2753

THE CHACE AIR INDICATOR

by

Michael M. Sprinkel
Research Scientist

and

Bryan Lee
Student Helper

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

February 1981
VHTRC 81-R37

2754

CONCRETE RESEARCH ADVISORY COMMITTEE

ABSTRACT

The study reported here has revealed very poor agreement between air contentsdetermined by the Chace air indicator (CAI) and those by the pressure method. In tests of highway concretes the pressure method gave values typically 30% higher than anticipated based on the CAI readings, which could result in the production of concrete with lower than anticipated strengths. The poor agreement was found to involve relationships between the volumes of the stems, the volume of the bowls, and the mortar correction factors supplied by the manufacturers of the CAI. Consequently, it is recommended that AASHTO Specification T199-72 be modified to account for these relationships.

It is concluded that the CAI can be used to provide a reasonably accurate indication of the air content of fresh concrete, when the results are based on the average of tests on a minimum of two samples and the results are corrected using a Chace conversion nomograph that takes into account the Chace factor (the volume of one graduation on the stem as a percentage of the volume of the bowl), the mortar content of the concrete, and the tendency of the CAI to provide a low result at high air contents.

THE CHACE AIR INDICATOR

by

Michael M. Sprinkel
Research Scientist

and

Bryan Lee
Student Helper

INTRODUCTION

For more than 20 years the Virginia Department of Highways and Transportation has been determining the air content of plastic concrete by two methods; namely, the pressure method, which is covered by ASTM Designation C231-75(1) and AASHTO Designation T152-76,(2) and the Chace air indicator (CAI) which is not covered by ASTM but is covered by AASHTO Designation T199-72.(3) The CAI has been used more often than not by the Department because of the relative ease with which it can be used. With the pressure method, one has to fill the bowl with concrete, add water, and subject the concrete to pressure. Inspectors like the CAI because only a small sample of mortar and alcohol is required for the test (see Figure 1).

In recent years, very poor agreement between the air contents as determined by the CAI and those by the pressure method has been noted. In fact, as shown in Figure 2,(4) concrete accepted with the CAI and noted as having an air content of 8%, which would be acceptable by the Department's specification, could actually have an air content of 12% or more, which could cause the concrete to fail the strength test. In many instances in recent years when concrete cylinders have failed the 28-day strength test, subsequent petrographic examinations of the hardened concrete have revealed that the air content was much too high.(5)

Figure 3 shows some relationships between the entrained air content and the strength of concrete.(6) For example, when all mixture proportions are held constant with the exception of the dosage of air-entraining admixture, a concrete having a strength of 6,000 psi when the air content is zero would have a strength of 4,500 psi when the air content is 4% and 3,500 psi when the air content is 8%. The strength would drop to 2,500 psi if the air content were 12%, which would occur if a double dose of air-entraining admixture were accidently added to the concrete. The Department requires 4% to 8% air and a 28-day strength ≥ 3,000 psi for its pavement concrete, and 5% to 8% air and a 28-day strength ≥ 4,000 psi for its bridge deck concrete.(7) It's easy to see how a strength problem can result if the concrete contains too much air.

2758

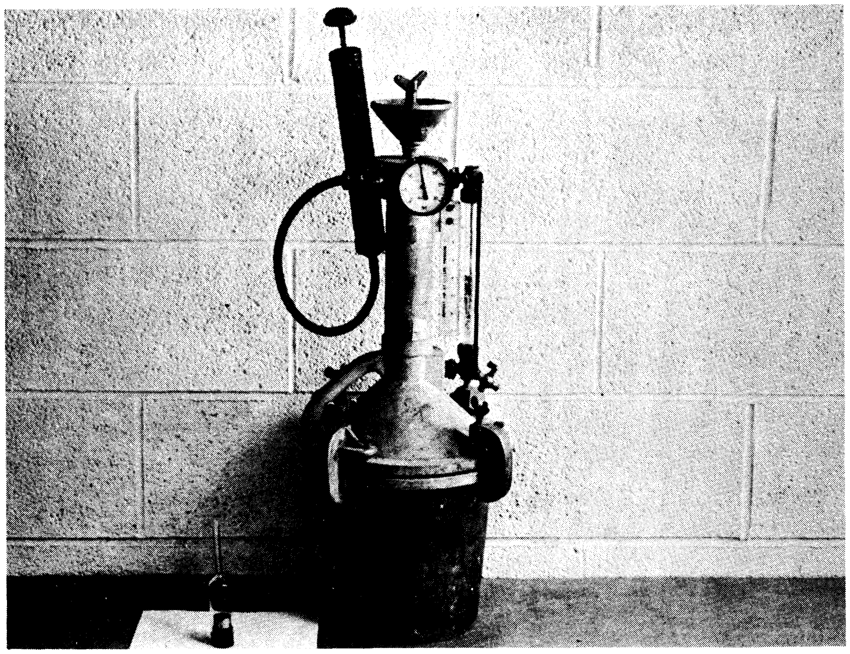

Figure 1. Apparatus used in pressure test (right) and Chace test.

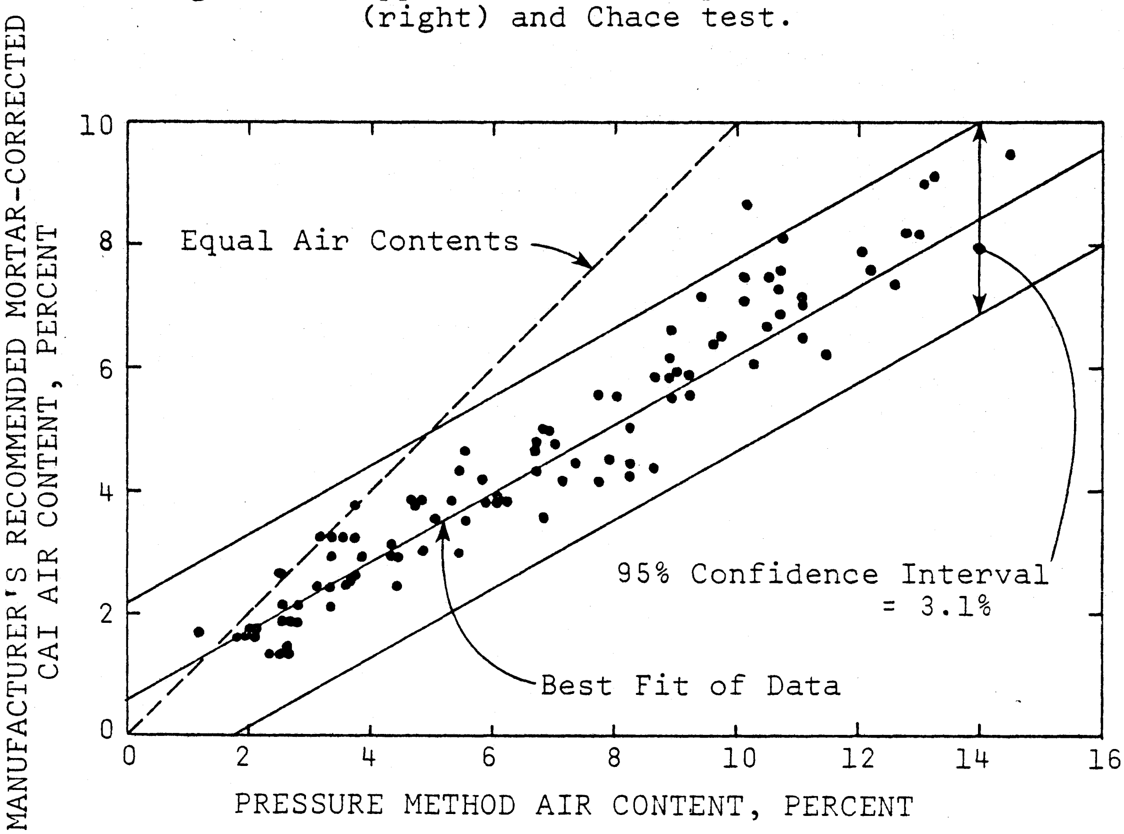

Figure 2. Relationship between air content as determined by the pressure method and mortar-corrected CAI measurements based on manufacturer's recommended mortar correction.

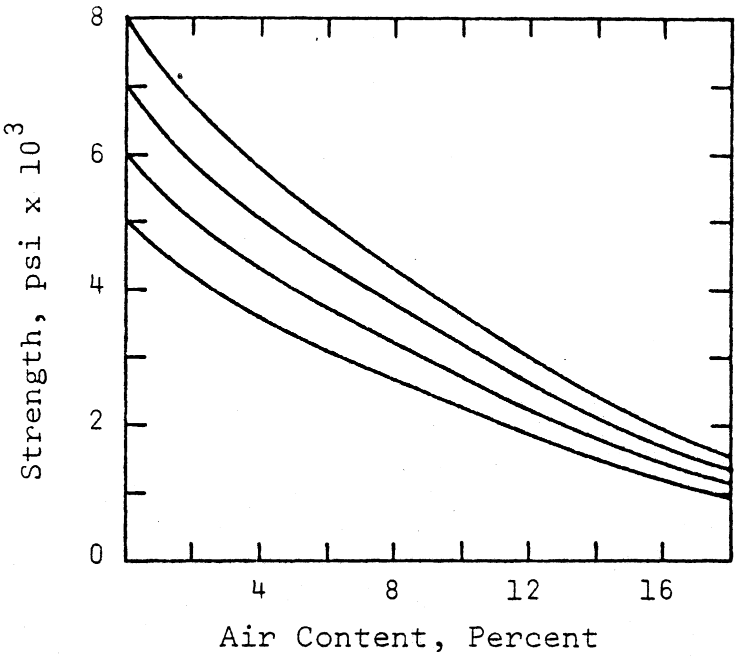

Figure 3. Relationship between entrained air content and strength. (After Neville, reference 6.)

DATA COLLECTION

The study reported here was conducted to quantify the relationship between air contents determined by the CAI and those determined by the pressure method. It was anticipated that the study would also provide an explanation as to why the CAI was indicating very low air contents and would develop corrective measures that could be implemented by the Department.

The study comprised the preparation and testing of 99 batches of pavement (A3) and bridge deck (A4) concretes typical of those currently used by the Department (see Table 1).[7] The 1.0 to 1.5 ft.^{3} batches were mixed in a pan type mixer and, by adding different amounts of air-entraining admixture to the mix water, the air contents were varied within the desired range, which included air contents higher and lower than those permitted by current specifications.

The air content of each of the 99 batches was determined once using the pressure method[1] and four times using the CAI.[3] The

CAI was used to measure the air content of each of two mortar samples obtained by passing a portion of the concrete through a number 10 sieve (screened samples) and each of two samples obtained by removing mortar from the concrete using a putty knife (unscreened samples). Figure 4 shows plots of the average air content of each of the two unscreened samples as a function of the air content as determined by the pressure method. The data for the CAI shown in Figure 4 have not been corrected for the mortar content of the concrete, which was typically 15 to 18 $ft.^3/yd.^3$ The relationship resulting from the application of the manufacturer's recommended mortar corrections was shown earlier in Figure 2. As can be seen by comparing Figures 2 and 4, for typical highway concretes the application of the manufacturer's recommended mortar corrections did little to improve the relationship between the air content determined by the pressure method and that by the CAI. A relationship similar to that shown in Figure 4 was obtained by plotting the average air content of each of the two screened samples as a function of the air content determined by the pressure method. The data obtained for the screened mortar samples was slightly more variable than those for the unscreened samples, with a standard deviation of 0.81% as compared to 0.71%.(4)

Table 1

Requirements for Portland Cement Concrete
(From reference 7.)

Class	A4	A3
Minimum 28-day compressive strength, psi	4,000	3,000
Nominal maximum aggregate size, in.	1	1
Minimum cement content, $lb./yd.^3$	635	564
Maximum water-cement ratio, lb./lb.	0.47	0.49
Slump, in.	2-4	0-5
Air, percent	5-8	4-8

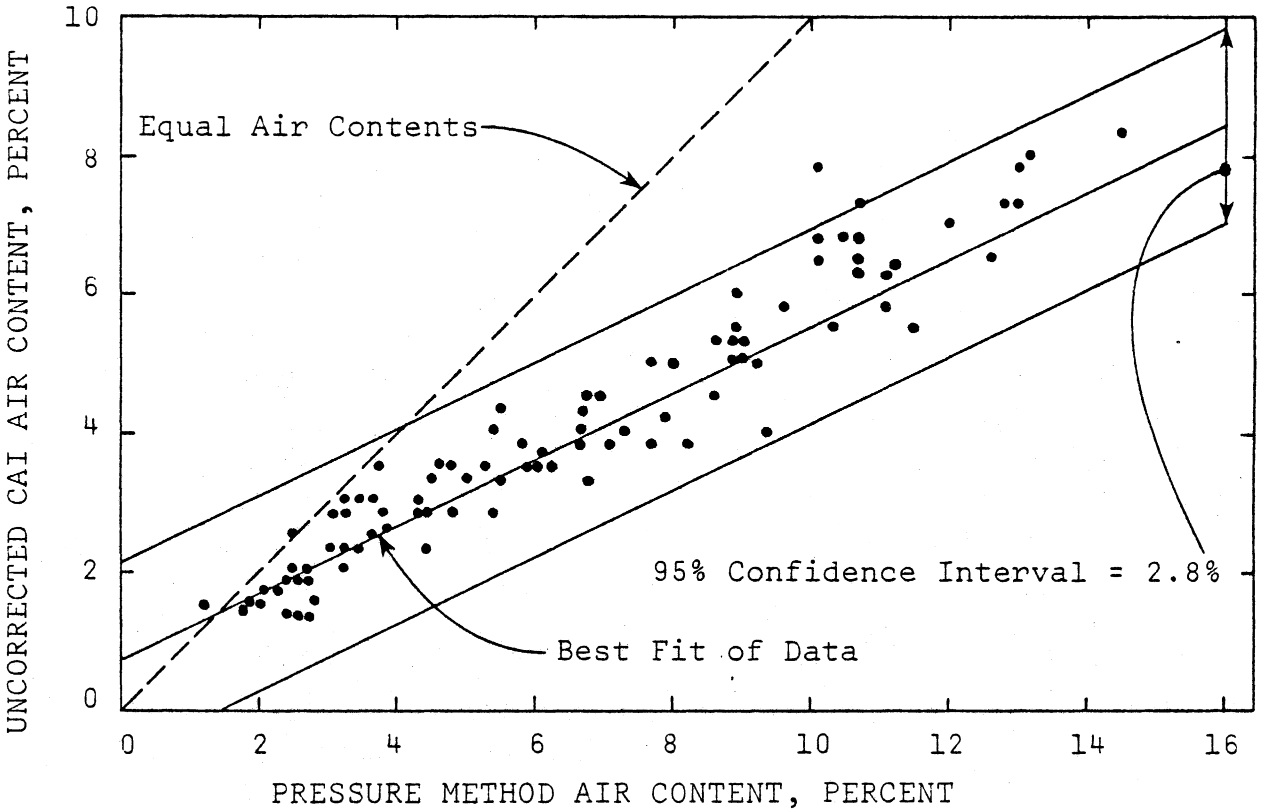

Figure 4. Relationship between air content as determined by the pressure method and uncorrected CAI measurements.

ANALYSIS OF CHACE DIMENSIONS

To determine why the CAI was indicating much too low air contents, measurements were made of the volumes of the bowls and stems of some 30 of these instruments obtained from five districts and six located at the Research Council. The important consideration was the Chace factor, which is defined here as the volume of one graduation on the stem, which represents 1% air, expressed as a percentage of the volume of the bowl, which contains the sample (see Figure 5).

The results of this analysis, shown in Table 2, revealed that for CAI's supplied by manufacturer H and manufacturer C, the average Chace factor was 2.30. The uniformity of the factors for the CAI's from these two manufacturers was good, exhibiting standard deviations of 0.05 and 0.03, respectively. The CAI from manufacturer L had an average factor of 1.87, but the variation among the instruments was broad; the standard deviation was 0.46. In fact, one CAI from manufacturer L had a Chace factor of 1.43 and another had a factor of 2.51. Figure 6 shows the stems for these two extreme cases. The CAI on the left has a small diameter and would give a high reading for the air content, whereas that on the right has a large diameter and would provide a very low reading. For example, a sample of mortar exhibiting an air content of 8.0% when checked with the CAI on the left would indicate an air content of 4.5% when checked with the one on the right. In theory, based on the mortar correction factors supplied by the manufacturers of the CAI's, the volume of one graduation of the stem should be 1.80% of the volume of the bowl. It's interesting to note that AASHTO requires that the CAI be manufactured so that the volume of one graduation on the stem is equal to 2.2% of the volume of the bowl.(3) The CAI's from manufacturers H and C are in reasonable compliance with the AASHTO specification.

Table 2

Chace Factors

Manufacturer	Number of Indicators	Chace Factor*	Standard Deviation
H	14	2.30	0.05
C	17	2.30	0.03
L	5	1.87	0.46

*Volume of one graduation on stem as a percentage of the volume of the bowl.

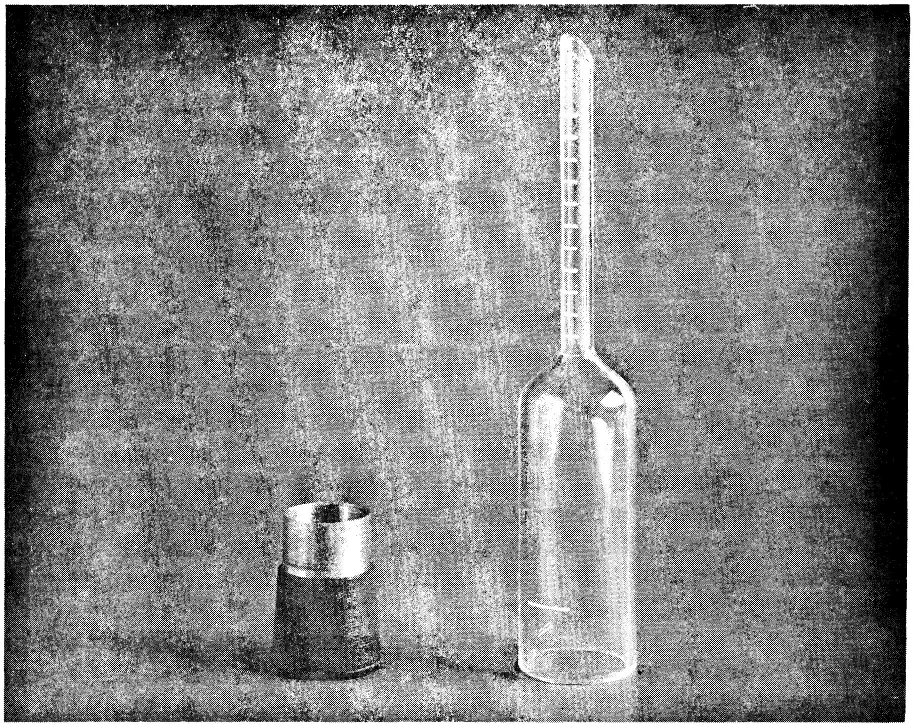

Figure 5. Typical Chace air indicator.

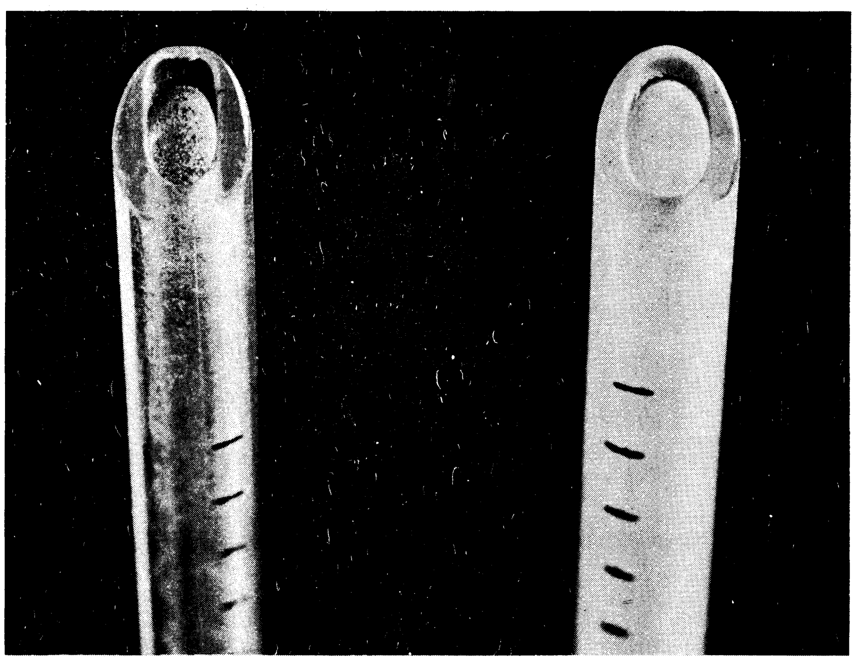

Figure 6. CAI having smallest inside diameter (Chace factor = 1.43) (left) and largest (Chace factor = 2.51) (right).

Mortar correction factors (Table 3) which are appropriate for the typical range of Chace factors were developed as a result of the dimensional analysis. The mortar correction factors for a Chace factor of 1.8 are the same as those currently supplied by all three manufacturers of the CAI. At the top of the column, it can be seen that for 27 cubic feet of mortar per yard the stem reading is multiplied by 1.8 to get the volume of air. If the concrete has a mortar content of 15 $ft.^3/yd.^3$, the air content is read directly since the correction factor is 1.0. Unfortunately, although the mortar correction factors provided by manufacturers were applicable to a CAI having a Chace factor of 1.8, the dimensional analysis, as mentioned previously, revealed that the actual volume of one graduation on the stem of most of the CAI's was 2.3% of the volume of the bowl. This means that for those CAI's the most appropriate mortar correction factors would be determined by computing the average of the mortar correction factors developed for Chace factors of 2.2 and 2.4. Using the average of these factors, the air content of a concrete with a mortar content of 15 $ft.^3/yd.^3$ would be 1.28 times the actual reading, rather than 1 as indicated by the mortar correction factors supplied by the manufacturers.

Table 3

Mortar Correction Factors

Mortar Content	Chace Factor*				
$ft.^3/yd.^3$	1.6	1.8**	2.0	2.2	2.4
27	1.60	1.80	2.00	2.20	2.40
20	1.19	1.33	1.48	1.63	1.78
19	1.13	1.27	1.41	1.55	1.69
18	1.07	1.20	1.33	1.47	1.60
17	1.01	1.13	1.26	1.39	1.51
16	0.95	1.07	1.19	1.30	1.42
15	0.89	1.00	1.11	1.22	1.33
14	0.83	0.93	1.04	1.14	1.24
13	0.77	0.87	0.96	1.06	1.16
12	0.71	0.80	0.89	0.98	1.07
11	0.65	0.73	0.81	0.90	0.98
10	0.59	0.67	0.74	0.81	0.89

*Volume of one graduation on stem as a percentage of the volume of the bowl.

**Factors supplied by the manufacturers.

The relationship shown in Figure 7 is the result of the modification of the data shown in Figure 4 by applying the mortar correction factors to take into account the particular Chace factors of the CAI used to produce the data. It can be seen from Figure 7 that once the Chace-factor-based mortar correction factors were applied to the data in Figure 4, there was fairly good agreement between the air contents as determined by the CAI and the pressure method, and there was a magnitude of improvement in comparison to the relationship shown on Figure 2, which is based on the manufacturer's recommended mortar corrections.

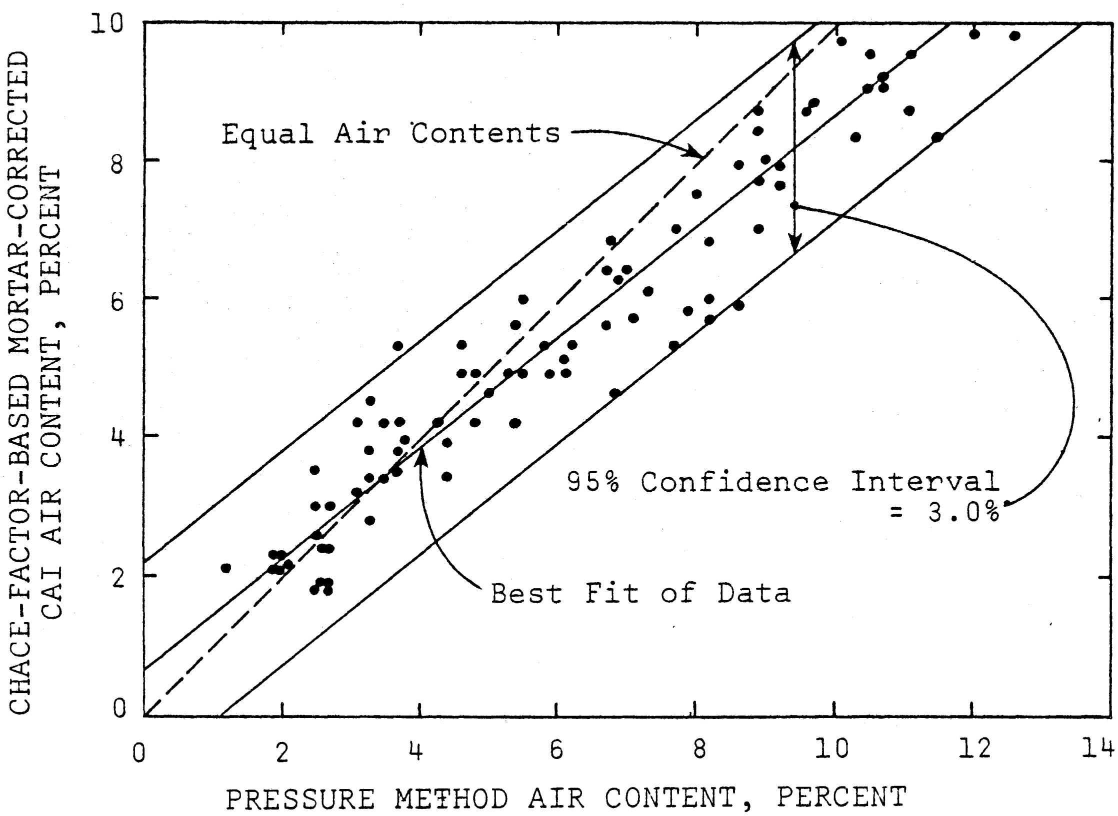

Figure 7. Relationship between air content as determined by the pressure method and the Chace-factor-based mortar-corrected CAI.

CURVE CORRECTION

The dashed line in Figure 7 is the line of equality, and it can be seen that even after the Chace-factor-based mortar correction factors are applied, the CAI reads slightly high at low air contents and low at high air contents. Reasons for the CAI readings being lower than those for the pressure method include the following.

1. The surface loss of air is potentially 12 times greater for the CAI than for the pressure method, because the surface/volume ratio is 12 times greater.

2. The surface loss of air is also potentially 1.5 to 1.8 times greater for the CAI than for the pressure method, because the sample consists of mortar rather than concrete.

3a. With unscreened samples, the large sand particles may not be removed; and

b. with screened samples (#10 sieve), the screening process may drive off some air.

Reasons for the CAI readings being higher than those for the pressure method include the following.

1. Alcohol is accidentally lost during the test (the loss should be negligible).

2. A liquid contraction occurs when the 70% isopropyl alcohol is mixed with the water in the mortar. The theoretical contraction is 0.70% to 1.05% for water-cement ratios of 0.36 to 0.62, and the observed contraction is less than 1%.

The application of another correction, designated "curve correction" here, improves the agreement between the air contents as determined by the CAI and the pressure method.

Figure 8 shows the average curve correction that must be applied to a Chace-factor-based mortar-corrected CAI reading to obtain agreement with the air content as determined by the pressure method. It's interesting to note in Figure 8 that after application of the Chace-factor-based mortar correction, the average correction (O VHTRC) agrees closely with those based on the manufacturer's recommended mortar corrections and reported by the Research Council (■ VCHIR), the Federal Highway Administration (▲ BPR), and the U. S. Army Corps of Engineers (■ WES) in studies made 18 years ago.[8]

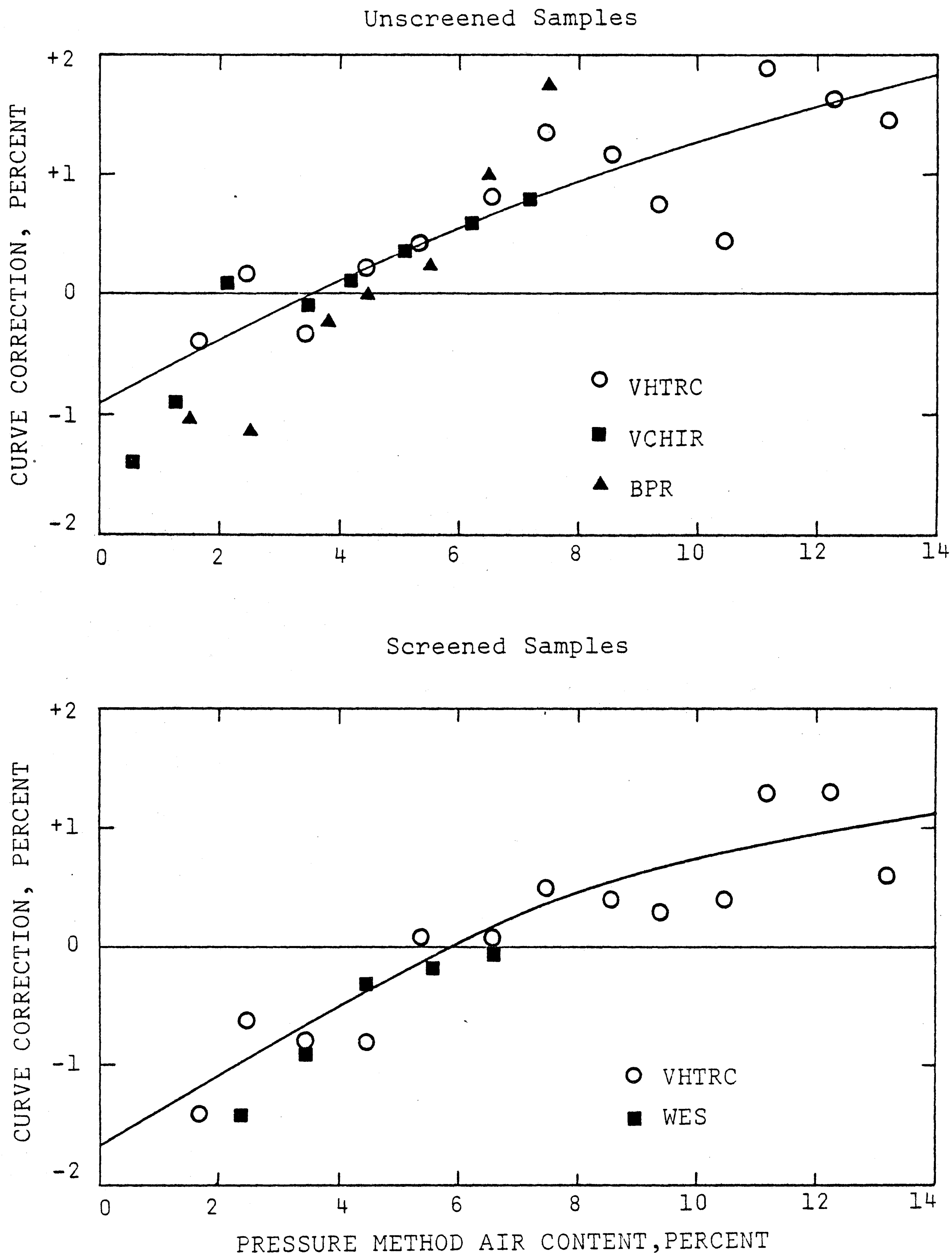

Figure 8. Curve corrections to be applied to the mortar-corrected CAI air contents.

The average curve correction appears to be somewhat different for unscreened as compared to screened samples. One can see that in the studies made 18 years ago air contents above 7% were not considered and most of the data taken at that time were for air contents of 3% to 5%. Also, in the studies made 18 years ago no corrections were applied to take care of differences in dimensions between CAI's. Perhaps at that time there were no differences and the CAI's were the correct size for the mortar correction factors supplied by the manufacturer. Over the years the specified air contents have gradually increased, but no evaluations have been made to determine the accuracy of the CAI when used to measure high air contents. Also, it would seem that over the years the dimensions of the CAI's have changed, with the inside diameters of the stems typically getting larger, which causes them to read low, but the manufacturers have continued to supply the same mortar correction factors appropriate for the dimensions of the indicators 18 years ago.

Figure 9 shows the relationship between the Chace-factor-based mortar-corrected CAI air content and that for the pressure method. The data points are the same as those in Figure 7, but the regression lines differ slightly, because the data for the CAI are the independent variable, whereas in Figure 7 they were the dependent variable. When using the CAI to estimate the air content of fresh concrete, this air content reading should be considered the independent variable. The equation for the line representing the best fit of the data in Figure 9 is

$$PM = (SR)(CF)(MC)(1.164)/27 - 0.308,$$

where PM = air content in percent by pressure method;

SR = stem reading;

CF = Chace factor; and

MC = mortar content in ft.^{3}/yd.^{3}

A similar equation for the line representing the best fit of the data for screened samples is

$$PM = (SR)(CF)(MC)(1.138)/27 - 0.869.$$

To take into account the fact that the CAI reads low at high air contents, the Chace-factor-based mortar-corrected values can be adjusted as shown in Table 4. The adjustments (curve corrections) are based on the equation for the line that best fits the data in Figure 9. For example, if the Chace-factor-based mortar-corrected air content of an unscreened sample is 8%, the curve correction is 1% and the actual air content is 9%.

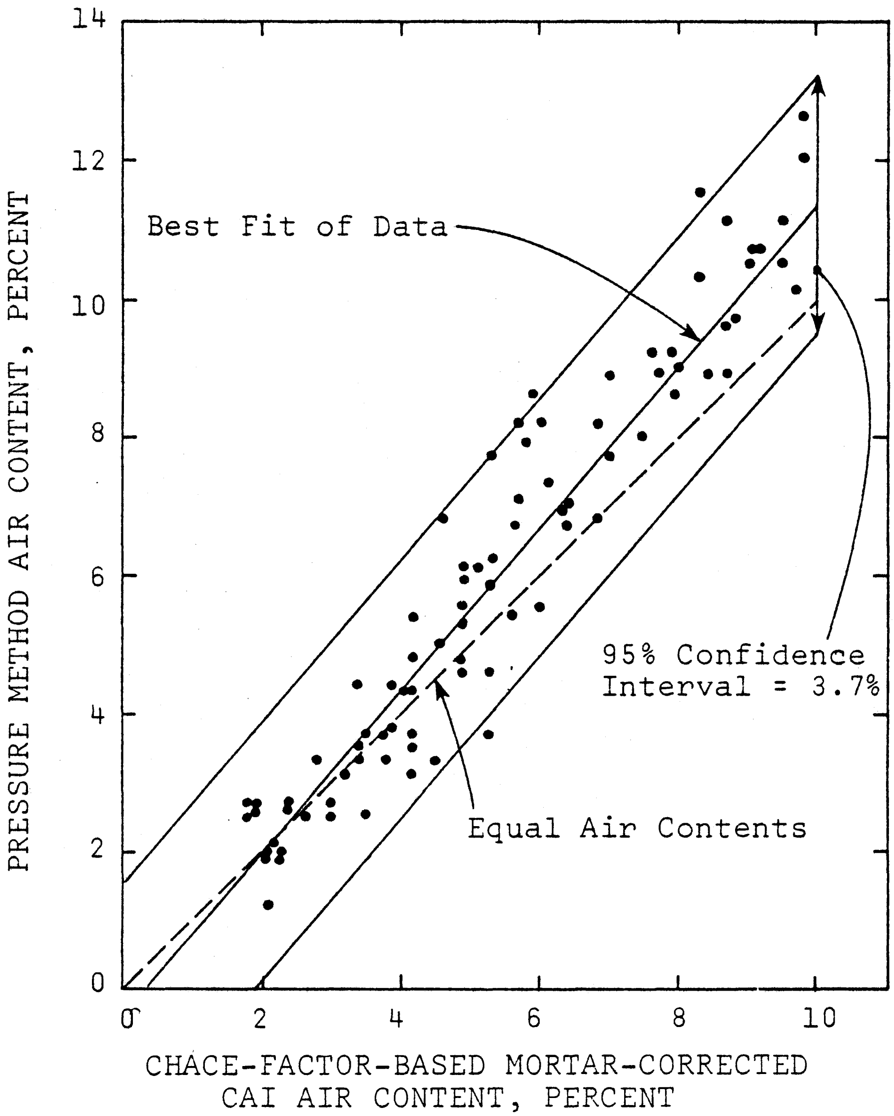

Figure 9. Relationship between air contents as determined by the Chace-factor-based mortar-corrected CAI and the pressure method.

Table 4

Relationship Between Chace-Factor-Based Mortar-Corrected and Actual Air Content Based on Curve Corrections obtained from Figure 9.

Chace-Factor-Based Mortar-corrected Air, %	Actual Air, %
1.0	0.9
2.0	2.0
3.0	3.2
3.5	3.8
4.0	4.3
4.5	4.9
5.0	5.5
5.5	6.1
6.0	6.7
6.5	7.4
7.0	7.8
7.5	8.4
8.0	9.0
8.5	9.6
9.0	10.2
9.5	10.8
10.0	11.3
11.0	12.5
12.0	13.7
13.0	14.8

As can be seen in Figure 10, once the Chace-factor-based mortar corrections and the curve corrections are applied, the air content as determined by the CAI agrees with that determined by the pressure method. Because of the inherent variability of concrete and the small size of the sample used with the CAI, for one operator the standard deviation for the average air content for two unscreened samples as compared to the air content as determined by the pressure method is 0.97%. The standard deviation for two screened samples is 1.08%, which is 11% greater than for unscreened samples. Therefore, screening should be avoided if the samples can be obtained without it. Because it is difficult to obtain a mortar sample from some high-range, water-reduced concretes and some low-slump concretes, it may be necessary to screen these concretes. A generally accepted standard deviation for a pressure test is 0.6%; therefore, the average CAI air content of 5 unscreened samples provides a confidence level equal to that provided by one pressure test. AASHTO Specification T199-72 states that the average of three CAI air content determinations can provide a reasonable indication of the entrained air content of a sample of concrete.(3)

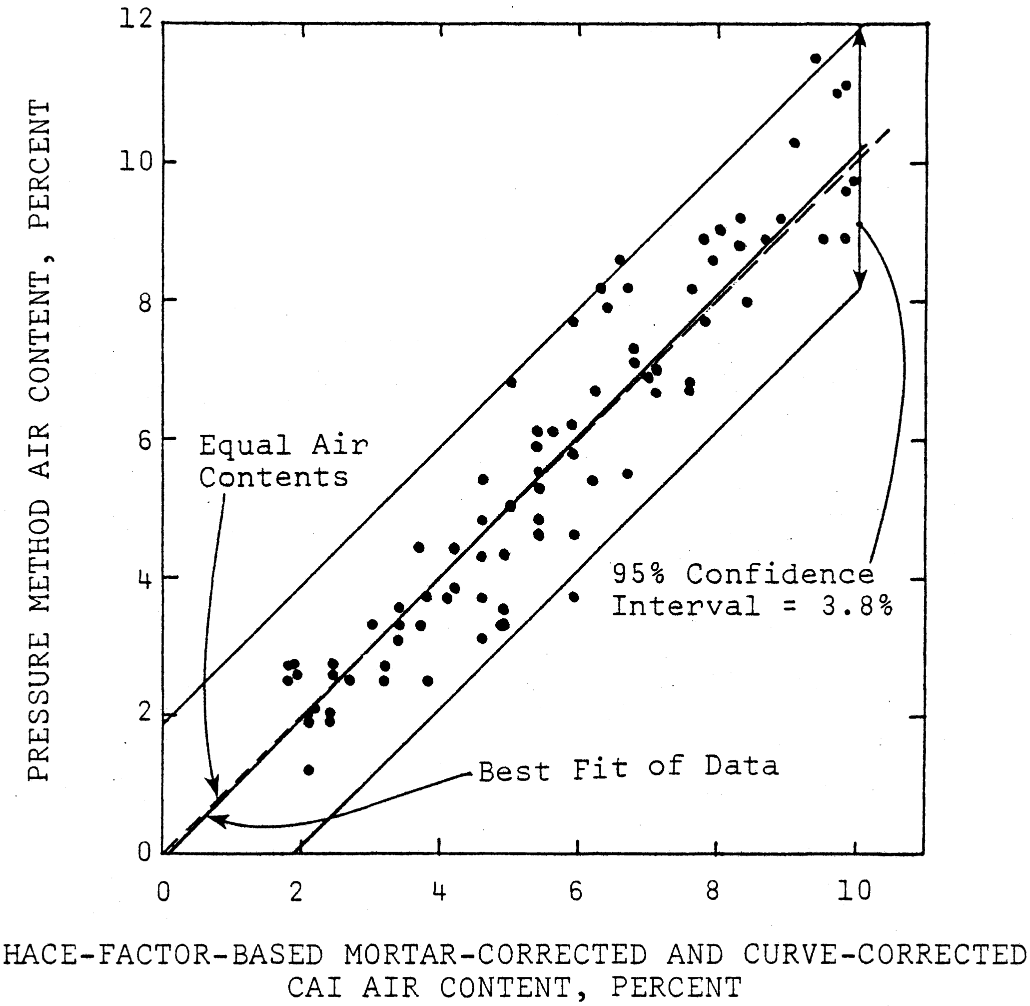

Figure 10. Relationship between air content as determined by the Chace-factor-based mortar-corrected and curve-corrected CAI and the pressure method.

IMPLEMENTATION OF RESULTS

The Department is determining the appropriate Chace factors for the CAI's on hand and furnishing field personnel with CAI's inscribed with the proper factors.(5) Field personnel have also been supplied with the Chace conversion nomograph shown in Figure 11.(9) This nomograph takes into account the relationships between the Chace factor, the mortar content of the concrete, and the curve corrections based on the data in Figure 9. The nomograph allows the operator to determine the air content without multiplying the stem reading by the Chace-factor-based mortar correction and without adding the curve correction. As an example of how to use the nomograph, assume that the indicator has a Chace factor of 2.3, the concrete has a mortar content of 15 $ft.^3/yd.^3$, and the stem reading is 6.0; then, the actual air content would be 8.6% (see Figure 11). When one uses the mortar correction factors supplied by the manufacturer, which are equivalent to a Chace factor of 1.8, the stem may be read directly; the mortar content is 15; therefore, you would get a value 6.0 for the air content, which is 2.6% less than the actual air content and represents an error of 30%.

The policy being implemented by the Department is as follows:

1. Test results for the acceptance of concrete will be based on stem readings that have been corrected with the Chace conversion nomograph (see Figure 11).

2. Test results for the acceptance of concrete will be based on the average air content of two samples, and if the results differ by more than 2% 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 test with the pressure method confirms that the concrete is unacceptable.

4. The pressure method will be used to determine if concrete to be placed in bridge decks meets Department specifications.

This policy allows the Department to continue to use the CAI and thereby minimize the workload on the inspector, and at the same time to have an acceptable level of assurance regarding the air content of the concrete. The policy is an economical one in that it allows old CAI's to remain in service once the Chace factors are determined rather than requiring the very costly statewide replacement of indicators.

2773

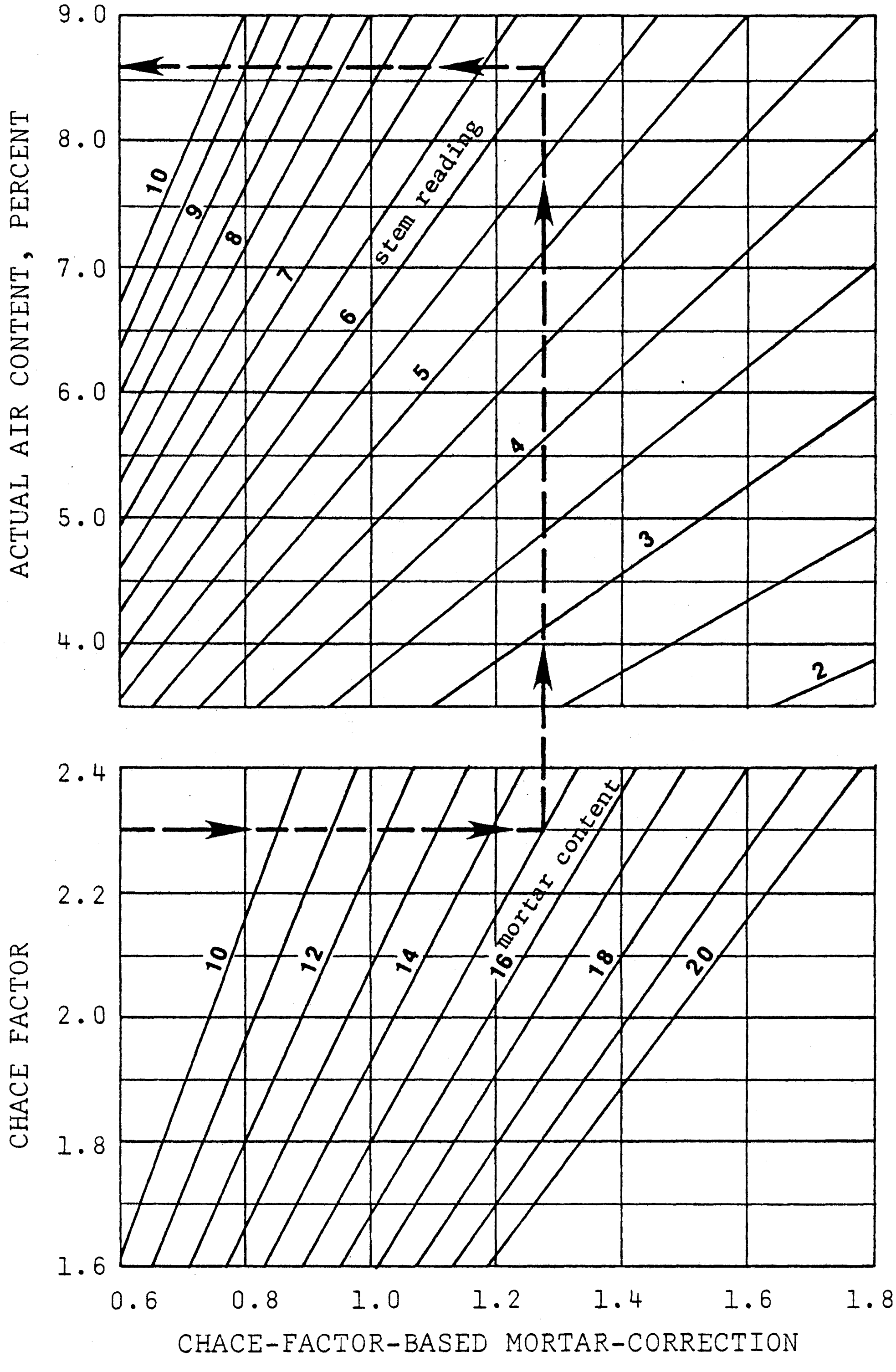

Figure 11. Chace conversion nomograph.

The Chace factor for a CAI can be determined in a few minutes with an insulin syringe by noting the quantity of alcohol injected into 10 graduations on the stem. Although the volume of the metal cup should not be overlooked, the cups have typically been found to be reasonably uniform in size. The stems tend to vary in size because they consist of drawn glass tubing that is difficult to control in the manufacturing process.

Rather than determine Chace factors and provide a Chace conversion nomograph, manufacturers may prefer to standardize the CAI, in which case a new standard should be developed to replace AASHTO specification T199-72. The new standard should require that the volume of one graduation on the stem be equal to 1.8% ± 0.1% of the volume of the bowl. With this requirement, the mortar correction factors in the current specification could be salvaged but curve corrections should be added to account for the fact that the Chace reads low at high air contents. The manufacturers could meet the proposed tolerance requirements in several ways, including adjusting the volume of the bowl or adjusting the distance between the graduation marks on the stem for each CAI. But it is believed that this would be more costly than manufacturing them under a large tolerance, inscribing them with a Chace factor, and providing the user with a Chace conversion nomograph.

CONCLUSIONS

1. The CAI can be used to provide a reasonably accurate indication of the air content of fresh concrete, when results are based on the average of tests of a minimum of two samples and the results are corrected using a Chace conversion nomograph that takes into account the Chace factor, the mortar content of the concrete, and the tendency of the CAI to read low at high air contents.

2. A test result based on the average Chace-factor-based mortar-corrected and curve-corrected CAI air contents of five samples typically provides the same confidence as is provided by one pressure test.

RECOMMENDATIONS

1. Each CAI should be inscribed with a Chace factor, which is defined as the volume of one graduation on the stem as a percentage of the volume of the bowl.

2. CAI test results should be based on stem readings that have been corrected using a Chace conversion nomograph, which takes into account the Chace factor, the mortar content of the concrete, and the curve correction.

3. CAI test results expected to provide a reasonably accurate indication of the air content of concrete should be based on the average air content of two samples. CAI test results expected to provide the same confidence as results of the pressure test should be based on the average air content of five samples.

4. CAI's should not be used to determine the air content of concretes that do not lend themselves to the extraction of a representative sample of mortar.

5. AASHTO Specification T199-72 should be modified to incorporate recommendations 1 through 4 above.

2777

REFERENCES

1. "Air Content of Freshly Mixed Concrete by the Pressure Method", ASTM Designation C231-75, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1975.

2. "Air Content of Freshly Mixed Concrete by the Pressure Method", AASHTO Designation T152-76, American Association of State Highway and Transportation Officials, Washington, D. C., 1976.

3. "Standard Method of Test for Air Content of Freshly Mixed Concrete by the Chace Indicator", AASHTO Designation T199-72, American Association of State Highway and Transportation Officials, Washington, D. C., 1976.

4. Lee, Bryan, "The Chace Air Indicator for Air Content in Concrete", A Thesis in Humanities 402; April 4, 1980; University of Virginia, Charlottesville, Virginia.

5. Galloway, J. E., Jr., Assistant State Materials Engineer, Memorandum to F. L. Burroughs, State Construction Engineer, Virginia Department of Highways and Transportation, May 23, 1980, File: 29.45.

6. Neville, S. M., Properties of Concrete, Sir Isaac Pitman and Sons, Ltd., Great Britain, 1963, p. 172.

7. Road and Bridge Specifications, Virginia Department of Highways and Transportation, Richmond, Virginia, January 1, 1978, p. 145.

8. Newlon, Howard H., Jr., "A Field Investigation of the AE-55 Air Indicator", VCHIR Report #35, October 1962.

9. Blackburn, T. R., "Chace Air Indicator", Memorandum to District Materials Engineers, Virginia Department of Highways and Transportation, Staunton, Virginia, December 5, 1980.

2778