TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-85/61+363-2F		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
EVALUATION OF CHACE AIR INDICATOR	October 1984
7. Author(s) Richard G. Henley, Dean Malkemus, David W. Fowler, and Alvin H. Meyer	8. Performing Organization Report No. Research Report 363-2F
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075	10. Work Unit No. 11. Contract or Grant No. Research Study 3-9-83-363
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "Evaluation of Chace Air Indicator for Use in Concrete Construction"

16. Abstract

This study was an evaluation of the Chace Air Indicator (CAI) for use in concrete construction. The CAI indicated higher values than the pressure method at low air contents and lower values at high air contents. The CAI readings corrected for mortar contents and Chace factors produced values approximately 15 percent higher than the pressure method over all ranges of air contents. A regression analysis procedure was used to determine a curve correction to account for the difference between the Chace factor-mortar corrected reading and the pressure meter. An indication of the reliability of the results was represented by confidence intervals. The CAI does not have sufficient accuracy to measure the air content of concrete for job control purposes.

17. Key Words	18. Distribution Statement
Chace Air Indicator (CAI), concrete construction, entrained air, pressure meter, air contents, regression analysis, job control	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	70	

Form DOT F 1700.7 (8-69)

EVALUATION OF CHACE AIR INDICATOR

by

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Alvin H. Meyer

Research Report Number 363-2F

Evaluation of Chace Air Indicator
for Use in Concrete Construction

Research Project 3-9-83-363

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

October 1984

PREFACE

Thanks are extended to the numerous employees of the Texas Department of Highways and Public Transportation for their cooperation throughout this research. The assistance given by David Whitney, Sue Sweeney, Rose Rung, Nancy Zett, Elizabeth Doubleday and the entire Center for Transportation Research staff was invaluable and also greatly appreciated. A special thanks is extended to Dean Malkemus for his assistance in the organization and completion, as well as his participation in the field testing program.

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ABSTRACT

This study was an evaluation of the Chace Air Indicator (CAI) for use in concrete construction. The CAI indicated higher values than the pressure method at low air contents and lower values at high air contents. The CAI readings corrected for mortar contents and Chace factors produced values approximately 15 percent higher than the pressure method over all ranges of air contents. A regression analysis procedure was used to determine a curve correction to account for the difference between the Chace factor-mortar corrected reading and the pressure meter. An indication of the reliability of the results was represented by confidence intervals. The CAI does not have sufficient accuracy to measure the air content of concrete for job control purposes.

SUMMARY

The objectives of this study were to determine the calibration and correlation requirements of the CAI, to identify the limits of the use of the CAI and to determine the ability of the CAI to measure entrained air with sufficient accuracy for job control purposes.

For purposes of this study, job control is defined as "the measurement of the air control of portland cement concrete with equal accuracy to that measured by a pressure meter."

The ACI readings were corrected for mortar contents and Chace factors as suggested by previous research. A set of curve correction equations with confidence intervals was determined to adjust for deviations with results based on the average of one, two or three readings per test sample. The results of the field phase were comparable to the laboratory results presented in SDHPT Research Report 363-1. The data from the field laboratory was combined and a new curve correction was determined. The correction equation has a 95 percent confidence interval of 4.8 percent air content for one CAI reading; for three readings the interval is reduced to 2.7 percent. Recommendations are made to improve the use of the CAI and to improve the accuracy of the air content determination.

The CAI does not have sufficient accuracy to measure the air content of concrete for job control purposes.

IMPLEMENTATION

The primary objective of this study was to determine if the Chace Air Indicator can be used with sufficient accuracy for job control purposes. This study indicates that the CAI should not be used for a determination of actual air content of fresh concrete. However, if the recommended modifications to the CAI test procedure reported herein are followed the CAI could be used in the field to provide an indication of the range (high, medium or low) of air content of fresh concrete.

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CHAPTER 1
INTRODUCTION

The Texas Department of Highways and Public Transportation (SDHPT) has used the Chace Air Indicator (CAI) to determine the approximate amount of entrained air in structural concrete for almost 15 years. The Texas Test Method 416-A (7) requires that the CAI be correlated daily with the pressure method and does not permit its use for measuring air content. The elimination of the daily correlation could possibly result in the savings of both testing time and manpower. Before the existing test method can be modified, certain aspects of the use of the CAI must be investigated to insure that the modifications do not jeopardize the quality of the concrete being placed.

This thesis is an investigation of the use of the Chace Air Indicator in determining the amount of entrained air in structural concrete.

The objectives of this study are the following:

1) To determine the calibration and correlation requirements for the CAI;
2) To identify the limits or tolerances for the use of the CAI for either job control or as an indicator as it is used presently; and
3) To determine if the CAI can measure the amount of entrained air with sufficient accuracy for job control purposes.

For purposes of this study, job control is defined as "the measurement of the air content of portland cement concrete with equal accuracy to that measured by a pressure meter."

The study consisted of a laboratory and a field phase. The laboratory phase permitted the study of many mix design variables under controled conditions and was presented in previous studies (3,6). The field phase allows for testing to establish the effect of normal variations encountered in field operations. The field phase of the study is presented in this report.

CHAPTER 2
PREVIOUS STUDIES

2.1 Bureau of Public Roads 1957

This study (2) found the CAI to be useful in determining the approximate amount of entrained air in concrete in the field.

The major conclusions were as follows:

1) The CAI yielded low readings for air contents above six percent and high readings for air contents below three percent.
2) Because of the small amount of mortar used in a test at least three readings should be made for each air content determination.
3) The CAI is not considered a suitable replacement for the pressure method but is a useful supplementary test.
4) The CAI appears to be most valuable for use in determining uniformity from one batch of concrete to the next when there is no change in the mix design or materials.
5) The CAI can also be used as a rapid check to determine if the air content is probably within specification limits.

2.2 Virginia Council of Highway Investigation and Research 1960

This research (4) compared CAI test results with the results of conventional pressure methods. Data from over 800 field tests were statistically analyzed and compared to results of previous laboratory research. The results of this study were in agreement with previous work and gave a field verification of the lab data available at that time.

The principal conclusions of this study were:

1) A mortar correction based on the mortar content of the mix was recommended to account for the fact that only a mortar

sample is used in the CAI test as opposed to the concrete sample used in the pressure method.

2) A curve correction was also recommended to account for the fact the CAI read high for low air contents and low for high air contents.
3) The CAI was found to be a reasonably accurate and moderately precise for the measurement of air content in the field.
4) The accuracy of the CAI is improved with multiple readings.

2.3 Texas Highway Department, Materials and Test Division 1970

This study (1) investigated the effect of excessive temperature differentials and varying strength concentrations of isopropyl alcohol used with the CAI. This study recommended the following:

1) Seventy percent isopropyl alcohol be used in the CAI.
2) The tests should be performed with care and as rapidly as possible.
3) The alcohol supply should be protected from excessive temperatures to insure the alcohol and mortar temperatures are relatively similar.

2.4 Virginia Highway and Transportation Research Council 1981

This research (5) found there was poor agreement between the pressure method and the CAI, even after the manufacturer's suggested correction factors were applied to the CAI readings. The Virginia study revealed that CAI manufacturers do not set strict limits on the tolerances during the fabrication of the instrument; therefore, it was recommended that the Chace Factor be determined for all CAI's used for air content determination. The Chace Factor is defined as the volume of one graduation on the stem expressed as a percentage of the volume of the cup. Correction factors were developed for verying Chace Factors tors, varying mortar contents and to account for the fact the CAI read high for low air contents and low for high air contents.

The principal conclusions of this study were the following:

1) Varying mortar contents and Chace Factors can be corrected for using the following equation:

$$\text{mortar correction factor} = \frac{\text{mortar content } (ft^3/yd^3) \times \text{Chace Factor}}{27}$$

2) Each CAI should be inscribed with its Chace Factor.
3) A test result based on the average Chace-factor-based mortar-corrected and curve-corrected CAI air contents of five samples provides the same confidence as is provided by one pressure method test.
4) CAI readings should be taken as the average of a minimum of two samples.
5) The concrete investigated should be suitable for retrieving representative samples.

As a result of this study, the AASHTO Standard Method of Test for Air Content of Freshly Mixed Concrete by the Chace Indicator (T199-82) (8) was modified to include the following recommended corrections:

1) Test results for the acceptance of concrete will be based on stem readings that have been mortar corrected, Chace Factor corrected and curve corrected.
2) Test results for the acceptance of concrete will be based on the average of two samples. If the results differ by more than two percent, a third sample will be taken and the test results will be based on the average air content of the three samples.
3) Concrete that is determined to be unacceptable by the CAI will not be rejected unless a pressure method test confirms that the concrete is unacceptable.
4) The pressure method test will be used to determine if concrete used in bridge decks meets specifications.

2.5 Texas Highway Department, Center for Transportation Research 1983

These studies (3,6) represent the laboratory phase of this project. The principle conclusions of these studies were the following:

1) Operator and instrument variabilities were negligible.
2) Two types of correction factors should be applied: the CAI reading, a Chace Factor and mortar correction and a curve correction.
3) A curve correction of the form $PM = 0.85X_{mc}$ was produced (the y-intercept of the best fit line being close to zero) where PM is the pressure meter reading and X_{mc} is the mortar-corrected CAI reading.
4) The correction to be applied was identical if one or more readings per sample were performed on the same batch. The difference was in the confidence interval indicating the reliability of the results. The 95 percent confidence interval decreased from 3.2 percent to 1.8 percent as the number of readings increased from 1 to 3.
5) It was observed that addition of high range water reducer at high air contents resulted in decreasing air content with time as measured by both the CAI and the pressure meter. Air contents measured with either device cannot be considered accurate under these circumstances.
6) Comparison of results with previously established corrections indicated a notable improvement. The confidence intervals were reduced and the best fit line of data became almost identical to the line of equality between the CAI and the pressure meter.

CHAPTER 3
FIELD TEST PROGRAM

3.1 List of Field Test Variables

The descriptions of the variables under investigation in the field phase of the project are presented below. A summary of the numerical values obtained in the field is given in Appendix A.

3.1.1 Variations Within Ready-Mix Trucks Loaded to Different Levels

Samples were taken from ready-mix trucks:

(a) loaded to capacity: trucks were considered loaded to capacity if they contained more than six cubic yards of concrete

(b) loaded to half capacity: if a truck contained less than six cubic yards of concrete it was considered loaded to half capacity

Samples were taken for each condition when the truck:

(a) began discharging concrete,

(b) had discharged half the load,

(c) was nearly empty.

3.1.2 Variations Between Ready-Mix Trucks

Samples were taken from different ready-mix trucks during large placements. This allowed the variation in CAI readings from truck to truck to be determined.

3.1.3 Day-to-Day Variations

Samples were taken from 10 trucks per day for three days at the same job site to enable the variation in CAI readings from day to day to be determined.

3.1.4 Transit Time

For all samples taken in the field the transit time was recorded. Transit time is defined as the interval between time the mix truck was loaded time and the time the sample was taken. Analyses performed to determine the effect of delivery times:

(a) less than 15 minutes,

(b) greater than 15 minutes and less than 30 minutes,

(c) greater than 30 minutes.

3.1.5 Concrete Mix Temperature

The mix temperature was recorded for all samples taken in the field. The variation between CAI readings and pressure meter readings was determined for the following categories of mix temperatures:

(a) mix temperatures less than 60°F,

(b) mix temperatures greater than 60°F and less than 80°F,

(c) mix temperatures greater than 80°F.

3.1.6 Ambient Temperatures

The ambient temperature at the time of testing was recorded for all samples. The variations between CAI readings and pressure meter readings were determined for the following categories of ambient temperatures.

(a) ambient temperatures less than 60°F,

(b) ambient temperatures greater than 60°F and less than 80°F,

(c) ambient temperatures greater than 80°F.

3.1.7 Slump

A slump test was performed on each sample. The variations between CAI readings and pressure meter readings were determined for the following categories of slumps:

(a) slumps less than 3 in.,

(b) slumps equal or greater than 3 in. and less than 6 in.,

(c) clumps equal or greater than 6 in.

3.1.8 Variability Between CAI Units

Four different CAI units were used in the field testing program to enable the variation between CAI units to be determined.

3.1.9 Variability Between Operators

Two operators did all the field testing and the variation between operators was determined.

3.1.10 Variation in Mortar Content

The mortar content for all samples was determined using the Concrete Mix Design Sheets furnished by the batch plants and district personnel. The variation between the CAI readings and the pressure meter readings was determined for variable mortar contents.

3.1.11 Air Content

The variations between CAI readings and pressure meter readings were determined for different ranges of air contents. The actual air content of the sample was assumed to be the pressure meter reading. The categories of air content investigated were:

(a) air contents less than 4 percent,
(b) air contents between 4 and 6 percent,
(c) air contents greater than 6 percent.

3.2 Field Test Procedures

The following procedure was performed on each concrete sample taken in the field:

(1) A wheelbarrow was used to take the concrete samples from the ready-mix trucks either from the beginning, middle or end of the discharge. Each sample was taken after mixing and water additions were completed. The truck number was recorded.

(2) Slump and pressure meter tests were performed after a thorough mixing of the concrete sample. Concrete temperature and ambient temperature was recorded at this time.

(3) Each of the two operators performed three CAI tests on every concrete sample. The samples of mortar were obtained in the following manner: (1) the surface of the concrete in the wheelbarrow was "flattened" using a trowel; (2) the flattened surface was then vibrated using the trowel to settle the aggregates leaving mortar at the surface; and (3) samples were taken from this "mortar rich" surface.

(4) The times were recorded for: truck arrival, sampling of the truck, pressure meter reading and each CAI reading.

(5) After all sampling was completed at a job site, the SDHPT Concrete Batch Ticket was copied for each truck sampled.

(6) A copy of the data sheet used in the field is included in Appendix B.

Thirty-seven field visits were made and 232 batches of concrete were sampled. Six CAI readings and one pressure meter reading were taken on each sample. A total of 1392 CAI readings and 232 pressure meter readings were recorded.

CHAPTER 4
DATA ANALYSIS

4.1 Summary of Statistical Procedures

4.1.1 Procedure for Determination of the Variations of Field Conditions

The variations between the average of three mortar corrected CAI readings and the pressure meter readings for each of the variables outlined in Chapter 3.0 were determined using statistical analysis. The mean, standard deviation and coefficient of variation (C_v) of the difference between the average of three mortar corrected CAI readings and the pressure meter reading were calculated for each variable. The coefficient of variation is defined as the ratio of the standard deviation to the mean and is expressed as a percentage. It is important to note that the coefficient of variation does not represent a percentage of air content, but rather a percentage variability which gives an indication of the variables that affect the accuracy of the CAI readings.

4.1.2 Regression Analysis Procedure

The regression analysis procedure used in this thesis was presented in companion studies by Jabri (3) and Tabbarah (6). A brief outline of the regression procedure follows.

4.1.2.1 Data Points

Three Chace Air Indicator tests and one pressure method test were performed on every sample taken in the field. The mortar corrected CAI readings or average of readings, (X_{mc}) and the pressure meter reading (PM) of a sample represent the data point for that sample.

A test for normal distribution was performed on the data points. The positive results of this test insured that the assumption of a normal distribution was accurate.

The regression procedure was performed on each of the following sets of data points:

(1) (X_{mc}, PM), where X_{mc} is the first mortar corrected reading

(2) (X_{mc}, PM), where X_{mc} is the average of the first two CAI readings

(3) (X_{mc}, PM), where X_{mc} is the average of the three CAI readings.

4.1.2.2 Best Fit Straight Line of Field Data

The best fit straight line of the field data was found by applying a regression analysis to the points (X_{mc}, PM). This best fit line is represented by the equation:

$$Y1 = (a1)\ X_{mc} + b1 \qquad (4.1)$$

where a1 and b1 are parameters of the line.

4.1.2.3 Accuracy of Best Fit Equation

The difference between Y1, as determined by equation 4.1, and the pressure meter readings, (PM-Y1) represents the accuracy of equation 4.1. A regression was performed on the set of points (Y1, (PMR-Y1)) to determine the value (d) to be added to Y1 to obtain PM. The linear equation evolving from this regression is represented by:

$$d = (a2)\ Y1 + b2 \qquad (4.2)$$

where a2 and b2 are parameters of the line.

4.1.2.4 Accuracy of the Sum (Y1 + d)

Since the field data was not perfectly linear it was necessary to determine the accuracy of the sum (Y1 + d) as a representation of PM. A regression was performed on the set of points ((Y1 + d), PM). The result of this regression is represented by the equation:

The result of this regression is represented by the equation:

$$Y = (A)\ (Y1 + d) + B \qquad (4.3)$$

where A and B are parameters of the line.

4.1.2.5 The Air Content Equation

The purpose of this analysis was to find an equation for air content (Y) in terms of the mortar corrected Chace readings (X_{mc}). This is accomplished by combining equations 4.1, 4.2 and 4.3. This combination gives the final equation for Y:

$$Y = [A\ (1 + a2)\ a1]\ X_{mc} + [A\ (1 + a2)\ b1 + AB2 + B] \qquad (4.4)$$

Equation 4.4 can be expressed in simpler terms as:

$$Y = S(X_{mc}) + I \qquad (4.5)$$

where

$S = A\ (1 + a2)\ a1$

$I = A\ (1 + a2)\ b1 + Ab2 + B$

4.1.2.6 Confidence Interval

A confidence interval of 95 percent was determined for equation 4.5. This confidence interval is denoted by 2k, where k is expressed as a percent of air content and is represented by the equation:

$$k = \frac{1.96\ (SD)}{n} \qquad (4.6)$$

where

n = the number of Chace readings used in determining X_{mc}

SD= the standard deviation derived from all (PMR-Y1) values.

4.2 Results

4.2.1 Variations in Field Conditions

The values of the coefficients of variation (C_V) between the pressure meter and the average of three mortar corrected CAI readings for the variables outlined in Chapter 3 are given below:

(1) Ready-Mix Trucks Loaded to Different Levels

a) trucks loaded to capacity C_V = 10.4 percent

b) trucks loaded to half capacity C_V = 12.5 percent

c) sample from beginning of discharge C_V = 9.7 percent

d) sample from middle of discharge C_V = 11.2 percent

e) sample from end of discharge C_V = 11.5 percent

(2) Variation Between Ready-Mix Trucks

the average coefficient of variation between trucks at the same job site C_V = 8.7 percent

(3) Day to Day Variations

the average coefficient of variation from day to day at the same job site C_V = 10.3 percent

(4) Transit Time

a) less than 15 minutes C_V = 11.5 percent

b) between 15 and 30 minutes C_V = 15.3 percent

c) greater than 30 minutes C_V = 16.2 percent

(5) Concrete Mix Temperature

a) less than 60° C_V = 27.2 percent

b) between 60° and 80° C_V = 15.5 percent

c) greater than 80° C_V = 16.9 percent

(6) Ambient Temperature

a) less than 60° C_V = 23.3 percent

b) between 60° and 80° C_V = 14.2 percent

c) greater than 80° C_V = 14.9 percent

(7) Slump

a) less than 3 in. C_v = 17.2 percent

b) between 3 and 6 in. C_v = 12.5 percent

c) greater than 6 in. C_v = 13.7 percent

(8) Variability Between CAI Units

a) CAI 2 C_v = 5.2 percent

b) CAI 3 C_v = 3.1 percent

c) CAI 4 C_v = 4.8 percent

d) CAI 6 C_v = 3.2 percent

(9) Variability Between Operator

a) Greg Henley C_v = 3.9 percent

b) Dean Malkemus C_v = 2.5 percent

(10) Variation in Mortar Content

a) less than 13.0 C_v = 11.5 percent

b) greater than 13.0 C_v = 15.1 percent

(11) Air Content

1) less than 4 percent C_v = 28.9 percent

2) between 4 and 6 percent C_v = 20.6 percent

3) greater than 6 percent C_v = 18.7 percent

The range of values for the coefficients of variation is as expected for field operations. This indicates that the variables tested did not significantly affect the test results.

The bar graphs in Fig. 4.1 through 4.7 provide a graphic illustration of the differences between the pressure meter readings and the mortar corrected Chace readings for each variable.

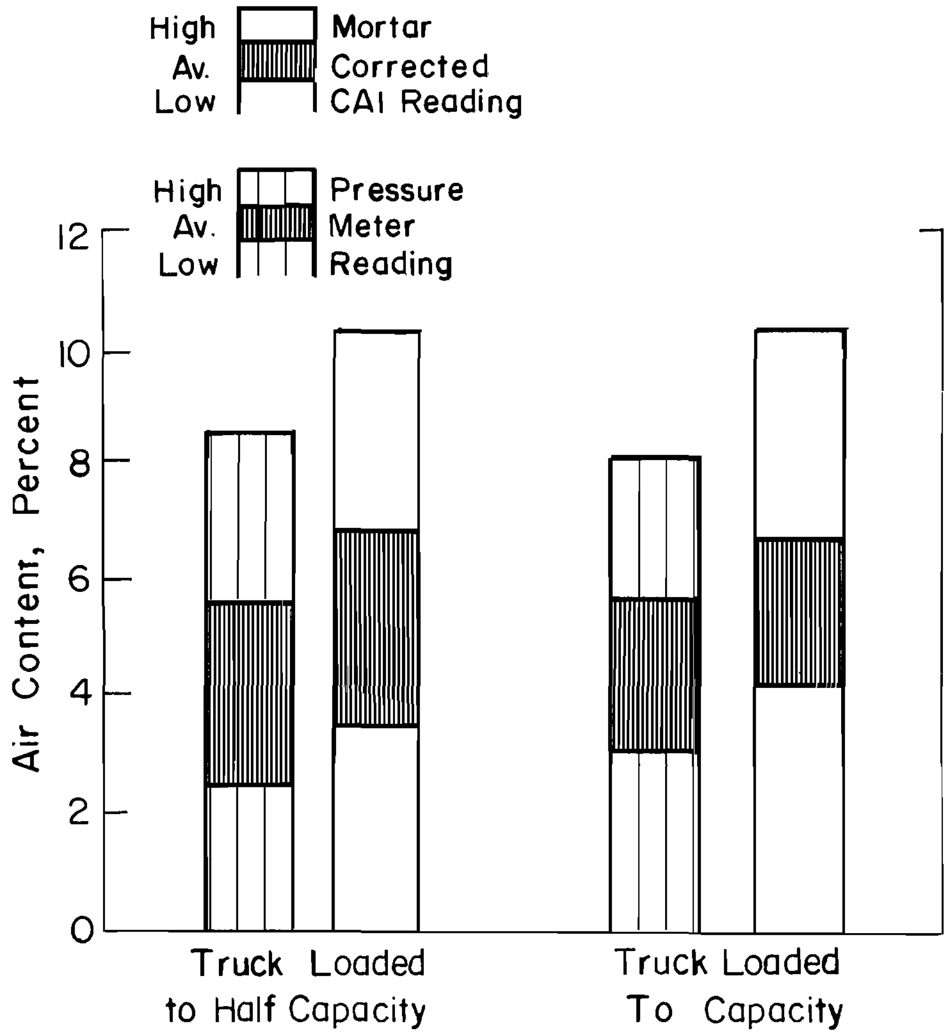

Fig. 4.1 Bar Graph of Field Test Results: Truck Capacity

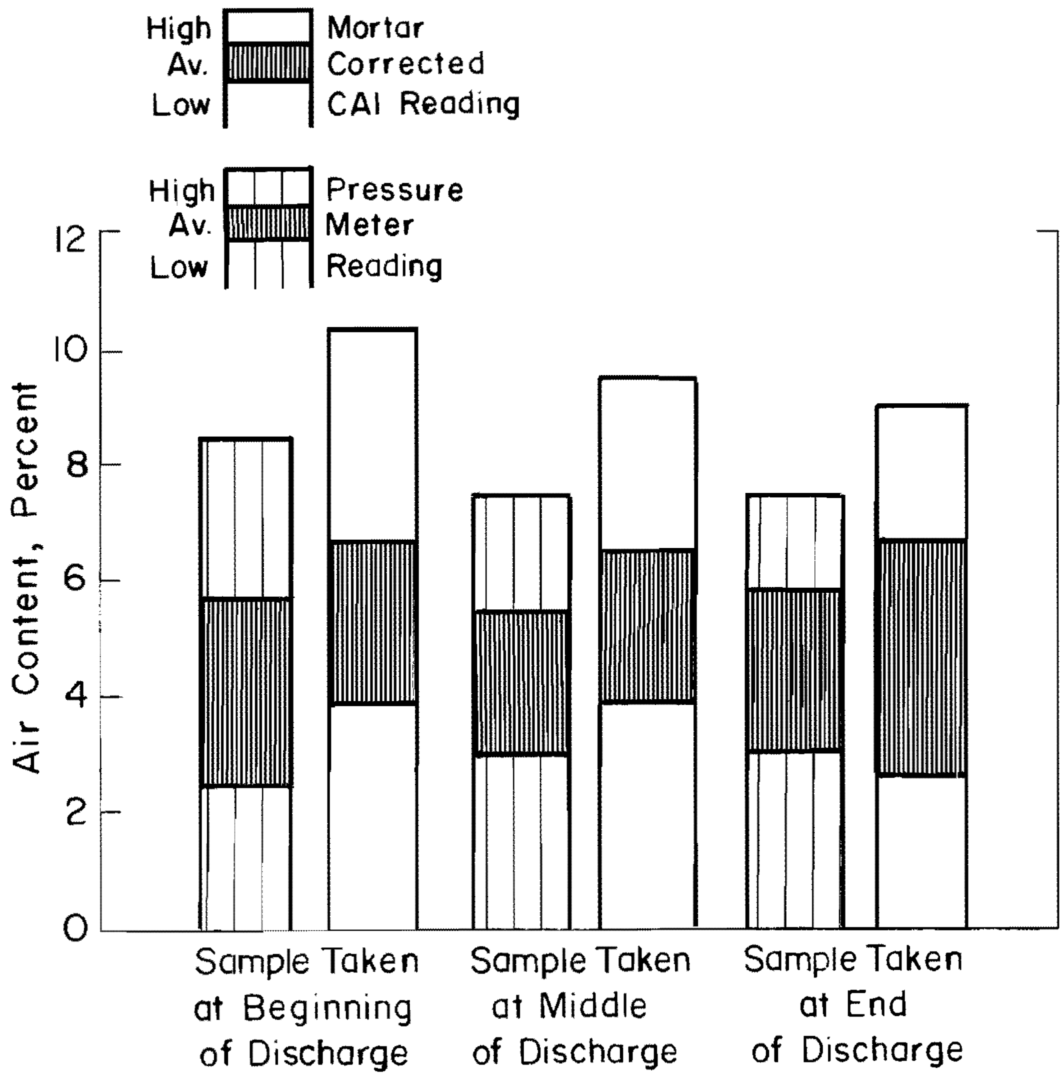

Fig. 4.2 Bar Graph of Field Test Results: Beginning, Middle or End of Discharge

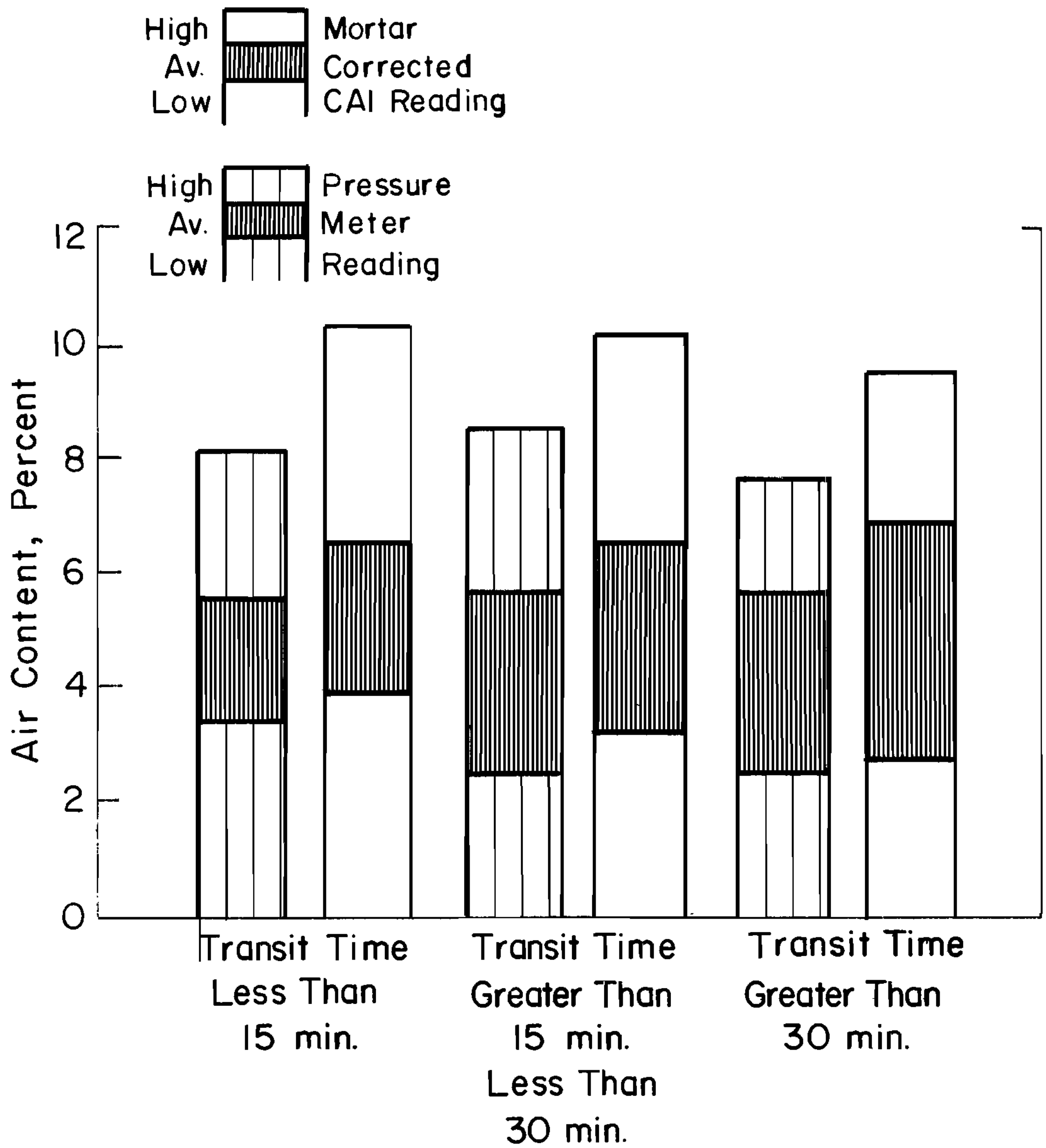

Fig. 4.3 Bar Graph of Field Test Results: Transit Time

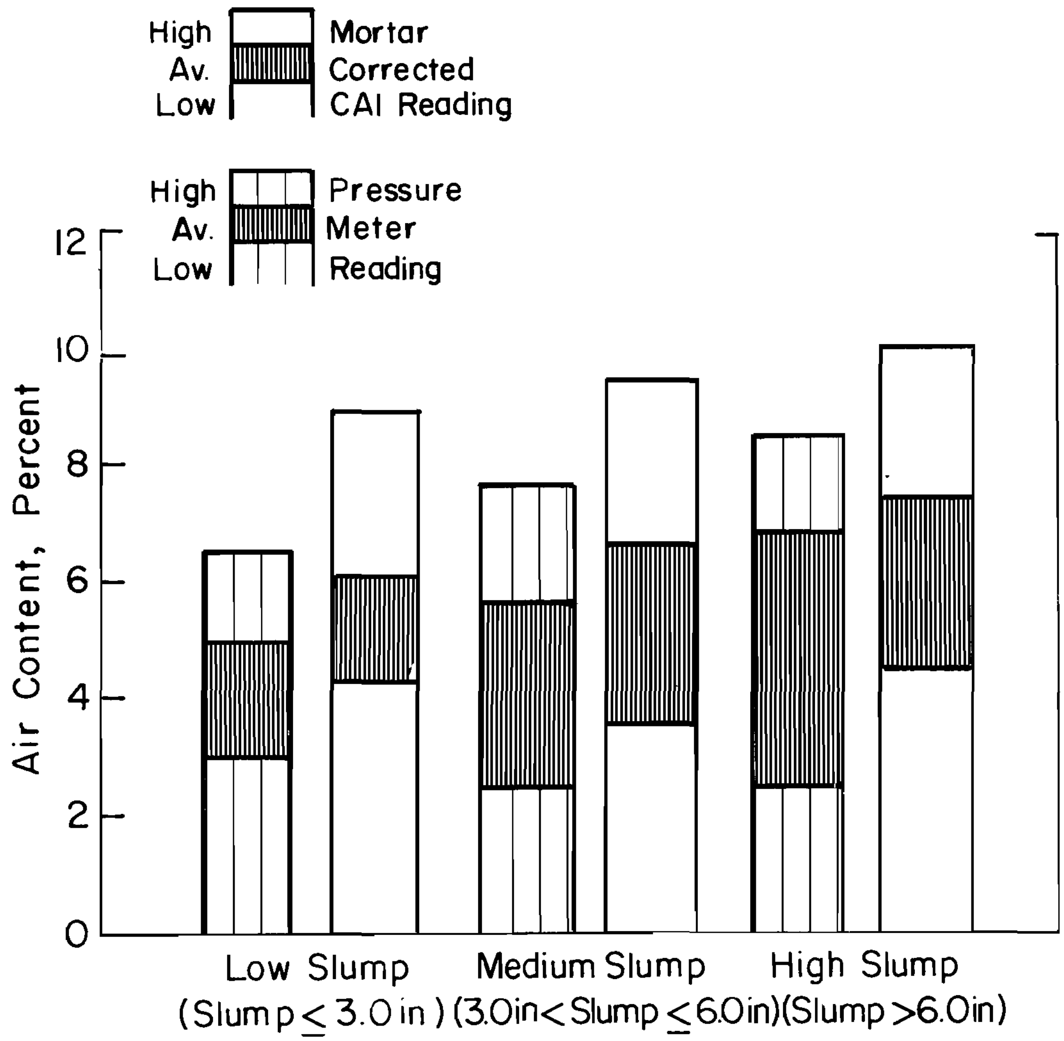

Fig. 4.4 Bar Graph of Field Test Results: Slump

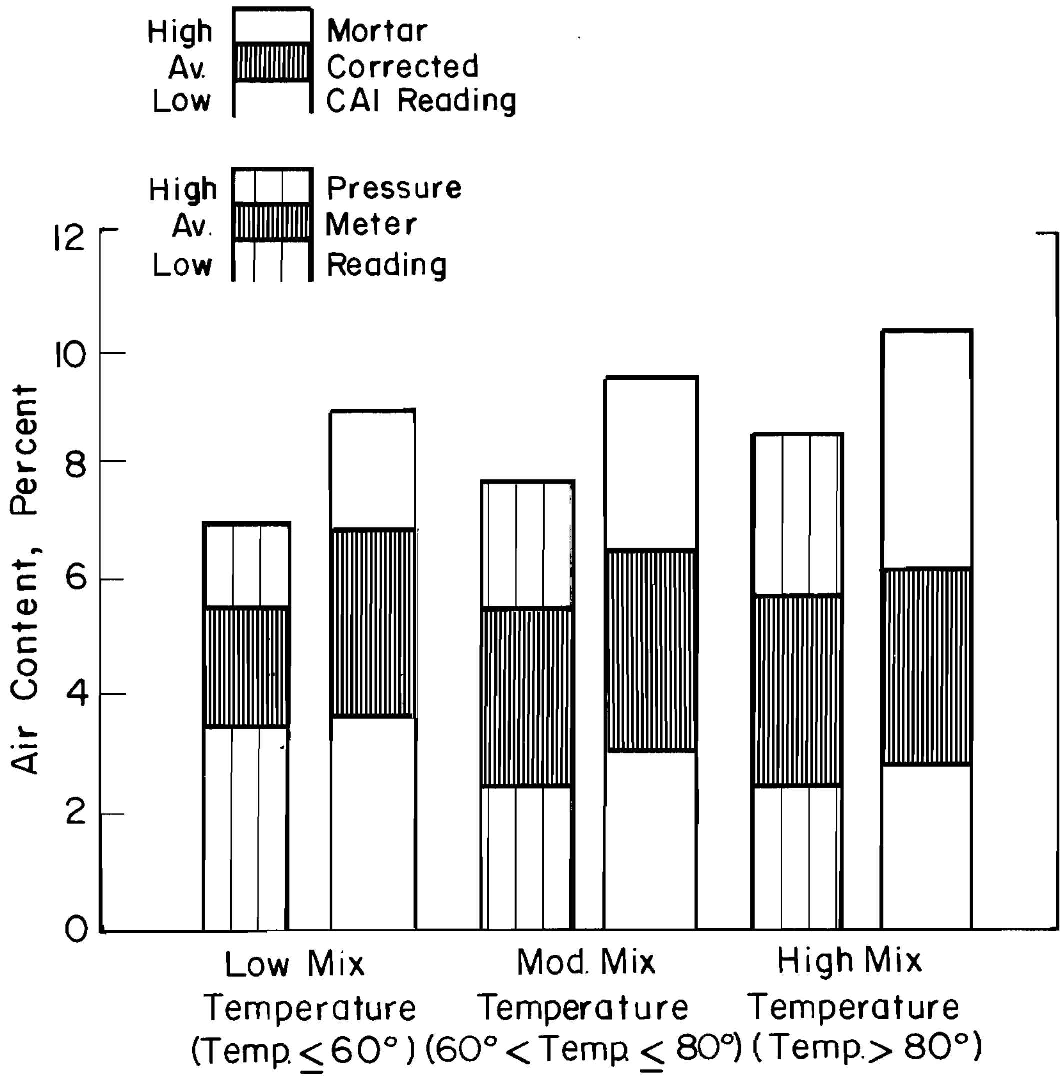

Fig. 4.5 Bar Graph of Field Test Results: Mix Temperature

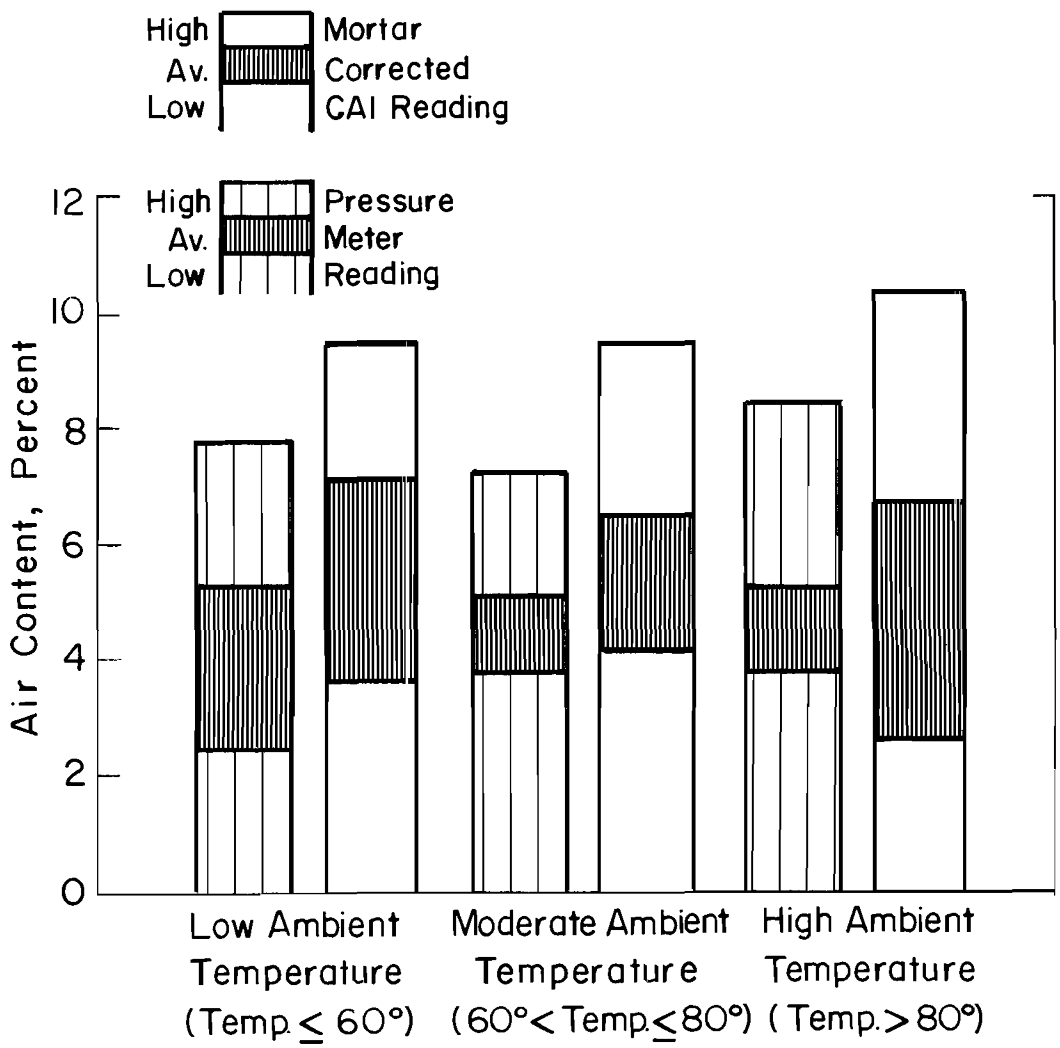

Fig. 4.6 Bar Graph of Field Test Results: Ambient Temperature

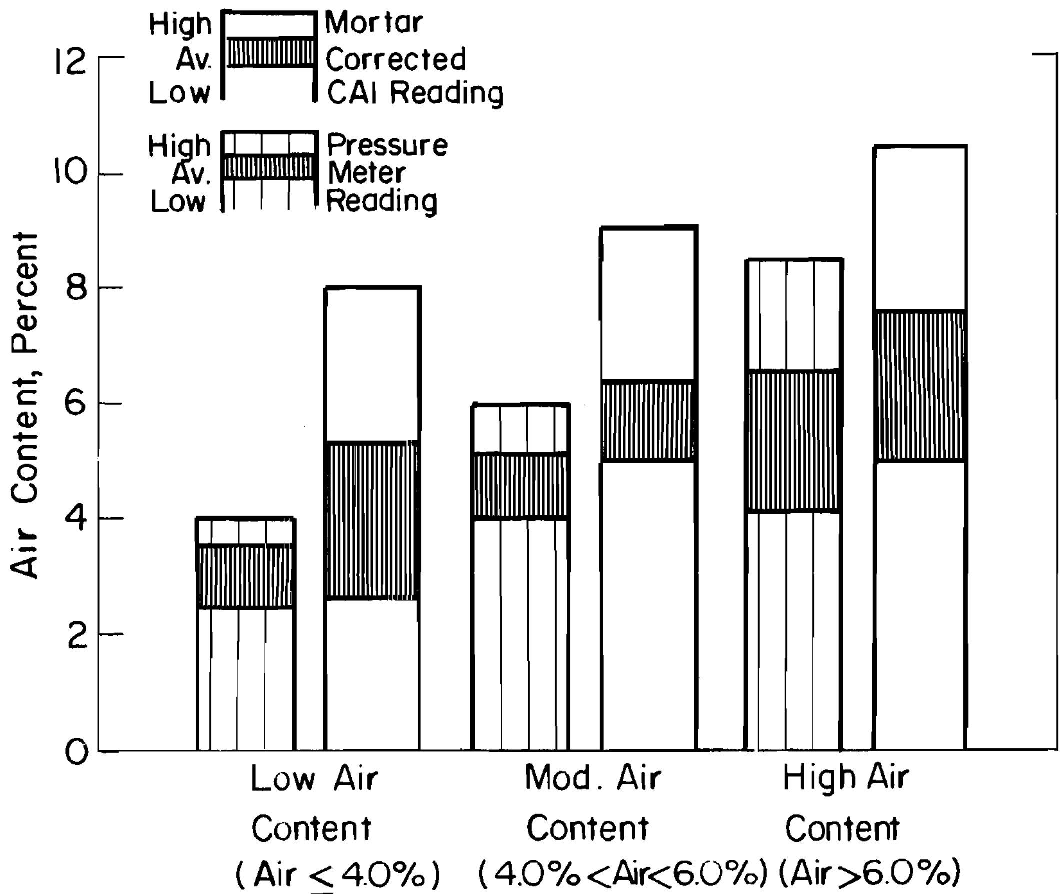

Fig. 4.7 Bar Graph at Field Test Results: Air Content

4.2.2 Regression Analysis Results

4.2.2.1 Field Study

The results of the regression analysis performed on the field data points are presented in this section.

The curve correction equation for the first stage regression (using one mortar corrected CAI reading for each data point) is represented by:

$$Y = 0.681\ X_{mc} + 1.02 \quad (4.7)$$

with a 95 percent confidence interval equal to 5.6 percent of air content. Figures 4.8 and 4.9 provide a graphic representation of this equation.

The curve correction equation for the second stage regression (using the average of two mortar corrected CAI readings for each data point) is represented by:

$$Y = 0.705\ X_{mc} + 0.897 \quad (4.8)$$

with a 95 percent confidence interval equal to 4.0 percent of air content. Figures 4.10 and 4.11 provide a graphic representation of this equation.

The curve correction equation for the third stage regression (using the average of three mortar corrected CAI readings for each data point) is represented by:

$$Y = 0.721\ X_{mc} + 0.829 \quad (4.9)$$

with a 95 percent confidence interval equal to 3.2 percent of air content. Figures 4.12 and 4.13 provide a graphic representation of this equation.

4.2.2.2 Laboratory Study

The results of the regression analysis performed by Jabri (3) and Tabbarah (6) in the laboratory phase of this project are summarized below.

The curve correction equation for the first stage regression is given as:

$$Y = 0.840\, X_{mc} + 0.068 \tag{4.10}$$

with a 95 percent confidence interval equal to 3.2 percent of air content. Figures 4.8 and 4.9 provide a graphic representation of this equation as well as a comparison with equation 4.7.

The curve correction equation for the second stage regression is given as:

$$Y = 0.843\, X_{mc} + 0.060 \tag{4.11}$$

with a 95 percent confidence interval equal to 2.4 percent of air content. Figures 4.10 and 4.11 provide a graphic representation of this equation as well as a comparison with equation 4.8.

The curve correction equation for the third stage regression is given as:

$$Y = 0.844\, X_{mc} + 0.064 \tag{4.12}$$

with a 95 percent confidence interval equal to 1.8 percent of air content. Figures 4.12 and 4.13 provide a graphic representation of this equation as well as a comparison to equation 4.9.

4.2.2.3 Combined Field and Laboratory Analysis

The regression analysis procedure outlined in 4.1.2 was applied to the combined laboratory and field data. This analysis was performed because the controlled environment in the laboratory was not a true representation of field conditions and the uncontrolled field environment did not allow for the testing of certain variables. For example, air contents greater than 10 percent or ambient temperatures less than 40°F.

The curve correction equation for the first stage regression is represented as:

$$Y = 0.729\ X_{mc} + 0.534 \tag{4.13}$$

with a 95 percent confidence interval equal to 4.8 percent of air content. A graphic comparison between this equation and equations 4.7 and 4.10 is provided in Fig. 4.8. Figure 4.14 represents equation 4.13 and its corresponding 95 percent confidence interval.

The curve correction equation for the second stage regression is represented by:

$$Y = 0.780\ X_{mc} + 0.475 \tag{4.14}$$

with a 95 percent confidence interval equal to 3.2 percent of air content. A graphic comparison between this equation and equations 4.8 and 4.11 is provided in Fig. 4.10. Figure 4.15 represents equation 4.14 and its corresponding 95 percent confidence interval.

The curve correction for the third stage regression is represented by:

$$Y = 0.784\ X_{mc} + 0.445 \tag{4.15}$$

with a 95 percent confidence interval equal to 2.7 percent of air content. A graphic comparison between this equation and equations 4.9 and 4.12 is provided in Fig. 4.12. Figure 4.16 represents equation 4.15 and its corresponding 95 percent confidence interval.

It should be noted that the SDHPT tolerance and the CAI confidence interval, even with three readings, almost preclude the use of the CAI for actual air content estimation. The SDHPT tolerance for air content of fresh content is ± 1.5 percent. The 95 percent confidence interval for the average of three Chace-factor-mortar corrected and curve corrected CAI readings is 2.7 percent or ± 1.4 percent. The difference of ± 0.1 percent between the tolerance and confidence interval is not large enough to justify the use of the CAI for the estimation of actual air content. Appendix C illustrates the relationship between the tolerance and confidence interval for a hypothetical CAI air content estimation.

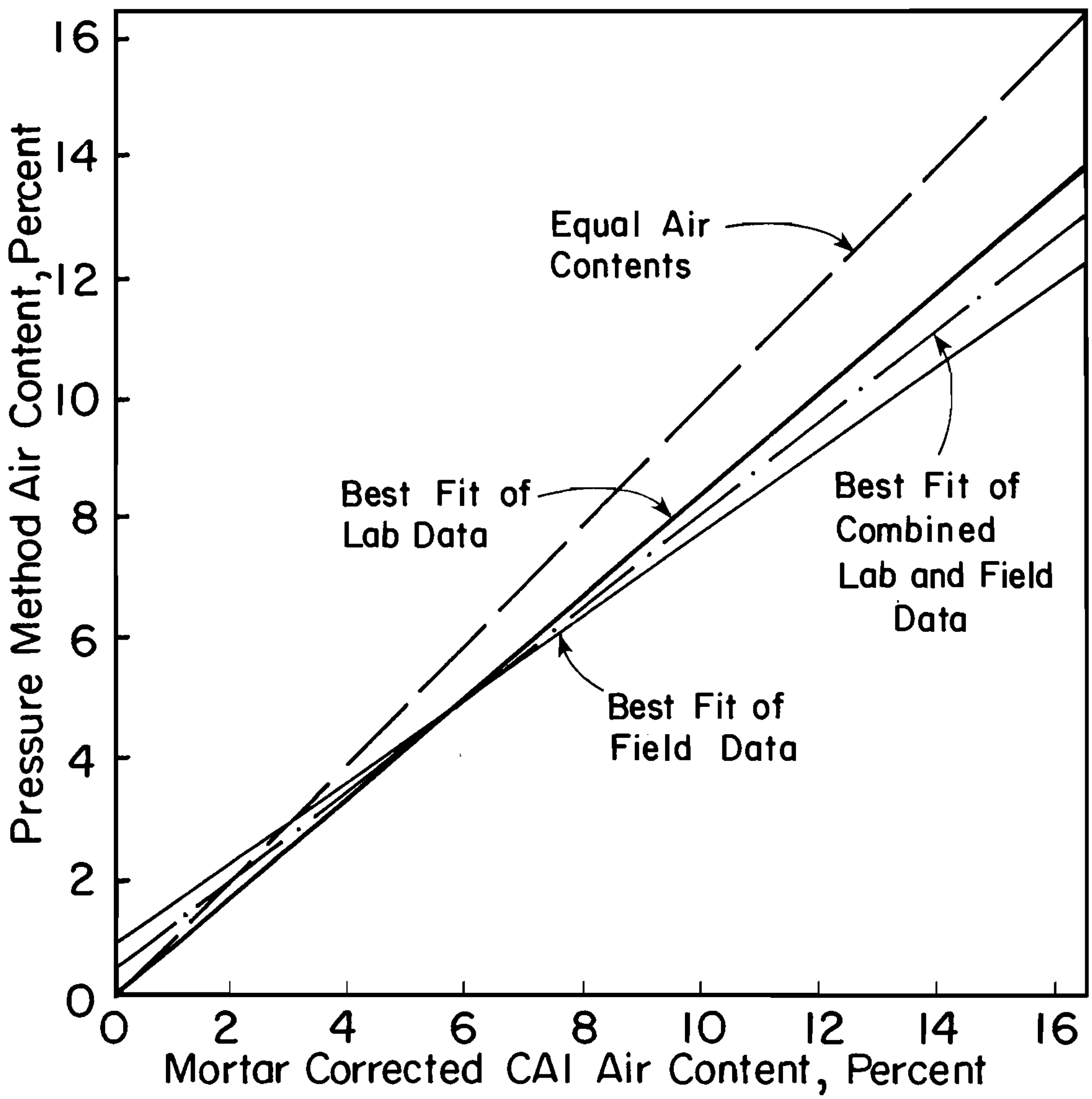

Fig. 4.8 Best Fit of Mortar Corrected Points
(One CAI Reading Per Data Point)

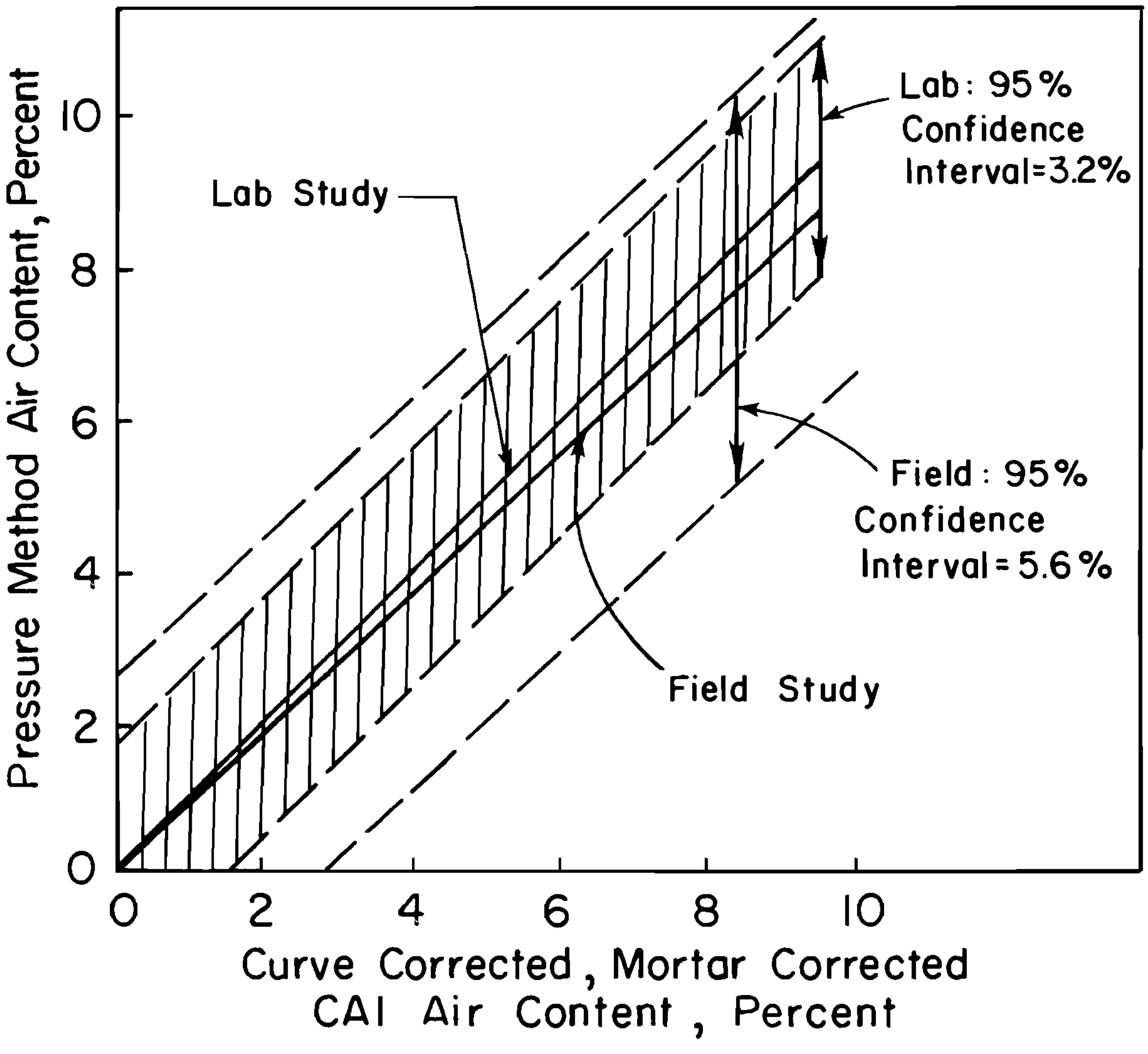

Fig. 4.9 Comparison of Field Curve Correction with Lab Curve Correction
(One CAI Reading Per Data Point)

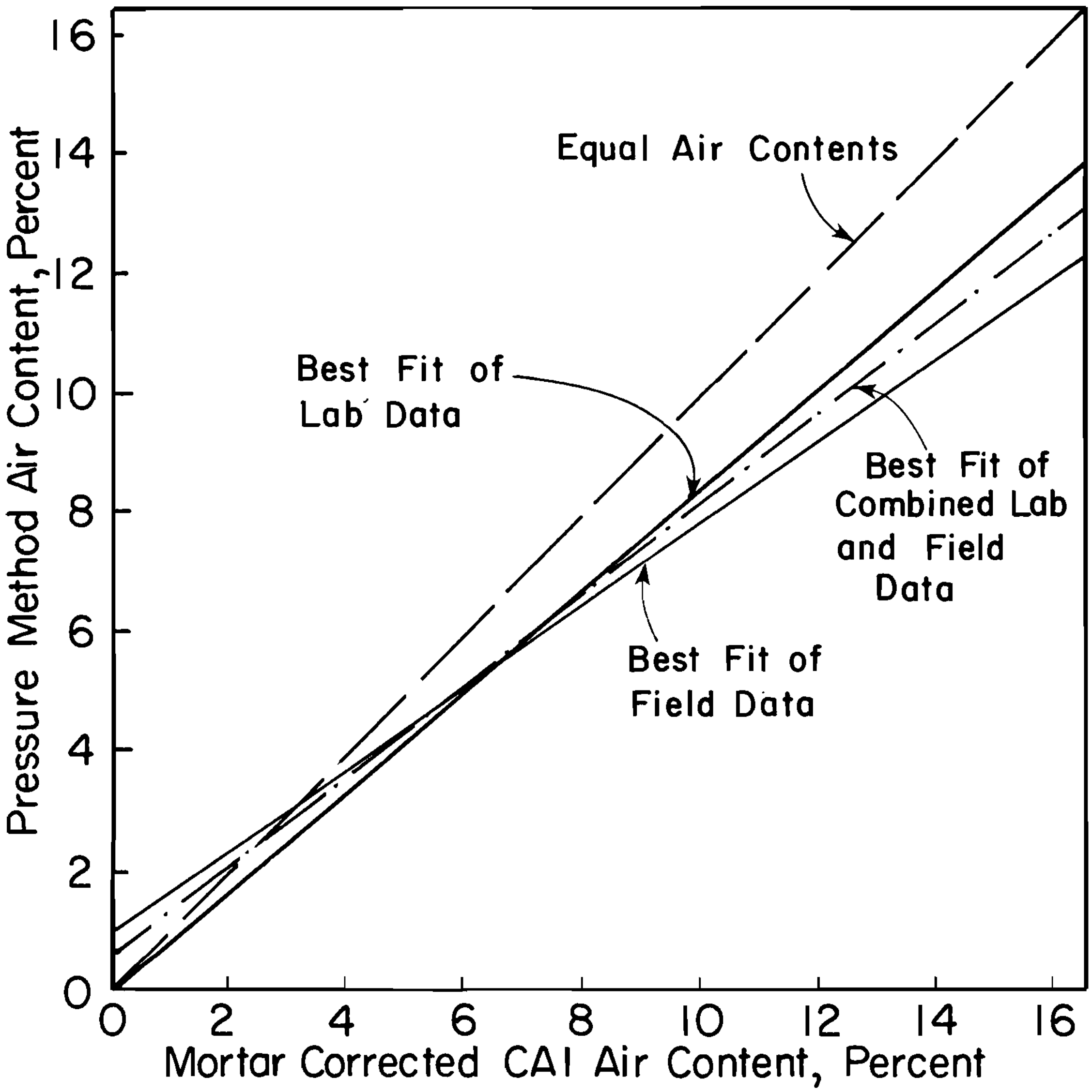

Fig. 4.10 Best Fit of Mortar Corrected Points
(Two CAI Readings Per Data Point)

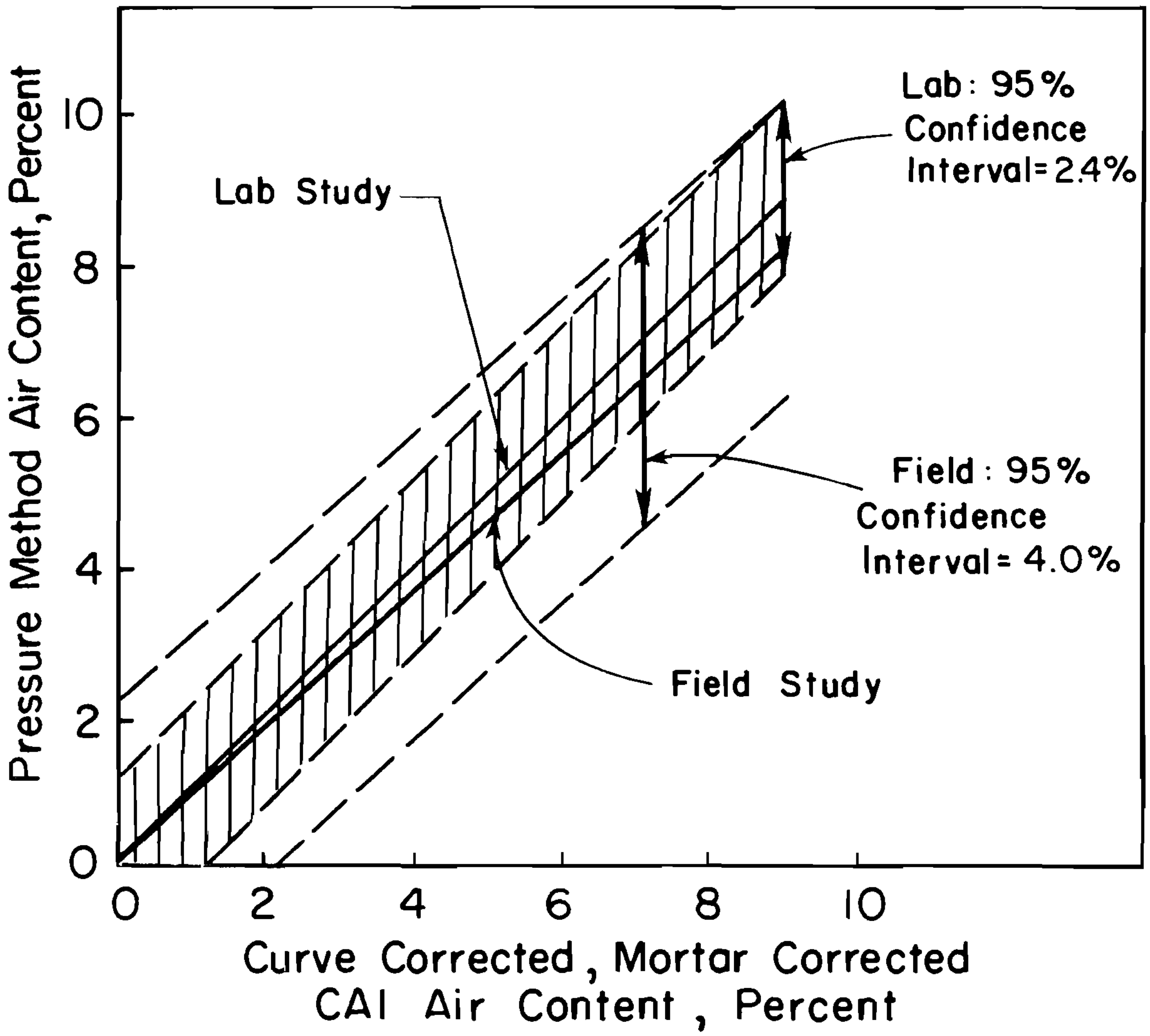

Fig. 4.11 Comparison of Field Curve Correction with Lab Curve Correction (Two CAI Readings Per Data Point)

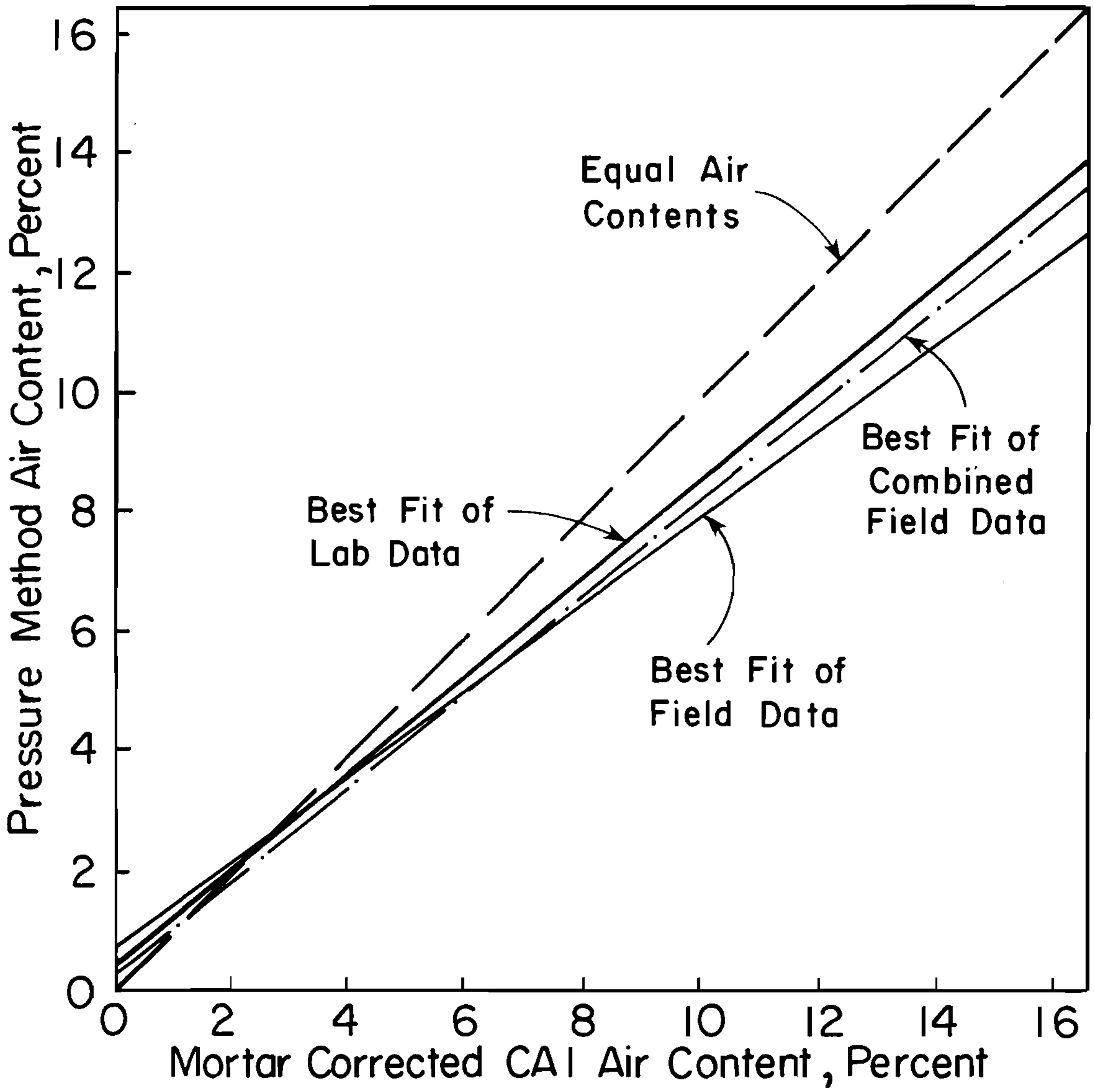

Fig. 4.12 Best Fit of Mortar Corrected Points (Three CAI Readings Per Data Point)

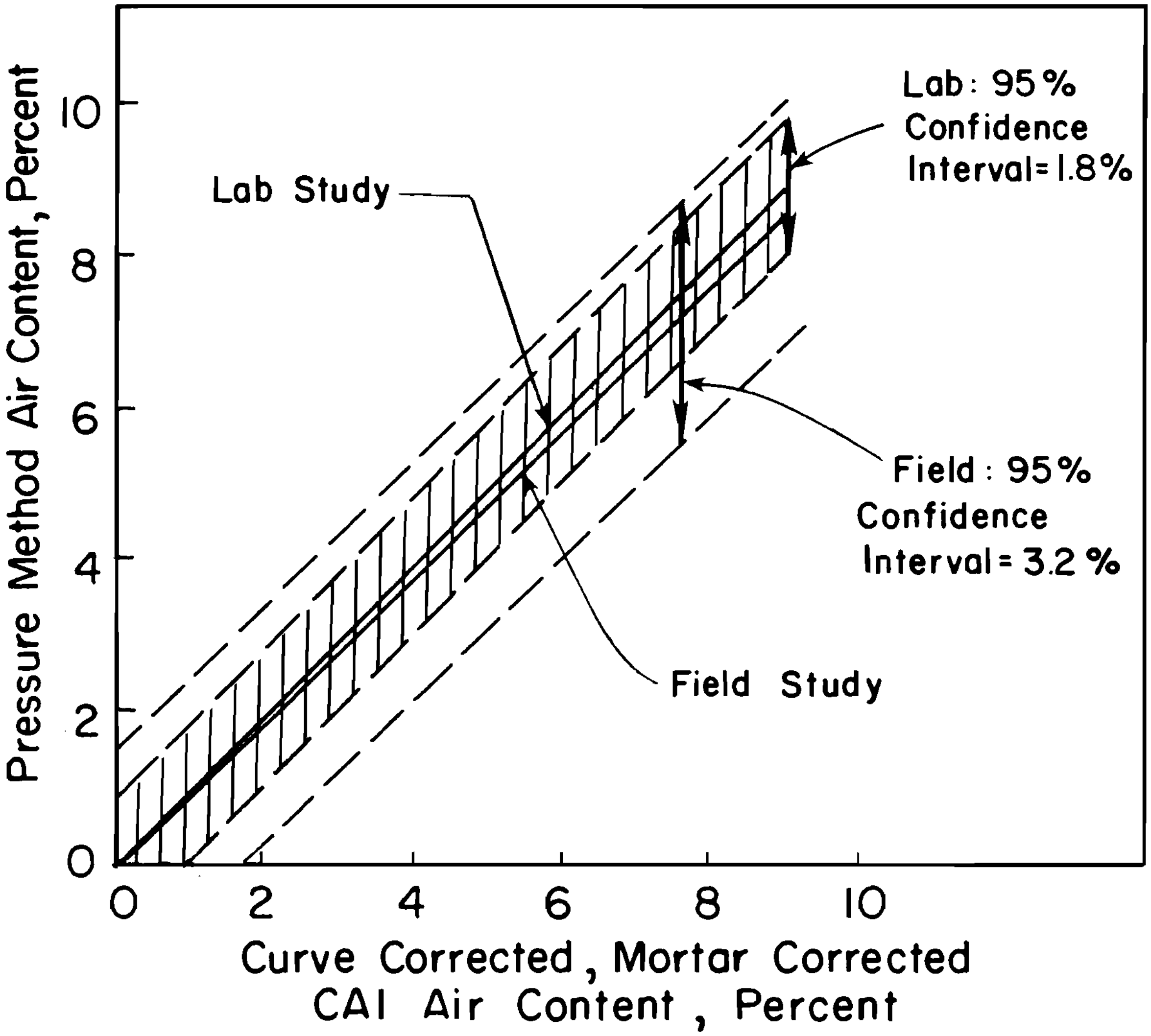

Fig. 4.13 Comparison of Field Curve Correction with Lab Curve Correction (Three CAI Readings Per Data Point)

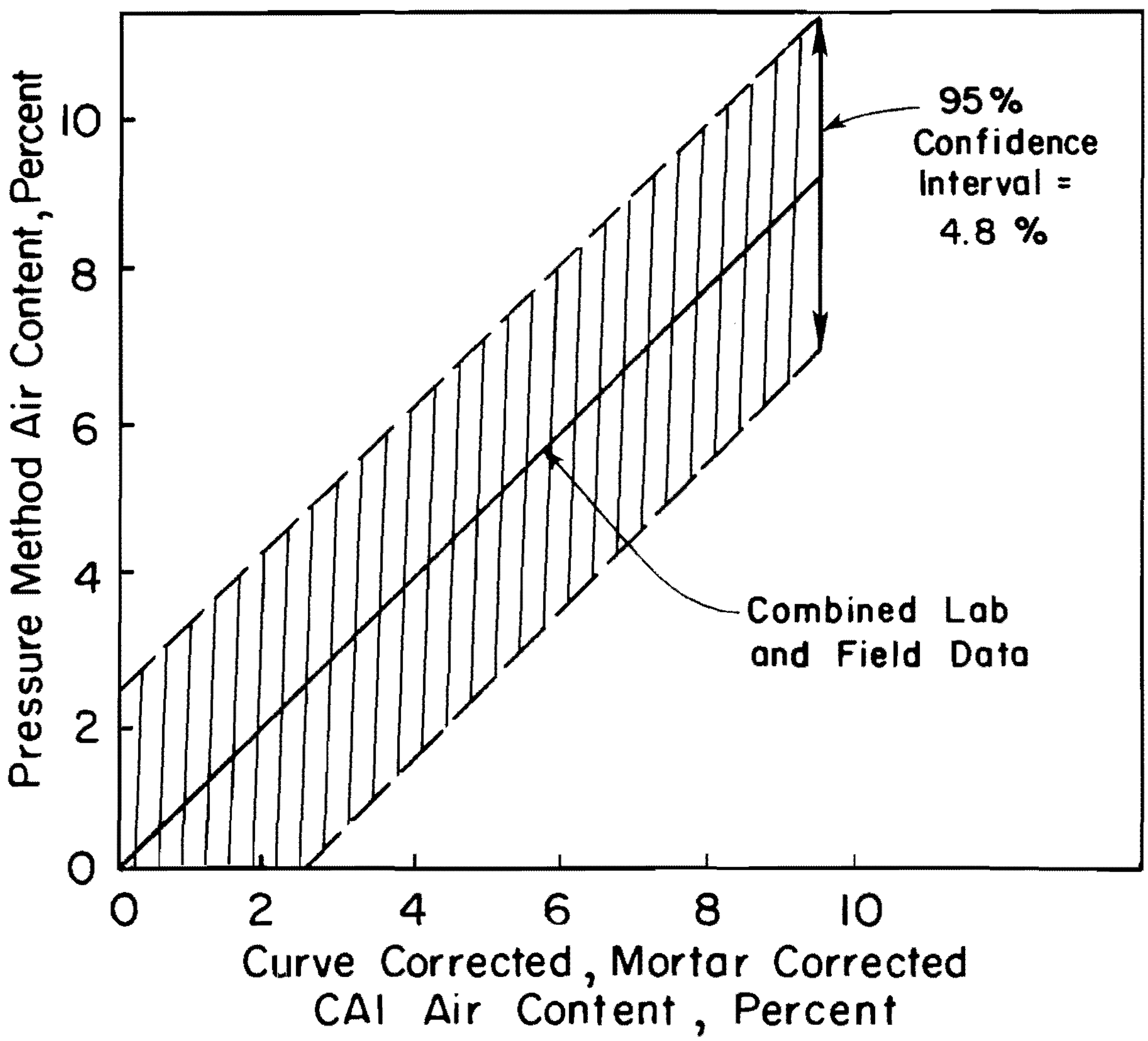

Fig. 4.14 Curve Correction for Combined Lab and Field Data
(One CAI Reading Per Data Point)

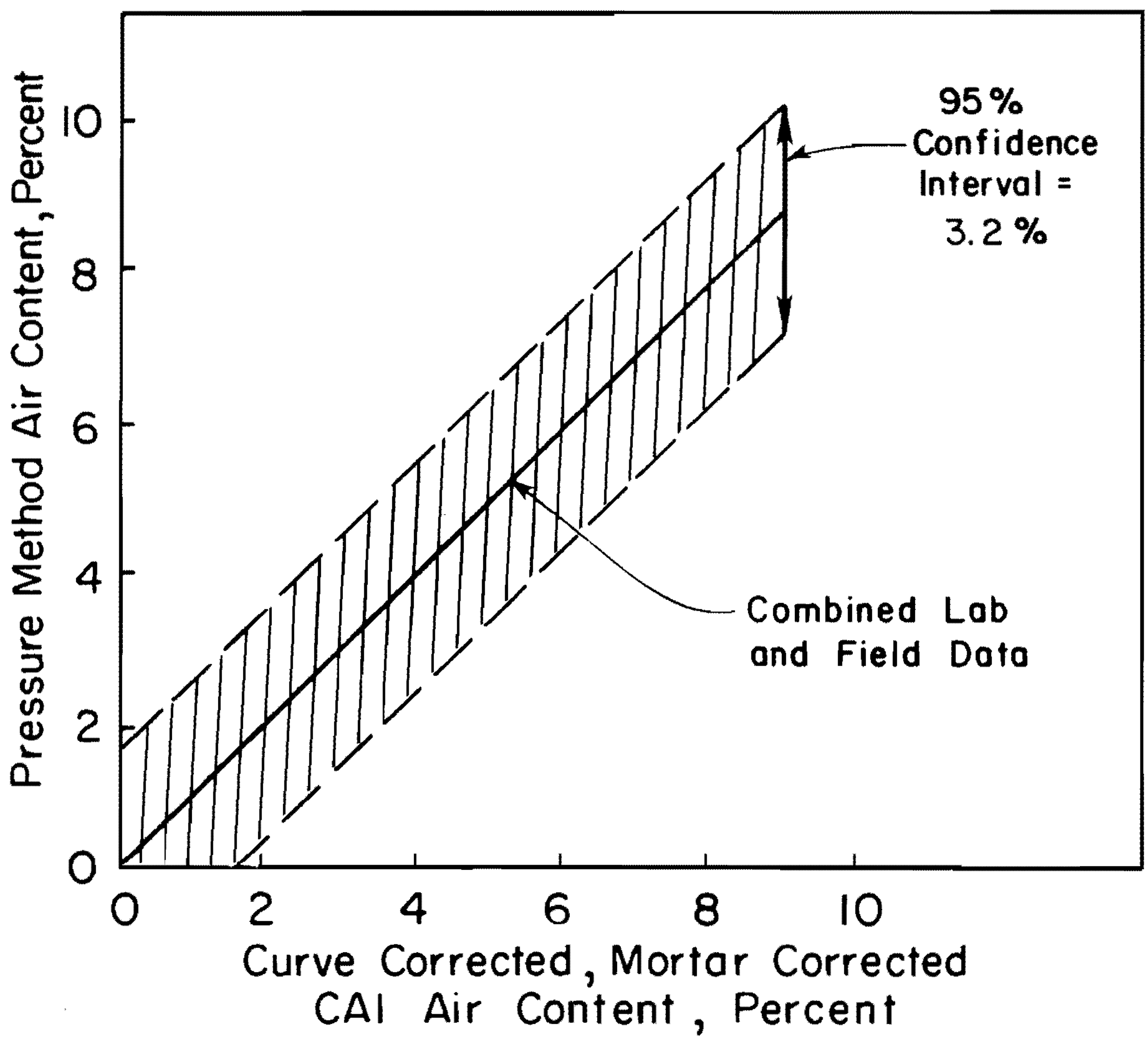

Fig. 4.15 Curve Correction for Combined Lab and Field Data
(Two CAI Readings Per Data Point)

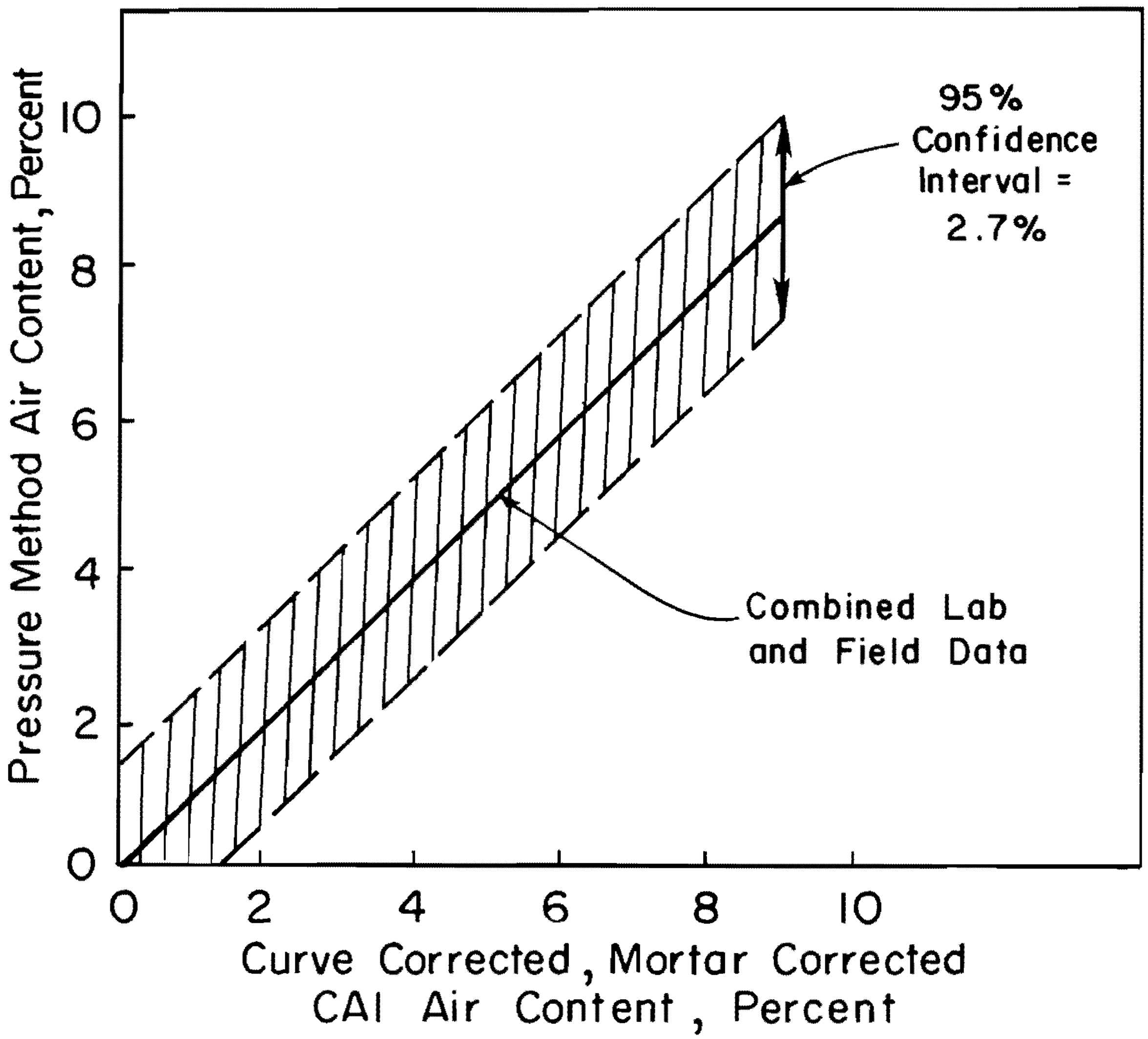

Fig. 4.16 Curve Correction for Combined Lab and Field Data
(Three CAI Readings Per Data Point)

CHAPTER 5
RECOMMENDED PROCEDURES

5.1 Use of the Chace Air Indicator

5.1.1 Determination of the Chace Factor

Manufacturers do not set strict limits on the tolerances during the fabrication of CAIs; therefore, it is necessary to determine the Chace factor for all CAIs to be used in the field. The Chace factor is defined as the volume of one graduation on the stem expressed as a percentage of the volume of the cup. The procedure for determining the Chace factor (CF) is outlined below.

1) Mercury or a mixture of fifty percent isopropyl alcohol, fifty percent water and a few drops of liquid detergent should be used in the Chace factor determination.
2) Determine the volume of one graduation on the stem.
   a) Fill the glass indicator with the alcohol mixture about 1/2 in. below the reference line. Insert the rubber stopper and cup into the tube. Invert the CAI and check for air bubbles. Slowly rotate the CAI at approximately a 45° angle to release any air bubbles trapped between the cup and stopper or between the glass cylinder and the cup or stopper.
   b) Place the CAI on a level surface.
   c) Fill the stem with the alcohol mixture so that the bottom of the meniscus coincides with the lower mark on the stem.
   d) Using a pipette or syringe graduated to 0.01 ml, measure the volume of alcohol mixture that is required to raise the bottom of the meniscus to the upper mark on the stem.
   e) Divide this volume by the number of graduations on the stem to determine the volume of one graduation (v1).

3) Determine the volume of the brass cup.
   a) Remove the stopper and cup from the tube and dry the brass cup. Make sure the brass cup is clean.
   b) Place the stopper on a level surface. Using a pipette or syringe graduated to 0.01 ml, add the alcohol mixture. Fill the cup until the meniscus levels into a flat plane coinciding with the top edge of the cup. This measurement is the volume of alcohol required to fill the cup (V).
4) Calculate the Chace factor (CF)
   Using the following equation calculate CF:

$$CF = \frac{v1}{V} (100) \tag{5.1}$$

If the CAI is kept clean, the value of the CF will not change as the apparatus ages. A CAI used for over 1000 readings in this study maintained a constant CF through both the lab and field phases. However, if the CAI becomes encrusted with mortar, it should be cleaned or replaced and a new CF calculated.

Every existing and new CAI should be calibrated. The Chace factor should be marked permanently on each instrument.

5.1.2 Recommended Procedure for Performing a Chace Air Indicator Test

The following procedure outlines the recommended modified Texas Test Method 416A for the performance of a Chace Air Indicator Test.

1) Fill the brass cup with cement mortar from the concrete to be tested, excluding particles of sand which would be retained on a number 10 sieve. A narrow spatula blade is most suitable to pick up the mortar. To obtain a sample of mortar: "flatten" the surface of the concrete using a trowel, vibrate the concrete surface with the trowel to

settle the aggregate leaving the surface "mortar rich." Take the sample from this "surface mortar."

2) Rod the mortar in the cup 25 times using a stiff wire (a No. 1 Gem paper clip is suitable). Remove any large sand particles detected during the rodding process.
3) Tap the sides of the brass cup 25 times with the handle of the spatula to allow air pockets to escape.
4) Strike off the mortar flush with the top of the brass cup by placing the spatula blade perpendicular to the surface of the cup and using a sawing motion to remove excess mortar.
5) Clean the sides of the cup and stopper using a finger or paper towel.
6) Invert the glass indicator, close the smaller end of the stem with the middle finger and hold the stem between the thumb and the forefinger.
7) Fill the tube with alcohol to the reference line.
8) Insert the stopper into the tube and invert the indicator with the stem facing upward.
9) Push the stopper farther into the tube until it is in a fixed and tight position.
10) Slowly rotate the CAI at approximately a 45° angle to allow any air bubbles trapped between the cup and stopper or the glass cylinder and the cup or stopper to escape.
11) Bring the level of the alcohol to the upper mark on the stem either by adding alcohol with a dropper or by removing excess alcohol using a small piece of paper towel twisted to fit in the stem. Be careful not to disturb the stopper once the alcohol level has been adjusted.
12) Wet the forefinger that will be used to close the stem with water or alcohol.
13) Place the wet forefinger over the opening of the stem. Hold the indicator with the forefinger, thumb and middle finger of one hand. Do not let the larger end of the

indicator rest in the palm of the hand. To prevent alcohol leakage, it is important to kep the stem opening tightly sealed with the forefinger until the final reading is taken.

14) Invert the CAI and shake with short rapid strokes to disperse the mortar. Slow the shaking by lengthening the arm strokes and rotating the CAI in a "fanning motion." Continue in this manner, until the mortar is dispersed completely. With low slump material sometimes it is necessary to tap the sides of the glass near the cup to disperse the mortar. To insure dispersion of mortar in the alcohol, stop the shaking and hold the indicator vertical without removing the forefinger. When the alcohol level stabilizes, take an approximate reading. Repeat the shaking process and take a new reading. If the two readings are the same, dispersion of the mortar is complete; if not, repeat the shaking until two consecutive readings are the same. Make sure there are no sand particles trapped in the stem.

15) After releasing the finger that sealed the stem tip, slowly rotate the CAI at an approximate 45° angle to release any air bubbles trapped between the cup and stopper seam or between the glass cylinder and the cup or stopper.

16) Hold the indicator vertically. Wait approximately 10 seconds for the alcohol level to stabilize. Then determine the level of the alcohol to the nearest half graduation. This is the uncorrected CAI reading (X_u).

17) To insure that no large sand particles were accidentally included in the mortar sample, pour the alcohol-mortar mix into the hand and examine the particle sizes. Also check the brass cup to be certain all the mortar was dispersed. If the sample included large sand particles or the mortar is not completely dispersed, steps 1 to 17 should be repeated. The time to run one test using the CAI from the

time of sampling to the time of the final reading is between 3 and 5 minutes. While running CAI tests keep the alcohol bottle in the shade to help keep the alcohol at a constant temperature. Alcohol temperature variations will affect CAI readings.

18) Steps 1 through 17 outline the procedure for obtaining one CAI reading.

SUGGESTION: To prevent air bubbles from being trapped between the cup and stopper, unscrew the stopper from the brass cup, clean and dry both surfaces. Add some silicone rubber on the stopper surface and screw it back into the brass cup to seal any gap. Wipe away the excess silicone, and 24 hours later, the instrument can be used.

5.2 Determination of the Mortar Corrected CAI Reading

The mortar corrected CAI reading (X_{mc}) is determined using the following equation:

$$X_{mc} = \frac{CF\ (MC)}{27}\ X_{uav} \qquad (5.1)$$

where

CF = Chace Factor as determined in 5.1.1,

MC = Mortar Content of concrete being tested $\frac{(cu\ ft)}{cu\ yd}$,

X_{uav} = Average of one or more uncorrected CAI readings as determined in 5.1.2.

To simplify the determination of X_{mc}, it is recommended that the Mortar Content (MC), as determined by The Concrete Mix Design Sheets, be included in the information on the Concrete Batch Ticket delivered by the mix truck driver to the site inspector.

5.3 Determination of Air Content

It is recommended that equation 4.12 be used in the determination of air content. This equation was chosen because it is a combination of the laboratory and field study results. Therefore, it should be a reasonable representation of the variables studied in the laboratory and the conditions encountered in the field.

The air content of a sample is determined by applying the equation:

$$Y = 0.784\ X_{mc} + 0.445 \qquad (5.2)$$

where

Y = Air Content (percent)

X_{mc} = Mortar Corrected CAI reading as determined in 5.2 using the average of three CAI readings.

The 95 percent confidence interval of 2.7 percent implies that there is a 95 percent probability that the value of the actual air content is between the values of $(Y - 1.4)$ and $(Y + 1.4)$. A 90 percent confidence interval was also computed and is equal to 2.3 percent.

A graphical determination of the air content is also possible. Equation 5.2 is plotted against a vertical axis representing air content (Y) and a horizontal axis representing mortar corrected Chace readings. The graph is entered with a mortar corrected CAI value and a line is projected vertically until the curve for equation 5.2 is intersected. The line is then projected horizontally to the vertical axis and the value for air content is determined.

An example air content determination using a graphical procedure is given in Figs. 5.1 and 5.2. Figure 5.1 illustrates the 95 percent confidence interval and Fig. 5.2 illustrates a 90 percent confidence interval. It is assumed a mortar corrected CAI reading of 8.0 was computed. The line projected vertically and horizontally reveals an estimated air content of 6.7 percent. Considering a 95 percent confidence interval, the air content should be in the range from

5.3 percent to 8.1 percent. If a 90 percent confidence interval is preferred, the range of air contents is 5.6 to 7.9 percent.

Air content can also be estimated using the nomograph in Fig. 5.3. This nomograph accounts for Chace factor corrections, mortar corrections, and curve corrections. An example air content determination is shown on the nomograph. This example assumes a Chace factor of 2.5, a mortar content of 10 cu ft/cu yd and a CAI reading of 8.5. Given these values, an air content of 6.7 percent is obtained from the nomograph.

5.4 Training Program

In both the laboratory and field phases of the project, a learning curve was evident as operators became accustomed to the CAI instrument and procedure. This observation indicates the need for a training program for all users. All users should be informed of the modifications to the current procedure (TEXAS TEST METHOD 416A) and then required to perform approximately 10 sets of 3 CAI tests. The purpose of the training program is to standardize the use of the CAI throughout the department.

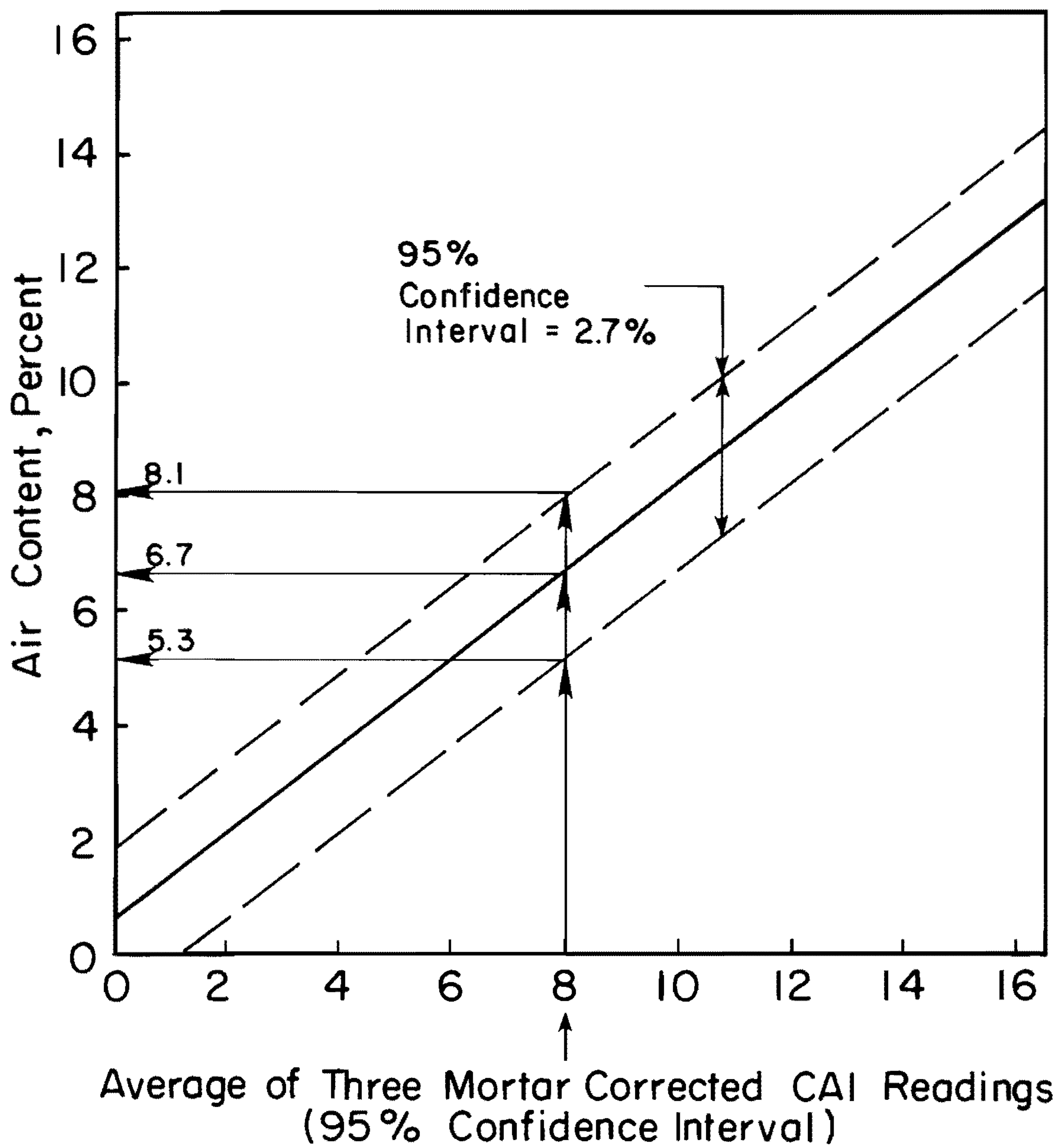

Fig. 5.1 Graphical Determination of Air Content (Three CAI Readings, 95% Confidence Interval)

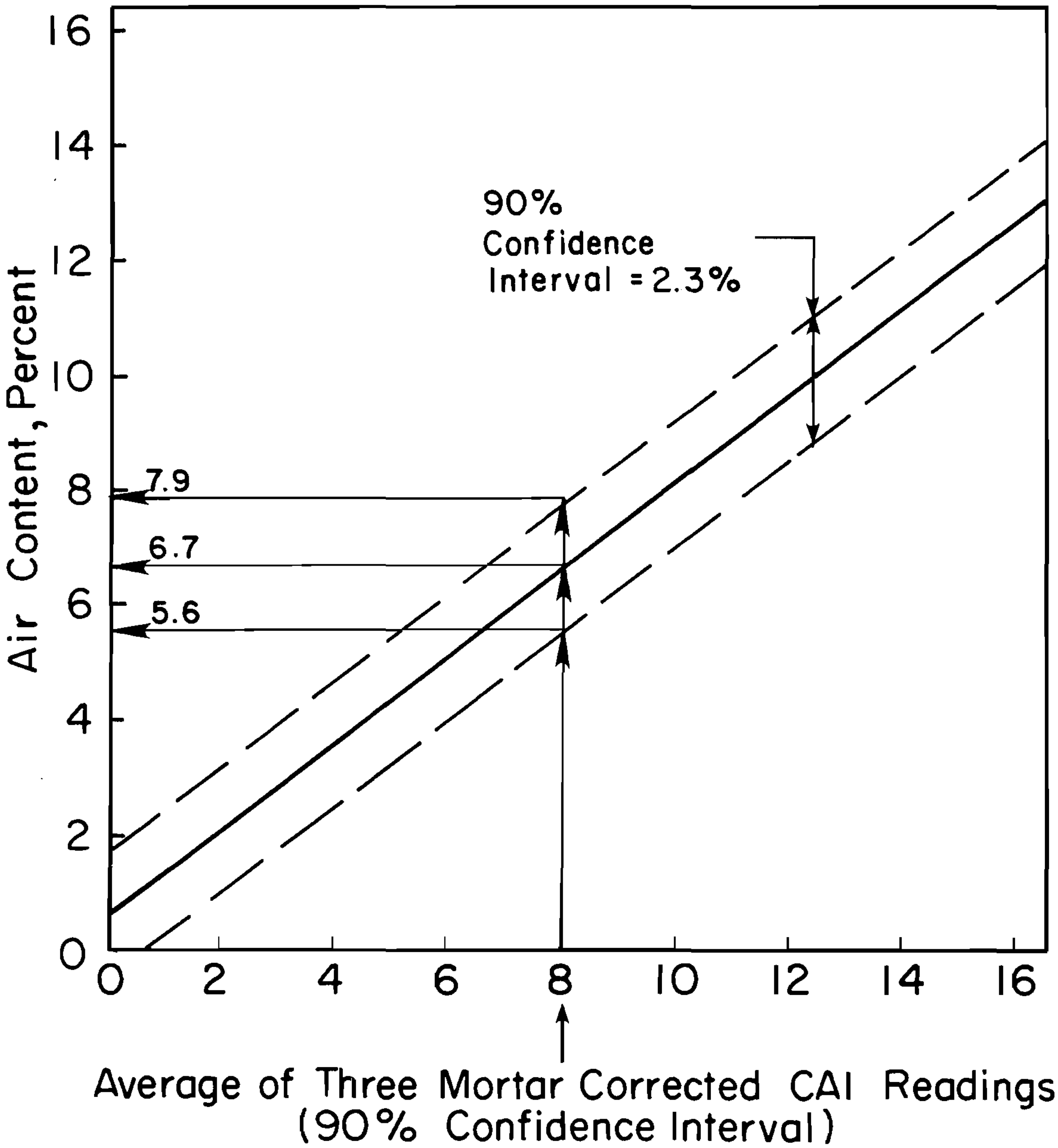

Fig. 5.2 Graphical Determination of Air Content (Three CAI Readings, 90% Confidence Interval)

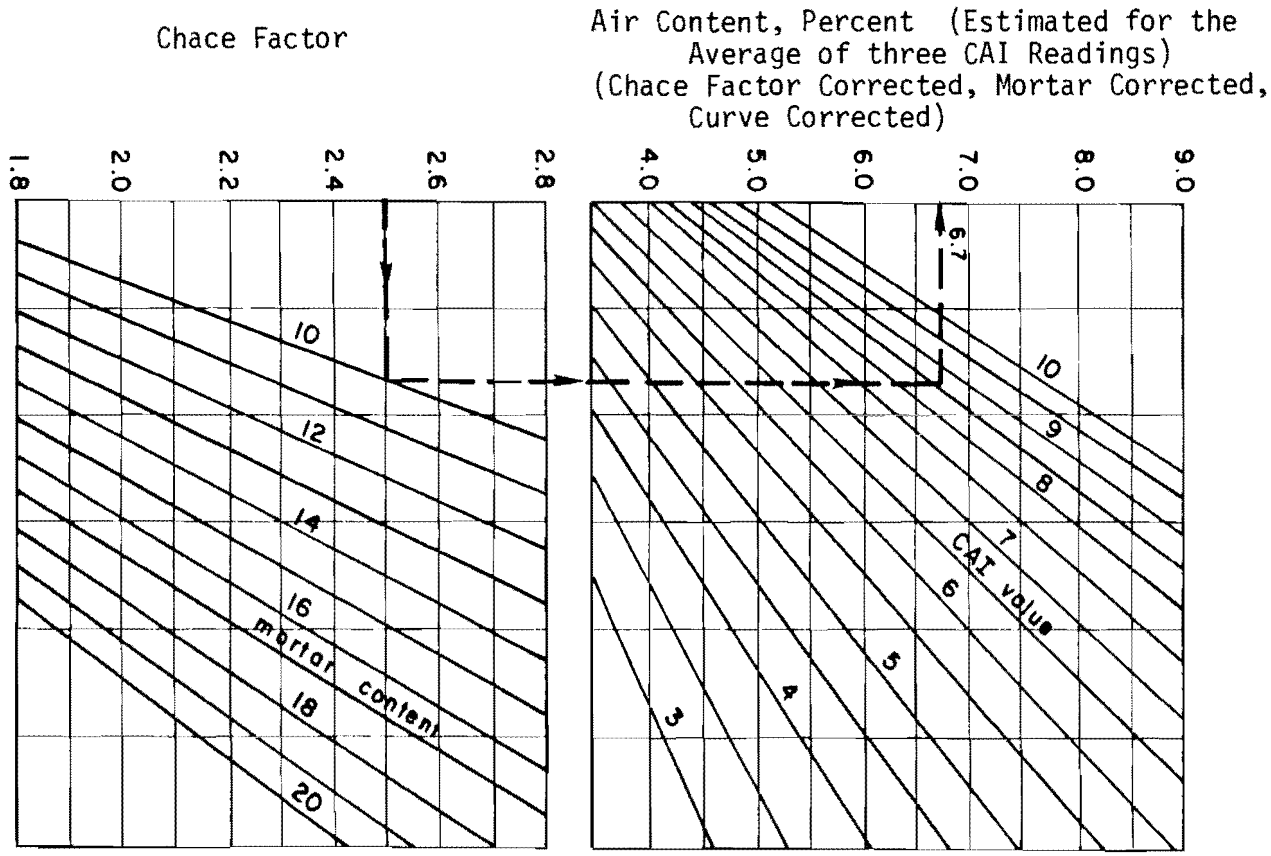

Fig. 5.3 Chance Conversion Nomograph

CHAPTER 6
SUMMARY AND CONCLUSIONS

6.1 Summary

The objectives of this study were:

(1) To determine the calibration and correlation requirements for the CAI.

(2) To determine if the CAI can measure the amount of entrained air with sufficient accuracy for job control purposes.

(3) To identify the limits or tolerances for the use of the CAI for either job control or as an indicator as it is presently used.

The laboratory phase of the study investigated a wide range of variables including air content range, slump range, temperature range, cement types, admixture types, aggregate types, operator variability and CAI variability. The results of the laboratory phase were presented in previous studies (3,6).

This thesis represents the field phase of the study. The field phase allowed for testing to establish the effect of normal variations encountered in field operations. The variables investigated in the field phase included:

1) Variation within ready-mix trucks loaded to different levels,
2) Variation between ready-mix trucks.
3) Day to day variations,
4) Transit time,
5) Concrete mix temperature,
6) Ambient temperature,
7) Slump,
8) Variation in mortar content,

9) Air content,

10) Variability between CAI units,

11) Variability between operators.

Thirty-seven field visits were made and 232 batches of concrete were sampled. Six CAI readings and one pressure meter reading were taken on each sample. A total of 1392 CAI readings and 232 pressure meter readings were recorded.

CAI readings were corrected for mortar contents and Chace factors as suggested by a previous study (5). A curve correction was determined using a regression analysis procedure. Three separate regression analyses were performed to determine curve corrections for:

1) the first of three CAI readings,

2) an average of two CAI readings,

3) an average of three CAI readings.

The results of the field phase were comparable to the laboratory results. The data from the field and laboratory was combined and a new curve correction was determined. This curve correction is the recommended equation for air content determination. Recommended modifications to the CAI test procedure were developed to improve the accuracy of the instrument.

6.2 Conclusions

(1) With the present SDHPT tolerances for air content of $\pm$ 1.5 percent, the CAI is not sufficiently accurate to measure the air content for job control purposes.

(2) Instrument and operator variability after training were not significant.

(3) There was a notable improvement of operator performance with training.

(4) Recommended modifications to the test procedure improved the precision and accuracy of results. These modifications are presented in Section 5.1.2.

(5) If the recommended procedure for performing a Chace Air Indicator test, as outlined in Section 5.1.2, is followed, the CAI could be used in the field to provide an indication of the range (high, medium, or low) of air content of fresh concrete.

(6) The 95 percent confidence interval decreased from 4.8 percent to 2.7 percent as the number of CAI readings increased from 1 to 3.

6.3 Recommendations

(1) Each CAI should be incribed with its Chace Factor.

(2) If the Chace factor of an instrument has been determined, there is no need for daily correlation with the pressure meter.

(3) A Chace factor-mortar correction should be applied to CAI readings.
This correction is determined from the equation:

$$S_{mc} = \frac{(CF)\ (MC)}{(27)} \ (X_u) \qquad (6.1)$$

with

X_{mc} = Chace factor-mortar corrected reading,
CF = Chace factor,
MC = mortar content of the concrete (cu ft/cu yd)
X_u = uncorrected CAI reading or average of readings.

(4) A curve correction described in section 5.3 should be applied to CAI readings corrected by equation 6.1.
The curve correction for the average three CAI readings is determined by the equation:

$$Y = 0.784\ X_{mc} + 0.445 \qquad (6.2)$$

(5) The observation of a notable improvement of operator performance with repeated measurements suggests a training period would improve the repeatability of results.

APPENDICES

APPENDIX A

SUMMARY OF VARIABLES IN FIELD CONDITIONS

SUMMARY OF VARIATION IN FIELD CONDITIONS

1. Variation Within Ready-Mix Trucks When Loaded to Different Levels
   - Samples from trucks loaded to capacity 131
   - Samples from trucks loaded to half capacity 101
   - Samples taken at beginning of discharge from truck 79
   - Samples taken at middle of discharge from truck 67
   - Samples taken at end of discharge from truck 86
2. Variation Between Ready-Mix Trucks
   - 5 sets of readings from 5 different trucks
   - 2 sets of readings from 6 different trucks
   - 5 sets of readings from 10 different trucks
3. Day to Day Variations
   - 2 sets of readings sampling 10 trucks per day for 3 days at the same job site
4. Transit Time
   - Samples with transit time less than 15 min.
   - Samples with transit time greater than 15 min. and less than 30 min.
   - Samples taken with transit time greater than 30 min.
5. Concrete Mix Temperature
   - Samples with mix temperature less than 60°
   - Samples with mix temperature greater than 60° and less than 80°
   - Samples with mix temperature greater than 80°
6. Ambient Temperature
   - Samples with ambient temperature less than 60° 53
   - Samples with ambient temperature greater than 60° and less than 80° 50
   - Samples with ambient temperatures greater than 80° 129
7. Slump
   - Samples with slumps less than 3 in. 75

- Samples with slumps greater than 3 in. and less than 6 in. 138
- Samples with slumps greater than 6 in. 19

8. Variability Between CAI Units
   - Four different CAI Units were used
     - CAI 2 with Chace Factor = 2.50
     - CAI 3 with Chace Factor = 2.24
     - CAI 4 with Chace Factor = 2.50
     - CAI 6 with Chace Factor = 2.11
9. Variability Between Operators

   Greg Henley and Dean Malkemus did all the field testing.
10. Variations in Mortar Content
    - Mortar Content range 12.15 - 15.84
11. Air Content
    - Samples with air contents less than 4 percent 22
    - Samples with air contents greater than 4 percent and less than 6 percent 121
    - Samples with air contents greater than 6 percent 89

SUMMARY OF FIELD TESTS

Date	Location	Amb. Temp. Range	Mix Temp. Range	Slump Range in.	Transit Time Range min.	Percent Air Range
10-27-83	Uhland	72°-74°F	80°-81°F	3-1/2 - 4-1/2	35 - 40	4.5 - 5.5
11- 1-83	Uhland	86°-88°F	87°-88°F	3 - 4-1/2	34 - 39	5.0 - 5.5
11- 8-83	Austin	72°-73°F	78°-80°F	5-3/4 - 6	19 - 23	6.5 - 7.0
11-15-83	Uhland	67°-68°F	72°-75°F	1-1/2 - 1-3/4	35 - 40	4.0 - 4.8
11-22-83	Dallas	58°F	62°F	4-1/2	22	5.4
11-29-83	Austin	56°-58°F	63°-66°F	4-1/2	35 - 55	6.5 - 7.8
11-29-83	Uhland	62°-64°F	67°-69°F	3-3/4 - 4	35 - 37	3.8 - 4.2
12- 1-83	Uhland	48°-52°F	60°-62°F	4 - 4-1/2	30 - 35	2.5 - 2.8
12- 8-83	Houston	73°F	68°-70°F	1-3/4 - 2	19 - 24	4.6 - 5.5
1-27-84	Elgin	62°F	65°-66°F	3 - 4-3/4	13 - 15	4.9 - 5.5
2- 1-84	San Antonio	47°-51°F	58°-61°F	3-1/2 - 5	30 - 45	3.5 - 6.0
2- 7-84	Houston	50°-56°F	60°-62°F	2-1/2 - 4-3/4	15 - 30	4.5 - 6.5
2-14-84	Houston	69°-76°F	70°-73°F	2-1/2 - 4-1/2	16 - 20	4.7 - 6.1
2-23-84	Houston	74°F	78°F	3 - 3-1/2	12 - 15	4.7 - 5.0
2-28-84	Houston	51°-52°F	62°-63°F	3 - 4	35 - 37	6.5
4-11-84	Houston	82°-84°F	82°-85°F	2-1/2 - 5-1/2	26 - 40	6.0 - 6.9
4-12-84	Houston	81°-86°F	82°-84°F	2-1/2 - 4-1/2	18 - 25	3.9 - 6.9
4-13-84	Houston	80°-87°F	84°-90°F	2 - 4	20 - 35	4.0 - 6.0
4-19-84	Austin	85°-92°F	81°-85°F	3-3/4 - 6	43 - 53	6.3 - 6.6
4-24-84	Austin	86°-88°F	82°-84°F	2-1/4 - 4-1/2	29 - 42	5.6 - 6.4
5-15-84	Austin	87°-89°F	86°F	4-1/4 - 5	45 - 51	5.8 - 7.0
5-17-84	Houston	80°-82°F	84°-94°F	2-1/2 - 7-1/2	15 - 55	3.8 - 8.5
5-18-84	Houston	78°-81°F	83°-87°F	3 - 5-3/4	35 - 49	1.8 - 6.5
5-21-84	Austin	90°-91°F	85°-90°F	1-1/2 - 3	20 - 25	4.4 - 6.5
5-23-84	Dallas	89°-90°F	91°-92°F	3-1/2 - 5	41 - 49	3.5 - 3.8
5-25-84	Houston	85°-90°F	89°-95°F	3 - 6-1/2	15 - 40	4.7 - 7.2
5-30-84	Houston	76°-78°F	84°-87°F	3 - 5	15 - 21	5.1 - 6.5
5-31-84	Houston	78°-79°F	82°-85°F	3-1/4 - 4-1/4	24 - 26	6.4 - 6.6
6- 7-84	Houston	80°F	81°-82°F	3-1/2 - 5	20 - 23	5.9 - 7.2
6- 8-84	Houston	79°-81°F	77°-80°F	3-1/4 - 7	15 - 50	4.8 - 6.0
6-20-84	Houston	82°-93°F	79°-88°F	2-1/4 - 4-1/2	6 - 25	3.9 - 5.4
6-21-84	Houston	81°-82°F	87°-88°F	1-1/2 - 3	10	5.6 - 8.1
7-12-84	San Antonio	81°-88°F	82°-88°F	1 - 1-1/2	12 - 20	3.5 - 5.3
7-16-84	Houston	81°-85°F	80°-90°F	4 - 8	15 - 25	5.0 - 6.5
7-17-84	Houston	85°-89°F	87°-93°F	2 - 3-1/2	13 - 21	4.9 - 6.6
7-18-84	Houston	83°-86°F	86°-93°F	1-1/5 - 3-3/4	15 - 27	5.8 - 7.4
7-19-84	Houston	84°-85°F	86°-93°F	2-1/4 - 4-3/4	12 - 28	5.0 - 7.6

APPENDIX B

FIELD DATA SHEET

*MAT'L	Ident: Cement Brand & Type, aggr Source; Admixtures - Name & Lab or Lot No.	
AEA		oz
RA		oz
WRA		oz
CA_1		lbs
CA_2		lbs
FA		lbs
Cement		lbs

CONCRETE BATCH TICKET

Ticket No ____

Date ____

AT PLANT:

County ____ Project ____

Plant ____ Des No ____ Truck No ____ C.Y. ____

Class ____ Air Temp ____ F. Mixer Chg'd ____ A.M. P.M. Max Time ____

*%Moist. CA_1 ____ CA_2 ____ FA ____ Water Added (gal.) ____ Ice (lbs) ____ W'held (gal.) ____

Mix. Rev. ____ Remarks: ____

Plant Insp ____

AT JOBSITE:

Water Added (gal.) ____ Ice (lbs.) ____ Mix Rev. ____

Slump ____ %Air ____ Conc. Temp. ____

p.s.i. Mixer Unloaded ____ A.M. P.M.

Remarks ____

____ Job Insp. ____

TEST DATA

ARRIVAL TIME ___________ - MIXER CHG'D T ___________ = TRANSIT TIME ___________

TIME SAMPLE TAKEN FROM TRUCK ___________ @ BEGINNING ____ MIDDLE ____ END ____

SLUMP __________ MORTAR CONTENT _______________

CAI READINGS

CAI # _____ CAI # _____ CAI # & DHPT-OP _____ ___________

READINGS: DM _____ _____ _____ GH _____ _____ _____ DHPT-OP _____ _____ _____

CAI TIMES: DM _____ _____ _____ GH _____ _____ _____ DHPT-OP _____ _____ _____

DHPT-OP CHACE FACTOR: Stem Unit Volume _____ ÷ Cup Volume _____ x 100 = _____

PRESSURE METER READINGS

READING _______ TIME _______ OPERATOR _____ PM # & CAL. DATE _____ _________

DHPT-OP _______ TIME _______ OPERATOR _____ PM # & CAL. DATE _____ _________

TEMPERATURE READINGS

AMBIENT TEMPERATURE _______ CONCRETE MIX TEMPERATURE _______

CONTACT PERSONNEL & COMMENTS

____

____

____

____

APPENDIX C

ILLUSTRATION OF DIFFERENCE BETWEEN TOLERANCE AND 95 PERCENT CONFIDENCE INTERVAL

Assuming an air content of 5.5 percent is specified and following the SDHPT guideline of 1.5 percent tolerance, the air content of a sample should fall between 4.0 and 7.0 percent. Allowing for the 95 percent confidence interval of ± percent, using the average of three CAI readings, the CAI range must be between 5.4 and 5.6. This tolerance of ± 0.1 percent is not adequate for any air content measuring device. This example is represented graphically in Fig. C.1.

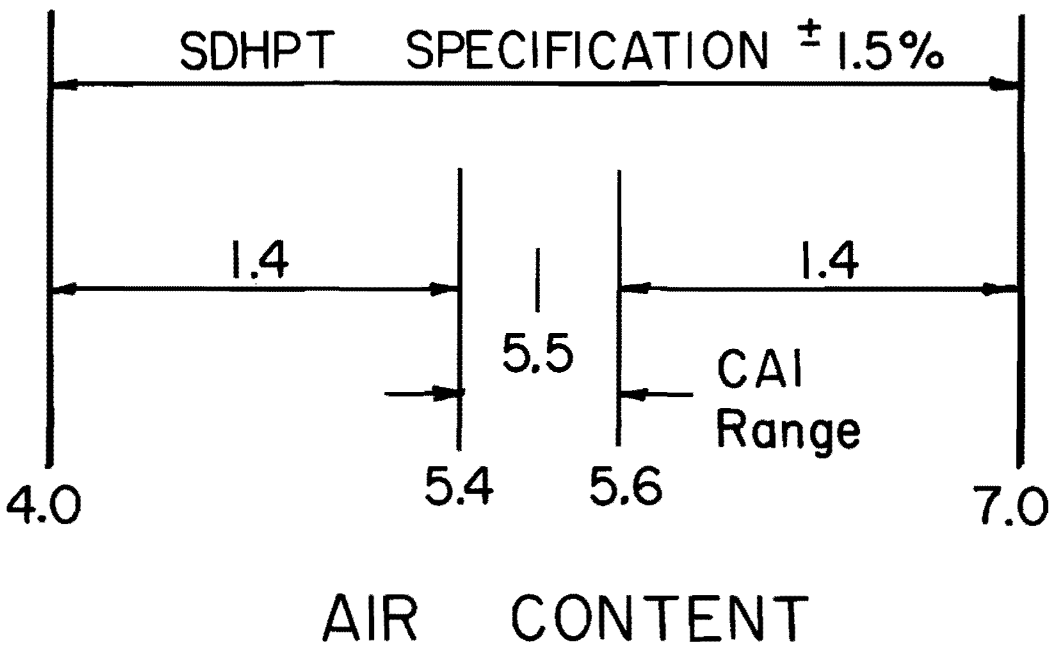

Fig. C.1 Example: Tolerance and Confidence Interval

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