

Commonwealth of Kentucky
Department of Highways

Highway Materials Research Laboratory
132 Graham Avenue, Lexington 29, Ky.

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To: Dean D. V. Terrell
Director of Research

In our report entitled "A Summary of Experiments With Air Entrainment in Cement Concrete" released last September, we recommended among other things that "The gravimetric method (A.S.T.M. Designation: C138-44) be used only as a temporary expedient for determining air contents until the pressure method or some method not dependent upon physical properties of aggregates and not influenced by other variables can be firmly established" (see item 3, page 66 of that report). At that time we were thinking of the pressure apparatus demonstrated by representatives of the Portland Cement Association during construction of the Lexington-Nicholasville Road (Project F 524 (1)-1; S.P. 34-124). Results from the few pressure tests made on that job and listed in Table VI of our report were in such close accord with those determined simultaneously by the gravimetric method, that we purchased an air meter for the purpose of conducting more comparative tests in the laboratory.

Results of seventeen comparative tests on mixes with different aggregates, cements, cement factors, and designed air contents are summarized in Table I attached to this memorandum. Also attached are some suggested changes in our 1945 Standard Specifications; changes which are in line with the recommendations which we made last September and which we are prepared to supplement on the basis of these tests with the air meter. One proposed addition to the Specifications, dealing with HP-7 as an admixture, has not been formulated because we did not have sufficient time to establish specific requirements on a product not included heretofore in other specifications. In our suggested version of Article 4.1.8 we made reference to an Article 7.42.3 intended to cover the HP-7, and information for such an article could be worked up possibly within a week's time if the Research Board so desires. Also, nothing has been suggested for the text of a Supplement to the Field Testing Manual which is referred to in every article. This supplement or an equivalent would be necessary in order to define the equipment and procedure for the test.

With regard to the tabulated data from our pressure tests, you will note that the tests were made at four different pressures, and the average result for the four determinations was compared with the air content determined by the gravimetric method (A.S.T.M. Designation: C138-46). In three of

the seventeen cases the variation was between 0.4 and 0.9 percent air and in five cases the variation was 0.1 percent air or less. It is hardly practicable to expect accuracy within 0.1 percent air content because neither method could be proven consistently accurate to that degree. On the other hand, the two methods should agree to within less than 0.4 percent if both are valid means for determining air contents.

We have no way of accounting for the inconsistencies in results for mixes designated as III A (-0.9 percent variation), III E (+0.6 percent variation), and IV B (+0.8 percent variation) except as experimental errors committed because of limited experience with the equipment and more especially because of insufficient time allotted to the work. All tests in Groups I and II were made on mixes prepared for our research with combined aggregates (Project C-23) where the pouring of beams and cylinders was of primary concern and pressure tests were incidental, but those tests in Groups III and IV were made on mixes prepared just for this purpose and then discarded.

All three sets of determinations that varied more than 0.4 percent were within the two latter groups. In two of these cases (marked by asterisks in the table) we have chosen the air content which has the greater probability of being correct because the mixes were designed for those air contents; and cement factors, water-cement ratios, and other actual properties of the mixes as they were turned out check closely with those established for the design. It is significant that in one case probability favors results from gravimetric calculations, but in the other it favors the pressure determinations.

One of the most outstanding features of the data was the invariable way in which the pressure-determined air contents increased with increasing pressure. Always, the indicated air content was higher when the pressure was 30.5 pounds per square inch than it was with 8 pounds per square inch, and always it increased or remained the same with each increment of increase in pressure. In the majority of cases the agreement between gravimetric and pressure air contents was better when the pressure was 8 pounds per square inch than when any other pressure was used; yet, there were a few cases when the lowest pressure caused deviations from gravimetric values that were greater than the average.

Other prominent trends in the results as related to different variables were:

1. Effect of cement content. High, medium and low cement contents were investigated in two of the groups and high and medium contents in another group. These variations in cement factor (between 1.25 and 1.76) had no apparent effect on the accuracy of the method, for the agreement in all cases except one was as good or better than average. In that one case the difference was great (+0.60), but probability favored the pressure method for reasons mentioned before.

2. Effect of amount of air entrained. Intentional variations in the amount of air were made in order to test the efficacy of the procedure for all reasonable air contents. Most of the large discrepancies, as shown in Fig. 1, occurred when the air contents were less than 4 percent. In fact, no difference greater than 0.35 percent occurred when the air content was greater than 4 percent as calculated by the gravimetric method. Two of the greatest differences occurred when the air contents were between 3 and 4 percent, and probability favored gravimetric in one case and pressure in the other.

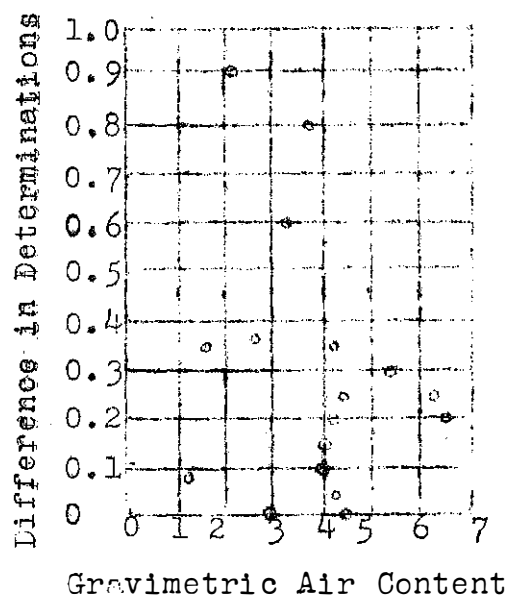


Fig. 1 Relationship Between Gravimetric Air Content and Difference in Determinations By Gravimetric and Pressure Methods.

The greatest disagreement resulted at 2.1 percent air entrained, and then the pressure method indicated a still lower air content.

3. Effect of type of cement. Four different cements, as indicated in the notes at the bottom of Table I, were used in the tests, but only one test each was made with the air entraining portland (agent interground) and the natural in a blend with portland. One other, the Lehigh portland definitely was air entraining even though it was not labeled as such. In the majority of cases air entrainment was accomplished by introducing a Vinsol resin-sodium hydroxide-water solution.

The one test with cement marketed as air-entraining portland (Test IV B) was poor, for the variation was +0.80 with a gravimetric air content of 3.6 percent, and probability favored that value. On the other hand, results from tests with the portland not labeled as air entraining (and with no additive

introduced in solution) were quite consistent, the values being as follows :

<u>Test</u>	<u>Gravimetric Air Content</u>	<u>Variation</u>
I B	4.1	- 0.20
II B	4.0	+ 0.15
II D	4.4	+ 0.25
II E	4.0	- 0.10
III C	6.5	+ 0.20

Results in the one test with the blended cement were fair (+0.37 percent variation at an air content of 2.7); those with the portland with no interground agent or additive were extremely changeable ranging from +0.09 at an air content of 1.1 percent to -0.9 at an air content of 2.1 percent; and when the Vinsol resin solution was used variations were from -0.3 to +0.24 with a corresponding range of gravimetric air contents from 4.2 to 6.2 percent.

4. Effect of coarse aggregate. All the large variations occurred in tests with limestone coarse aggregates. Among the eight tests with limestone (all from one source), the air contents ran from 2.1 percent to 6.5 percent, and the variations ranged from -0.9 to +0.8 with one being a case of exact agreement. Agreement was good to excellent with glacial gravel (maximum variation -0.3 for air contents from 1.7 to 5.5 percent) and Ohio River gravel (maximum variation +0.25 for air contents from 1.1 to 6.2 percent), and in the one test with combined limestone and glacial gravel there was no disagreement. It should be noted at this stage that all mixes with limestone were in the Groups III and IV which, as stated before, were the groups in which accuracy was probably impaired by the conditions under which the tests were made.

5. Direction of variation. In about half the cases, (9 of the 17) determinations by the pressure method were higher than those calculated by the gravimetric method; in six instances the results with pressure were lower; and twice the air contents by both methods were in agreement.

Actually, among all the results listed in Table I and discussed in preceding pages, there were but a few serious differences between air contents determined by the two methods, and these were confined principally to the amounts of air near or below the lower limit which were proposed in our report last September. Probably, as a matter of opinion which cannot be proved or disproved in fact, the air meter over a long series of tests would have a better record of accuracy than the gravimetric method. Variations in aggregates, free water and absorbed water, batching, and other influencing factors can easily affect the gravimetric calculations whereas they hardly

enter into pressure determinations. Also, the possibilities of introducing errors by mishandling of the concrete are slight in the pressure method as compared with the gravimetric.

In view of all these conditions and the data which have been compiled, the Research Laboratory recommends that the pressure method be adopted tentatively as a means for checking and controlling air entrained concrete on construction projects, and that specifications similar to those outlined in the attached suggested amendment be enacted. For the test a low pressure of 8 or 10 pounds is recommended since the accuracy seems to be better in that range. So far as it is practicable, both the pressure and gravimetric methods should be run during the construction of any pavements that may be in the program for the coming year, in order that more data may be compiled as a basis for further altering specifications or methods at a later date if conditions warrant it.

With regard to the equipment for this test, our air meter, costing \$138.50, was ordered from George J. Heck, Machinist, 562 Minnesota Street, St. Paul, Minnesota. Delivery on this as an emergency purchase was made within approximately three weeks time.

Respectfully submitted,


L. E. Gregg

LG:mr

cc: Research Board Members:

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AIR CONTENT DETERMINATIONS				
Mix No.	Course	Test Method		Average Percent Variation Pressure vs. Gravimetric
		20 lb.	30.5 lb.	
I A	No. 6 G	-	5.20	- 0.3
I B		-	3.90	- 0.2
I C		1.00	1.50	- 0.35
II A	No. 6 F	1.25	1.30	+ 0.09
II B		4.20	4.30	+ 0.15
II C		6.30	6.35	+ 0.24
II D		4.65	4.75	+ 0.25
II E		3.95	3.95	- 0.10
III A	No. 6 C	1.05	1.15	- 0.5
III B		3.05	3.05	0
III C		-	-	+ 0.2
III D		3.85	4.25	- 0.35
III E		3.75	3.90	+ 0.60 *
IV A	No. 6 E	1.25	4.30	+ 0.04
IV B	No. 3 F	1.70	4.70	+ 0.80
IV C	No. 6 D	3.15	3.15	+ 0.37
IV D	No. 6 B No. 3 I	4.60	4.60	0

Notes: Concrete

* Probably coarse

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

Suggested

AMENDMENT NO. _____
TO
1945 STANDARD SPECIFICATIONS

This Amendment No. _____ revises the stipulations for air-entrained concrete, air-entraining cements, and air-entraining admixtures in Articles 4.1.6, 4.1.7, 4.1.8, 7.1.4, 7.1.5, and 7.42.2 of the Department's 1945 Standard Specifications for State and Federal Road and Bridge Construction, and specifies a new method for determining the amount of air entrained in the concrete. Unless otherwise indicated the amended version of each article replaces the previous version in its entirety.

ARTICLE 4.1.6, TREATED PORTLAND CEMENT CONCRETE.

Concrete made with treated portland cement meeting the requirements of Article 7.1.4 shall have a net air content of not less than three (3) percent nor more than six (6) percent of the volume of the mix, as measured by the pressure method described in Supplement No. _____ to the Department of Highways Field Testing Manual. The desired consistency and specified cement content of 1.5 barrels per cubic yard of concrete shall be maintained by adjusting the quantities of coarse and fine aggregates and water used in the mix.

ARTICLE 4.1.7, BLENDED CEMENT CONCRETE.

Blended cement concrete shall be made with a combination of portland cement meeting the requirements of Article 7.1.2 and natural cement meeting the requirements of Article 7.1.5 in the proportion of five (5) bags of portland cement to one (1) bag of natural cement weighing 94 pounds. This concrete shall have a net air content of not less than three (3) percent nor more than six (6) percent of the volume of the mix as measured by the pressure method described in Supplement No. _____ to the Department of Highways Field Testing Manual. The desired consistency and specified cement content of 1.5 barrels per cubic yard of concrete shall be maintained by adjusting the quantities of coarse and fine aggregates and water used in the mix.

measured by the pressure method described in Supplement No. _____ to the Department of Highways Field Testing Manual. The other ingredients and proportions of all ingredients used in preparing the mix shall be those tentatively set for the project in which the cement is to be used.

ARTICLE 7.1.5, NATURAL CEMENT.

Natural cement shall conform to the requirements of A.S.T.M. Designation: C10-37, with the following additions:

- (a) The composition of the natural cement shall be such that when blended with portland cement meeting the requirements of Article 7.1.2 in the ratio of 5 parts portland cement to 1 part natural cement by weight, the resultant concrete prepared with this combined cement and made in accordance with A.S.T.M. Designation: C192-44T shall have a net air content of not less than three (3) nor more than six (6) percent of the volume of the concrete mix as measured by the pressure method described in Supplement No. _____ to the Department of Highways Field Testing Manual. The other ingredients and proportions of all ingredients used in preparing the mix shall be those tentatively set for the project in which the cement is to be used.
- (b) When cement is delivered in packages, the name and brand of the manufacturer shall be plainly marked thereon. Similar information shall be provided in the shipping advices accompanying the shipment of packaged or bulk cement. A bag shall contain 94 pounds net. A barrel shall contain 376 pounds net. All packages shall be in good condition at the time of inspection.

ARTICLE 7.42.2, VINSOL RESIN SOLUTION.

Delete the paragraphs on page 675 and page 676 of the 1945 Standard Specifications and substitute:

The Vinsol resin solution for the purposes of entraining air in concrete as specified in Article 4.1.8, shall consist of a solution of Vinsol resin, sodium hydroxide, and water, prepared in the presence of the Engineer and introduced into the mix in the amounts which the Engineer shall establish. Preparation and proportioning of the Vinsol resin solution shall be in accordance with the following table, and the solution shall be added to the mix at the rate of one (1) quart per batch unless otherwise directed by the Engineer.