit is increased to 0.375 mm (0.0150 in.) and the C457 spacing factor remains the same, the agreement increases to 95%. In either case, only one of the samples (representing 3%) lies in Q2 with an acceptable AVA spacing factor and an unacceptable C457 spacing factor.

[2] Unit conversions for limits and specification requirements are based on a *soft* conversion of 25 mm/in. The conversion factor for actual data is based on 25.4 mm/in. (see Section 1.2.1).

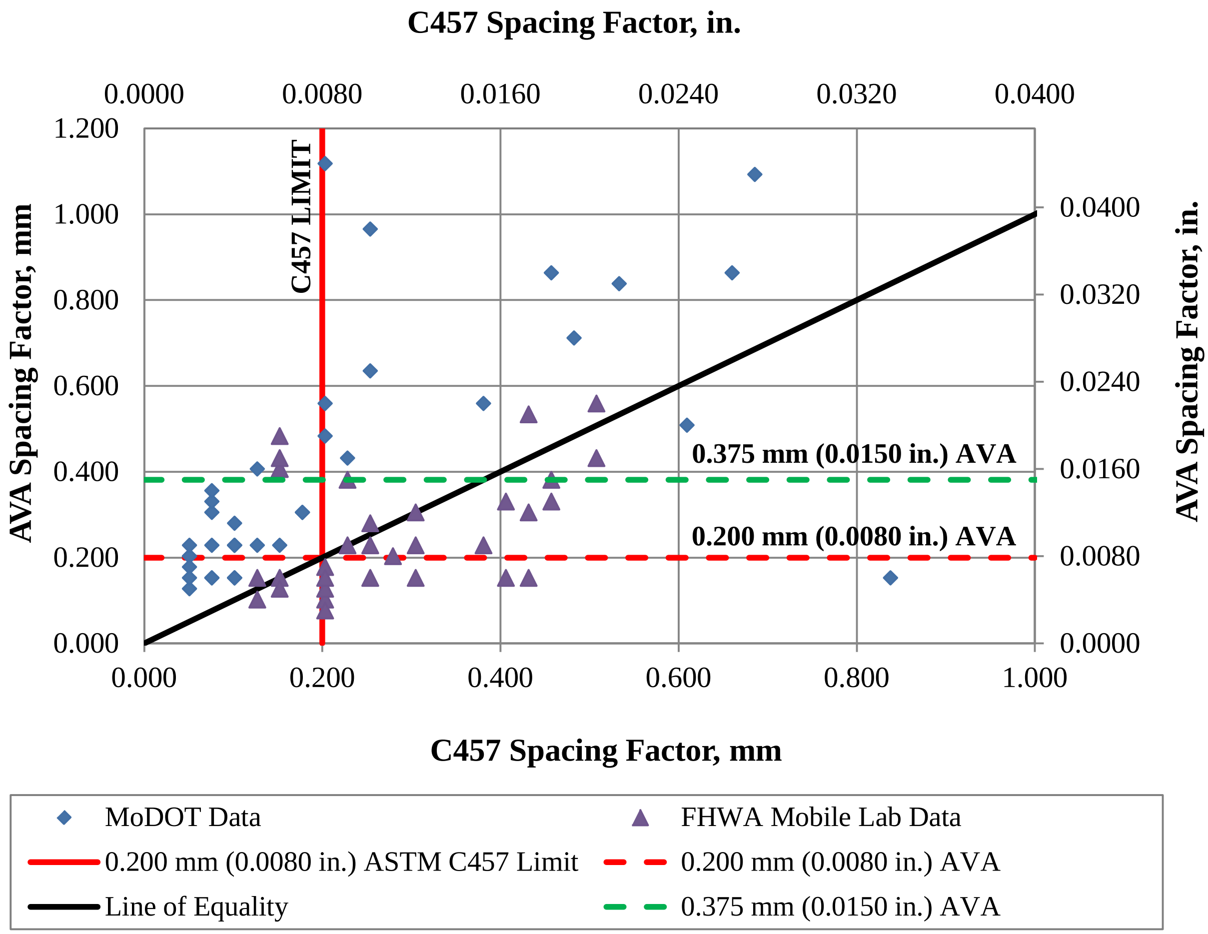


Figure 1.4: Pass-Fail Criterion Agreement for MoDOT and FHWA Mobile Lab Data Pairs
Adapted from Wang et al. (2008)

Conversely, the AVA spacing factors for the FHWA mobile lab tend to be less than the C457 spacing factors, but show similar agreement (59% compared to 55% for the MoDOT data) when pass-fail criteria is used with AVA and C457 spacing factor limits of 0.200 mm (0.0080 in.). Increasing the AVA spacing factor limit to 0.375 mm (0.0150 in.), however, decreases the test agreement to 28%. A number of factors could be responsible for the difference observed between the two data sets, including test conditions and environment as well as the materials used for testing. In any case, the variability in the AVA results (particularly for those performed by different organizations) warrants development and evaluation using data obtained from the State of Kansas.

1.4 Scope and Objective

From 2001 to 2012, KDOT collected a total of 270 data pairs including AVA and ASTM C457 spacing factors. Four-inch diameter concrete cores were taken for hardened air void analysis (ASTM C457) at the same location where the spacing factor was determined using the AVA. When the core drill was not available, a 4-inch diameter cylinder was cast from concrete taken adjacent to the AVA sample location. The raw data are provided in Table A.1 and include 270 data pairs from laboratory mixtures prepared at the Materials and Research Center Lab and pairs taken from projects in Kansas.

This report provides a comparison between spacing factors obtained with the AVA and following ASTM C457 Procedure A (linear traverse). The overall objective of the project is to evaluate the effectiveness of the AVA as a field verification and screening tool in mitigating the risk of KDOT accepting non-durable concrete. The data pairs collected are used to evaluate KDOT's current use of the AVA and ASTM C457 tests, and to determine if a correlation (either direct or pass-fail criteria) exists between spacing factors obtained with ASTM C457 and the AVA.

Chapter 2: Experimental Program

2.1 General

The experimental program described in this chapter involves the collection of paired plastic and hardened concrete samples for air void analysis. The hardened concrete air void analysis was performed in accordance with ASTM C457 (2012) *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete* using Procedure A (linear traverse), and the plastic analysis was performed with an Air Void Analyzer (AVA) in accordance with KT-71 (2015) and AASHTO TP 75-08 (2008). A total of 270 paired samples were collected between 2001 and 2012 in the field and the laboratory.

2.2 Equipment and Methods

Hardened concrete air void analysis was performed in accordance with ASTM C457 using the linear traverse method Procedure A (linear traverse). KDOT purchased an automated image analysis system (CAS-2000 Air Void Analysis System) to perform the testing in the mid-1990s, which was replaced in 2007 with the AV-2000 Air Void Analysis System. The AV-2000 has the capability to eliminate any void size desired and can differentiate between entrapped and entrained air. Testing follows ASTM C457 at a magnification of 100 times and includes all of the voids in the total air evaluation. The operator performing the analysis will generally comment on the number of voids over 0.500 mm (0.0200 in.), considering them as non-entrained air voids, but they are still included in the results reported. The range of two spacing factor tests of samples prepared and tested in the same lab (single operator) is 22.6% of their average (D2s%) which increases to 49.5% when the specimens are prepared and tested in separate laboratories. The corresponding coefficients of variation (1s%) are 8.0% and 17.5%, respectively (ASTM C457, 2012).

Plastic concrete air void analysis was performed using the AVA-2000 Air Void Analyzer. Testing was conducted in accordance with KT-71, which formed the basis for the American Association of State Highway and Transportation Officials (AASHTO) provisional test method TP 75-08, *Air-Void Characteristics of Freshly Mixed Concrete by Buoyancy Change*. Details regarding the testing principles used by the AVA are presented by Henrichsen and Vyncke

(1995). Only air voids less than 3 mm (0.1 in.) in diameter are included in the determination. An official precision statement has not been adopted by AASHTO, but Germann Instruments, Inc. (n.d.) reports that the single-operator coefficient of variation for the AVA spacing factor is between 8 and 10%. Distlehorst and Kurgan (2007) reported single-operator and multi-machine standard deviations of 0.0185 mm (0.0007 in.) and 0.0256 mm (0.0010 in.), respectively. Therefore, results of two properly conducted tests by the same operator should not differ by more than 0.050 mm (0.0020 in.) and the results of two properly conducted tests on different machines should not differ by more than 0.070 mm (0.0028 in.).

Intensive multi-laboratory testing during the 2008 two-lift project on I-70 uncovered a potential issue related to the water used for testing. It was determined that AVA data from KDOT District 2 performed using Salina, KS, city water introduced a higher-than-normal amount of variability in the test results. The decision was made to discontinue use of the municipal water, and since that time, all KDOT AVA testing has been performed using deionized water from the Materials and Research Center in Topeka, KS. The analysis presented herein does not include any of the tests performed using Salina, KS, city tap water. Other municipal sources are included in the analysis and compared with the results obtained using deionized water.

2.3 Data Sources

From 2001 to 2012, KDOT collected a total of 270 data pairs including AVA and ASTM C457 spacing factors. Four-inch diameter concrete cores were taken for hardened air void analysis (ASTM C457) at the same location where the spacing factor was determined using the AVA. When the core drill was not available, a 4-inch diameter cylinder was cast from concrete taken adjacent to the AVA sample location. A total of 153 of the 270 (56.7%) data points were collected from the 2008 two-lift construction of I-70 in Saline County, KS. Another 77 samples were taken in the field, and 40 were batched, sampled, and tested in a laboratory. Of the 270 samples, 50 of the AVA spacing factor tests were performed with deionized water and 220 were tested with municipal water local to the project. The raw data are provided in Table A.1.

In 2005, 70 additional AVA and C457 data pairs were obtained during the construction of I-70 in Dickinson County (Project No. 70-21 K-6794-01). For this report, however, data from this project is *not* included in the analysis. Very few passing AVA tests were obtained during construction but the reason was not determined until 2008 during the I-70 two-lift project. At the time, KDOT personnel could not explain the scatter and high overall AVA spacing factors obtained during the project. Following the 2008 multi-laboratory testing, it was discovered that the 2005 I-70 AVA testing was conducted using the problematic Salina, KS, city water. Spacing factor data for this project is provided in Table A.2, but it is not included in the results presented in Chapter 3. Future analysis could work to quantify the effect of water source on variability and skew; however, all testing is now conducted with deionized water from the Materials and Research Center in Topeka, KS.

2.4 Statistical Methods

The analysis presented in Chapter 3 includes a number of comparisons between spacing factors obtained with the AVA and ASTM C457. When the data are separated into categories based on AVA threshold values (as shown in Figure 1.2), it is instructive to calculate the percentages of these samples within each category as well as the expected range (margin of error) of values based on a predetermined level of confidence. The margin of error (ME) for normally-distributed data is calculated using Equation 2.1.

$$\mathbf{ME} = \boldsymbol{z}\sqrt{\frac{\hat{\boldsymbol{p}}(\mathbf{1}-\hat{\boldsymbol{p}})}{\boldsymbol{n}}}$$ **Equation 2.1**

Where:

$\mathbf{ME}$ = margin of error

$\boldsymbol{z}$ = *z*-score (normal distribution) based on the confidence interval

$\hat{\boldsymbol{p}}$ = estimate of the percentage of values in each category

$\boldsymbol{n}$ = sample size

The estimated percentage in each category $\hat{\boldsymbol{p}}$ is taken as the actual percentage of samples within the category under investigation.

The t-distribution is also used to assess the difference between sample means (Student's t-test) and to construct prediction intervals enveloping linear trend lines. The t-test is parametric and is frequently used when samples are small and the true population characteristics are unknown. The t-test relies on the means of the two sample groups, the size of the samples, and the standard deviation of each group to determine statistical significance or to develop prediction intervals at a specified level of confidence α. Two-sided tests are used, meaning that there is a probability of $\alpha/2$ that the population means are different (smaller or larger) when in fact, they are equal.

Chapter 3: Results and Evaluation

3.1 General

Comparisons between spacing factors collected with the Air Void Analyzer (AVA) and ASTM C457 (denoted as C457) are presented in the following sections. The data is divided into two categories depending on the source of water used to perform the AVA testing. The raw data, including the source of water used for testing (when available), is provided in Table A.1. Figures 3.1 through 3.3 present the results obtained without regard to water source (Salina, KS, city tap water is excluded as indicated in Chapter 2) and Figures 3.4 through 3.6 include only data pairs tested with deionized water. In both cases, emphasis is placed on using the data collected since 2001 to evaluate the *current specification limits* for AVA spacing factors and to provide recommendations moving forward.

3.2 Distribution of Spacing Factor Data

The comparisons between AVA and ASTM C457 spacing factors include confidence intervals based on the underlying assumption that the data is normally distributed. Histograms with normal probability distributions are shown in Figure 3.1 for both the AVA (with and without deionized water) and C457 spacing factors to assess normality. Figure 3.1b appears to have a slight positive skew, although the difference is not believed to justify an alternate skewed distribution. In fact, for the purpose of calculating confidence intervals, the normal distribution will conservatively estimate the upper confidence limit.

The average AVA spacing factor for tests conducted with municipal water is 0.271 mm (0.0107 in.)[3] with a standard deviation of 0.120 mm (0.0047 in.). For tests conducted with deionized water, the average and standard deviation increase to 0.305 mm (0.0120 in.) and 0.158 mm (0.0062 in.), respectively. This difference is not statistically significant (90% confidence, p-value = 0.148) based on a two-tailed t-test assuming unequal variances. As a result, this increase is not believed to be a result of the test, but potentially indicative of the general increase in spacing factors that began in 2006 (see Figure 1.1) and overall variability of the test. As shown

[3] Unit conversions for limits and specification requirements are based on a soft conversion of 25 mm/in. The conversion factor for actual data is based on 25.4 mm/in. (see Section 1.2.1).

in Figure 3.1c., the C457 spacing factors have both a lower average of 0.161 mm (0.0063 in.) and standard deviation of 0.060 mm (0.0024 in.).

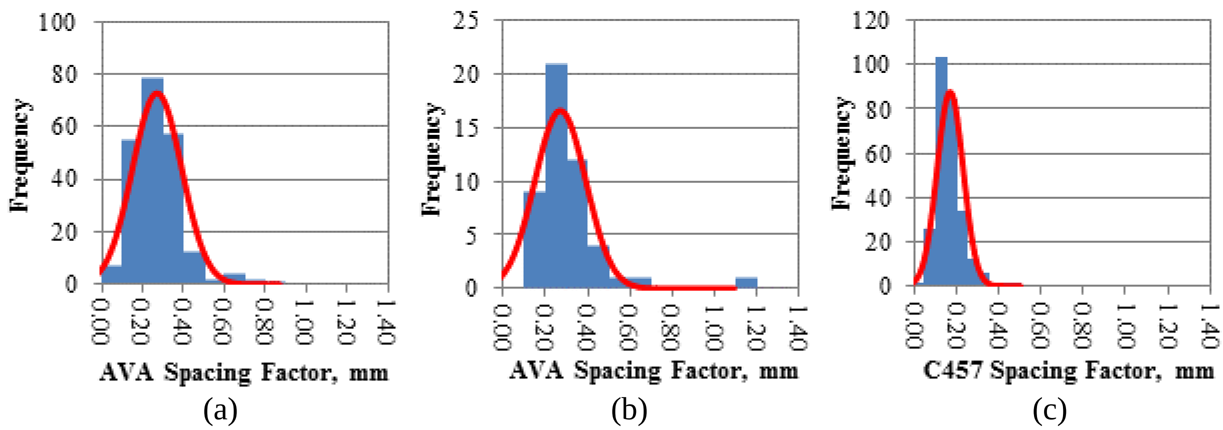


Figure 3.1: Histograms and Normal Distributions to Assess Normality for Spacing Factors Obtained by (a) the AVA Conducted with Municipal Water, (b) the AVA Conducted with Deionized Water, and (c) ASTM C457
Note: 25.4 mm = 1 in.

Figure 3.2 presents a comparison of spacing factors obtained with C457 versus the corresponding AVA spacing factor determined with deionized water and municipal water local to the project. The majority of the AVA spacing factors are greater than their corresponding C457 spacing factors (plot above the line of equality) and very little difference can be identified between AVA water sources. This is consistent with manufacturer recommendations and AASHTO TP 75-08 (2008) that only require potable water and does not differentiate between results obtained with various potable water sources. However, KDOT will continue to use single-source deionized water based on issues with at least one source in the state and the potential for other sources to bias the test results. The potential for error due to water source is greater than the cost of using a single deionized water source.

Two analyses are presented in the balance of this section. The first comparison includes all of the AVA data (testing with municipal water and deionized water as shown in Figure 3.2) since there is no statistical justification to analyze them separately. A second analysis including just the AVA spacing factor data collected with deionized water is also presented and is indicative of the testing procedure currently used by KDOT.

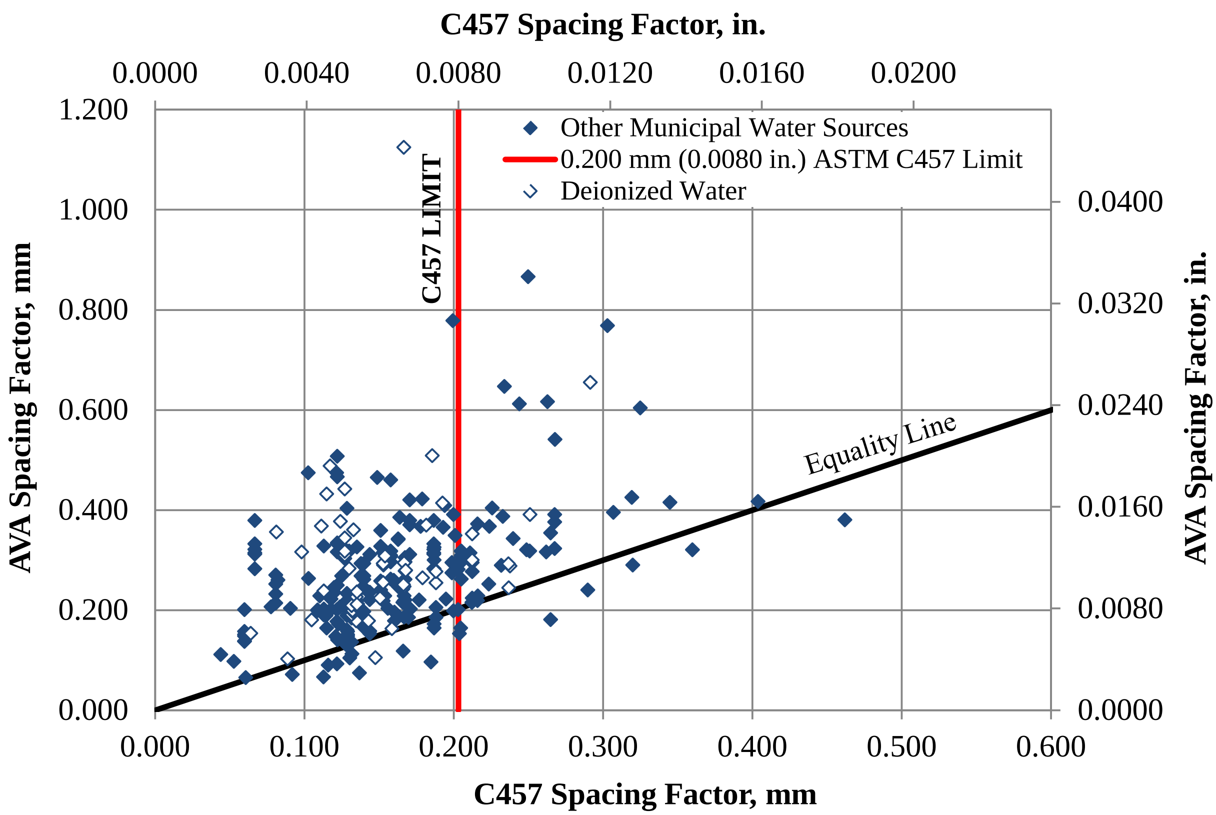


Figure 3.2: AVA Spacing Factor versus C457 Spacing Factor for AVA Tests Conducted With and Without Deionized Water

3.3 Comparison Based on All Data Collected

Hardened air spacing factors as measured by ASTM C457 are compared with the corresponding AVA spacing factor in Figure 3.3 for all of the collected data. The figure includes a linear trend line, prediction intervals (based on a t-distribution), and for comparison, the maximum allowable ASTM C457 spacing factor in the hardened concrete. The upper prediction interval (labeled as 80% U) indicates the spacing factors that have a 10% probability of being exceeded. The lower prediction interval (labeled as 80% L) indicates the spacing factors that have a 90% probability of being exceeded. Four data pairs are identified as outliers based on a standardized residual greater than 3. For normally distributed data, 99.7% of the pairs should have a standardized residual within ±3 standard deviations (assuming random errors only). These data pairs are not included in the analysis and discussion that follows.

The average hardened air spacing factor as measured by ASTM C457 is 0.160 mm (0.0063 in.) with values between 0.044 and 0.462 mm (0.0017 and 0.0182 in.). A significant percentage of these samples (20.0% [24.6% with a 10% probability of exceedance]) have a C457 spacing factor greater than 0.200 mm (0.0080 in.) and do not meet the minimum requirements for an acceptable air-void system (ACI Committee 201, 2008). The percentage of failing samples decreases to 7.5% (10.4% with a 10% probability of exceedance) when the C457 limit is increased to 0.250 mm (0.0100 in.). The average AVA spacing factor is 0.267 mm (0.0105 in.) with values between 0.065 and 0.655 mm (0.0026 and 0.0258 in.). The average difference between the two methods is 0.108 mm (0.0042 in.) with the average AVA spacing factor 67% higher (1.67 times) than the average obtained using C457. These values are consistently higher than the plus or minus 10% reported by Henrichsen and Vyncke (1995). No meaningful direct correlation is observed between the spacing factors as the data shows considerable scatter with a linear coefficient of determination of only 0.20.

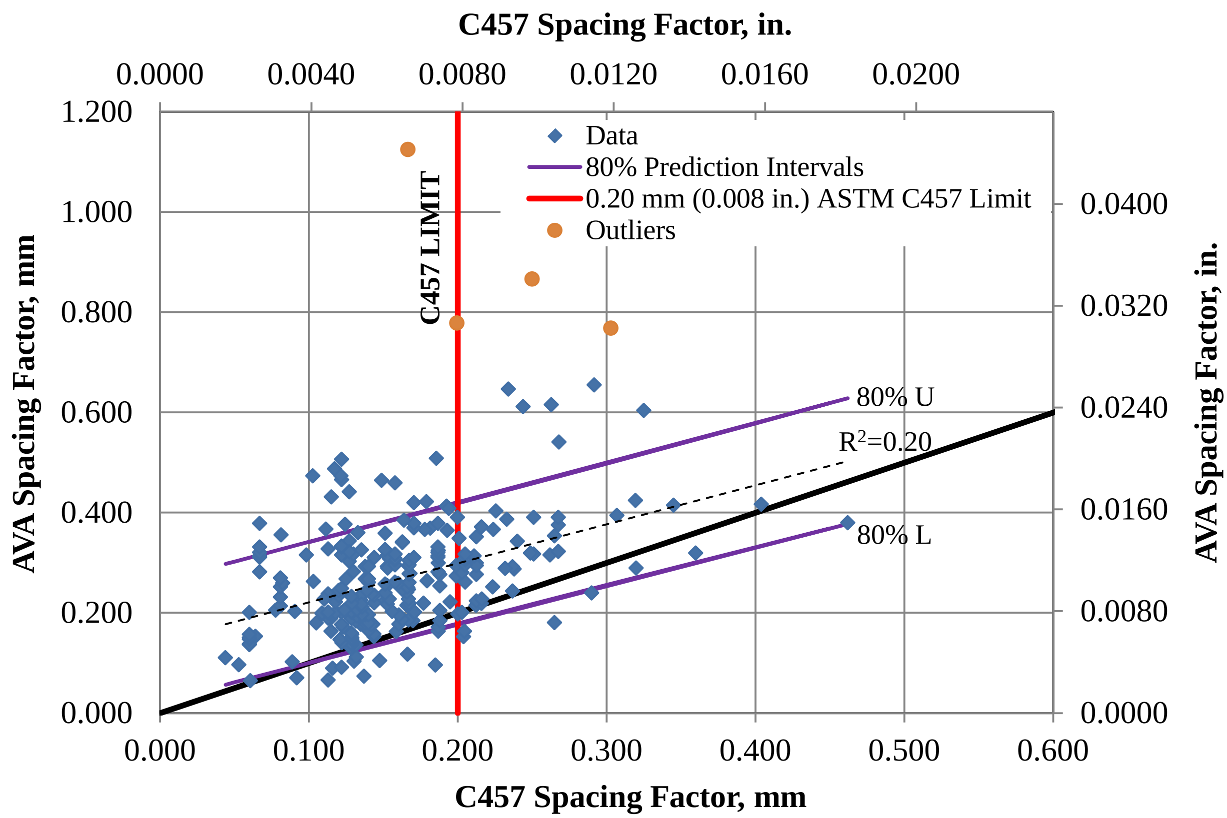


Figure 3.3: AVA and ASTM C457 Spacing Factors for All Data

Spacing factors obtained with C457 are plotted versus the corresponding AVA spacing factor for all data in Figure 3.4 (a subsequent analysis will only include AVA samples tested using deionized water). The specification limits for the AVA and C457 are also included and create the four quadrants described in Figure 1.2 with a summary of the data for each quadrant provided in Table 3.1. Of the 266 data pairs (four outliers excluded), 128 (48.1%) meet the *design* KDOT limit with AVA spacing factors less than 0.250 mm (metric units are not used in the current specification, but the equivalent requirement using a soft conversion of 25 mm/in. is 0.0100 in.). The number of passing samples increases to 195 (73.3%) when compared to the current maximum specification limit of 0.313 mm (equivalent to the specification value of 0.0125 in.), that triggers hardened air testing (AVA threshold). Of these 195 samples, 26 (9.8% of the total) of the data pairs meet the AVA spacing requirements but, in fact, have a C457 spacing factor greater than the specified limit 0.200 mm (equivalent to 0.0080 in.). This concrete was accepted and would have also been accepted under the current specification. This outcome represents KDOT's risk of accepting concrete with an inadequate spacing factor. When an 80% confidence interval (10% probability of exceedance) is included (also shown in Table 3.1 for each quadrant), the potential future risk to KDOT could be as high as 12.1% of the total number of tests.

Overall, 73.7% (63.5+10.2%) of the AVA and C457 tests are in agreement (26.3% disagree). An additional 16.5% (for a total of 90.2%) of the data pairs failed the AVA threshold screening requirement (spacing factor greater than 0.0125 in. [equivalent to 0.313 mm]) but would have ultimately been accepted based on C457. Samples meeting these criteria (see Q4 in Figure 1.2) require additional testing, however, that is the extent of the risk to KDOT as the in-place concrete has an adequate spacing factor to withstand freeze-thaw cycles. As previously discussed, the remaining 9.8% passed the initial AVA screening test but had an actual C457 spacing factor greater than the recommended limit for concrete subject to freezing and thawing. Reducing the AVA spacing factor threshold that triggers further testing will reduce the risk of KDOT accepting non-durable concrete, but at the same time, increase the number of additional tests required. Targeting a lower spacing factor in the field will also reduce KDOT risk and would have the effect of shifting the data shown in Figure 3.4 towards Q3 (down and to the left).

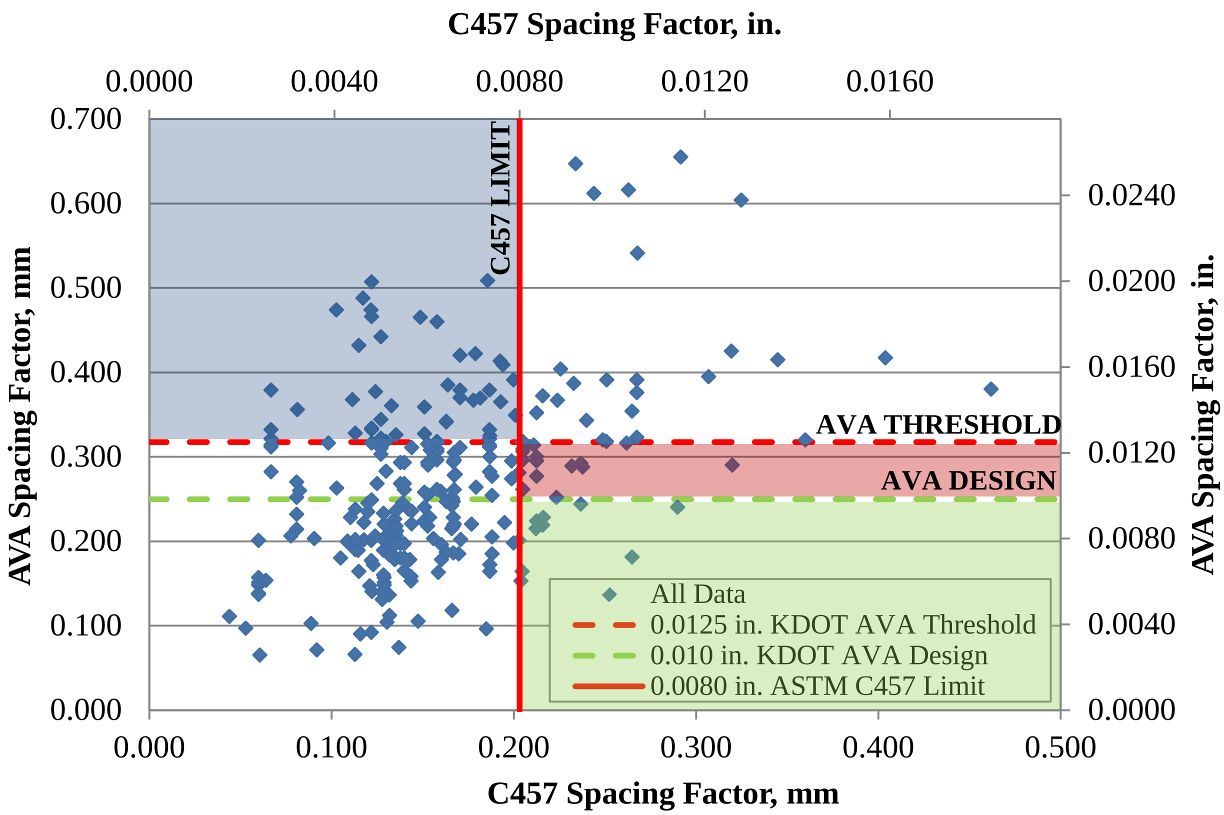


Figure 3.4: Acceptance and Rejection Agreement in Spacing Factors Measured by the AVA and ASTM C457

Table 3.1: Results of Using the AVA as a Screening Tool to Trigger C457 for Verification

<table>
<tr><th colspan="2">Subcategory
No. data pairs</th><th>% of Total number of data points†</th><th>% of subcategory†</th><th>Notes</th></tr>
<tr><td rowspan="2">Pass AVA‡
≤0.313 mm
(≤0.0125 in.)</td><td>169</td><td>63.5
(59.8 to 67.3)</td><td>86.7
(83.5 to 89.8)</td><td>Both Tests Pass – agree</td></tr>
<tr><td>26</td><td>9.8
(7.4 to 12.1)</td><td>13.3
(10.2 to 16.5)</td><td>AVA Pass & C457 Fail – disagree
(False Positive & KDOT Risk)</td></tr>
<tr><td rowspan="2">Fail AVA‡
>0.313 mm
(>0.0125 in.)</td><td>27</td><td>10.2
(7.8 to 12.5)</td><td>38.0
(30.6 to 45.4)</td><td>Both Tests Fail – agree</td></tr>
<tr><td>44</td><td>16.5
(13.6 to 19.4)</td><td>62.0
(54.6 to 69.4)</td><td>AVA Fail & C457 Pass – disagree
(False Negative)</td></tr>
<tr><td colspan="2">266 Total</td><td>100.0%</td><td></td><td></td></tr>
</table>

†The range shown represents the two-tailed 80% confidence interval (10% probability of exceeding the highest value and 10% probability of falling below the lowest).
‡Current AVA spacing factor threshold (Pass/Fail) that triggers C457 testing is 0.313 mm (equivalent to 0.0125 in.).

Table 3.1 also presents the data divided into two subcategories—concrete with an AVA spacing factor above and below the AVA spacing factor threshold. A total of 169 out of the 195 data pairs (86.7%) with a passing AVA spacing factor also pass C457. The remaining 26 (13.3%) pass the AVA threshold used to screen field test results and would be accepted by KDOT but have a C457 spacing factor that exceeds the specification limit of 0.200 mm (equivalent to the specification value of 0.0080 in.). Of the 71 samples that failed the AVA screening test, 27 (38.0%) also failed C457 and 44 (62.0%) passed. The goal is to establish an AVA threshold level (currently 0.0125 in.) that produces an acceptable level of risk to KDOT (*i.e.*, concrete that passes the AVA but fails C457), and to a much lesser extent, limits the amount of false negatives (*i.e.*, concrete that fails the AVA but passes C457). These percentages expressed as a function of the specified AVA threshold are discussed next.

The percentage of concrete samples with spacing factors that pass the AVA but fail C457 (*i.e.*, false positive and KDOT's level of risk shown in Figure 1.2 in Q2) and that fail the AVA but pass C457 (*i.e.*, false negatives, Q4 in Figure 1.2) are shown as a function of the AVA spacing factor threshold in Figure 3.5. Figure 3.5 is used to select an appropriate AVA spacing factor threshold that balances KDOT's risk with the number of false negatives. The threshold values shown along the *x-axis* of Figure 3.5 are shown in metric units to preserve the units of the original data. Linear trend lines and error bars representing 80% confidence intervals (10% probability of being above or below the designated range) are included. For example, with an AVA spacing factor threshold of 0.0125 in. (equivalent to 0.313 mm), 13.3% (16.5% with a 10% probability of exceedance) of the samples that pass the AVA can be expected to have a C457 spacing factor greater than 0.200 mm (equivalent to the specification value of 0.0080 in.), and 62.0% (69.4% with a 10% probability of exceedance) of the samples that fail the AVA in fact have a spacing factor less than the C457 limit for freeze-thaw durable concrete.

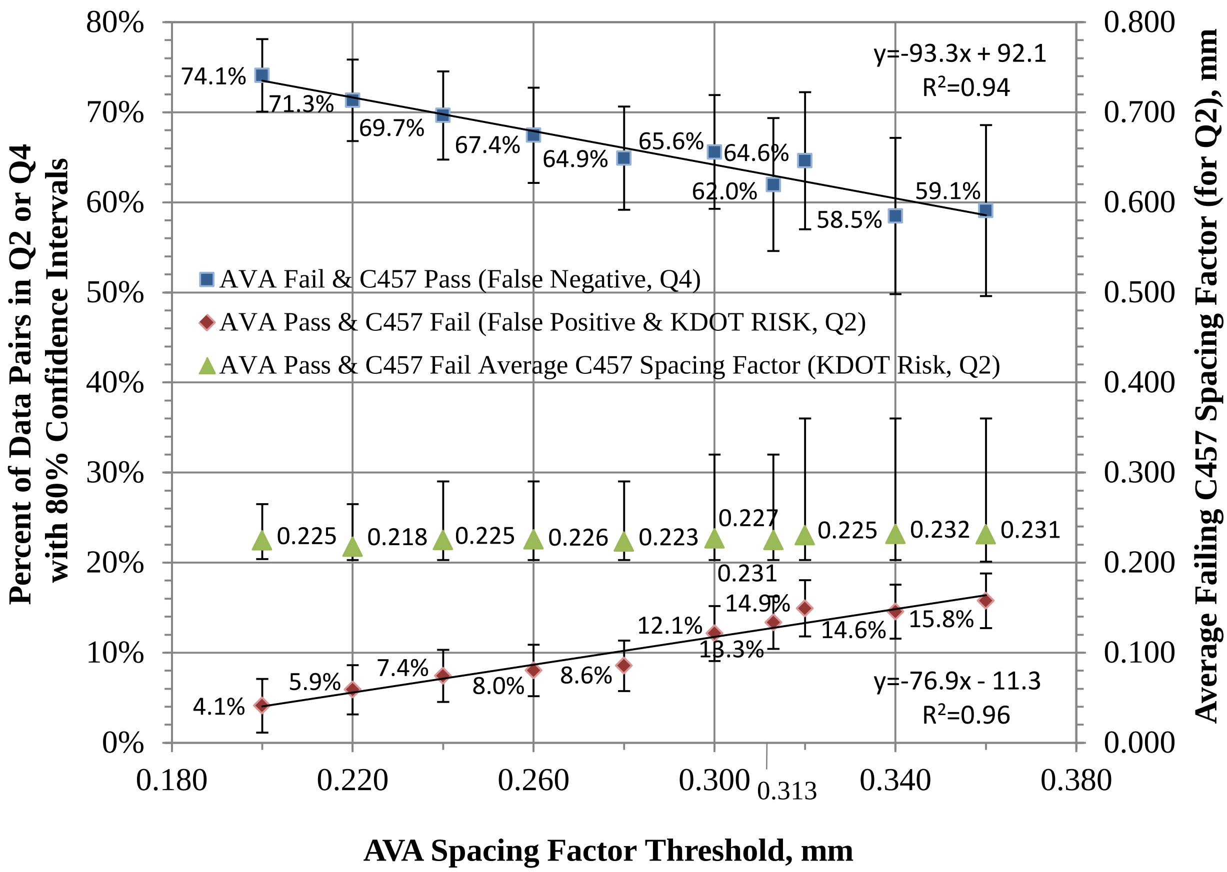


Figure 3.5: Percent of AVA Test Results that Disagree (False Positive or False Negative, Q2 or Q4 in Figure 1.2) with ASTM C457 Test Results as a Function of the AVA Spacing Factor Threshold Triggering Hardened Air Testing and Average Failing C457 Spacing Factor for Samples in Q2
Note: 25.4 mm = 1 in.

As the AVA spacing factor limit is increased, more samples meet the screening requirement that do not have an adequate C457 spacing factor and increase KDOT's risk of accepting concrete with an inadequate spacing factor. A smaller percentage of samples will fail the AVA and pass C457, but over the range of potential AVA threshold values, the probability of false negatives does not change significantly. Historically, the level of acceptable risk to KDOT may be on the order of 10%. In order to meet this level of risk based on the linear trend line shown in Figure 3.5, the AVA threshold should be set at 0.280 mm corresponding to a *specification* value of 0.0110 in. (rounded to the nearest 0.001 in.). For samples at this AVA threshold and below, the average C457 spacing factor is 0.141 mm (0.0055 in.) compared to 0.147 mm (0.0058 in.) with the current AVA threshold (0.313 mm [0.0125 in.]). The expected level of KDOT's risk is 8.6% at this threshold value. The actual percentages (with 80% confidence intervals) based on the collected data are 8.6% (5.7 to 11.4%) and 64.9% (59.0 to 70.6%) for KDOT's risk and false negatives, respectively.

The average failing C457 spacing factor for data pairs in Q2 (passing the AVA and failing ASTM C457, see Figure 1.2) is also shown in Figure 3.5 plotted on a secondary vertical axis. The average is nearly independent of the AVA spacing factor threshold, however, the range of values (shown with the error bars in Figure 3.5) increases with the AVA spacing factor threshold. The average failing C457 spacing factor is 0.223 mm (0.0088 in.) with values that range between 0.203 and 0.290 mm (0.0080 and 0.0114 in.) when the AVA spacing factor threshold is 0.280 mm (equivalent to 0.0110 in.). The average increases slightly to 0.225 mm (0.0089 in.) with values that range between 0.203 and 0.320 mm (0.0080 and 0.0126 in.) for the current *specification* threshold value 0.313 mm (0.0125 in.).

3.4 AVA Testing Performed with Deionized Water

The source of water used to conduct AVA testing was discovered to have an influence on the measured spacing factor. AASHTO TP 75-08 (2008) only requires potable de-aerated water. The AVA test method utilizes Stoke's Law which relates the velocity of the air bubbles in the chamber to their size using the dynamic viscosity of the fluid, so it comes as no surprise that the source of the water (and possible differences in viscosity) may have an influence on the results. In particular, tests conducted using city tap water from Salina, KS, resulted in abnormally high spacing factors. Rather than conduct an exhaustive evaluation of the test procedure using water from various sources, the AVA test procedure (used in Kansas) was changed to only include deionized and de-aerated water from the Materials and Research Center in Topeka, KS.

An additional comparison between the average hardened air spacing factor as measured by ASTM C457 and the corresponding average AVA spacing factor is shown in Figure 3.6. For this data, however, only AVA tests conducted using the single-source deionized water are included. A linear trend line, 80% prediction intervals, and the maximum allowable C457 spacing factor in the hardened concrete (KDOT, 2015) are included. One data pair is identified as an outlier based on a standardized residual greater than three and is not included in the analysis and discussion that follows.

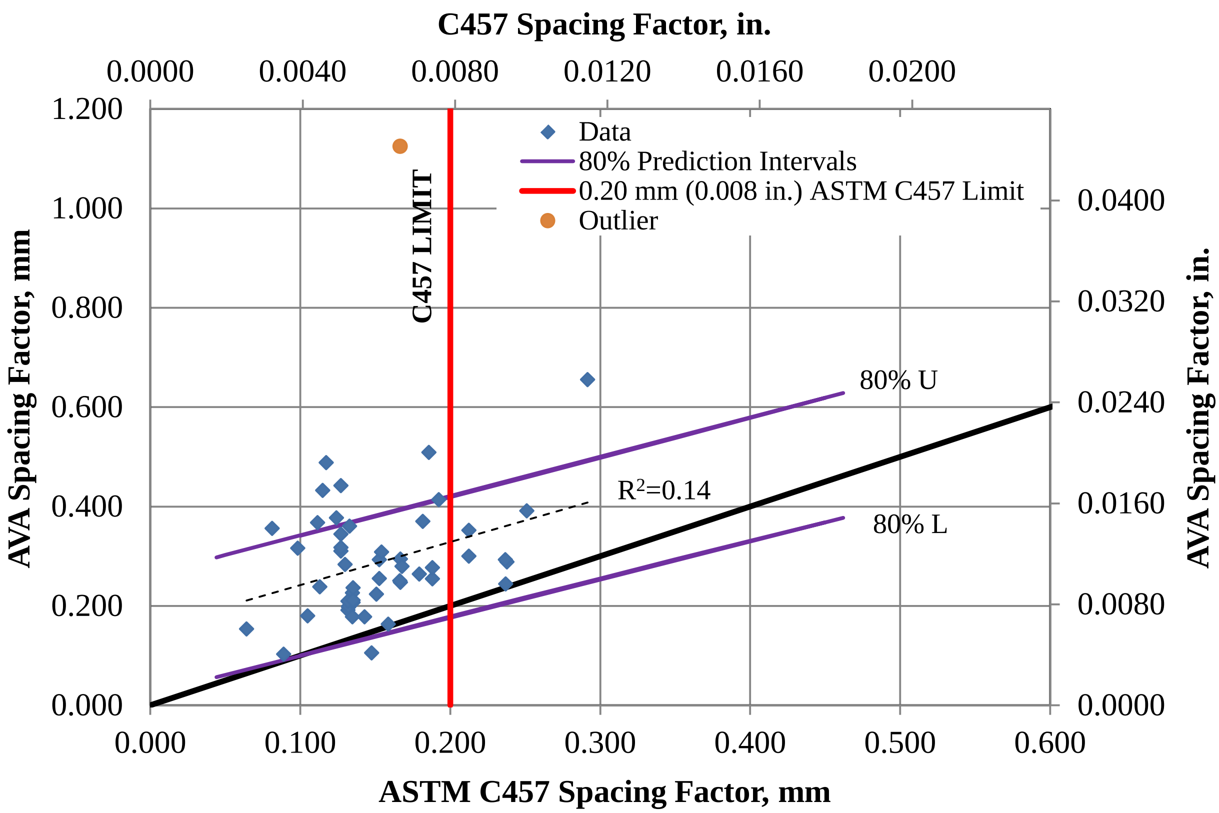


Figure 3.6: Spacing Factor for AVA versus ASTM C457 with AVA Testing Performed Using Deionized Water

There is less scatter in the data at the high end of the measured spacing factors when the tests conducted with non-deionized water are excluded. This is one indication that water source was affecting the AVA test results. The average hardened air spacing factor as measured by ASTM C457 is 0.153 mm (0.0060 in.) with values between 0.064 and 0.292 mm (0.0025 and 0.0115 in.). The average AVA spacing factor is 0.288 mm (0.0113 in.) with values between 0.103 and 0.655 mm (0.0041 and 0.0258 in.). The average difference between the two methods is 0.135 mm (0.0053 in.) with the average AVA spacing factor 88% higher (1.88 times) than the average obtained using ASTM C457 (compared to 0.108 mm [0.0042 in.] and 67% when all of the data is included). No meaningful correlation is observed between the two spacing factors with a linear coefficient of determination of 0.14.

The spacing factor data in Figure 3.6 is included with specification limits and the corresponding quadrants (see Figure 1.2) in Figure 3.7, and the data is tabulated in Table 3.2. Of the 49 data pairs (one outlier excluded), 18 (36.7%) meet the *design* KDOT limit with AVA spacing factors less than 0.250 mm (0.0100 in.). The number of passing samples increases to 35 (71.5%) when compared to the current maximum specification limit (0.313 mm [0.0125 in.]) that triggers hardened air testing. Of these 35 samples, four (8.2% of the total, compared to 9.8% for the tests performed with non-deionized water) of the data pairs meet the AVA spacing requirements but have a C457 spacing factor greater than 0.200 mm (0.0080 in.). KDOT's risk with an 80% probability of occurring (based on this data set only) is 3.2 to 13.2%, compared to 7.4 to 12.1% when all of the data is included.

Overall, 69.4% (63.3+6.1%) of the AVA and C457 tests are in agreement (30.6% disagree). An additional 22.4% (for a total of 91.8%) of the data pairs failed the AVA screening requirement (spacing factor greater than 0.313 mm [equivalent to 0.0125 in.]) but would have been accepted based on C457. This is similar to the 90.2% obtained when all of the data is included in the analysis. The remaining 8.2% passed the initial AVA screening test but failed C457 testing (*i.e.*, KDOT's risk). A total of 31 out of the 35 data pairs (88.6% compared to 86.7% when all samples are included) that pass the AVA requirement also pass C457. The remaining four (11.4% of the samples passing the AVA compared to 13.3%) samples meet the AVA spacing factor requirement and not the C457 requirement. Of the 14 samples that failed the AVA screening test, three (21.4% compared to 38.0%) also failed C457 and 11 (78.6% compared to 62.0%) passed. These percentages will be examined in further detail in the following section.

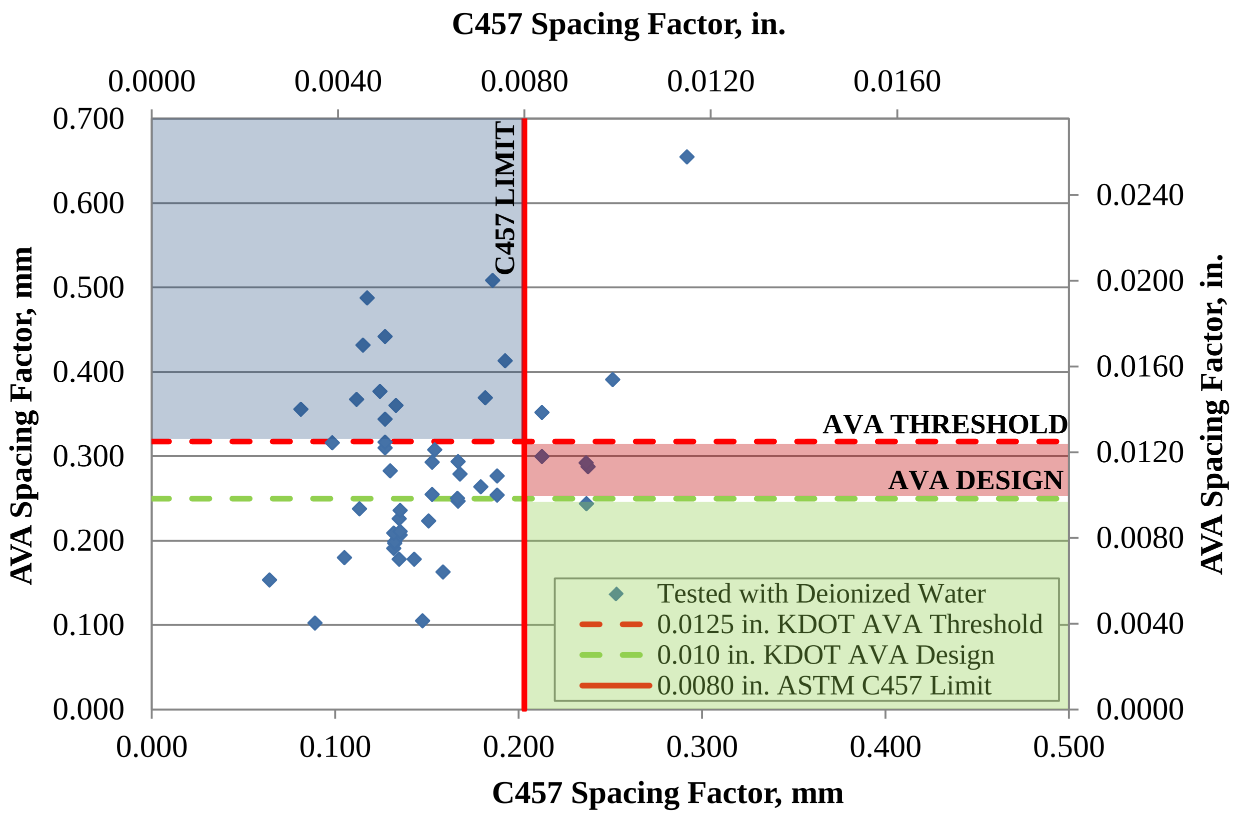


Figure 3.7: Spacing Factors from AVA (Testing Performed with Deionized Water) and ASTM C457 Testing with Specification Limits

Table 3.2: Results of Using AVA as a Screening Tool to Trigger C457 for Verification (Including Only Samples Tested with Deionized Water)

Subcategory	No. data pairs	% of Total number of data points†	% of subcategory†	Notes
Pass AVA‡ ≤0.313 mm (≤0.0125 in.)	31	63.3 (54.4 to 72.1)	88.6 (81.7 to 95.5)	Both Tests Pass – agree
	4	8.2 (3.2 to 13.2)	11.4 (4.5 to 18.3)	AVA Pass & C457 Fail – disagree (False Positive & KDOT Risk)
Fail AVA‡ >0.313 mm (>0.0125 in.)	3	6.1 (1.7 to 10.5)	21.4 (12.5 to 30.3)	Both Tests Fail – agree
	11	22.4 (14.8 to 30.1)	78.6 (64.5 to 92.6)	AVA Fail & C457 Pass – disagree (False Negative)
	49 Total	100.0%		

†The range shown represents the two-tailed 80% confidence interval (10% probability of exceeding the highest value and 10% probability of falling below the lowest).
‡Current AVA spacing factor threshold (Pass/Fail) that triggers C457 testing is 0.313 mm (equivalent to 0.0125 in.).

The percentages of samples with AVA and C457 test results that do not agree (either false negatives or positives) are shown in Figure 3.8 as a function of the AVA spacing threshold for the samples tested with deionized water. As the threshold value is increased, more samples meet the screening requirement that do not have an adequate C457 spacing factor and increase KDOT's risk of accepting concrete with an inadequate spacing factor. If a spacing factor of 0.280 mm (0.0110 in.) is selected as suggested previously, the calculated level of risk based on the linear trend line is 6.2%. The actual percentage based on the collected data is only 4.0% which could be as high as 9.0% with a 10% probability of exceedance. The percentage of samples that fail the AVA and pass C457 remains approximately constant over the range of potential AVA limits. The estimated percentage (based on the linear trend line) of samples failing the AVA screening test but ultimately passing C457 is 79.6%. In both cases, however, the number of samples is small—only four data pairs in Q2 and 11 in Q4 (see Figure 1.2). Based on this information and the small number of samples, 0.280 mm (0.0110 in.) appears to be an appropriate limit for the AVA spacing factor threshold. As shown in Figure 3.8, this limit could be increased to 0.300 mm (0.0120 in.) based on the trend line, but the calculated risk based on the actual field data indicates a potential risk as high as 20.6%—well above that acceptable to KDOT. The average failing C457 spacing factor (data pairs in Q2 as shown in Figure 1.2) is 0.230 mm (0.0091 in.) even as the AVA threshold is increased to as high as 0.360 mm (0.0144 in.). The average failing C457 spacing factor as a function of the AVA spacing factor threshold (see Figure 3.5) is not shown in Figure 3.8 due to a lack of available data.

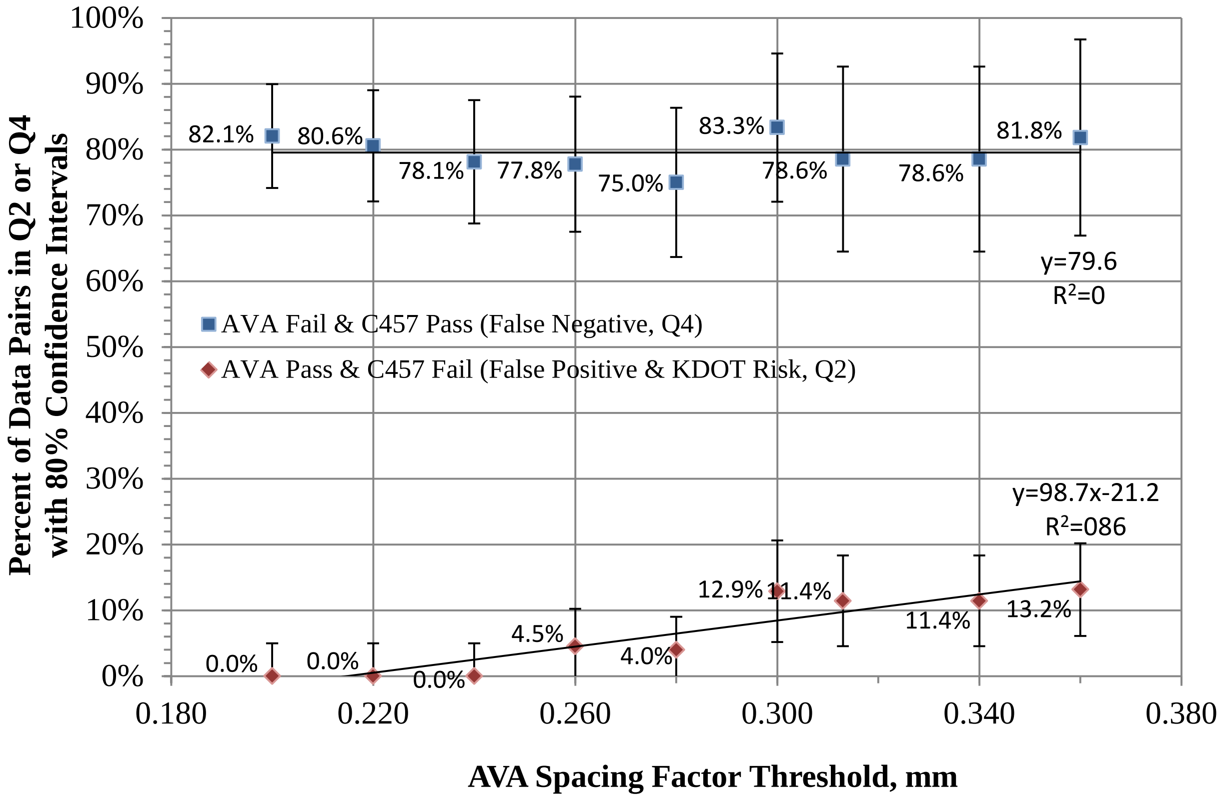


Figure 3.8: Percent of AVA Test Results that Disagree (False Positive or False Negative) with C457 Test Results as a Function of the AVA Spacing Factor Threshold Triggering Hardened Air Testing

Chapter 4: Conclusions and Recommendations

4.1 General

The purpose of this study is to evaluate the efficacy of the AVA system and establish specification limits for the AVA spacing factor that correspond to concrete with an adequate spacing factor as measured in the hardened concrete by ASTM C457 (2012). The study includes a total of 270 data pairs collected between 2001 and 2012. Four-inch diameter concrete cores were taken for hardened air void analysis (ASTM C457) at the same location where the spacing factor was determined using the AVA in the plastic concrete. The evaluation includes AVA tests performed with municipal water obtained at or near the project location as well as tests performed with deionized water. Of the 270 data pairs in the study, 50 include AVA test results obtained with deionized water while the remaining were obtained from a municipal source.

4.2 Conclusions

The following observations and conclusions are based on the results and analyses presented in this report. Unless noted, probabilities are based on all of the data (testing performed with municipal water and deionized water) included in this study.

1. KDOT should continue to use deionized water from the Materials and Research Center in Topeka, KS, due to issues with specific sources of water identified in the field (*e.g.*, city of Salina, KS, tap water). This will ensure that potential testing issues related to water source will not bias the results.
2. AVA spacing factors are, on average, 1.67 times higher than spacing factors determined using ASTM C457. When only the AVA tests conducted with deionized water are included, the AVA spacing factors are, on average, 1.88 times higher. In both cases, however, there is not a strong direct linear correlation between tests methods.

3. Twenty percent (up to 24.6% with a 10% probability of exceedance) of the samples do not meet standards for an “acceptable air-void system” with spacing factors measured using ASTM C457 greater than 0.0080 in. (0.200 mm).
4. At the *current* specification threshold of 0.0125 in. (equivalent to 0.313 mm) that triggers C457 testing:

   63.5% of the samples pass both tests,

   10.2% fail both tests, and

   26.3% fail exactly one of the tests.
5. Of the samples with an AVA spacing factor less than the *current* specification threshold of 0.0125 in. (equivalent to 0.313 mm), 13.3% (16.5% with a 10% probability of exceedance) have an actual spacing factor greater than the *current* C457 specification limit of 0.0080 in. (0.200 mm). This exceeds KDOT’s traditional risk tolerance of 10%.
6. Of the samples with an AVA spacing factor greater than the *current* specification threshold of 0.0125 in. (equivalent to 0.313 mm), 62.0% (69.4% with a 10% probability of exceedance) have an actual spacing factor less than the C457 limit.

4.3 Recommendations

Based on the observations and conclusions in this report, the following recommendations are made to ensure freeze-thaw durable concrete is used and accepted for KDOT projects.

1. Set the AVA spacing factor threshold (limit that triggers additional C457 testing) at 0.011 in. (equivalent to 0.28 mm). At this level, KDOT’s risk of accepting concrete based on AVA testing that does not actually have an adequate spacing factor is approximately 10%. Historically, the average C457 spacing factor for samples that do not meet this requirement is 0.223 mm (0.0088 in.).

2. Because the statewide spacing factor average has increased since 2005, including large increases in 2011 and 2012, it may be necessary to reconsider remove-and-replace or other punitive action such as QC/QA pay factors. At a minimum, KDOT should continue efforts to improve the passing rates of the air void system and evaluate the effectiveness of the 2015 specification requirements.
3. Increase the frequency of testing with the AVA to one test performed randomly for each four weeks of production for non-QC/QA projects to verify consistency of the in-place concrete. This recommendation matches the testing frequency currently required for QC/QA projects.
4. Continue efforts studying the impact of statewide AVA testing begun in 2000 on the paste freeze-thaw durability of concrete. The 10-year follow-up study of pavements constructed before and after implementation of AVA testing will be a valuable guide for future specifications.

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Appendix: Raw Spacing Factor Data

Table A.1: Spacing Factors of Concrete Using the Air Void Analyzer and ASTM C-457 from 2001 to 2011

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
04/19/01	50-57 K-5385-01	12+550	0.360	0.320			
04/19/01	50-57 K-5385-01	13+675	0.320	0.290			
04/19/01	50-57 K-5385-01	13+676	0.290	0.240			
2001 Study	2001 Study	M & R lab	0.462	0.380	Research	Research	Research
2001 Study	70-89 K-2442-01	M & R lab	0.404	0.417	Research	Research	Research
5/2005	35-105 K-6391-01	13+365	0.265	0.181			
5/2005	35-105 K-6391-01	13+620	0.345	0.415			
07/29/05	69-6 K-7412-01	12+845	0.212	0.215			
08/01/05	135-87 K-6780-01	19+870	0.216	0.228			
08/12/05	56-05 K-8615-01	10th&Col	0.187	0.164			
08/19/05	54-8 K-8001-02	1+805	0.128	0.140			
10/13/05	69-61 K-1591-01	26+200	0.195	0.222			
10/27/05	69-54K-7413-01	28+796	0.187	0.172			
11/10/05	89 U-1840-01	6th and Gage	0.128	0.131			
04/17/06	69-6 K-7412-01	23+645	0.115	0.164			
04/18/06	69-54 K-7890-01	99+025	0.121	0.147			
05/31/06	69-54 K-7890-01	97+494	0.114	0.199			
06/29/06	85 K 8307-01	10+414	0.124	0.206			
07/20/06	70-21K 6794-01	21+237	0.160	0.259			
07/20/06	70-21K 6794-01	21+837	0.130	0.318			
07/20/06	70-21K 6794-01	22+178	0.144	0.311			
07/26/06	77-81K 9182-01	40+310	0.200	0.391			
07/28/06	77-81K 9182-01	46+490	0.226	0.404			
08/02/06	77-81K 9182-01	not known	0.166	0.118			
08/03/06	54-60 K7410-01	22+335	0.179	0.422			
08/09/06	54-60 K7410-01	22+448	0.140	0.261			
08/09/06	54-60 K7410-01	22+600	0.201	0.349			
08/09/06	54-60 K7410-01	22+780	0.193	0.365			
08/11/06	54-60 K7410-01	23+015	0.164	0.385			
4/24/2007	435-46 K-7451-01		0.137	0.074			
5/23/2007	I-70 2-lift	M & R lab	0.154	0.228	Research	Research	Research
5/23/2007	I-70 2-lift	M & R lab	0.123	0.172	Research	Research	Research
5/25/2007	I-70 2-lift	M & R lab	0.234	0.647	Research	Research	Research

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
5/25/2007	I-70 2-lift	M & R lab	0.244	0.612	Research	Research	Research
5/30/2007	I-70 2-lift	M & R lab	0.163	0.247	Research	Research	Research
5/30/2007	I-70 2-lift	M & R lab	0.203	0.201	Research	Research	Research
6/1/2007	I-70 2-lift	M & R lab	0.142	0.177	Research	Research	Research
7/17/2007	70-85 K-6779-01		0.203	0.281			
7/23/2007	28 U-1898-01		0.232	0.289			
7/26/2007	156-28 K-9177-01		0.200	0.198			
7/26/2007	24-105 K-8248-01		0.177	0.220			
7/31/2007	54-60 K-7410-01		0.163	0.187			
7/31/2007	24-105 K-8248-01		0.216	0.219			
9/20/2007	283-42 KA-0488-01		0.307	0.395			
10/4/2007	50-78 K-7409-01		0.251	0.318			
10/4/2007	50-78 K-7409-01		0.240	0.343			
10/9/2007	50-78 K-7409-01		0.263	0.616			
10/16/2007	50-78 K-7409-01		0.268	0.541			
11/13/2007	Research 07-4081	M & R lab	0.250	0.866		Research	Research
11/13/2007	Research 07-4082	M & R lab	0.167	0.186		Research	Research
11/13/2007	Research 07-4083	M & R lab	0.171	0.202		Research	Research
11/13/2007	Research 07-4084	M & R lab	0.122	0.092		Research	Research
11/13/2007	Research 07-4085	M & R lab	0.092	0.071		Research	Research
11/14/2007	Research 07-4086	M & R lab	0.185	0.096		Research	Research
11/14/2007	Research 07-4087	M & R lab	0.204	0.153		Research	Research
11/14/2007	Research 07-4088	M & R lab	0.113	0.066		Research	Research
11/14/2007	Research 07-4089	M & R lab	0.116	0.090		Research	Research
11/14/2007	Research 07-4090	M & R lab	0.156	0.203		Research	Research
11/14/2007	Research 07-4091	M & R lab	0.265	0.354		Research	Research
11/15/2007	Research 07-4092	M & R lab	0.140	0.165		Research	Research
11/15/2007	Research 07-4093	M & R lab	0.129	0.220		Research	Research
11/15/2007	Research 07-4094	M & R lab	0.158	0.460		Research	Research
11/15/2007	Research 07-4095	M & R lab	0.178	0.367		Research	Research
11/15/2007	Research 07-4096	M & R lab	0.224	0.367		Research	Research
11/15/2007	Research 07-4097	M & R lab	0.233	0.387		Research	Research
2008	US 69 2-lift	4+723	0.134	0.194			
2008	US 69 2-lift	4+950	0.122	0.141			
2008	I-70 2-lift	M & R lab	0.319	0.425	Research	Research	Research
2008	K-8262-01		0.131	0.104	Research	Research	Research
2008	U.S. 24/7		0.205	0.164			
2008	U.S. 24/7		0.170	0.185			

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
2008	Mac Vicar, Topeka		0.142	0.238			
2008	Mac Vicar		0.153	0.290			
2008	50 K-7409-01		0.211	0.314			
2008	50 K-7409-01		0.262	0.316			
2008	50 K-7409-01		0.249	0.320			
2008	50 K-7409-01		0.216	0.372			
2008	435 K-7451-01		0.194	0.409			
2008	435 K-7451-01		0.149	0.465			
2008	50 K-7409-01		0.325	0.604			
3/14/2008	K-8262-01	M & R lab	0.132	0.112	Research	Research	Research
5/22/2008	Ricks perm study	M & R lab	0.144	0.221	Research	Research	Research
5/22/2008	Ricks perm study	M & R lab	0.144	0.236	Research	District 1	Research
5/22/2008	Ricks perm study	M & R lab	0.139	0.245	Research	Research	Research
5/22/2008	Ricks perm study	M & R lab	0.200	0.778	Research	Research	Research
5/29/2008	Ricks perm study	M & R lab	0.103	0.263	Research	Research	Research
5/29/2008	Ricks perm study	M & R lab	0.303	0.768	Research	Research	Research
5/29/2008	Ricks perm study	M & R lab	0.078	0.206	Research	Research	Research
7/3/2008	US 69 2-lift	4+723	0.111	0.228			
7/10/2008	US 69 2-lift	4+950	0.125	0.268			
7/15/2008	I-70 2-lift	M & R lab	0.224	0.252	Research	Research	Research
7/15/2008	I-70 2-lift	M & R lab	0.166	0.252	Research	Research	Research
7/16/2008	I-70 2-lift	M & R lab	0.122	0.474	Research	Research	Research
7/16/2008	I-70 2-lift	M & R lab	0.103	0.474	Research	Research	Research
7/24/2008	U.S. 24/7	M & R lab	0.115	0.189	Research	Research	Research
8/21/2008	Ricks perm study	M & R lab	0.053	0.097	Research	Research	Research
8/21/2008	Ricks perm study	M & R lab	0.061	0.065	Research	Research	Research
8/21/2008	Ricks perm study	M & R lab	0.091	0.203	Research	Research	Research
8/21/2008	Ricks perm study	M & R lab	0.083	0.260	Research	Research	Research
8/21/2008	Ricks perm study	M & R lab	0.044	0.111	Research	Research	Research
9/4/2008	I-70 2-lift	20+752	0.060	0.151		Dist 1	Research
9/4/2008	I-70 2-lift	20+752	0.060	0.157		Dist 2	Research
9/4/2008	I-70 2-lift	20+752	0.060	0.148		Dist 5	Research
9/4/2008	I-70 2-lift	20+752	0.060	0.201	Hutch Water	Research	Research
9/4/2008	I-70 2-lift	20+752	0.060	0.137	Ames Tap	CP Tech Center	Research
9/4/2008	I-70 2-lift	20+752	0.060	0.138	Ames Tap	CP Tech Center	Research
9/4/2008	I-70 2-lift	20+752	0.129	0.151		Dist 1	CP Tech Center

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
9/4/2008	I-70 2-lift	20+752	0.129	0.157		Dist 2	CP Tech Center
9/4/2008	I-70 2-lift	20+752	0.129	0.148		Dist 5	CP Tech Center
9/4/2008	I-70 2-lift	20+752	0.129	0.201	Hutch Water	Research	CP Tech Center
9/4/2008	I-70 2-lift	20+752	0.129	0.137	Ames Tap	CP Tech Center	CP Tech Center
9/4/2008	I-70 2-lift	20+752	0.129	0.138	Ames Tap	CP Tech Center	CP Tech Center
9/4/2008	I-70 2-lift	20+797	0.205	0.309	Topeka Tap	Dist 1	Research
9/4/2008	I-70 2-lift	20+797	0.205	0.296	Topeka Tap	Dist 2	Research
9/4/2008	I-70 2-lift	20+797	0.205	0.307	Topeka Tap	Dist 5	Research
9/4/2008	I-70 2-lift	20+797	0.205	0.262	Topeka Tap	Research	Research
9/4/2008	I-70 2-lift	20+797	0.205	0.317	Ames Tap	CP Tech Center	Research
9/4/2008	I-70 2-lift	20+797	0.205	0.318	Ames Tap	CP Tech Center	Research
9/4/2008	I-70 2-lift	20+797 AVA/ 20+796 HA	0.158	0.309	Topeka Tap	Dist 1	CP Tech Center
9/4/2008	I-70 2-lift	20+797 AVA/ 20+796 HA	0.158	0.296	Topeka Tap	Dist 2	CP Tech Center
9/4/2008	I-70 2-lift	20+797 AVA/ 20+796 HA	0.158	0.307	Topeka Tap	Dist 5	CP Tech Center
9/4/2008	I-70 2-lift	20+797 AVA/ 20+796 HA	0.158	0.262	Topeka Tap	Research	CP Tech Center
9/4/2008	I-70 2-lift	20+797 AVA/ 20+796 HA	0.158	0.317	Ames Tap	CP Tech Center	CP Tech Center
9/4/2008	I-70 2-lift	20+797 AVA/ 20+796 HA	0.158	0.318	Ames Tap	CP Tech Center	CP Tech Center
9/4/2008	I-70 2-lift	20+940	0.122	0.201	Ames Tap	CP Tech Center	CP Tech Center
9/4/2008	I-70 2-lift	20+940	0.122	0.177	Ames Tap	CP Tech Center	CP Tech Center
9/4/2008	I-70 2-lift	20+946 AVA/ 21+050 HA	0.081	0.232	Topeka Tap	Dist 1	Research
9/4/2008	I-70 2-lift	20+946 AVA/ 21+050 HA	0.081	0.252	Topeka Tap	Dist 2	Research
9/4/2008	I-70 2-lift	20+946 AVA/ 21+050 HA	0.081	0.270	Topeka Tap	Dist 5	Research
9/4/2008	I-70 2-lift	20+946 AVA/ 21+050 HA	0.081	0.214	Topeka Tap	Research	Research
9/4/2008	I-70 2-lift	20+994	0.187	0.314	Topeka Tap	Dist 1	Research
9/4/2008	I-70 2-lift	20+994	0.187	0.379	Hutch Tap	Dist 2	Research
9/4/2008	I-70 2-lift	20+994	0.187	0.321	Topeka Tap	Dist 5	Research
9/4/2008	I-70 2-lift	20+994	0.187	0.312	Topeka Tap	Research	Research

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
9/4/2008	I-70 2-lift	20+994	0.187	0.332	Ames Tap	CP Tech Center	Research
9/4/2008	I-70 2-lift	20+994	0.187	0.282	Ames Tap	CP Tech Center	Research
9/4/2008	I-70 2-lift	20+994	0.067	0.314	Topeka Tap	Dist 1	CP Tech Center
9/4/2008	I-70 2-lift	20+994	0.067	0.379	Hutch Tap	Dist 2	CP Tech Center
9/4/2008	I-70 2-lift	20+994	0.067	0.321	Topeka Tap	Dist 5	CP Tech Center
9/4/2008	I-70 2-lift	20+994	0.067	0.312	Topeka Tap	Research	CP Tech Center
9/4/2008	I-70 2-lift	20+994	0.067	0.332	Ames Tap	CP Tech Center	CP Tech Center
9/4/2008	I-70 2-lift	20+994	0.067	0.282	Ames Tap	CP Tech Center	CP Tech Center
9/9/2008	I-70 2-lift	21+293	0.109	0.199	Ames Tap	CP Tech Center	CP Tech Center
9/9/2008	I-70 2-lift	21+293	0.109	0.200	Ames Tap	CP Tech Center	CP Tech Center
9/9/2008	I-70 2-lift	21+478	0.199	0.295	Ames Tap	CP Tech Center	CP Tech Center
9/9/2008	I-70 2-lift	21+478	0.199	0.274	Ames Tap	CP Tech Center	CP Tech Center
9/9/2008	I-70 2-lift	21+485	0.122	0.466	Topeka Tap	Dist 2	Research
9/9/2008	I-70 2-lift	21+485	0.122	0.507	Topeka Tap	Dist 2	Research
9/9/2008	I-70 2-lift	21+485	0.122	0.334	Chanute Tap	Dist 4	Research
9/9/2008	I-70 2-lift	21+485	0.122	0.316	Koss Plant	Dist 4	Research
9/9/2008	I-70 2-lift	21+485	0.122	0.332	Koss Plant	Research	Research
9/9/2008	I-70 2-lift	21+485	0.122	0.249	Topeka Tap	Research	Research
9/9/2008	I-70 2-lift	21+500	0.268	0.376	Koss Plant	Dist 2	Research
9/9/2008	I-70 2-lift	21+500	0.268	0.391	Chanute Tap	Dist 4	Research
9/9/2008	I-70 2-lift	21+500	0.268	0.323	Koss Plant	Research	Research
9/10/2008	I-70 2-lift	21+910	0.151	0.359	Koss Plant	Dist 4	Research
9/10/2008	I-70 2-lift	21+910	0.151	0.327	Topeka Tap	Research	Research
9/10/2008	I-70 2-lift	21+910	0.151	0.258	Ames/Koss	CP Tech Center	Research
9/10/2008	I-70 2-lift	21+910	0.151	0.240	Ames/Koss	CP Tech Center	Research
9/10/2008	I-70 2-lift	21+977	0.138	0.293	Topeka Tap	Dist 4	Research
9/10/2008	I-70 2-lift	21+977	0.138	0.268	Koss Plant	Research	Research
9/10/2008	I-70 2-lift	21+977	0.138	0.197	Ames/Koss	CP Tech Center	Research
9/10/2008	I-70 2-lift	21+977	0.138	0.180	Ames/Koss	CP Tech Center	Research

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
9/10/2008	I-70 2-lift	21+977	0.140	0.293	Topeka Tap	Dist 4	CP Tech Center
9/10/2008	I-70 2-lift	21+977	0.140	0.268	Koss Plant	Research	CP Tech Center
9/10/2008	I-70 2-lift	21+977	0.140	0.197	Ames/Koss	CP Tech Center	CP Tech Center
9/10/2008	I-70 2-lift	21+977	0.140	0.180	Ames/Koss	CP Tech Center	CP Tech Center
9/10/2008	I-70 2-lift	22+207 AVA/ 22+212 HA	0.129	0.160	Ames/Koss	CP Tech Center	Research
9/10/2008	I-70 2-lift	22+212	0.129	0.189	Koss Plant	Dist 4	Research
9/10/2008	I-70 2-lift	22+212	0.129	0.233	Topeka Tap	Dist 4	Research
9/10/2008	I-70 2-lift	22+212	0.129	0.203	Koss Plant	Research	Research
9/10/2008	I-70 2-lift	22+212	0.129	0.403	Salina Tap	Research	Research
9/10/2008	I-70 2-lift	22+257	0.166	0.242	Ames/Koss	CP Tech Center	CP Tech Center
9/10/2008	I-70 2-lift	22+257	0.166	0.215	Ames/Koss	CP Tech Center	CP Tech Center
9/10/2008	I-70 2-lift	22+262	0.171	0.420	Koss Plant	Dist 4	Research
9/10/2008	I-70 2-lift	22+262	0.171	0.379	Topeka Tap	Dist 4	Research
9/10/2008	I-70 2-lift	22+262	0.171	0.370	Koss Plant	Research	Research
9/10/2008	I-70 2-lift	22+262	0.171	0.311	Topeka Tap	Research	Research
9/10/2008	I-70 2-lift	22+413	0.187	0.300	Koss Plant	Dist 2	Research
9/10/2008	I-70 2-lift	22+413	0.187	0.325	Koss Plant	Dist 4	Research
9/10/2008	I-70 2-lift	22+413	0.187	0.282	Koss Plant	Research	Research
9/11/2008	I-70 2-lift	22+853	0.168	0.296	Koss Plant	Dist 2	Research
9/11/2008	I-70 2-lift	22+853	0.168	0.261	Topeka Tap	Dist 2	Research
9/11/2008	I-70 2-lift	22+853	0.168	0.278	Koss Plant	Research	Research
9/11/2008	I-70 2-lift	22+853	0.168	0.305	Topeka Tap	Research	Research
9/11/2008	I-70 2-lift	22+853	0.168	0.220	Topeka Tap	Research	Research
9/15/2008	I-70 2-lift	23+296	0.136	0.212	Topeka Tap	Dist 2	Research
9/15/2008	I-70 2-lift	23+296	0.136	0.198	Topeka Tap	Research	Research
9/16/2008	I-70 2-lift	23+820	0.144	0.153	Topeka Tap	Dist 2	Research
9/16/2008	I-70 2-lift	23+820	0.144	0.158	Topeka Tap	Research	Research
9/16/2008	I-70 2-lift	23+840	0.118	0.222	Topeka Tap	Dist 2	Research
9/16/2008	I-70 2-lift	23+840	0.118	0.202	Topeka Tap	Research	Research
9/16/2008	I-70 2-lift	24+212	0.161	0.196	Topeka Tap	Dist 2	Research
9/16/2008	I-70 2-lift	24+212	0.161	0.178	Topeka Tap	Research	Research
9/17/2008	I-70 2-lift	24+560	0.113	0.238	Deionized	Dist 2	Research
9/17/2008	I-70 2-lift	24+560	0.113	0.202	Topeka Tap	Dist 2	Research
9/17/2008	I-70 2-lift	24+560	0.113	0.190	Topeka Tap	Dist 2	Research

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
9/17/2008	I-70 2-lift	24+560	0.113	0.328	Topeka Tap	Research	Research
9/17/2008	I-70 2-lift	24+560	0.113	0.200	Topeka Tap	Research	Research
9/18/2008	I-70 2-lift	25+133	0.127	0.344	Deionized	Dist 1	Research
9/18/2008	I-70 2-lift	25+133	0.127	0.317	Deionized	Dist 1	Research
9/18/2008	I-70 2-lift	25+133	0.127	0.442	Deionized	Dist 2	Research
9/18/2008	I-70 2-lift	25+133	0.127	0.322	Distilled	Dist 2	Research
9/18/2008	I-70 2-lift	25+133	0.127	0.310	Deionized	Research	Research
9/18/2008	I-70 2-lift	25+133	0.127	0.303	Distilled	Research	Research
9/18/2008	I-70 2-lift	25+212	0.135	0.236	Deionized	Dist 1	Research
9/18/2008	I-70 2-lift	25+212	0.135	0.180	Distilled #1	Dist 1	Research
9/18/2008	I-70 2-lift	25+212	0.135	0.218	Distilled #1	Dist 2	Research
9/18/2008	I-70 2-lift	25+212	0.135	0.326	Distilled #2	Dist 2	Research
9/18/2008	I-70 2-lift	25+212	0.135	0.207	Deionized	Research	Research
9/18/2008	I-70 2-lift	25+212	0.135	0.211	Deionized	Research	Research
9/18/2008	I-70 2-lift	25+375	0.213	0.300	Deionized	Dist 1	Research
9/18/2008	I-70 2-lift	25+375	0.213	0.224	Topeka Tap	Dist 1	Research
9/18/2008	I-70 2-lift	25+375	0.213	0.352	Deionized	Dist 2	Research
9/18/2008	I-70 2-lift	25+375	0.213	0.295	Distilled	Dist 2	Research
9/18/2008	I-70 2-lift	25+375	0.213	0.277	Distilled	Research	Research
9/19/2008	I-70 2-lift	25+408	0.120	0.245	Ames/Koss	CP Tech Center	CP Tech Center
9/19/2008	I-70 2-lift	25+408	0.120	0.235	Ames/Koss	CP Tech Center	CP Tech Center
9/19/2008	I-70 2-lift	25+416 AVA/ 25+425 HA	0.153	0.315	Distilled	Dist 2	Research
9/19/2008	I-70 2-lift	25+416 AVA/ 25+425 HA	0.153	0.218	Topeka Tap	Dist 2	Research
9/19/2008	I-70 2-lift	25+416 AVA/ 25+425 HA	0.153	0.255	Deionized	Research	Research
9/19/2008	I-70 2-lift	25+416 AVA/ 25+425 HA	0.153	0.293	Deionized	Research	Research
9/19/2008	I-70 2-lift	25+561 AVA/ 25+562 HA	0.132	0.197	Deionized	Dist 2	Research
9/19/2008	I-70 2-lift	25+561 AVA/ 25+562 HA	0.132	0.207	Topeka Tap	Dist 2	Research
9/19/2008	I-70 2-lift	25+561 AVA/ 25+562 HA	0.132	0.199	Deionized	Research	Research
9/19/2008	I-70 2-lift	25+561 AVA/ 25+562 HA	0.132	0.194	Topeka Tap	Research	Research
9/19/2008	I-70 2-lift	25+627	0.163	0.341	Ames/Koss	CP Tech Center	CP Tech Center
9/19/2008	I-70 2-lift	25+627	0.163	0.342	Ames/Koss	CP Tech Center	CP Tech Center

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
9/19/2008	I-70 2-lift	25+675	0.132	0.184	Topeka Tap	Dist 2	Research
9/19/2008	I-70 2-lift	25+675	0.132	0.209	Deionized	Dist 2	Research
9/19/2008	I-70 2-lift	25+675	0.132	0.191	Deionized	Research	Research
9/19/2008	I-70 2-lift	25+675	0.132	0.136	Topeka Tap	Research	Research
9/20/2008	I-70 2-lift	26+102	0.167	0.218	Topeka Tap	Dist 2	Research
9/20/2008	I-70 2-lift	26+102	0.167	0.247	Deionized	Dist 2	Research
9/20/2008	I-70 2-lift	26+102	0.167	0.228	Topeka Tap	Dist 2	Research
9/20/2008	I-70 2-lift	26+102	0.167	0.218	Topeka Tap	Research	Research
9/20/2008	I-70 2-lift	26+102	0.167	0.294	Deionized	Research	Research
9/20/2008	I-70 2-lift	26+275	0.188	0.205	Topeka Tap	Dist 2	Research
9/20/2008	I-70 2-lift	26+275	0.188	0.254	Deionized	Dist 2	Research
9/20/2008	I-70 2-lift	26+275	0.188	0.185	Topeka Tap	Research	Research
9/20/2008	I-70 2-lift	26+275	0.188	0.277	Deionized	Research	Research
2/27/2009	Klaver lab mix	M & R lab	0.186	0.509	Deionized	Research	Research
2/27/2009	Klaver lab mix	M & R lab	0.292	0.655	Deionized	Research	Research
2/27/2009	Klaver lab mix	M & R lab	0.154	0.308	Deionized	Research	Research
6/4/2009	SCMs in paving	M & R lab	0.237	0.244	Deionized	Dist 1	Research
6/4/2009	SCMs in paving	M & R lab	0.151	0.224	Deionized	Dist 1	Research
6/17/2009	SCMs in paving	M & R lab	0.167	0.251	Deionized	Dist 1	Research
6/30/2009	081 U-2156-01	99+15	0.167	1.125	Deionized	Dist 1	
1/21/2010	Volcanic Ash Study	M & R lab	0.089	0.103	Deionized	Dist 1	Research
1/21/2010	Volcanic Ash Study	M & R lab	0.148	0.105	Deionized	Dist 1	Research
1/28/2010	Volcanic Ash Study	M & R lab	0.135	0.178	Deionized	Dist 1	Research
1/28/2010	Volcanic Ash Study	M & R lab	0.159	0.163	Deionized	Dist 1	Research
6/9/2010	70-105-KA-1666-01	626+42	0.182	0.370	Deionized	KC Metro	
6/15/2010	50-28-K-8246-01	112+05	0.237	0.293	Deionized	Dist 6	
6/23/2010	135-87-K-7332-01	1152+30	0.179	0.264	Deionized	Dist 5	
6/29/2010	69-46-K-8251-7	55+350	0.251	0.391	Deionized	KC Metro	
8/3/2010	7-46-K-7925-02	592+40	0.112	0.368	Deionized	KC Metro	
8/19/2010	61-59-K-8253-02	1102+80	0.135	0.009	Deionized	Dist 2	
9/15/2010	54-76-K-8243-03	1511+70	0.193	0.414	Deionized	Dist 5	
9/29/2010	61-59-K-8253-01	714+70	0.238	0.011	Deionized	Dist 2	
10/14/2010	54-48-K-8244-04	1585+30	0.133	0.360	Deionized	Dist 5	
10/21/2010	18-81-KA-410-03	33+92.44	0.064	0.154	Deionized	Dist 1	
10/28/2010	69-46-K-8251-11	57+750	0.098	0.316	Deionized	KC Metro	
4/5/2011	50-28 K-8246-01	651+00	0.143	0.178	Deionized	D6	
6/8/2011	61-78 K-8252-01	353+00	0.168	0.279	Deionized	D5	

Date	Project	Sample Location, Station	C-457 Spacing Factor, mm	AVA Spacing Factor, mm	Source of AVA Water	AVA Testing Performed by	C-457 Testing Performed by
8/11/2011	70-27 K-0729-01	529+20	0.130	0.283	Deionized	D2	
10/11/2011	59-23 K-7888-02	434+20	0.105	0.180	Deionized	D1	
6/26/2012	70-27 KA-0728-01	51+75	0.117	0.488	Deionized	2	
6/26/2012	70-27 KA-0728-01	61+25	0.115	0.432	Deionized	2	
6/27/2012	70-27 KA-0728-01	108+80	0.124	0.377	Deionized	2	
7/9/2012	70-27 KA-0728-01	330+75	0.081	0.356	Deionized	2	

Table A.2: Spacing Factors of Concrete Using the Air Void Analyzer and ASTM C457 from the "I-70 in Dickinson County" Project 70-21 K-6794-01 Placed in 2005

Date	Station	C-457 Hardened Air Spacing Factor (mm)	AVA Spacing Factor (mm)
9/9/2005	10+090.9	0.350	0.401
9/9/2005	right side	0.323	0.313
9/13/2005	10+97.5	0.289	0.310
9/13/2005	left side	0.256	0.368
9/13/2005	10+97.5	0.274	0.365
9/13/2005	left side	0.154	0.366
9/16/2005	11+570	0.175	0.420
9/16/2005	left side	0.174	0.412
9/16/2005	11+932.5	0.186	0.361
9/16/2005	left side	0.198	0.365
9/17/2005	11+932.5	0.200	0.330
9/17/2005	left side	0.254	0.352
9/17/2005	12+552	0.254	0.407
9/17/2005	left side	0.238	0.393
9/19/2005	12+858	0.203	0.389
9/19/2005	left side	0.226	0.324
9/19/2005	12+858	0.203	0.320
9/19/2005	left side	0.226	0.413
9/19/2005	13+141.5	0.234	0.314
9/19/2005	left side	0.242	0.356
9/19/2005	13+141.5	0.234	0.261
9/19/2005	left side	0.242	0.299
9/20/2005	13+500	0.190	0.320
9/20/2005	left side	0.223	0.331
9/20/2005	13+500	0.190	0.236
9/20/2005	left side	0.223	0.318
9/20/2005	14+026	0.180	0.332
9/20/2005	P 4.55 from Lt.	0.208	0.366
9/20/2005	14+026	0.180	0.251
9/20/2005	P 4.55 from Lt.	0.208	0.240
9/22/2005	14+702	0.183	0.258
9/22/2005	left side	0.213	0.212
9/22/2005	14+702	0.213	0.238
9/22/2005	left side	0.183	0.259


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