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16. Abstract
The two main test methods that measure the air content in plastic concrete are the pressure method and the volumetric or roll-a-meter method. Although these methods report the total air in the concrete, they do not distinguish between entrained air and entrapped air or the quality of the air void system. The quality of the air void system consists of the content, distribution, and size of the air bubbles in the concrete matrix. In order to analyze the quality of the air void system, a petrographic analysis is required on the hardened concrete. The downside of this procedure is that it requires analysis of hardened concrete under a microscope which is time consuming, expensive, and results are determined well after placement of the concrete. The air void analyzer (AVA) is a new device developed as an alternative to the petrographic method that promises to provide air void system properties in a more timely matter while the concrete is still in the plastic stage.

The intent of this research was to first, evaluate the air void analyzer and compare results with the petrographic method to verify its results. Secondly, it was to correlate the use of various types of water reducing admixtures (WRA) with various types of air entraining admixtures (AEA) into a generalized declaration that would state which WRA and AEA is good at developing a quality air void system in concrete. In the initial course of this investigation, the AVA demonstrated it was incapable of reliably reproducing results from the same batch of concrete about 60 percent of the time. It was decided to end this study. This report presents the study findings.

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Air Void Analyzer for Plastic Concrete

by
John Eggers, P.E.

Louisiana Transportation Research Center
4101 Gourrier Ave.
Baton Rouge, LA 70808

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ABSTRACT

The two main test methods that measure the air content in plastic concrete are the pressure method and the volumetric or roll-a-meter method. Although these methods report the total air in the concrete, they do not distinguish between entrained air and entrapped air or the quality of the air void system. The quality of the air void system consists of the content, distribution, and size of the air bubbles in the concrete matrix. In order to analyze the quality of the air void system, a petrographic analysis is required on the hardened concrete. The downside of this procedure is that it requires analysis of hardened concrete under a microscope which is time consuming, expensive, and results are determined well after placement of the concrete.

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In the initial course of this investigation, the AVA demonstrated it was incapable of reliably reproducing results from the same batch of concrete about 60 percent of the time. It was decided to end this study. This report presents the study findings.

IMPLEMENTATION STATEMENT

Protection for concrete pavements and structures that experience numerous freeze-thaw cycles in their life is a necessity. The protection against freeze-thaw deterioration is provided by a well defined air void system in the concrete. Due to Louisiana's geographical location and its mild climate, a well defined air void system necessary for freeze-thaw protection is not as critical as those required in colder climates. It was never the intent of this research to prescribe specifications for quality control or quality assurance with regard to the air void analyzer. The anticipated results were to be generalized recommendations pertaining to the use of certain types of AEA and WRA and their effect on the air void system of concrete used for LADOTD structures. This knowledge would have been of value to LADOTD as an additional bonus to the quality of concrete used in the state. This is especially true concerning bridge decks which are the most susceptible, though sporadic, to the freeze-thaw cycle.

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INTRODUCTION

The best protection against freeze-thaw cycles in concrete is to have a good air void system. Although microscopic, concrete is a porous material. This porosity varies depending on the mix design and the materials used in that mix design. To some extent, moisture is virtually always present in concrete. When the surrounding temperatures fall below freezing the free water within the concrete also freezes and expands creating pressure. This pressure forces the water to follow the path of least resistance, which is optimally the nearest air void. When this water migrates to an air void or bubble, there is then sufficient space for the water to expand, thus the pressure is relieved. If an air void is not close enough, the pressure exerted by the expanding water may lead to micro-cracking and future accelerated deterioration after repeated cycles of freezing. For this freeze-thaw protection mechanism to efficiently work, it is paramount to not only have a sufficient volume of air voids in the concrete but also to have proper distribution. Hence, numerically more and smaller closely spaced air voids, shorter travel paths, provide superior freeze-thaw protection compared to fewer, larger and more distant air voids.

Conventional field tests, such as the volumetric or pressure tests, only provide the volume of air voids in the concrete. These tests do not offer any information on the size or spacing of the air voids. Petrographic analysis does provide this missing information but only on hardened concrete well after placement. The development of the AVA offers to provide volume and size distribution of entrained air voids (< 3 mm) to allow an estimation of the spacing factor and to give the specific surface and the total amount of entrained air all within 30 min. of sampling the fresh and still plastic concrete. This development provides opportunity for changes in the mix while placement operations are still ongoing.

Several cold-climate states have implemented the AVA into their specifications mainly for portland cement concrete pavements (PCCP). These states all have a great need for a proper air void system due to their seasonal climate and past history of freeze-thaw deterioration in their PCCP. Climatic conditions in Louisiana do not pose the devastating freeze-thaw effects experienced by these states. This research was intended to verify the AVA results with petrographic analysis and then attempt to establish a generalized relationship between AEA types and WRA types and the air void system.

OBJECTIVE

The objectives of this research were two fold. First was to statistically validate the AVA results with petrographic analysis as per ASTM C 457 (Standard Test Method for Determination of the Parameters of the Air-Void System in Hardened Concrete). With this validation, the second objective was to evaluate the effects of different types AEA and WRA and optimistically draw some general conclusions on their use in concrete mixes for LADOTD. If successful and some generalized conclusions could be drawn concerning typical mixes designed for LADOTD, the second objective was not intended to be incorporated into LADOTD specifications. The results would be for informational purposes or more precisely as an assessment of typical concrete mix designs used in Louisiana.

SCOPE

For the first objective, to compare the AVA results with petrographic analysis, the initial strategy was to produce several trial batches of two types of concrete used for LADOTD projects. A Type B PCCP mixture and a Class AA structural mixture used for bridge decks were selected. These mixes were to serve as a baseline from which other changes and adjustments will be made. Statistical criteria for this analysis was to allow a deviation of 10 percent between the AVA results and the results established by linear traverse measurement on harden concrete as per ASTM C 457.

After successful completion of the first objective, the second objective was to use these two mix types, PCCP and structural, to establish an “what could be expected” impression of the air void system with varying types and amounts of AEA and WRA that are commonly used in these two mix types. This analysis would be based on the results from the AVA. Statistical analysis from these results would indicate the scale and confidence of “what we could expect.”

Due to problems in the initial effort to validate the AVA, the first objective’s scope was expanded in an attempt to rectify the problems experienced with the AVA. Elaboration and details on these problems is clarified in the discussion chapter of this report.

METHODOLOGY

A literature review was conducted prior to beginning the first objective. As previously noted, several states have evaluated and implemented the AVA into their Department of Transportation (DOT), specifically PCCP specifications. American Association of State Highway and Transportation Officials (AASHTO) has also initiated a Technology Implementation Group on the AVA in 2003.

For the first objective of the research, ten separate batches were proposed; five batches of the most common LADOTD (Type B) PCCP mixture design and five of the LADOTD (Class AA) structural mixture design as used for bridge decks. The (Type B) PCCP mixture design utilized 475 lb. of Type I portland cement, a maximum water-to-cement ratio (w/c) of 0.53, a moderately restrictive aggregate gradation, a total air content of 5 percent (+/- 2 percent), and a slump requirement of 1 to 2.5 in. as specified for slip-form paving. The (Class AA) structural mix design utilized 560 lb. of Type I portland cement, a maximum w/c ratio of 0.44, traditional aggregate gradation, total air content of 5 percent (+/- 2 percent), and a slump requirement of 2 to 4 in. which is allowed up to 8 in., if appropriate for the application, with the use of high range water reducers (HRWR). For this first objective, the AEA and WRA used in these mixes were kept constant in brand and type. Standard lab mixing procedures (ASTM C 192) were used for all batches produced.

Standard lab testing for these mixes included: air and concrete temperature (ASTM C 1064), slump (ASTM C 143), pressure air content (ASTM C 231), volumetric air content (ASTM C 173), and unit weight (ASTM C 138). Figures 1 and 2 show the equipment used to measure the volumetric air content and pressure air content, respectively.

Figure 1
Volumetric roller meter (ASTM C 173)

Figure 2
Pressure meter (ASTM C 231)

From each of the ten batches, two samples of the plastic concrete were analyzed in the AVA and two 4 x 8 in. cylinders were made for future petrographic analysis as per ASTM C 457. The use of two samples for the AVA was deemed appropriate considering the time allocated for testing, approximately 40 min. per test, versus ongoing hydration process of the plastic concrete sample. As a measure of success for validation of the AVA, figure 3, a variability of 10 percent was set as the maximum allowance.

Figure 3
AVA

It should be noted that the second objective of this research project was never fulfilled due to the inconsistency of the AVA to provide consistent and reliable test results. See discussion of the results for a further description and narrative of the problems encountered with the AVA.

The second objective was to continue by utilizing the same to mixtures, Type B and Class AA, and examine the effects of various AEA and WRA combinations and their affect on the air void system as determined by the AVA. As in the first objective, two samples of the plastic concrete were to be used for the AVA analysis. The preliminary expectation was to use six popular AEA types and six popular WRA types. These six AEA and WRA types are commonly used in LADOTD concrete mixes. Allowable ranges for the total air content was 5 percent (+/- 2 percent) with slump allowances as per the LADOTD specifications.

The initial anticipated factorial was 20 batches for each of the two mix designs, Type B and Class AA. These 20 batches, 40 total batches, were an approximation. The actual number of batches depended solely upon the ongoing results from the AVA analysis, thus the research may have required more or less batching depending on the AVA test data as it became available. Furthermore, dependent on initial results and time consumed, concrete mixing times and possibly the effects of severe gap graded aggregates might be investigated.

DISCUSSION OF RESULTS

The first objective testing commenced as planned and immediately ran into problems. The AVA test results from the two samples, from the same batch of concrete, were not precise enough to instill confidence in either the testing procedure or the analysis provided by the AVA. In fact, no two consecutive AVA test results were completed without an error indication from the testing equipment.

Over a 22 month period, a total of 57 AVA tests were performed on 32 batches of concrete. Two sequential AVA tests, about 40 min. apart, were performed for 23 of the 32 batches produced. Of these 23 batches and 46 AVA tests performed, not one batch provided two consecutive successful AVA tests to use for comparative purposes. The vast majority of these failures was attributed to the error of "Air % content < 2 mm out of range," figure 4. Of the 32 batches of concrete produced, only two were out of range in total air content, as determined by the pressure and volumetric meter, one being low at 3.4 percent total air and the other at approximately 14 percent air content. All batches included AEA and a WRA but still the AVA test results from at least one of the tests per batch indicated that we did not have entrained air within the range of 3.5 to 10 percent. This performance was unacceptable for any testing equipment considering that one test indicated a good air void system with reasonably expected results and the subsequent or prior test failing due to "Air % content < 2 mm out of range." All AVA test data is available in the Appendix.

Operator error or machine malfunction comes to mind as a possible explanation for these errors. Other sources of error include: improper machine or sample preparation, improper sampling, or improper testing procedure. Every effort was expended to rule out operator error in all of the requirements and procedures for this test as stated in the manual. All procedures, calculations, temperatures, equipment setup, and precautions were double-checked. An inclusive check list was adhered too. The effort expended to achieve two successful tests for one batch on concrete became a challenge to the lab personnel (57 years combined experience for three technicians) only to be met with failure. Frustration and bewilderment was felt considering the reported success with the AVA that other states had experienced as described in reports from the literature reviews.

Machine malfunction was ruled uncertain since it appeared to function appropriately for one test but not the succeeding test. It is doubtful that the testing operations and procedures or the concrete being analyzed was the culprit. Opinions differed on how to deal with the inconsistency of the AVA results. One opinion focused around the prospect of conducting a larger number of tests until two separate test results were within a predetermined percentage of each other. These two results would then be averaged and reported. This option was not acceptable for all the obvious reasons regarding statistics, sampling, research, and proper testing protocols. Consistency was absent in the AVA.

Recently research conducted by the Kansas Department of Transportation determined the allowable coefficient of variation (CV) for the AVA test results. They noted that a CV < 15 percent is deemed acceptable when looking at the spacing factor. When using these guidelines, rather than the previously mentioned 10 percent, eight of the 23 test batches are statistically valid. Although they are valid, the results for the remaining 65 percent of the batches show that the AVA may not be a good tool as of yet.

The main problem experienced during the tests was the inability of the magnetic stirrer to consistently and completely disperse the sample. When this occurred, there were portions of the sample, up to half in some cases, left intact. It was not due to the brief 30 sec. of active stirring time as automated by the computer but due to the magnetic stirrer becoming ensnared or bogged-down in the sample. This resulted in the stirring rod coming to a complete stop before the 30 sec. of stir time was complete. Incomplete sample dispersion may have been due to inadequate torque of the testing apparatus or something unique with the local fine aggregate that may have inhibited or jammed the stirring rod.

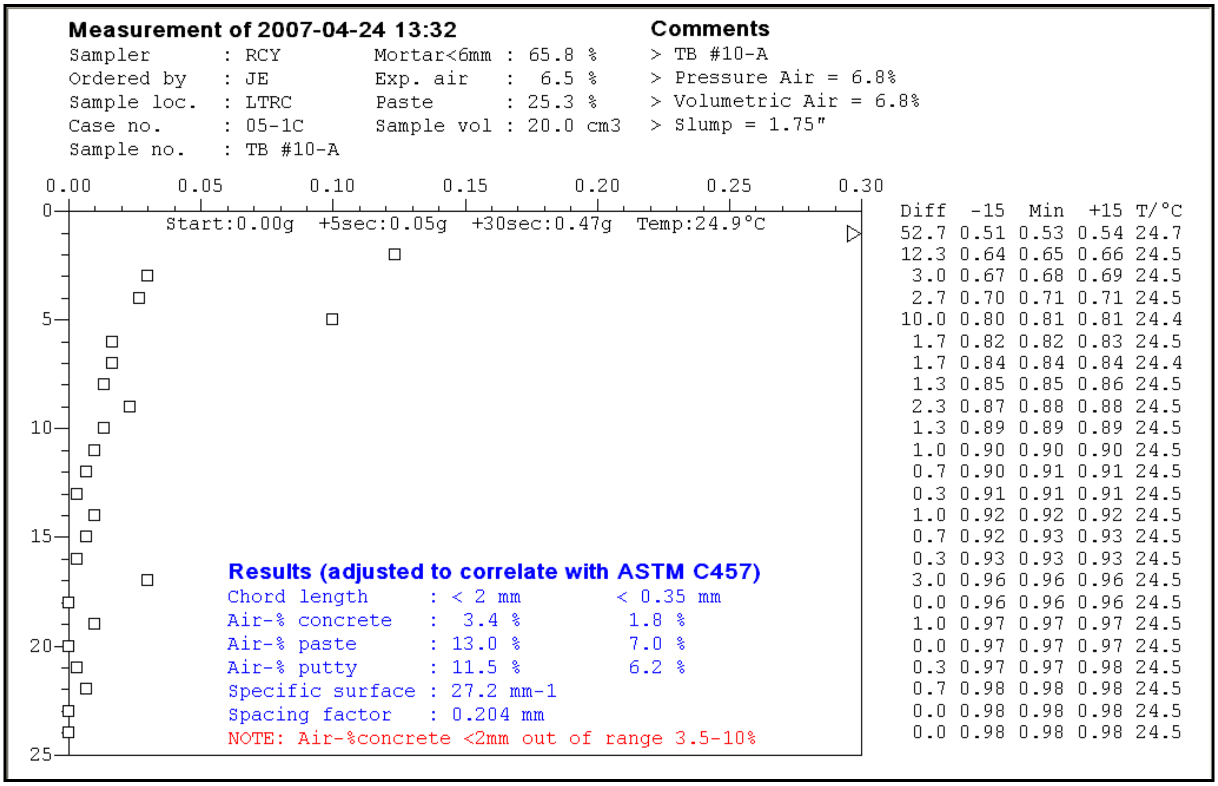

Figure 4
Typical AVA output graph with error message

Several methods were varied in attempts to overcome this problem. Initially, the mortar sample was steadily and promptly injected into the column. This was successful sometimes but more frequently caused the stirrer to ensnare and bog down due to what appeared to be the load or weight of the sample. The other method experimented with was a gradual insertion of the mortar sample into the column. This allowed the initial first half of the sample to be dispersed, but by the time the remainder of the sample was injected, the stirrer became ensnared or time ran out for proper dispersion of the complete mortar sample. These insertion techniques were tried on numerous batches not just on the single run batches as shown in the Appendix. No ideal method was determined. It should also be noted that many of the mixtures were structural mixes that have higher slumps and are more workable than the pavement mixtures which have lower slumps.

Another problem experienced, less frequently, was the AVA's internal heater would switch on and remain on too long forcing the temperature beyond the upper allowable limit thus nullifying the test. This problem was noticeable when the mortar samples were cooler than the column liquid. It is believed that the cooler mortar samples are responsible for initiating the internal heater to switch on, but why the heater continues to heat the column liquid beyond the upper limit is not known.

Although it should have negligible effect, testing procedures call for the deaerated water to be stored at approximately 20ºC (68ºF) for a minimum of 12 hrs. before use. The ambient temperature of the concrete lab averages a cool 21ºC (70º -71ºF) year round, even in summer. It should be noted that it was in this environment that the deaerated water was stored for the 12 hr. minimum. Within the limits of what can be logically called "approximately," did this storage condition contribute to the negative experienced with the AVA? This question like all the other questions broached by the research remains obscure at best and generally unanswered.

CONCLUSIONS

The difficulty experienced in this evaluation of the AVA was unanticipated and a disappointment though every effort was made to rectify the problems. The meticulousness nature of running this test alone makes it questionable for use in a field or construction environment unless essential. The desired variation in AVA test results was only achieved for 35 percent of the mixtures tested. With this result, the AVA cannot be recommended as a quality control/quality assurance (QC/QA) test at this time. These conclusions are based on the findings and insight experienced in this research project. Furthermore, they are based on the limitations and assumptions that 30 of the 32 batches of AEA and WRA enhanced concrete did provide an acceptable air void system that should have been measurable by the AVA and that the AVA testing equipment was operating properly.

RECOMMENDATIONS

Taking into consideration LADOTD's current PCCP needs, it is recommended that no action be taken with regards to implementation pertaining to the AVA. The intricate steps involved in sampling and testing using the AVA along with the questionable test results justifies this recommendation.

If future needs give reason for further investigation into the air void systems for LADOTD PCCP, it is recommended that research from those state DOTs that require a superior air void system be investigated thoroughly. It is anticipated by that time, the troubles experienced with the AVA in this project will be resolved.

APPENDIX

Mixture Properties

LTRC Lab. No.	C-2700	C-2716	C-2717
Date Made	5/12/2006	6/1/2006	6/20/2006
0754 Holcim Type I Portland Cement (lbs/yd³)	560	560	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1436	1444	1444
#67 Limestone, AB29 Martin Marietta (lbs/yd³)	1595	1609	1609
% by volume Fine Aggregate	47.9	47.9	47.9
% by volume Coarse Aggregate	52.1	52.1	52.1
Water (lbs/yd³)	245	245	266.0
Water Cement Ratio	0.438	0.438	0.474
Admixture 1	Daravair 1000	Daravair 1000	Daravair 1000
Dosage (oz/100ct)	1.00	0.75	0.50
Admixture 2	N/A	WRDA 35	WRDA 35
Dosage (oz/100ct)	N/A	3.00	4.00
ASTM C 1064 Air Temperature (°F)	70.5	70.3	70.7
ASTM C 1064 Concrete Temperature (°F)	71.8	72	72.5
ASTM C 143 Slump (inches)	3.75	2.75	2.0
ASTM C 231 Pressure Air Content (%)	6.7	6.2	5.5
ASTM C 173 Volumetric Air Content (%)	6.6	N/A	N/A
ASTM C 138 Unit Weight (lbs/ft³)	142.4	143.2	144.0

Air Void Analyzer (AVA) Test Properties

LTRC Lab. No.	**C-2700**				**C-2716**				**C-2717**			
	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.
Chord Length	< 2 mm				< 2 mm				< 2 mm			
Air - % concrete	2.0	2.1	0.1	3.4	1.1	0.9	0.1	14.1	3.3	1.7	1.1	**45.3**
Air - % paste	7.4	7.8	0.3	3.7	4.1	3.3	0.6	15.3	12.7	6.6	4.3	**44.7**
Air - % putty	6.9	7.2	0.2	3.0	4.0	3.2	0.6	15.7	11.2	6.2	3.5	**40.6**
Chord Length	< 0.35 mm				< 0.35 mm				< 0.35 mm			
Air - % concrete	0.9	1.3	0.3	**25.7**	0.5	0.7	0.1	**23.6**	1.0	1.1	0.1	6.7
Air - % paste	3.2	5.0	1.3	**31.0**	2.0	2.7	0.5	**21.1**	3.8	4.2	0.3	7.1
Air - % putty	3.0	4.6	1.1	**29.8**	1.9	2.6	0.5	**22.0**	3.4	3.9	0.4	9.7
Specific surface (mm-1)	23.0	33.9	7.7	**27.1**	16.9	39.1	15.7	**56.1**	10.9	21.2	7.3	**45.4**
Spacing factor (mm)	0.308	0.204	0.074	**28.7**	0.539	0.255	0.201	**50.6**	0.513	0.352	0.114	**26.3**
Notes	Air content out of range	Air content out of range			Air content out of range	Air content out of range			Air content out of range	Air content out of range		

Mixture Properties

LTRC Lab. No.	**C-2735**	**C-2736**	**C-2809**
Date Made	9/21/2006	9/22/2006	3/29/2007
0754 Holcim Type I Portland Cement (lbs/yd³)	560	560	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1449	1236	1499
#67 Limestone, AB29 Martin Marietta (lbs/yd³)	1619	1825	1676
% by volume Fine Aggregate	47.8	40.7	47.8
% by volume Coarse Aggregate	52.2	59.3	52.2
Water (lbs/yd³)	266.0	266.0	224.0
Water Cement Ratio	0.474	0.474	0.400
Admixture 1	Darex II AEA	Darex II AEA	Darex II
Dosage (oz/100ct)	0.50	0.50	0.50
Admixture 2	N/A	N/A	ADVA 170
Dosage (oz/100ct)	N/A	N/A	3.00
ASTM C 1064 Air Temperature (°F)	70.0	70.6	69.0
ASTM C 1064 Concrete Temperature (°F)	71.5	72.7	70.6
ASTM C 143 Slump (inches)	2.25	5.00	1.25
ASTM C 231 Pressure Air Content (%)	5.0	4.0	7.5
ASTM C 173 Volumetric Air Content (%)	5.1	4.6	7.5
ASTM C 138 Unit Weight (lbs/ft³)	143.6	146.4	142.4

Air Void Analyzer (AVA) Test Properties

LTRC Lab. No.	**C-2735**				**C-2736**				**C-2809**			
	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.
Chord Length	< 2 mm				< 2 mm				< 2 mm			
Air - % concrete	1.6	2.0	0.3	15.7	1.9	1.1	0.6	**37.7**	1.3	3.1	1.3	**57.9**
Air - % paste	6.0	7.5	1.1	15.7	7.1	4.1	2.1	**37.9**	5.1	12.8	5.4	**60.8**
Air - % putty	5.7	7.0	0.9	14.5	6.6	3.9	1.9	**36.4**	4.9	11.3	4.5	**55.9**
Chord Length	< 0.35 mm				< 0.35 mm				< 0.35 mm			
Air - % concrete	0.4	0.6	0.1	**28.3**	0.5	0.4	0.1	15.7	0.5	1.3	0.6	**62.9**
Air - % paste	1.3	2.3	0.7	**39.3**	2.0	1.5	0.4	**20.2**	2.2	5.2	2.1	**57.3**
Air - % putty	1.2	2.1	0.6	**38.6**	1.8	1.5	0.2	12.9	2.1	4.6	1.8	**52.8**
Specific surface (mm-1)	8.8	9.8	0.7	7.6	9.3	13.4	2.9	**25.5**	12.5	20.5	5.7	**34.3**
Spacing factor (mm)	0.885	0.723	0.115	14.2	0.783	0.688	0.067	9.1	0.670	0.274	0.280	**59.3**
Notes	Air content out of range	Air content out of range			Air content out of range	Air content out of range			Air content out of range	Air content out of range		

Mixture Properties

LTRC Lab. No.	Trial Mix #5	Trial Mix #6	Trial Mix #7
Date Made	4/3/2007	4/4/2007	4/9/2007
0754 Holcim Type I Portland Cement (lbs/yd³)	560	560	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1462	1443	1442
#67 Limestone, AB29 Martin Marietta (lbs/yd³)	1643	1608	1607
% by volume Fine Aggregate	47.7	47.9	47.9
% by volume Coarse Aggregate	52.4	52.1	52.1
Water (lbs/yd³)	250.0	245.0	245.0
Water Cement Ratio	0.446	0.438	0.438
Admixture	Darex II	Daravair 1000	Daravair 1000
Dosage (oz/100ct)	0.50	0.50	0.50
Admixture	ADVA 170	ADVA 170	WRDA 35
Dosage (oz/100ct)	3.00	2.00	6.00
ASTM C 1064 Air Temperature (°F)	70.3	68.5	70.9
ASTM C 1064 Concrete Temperature (°F)	70.6	71.1	70.7
ASTM C 143 Slump (inches)	0.75	1.25	1.00
ASTM C 231 Pressure Air Content (%)	8.0	5.6	5.5
ASTM C 173 Volumetric Air Content (%)	8.1	5.9	5.5
ASTM C 138 Unit Weight (lbs/ft³)	142.0	146.8	146.8

Air Void Analyzer (AVA) Test Properties

LTRC Lab. No.	Trial Mix #5				Trial Mix #6				Trial Mix #7			
	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.
Chord Length	< 2 mm				< 2 mm				< 2 mm			
Air - % concrete	3.0	3.3	0.2	6.7	3.8	2.4	1.0	**31.9**	2.1	1.9	0.1	7.1
Air - % paste	11.7	12.8	0.8	6.3	14.7	9.0	4.0	**34.0**	8.0	7.1	0.6	8.4
Air - % putty	10.5	11.4	0.6	5.8	12.8	8.3	3.2	**30.2**	7.4	6.6	0.6	8.1
Chord Length	< 0.35 mm				< 0.35 mm				< 0.35 mm			
Air - % concrete	1.6	1.5	0.1	4.6	1.6	1.2	0.3	**20.2**	0.8	0.7	0.1	9.4
Air - % paste	6.2	5.8	0.3	4.7	6.2	4.7	1.1	19.5	2.9	2.8	0.1	2.5
Air - % putty	5.6	5.1	0.4	6.6	5.4	4.3	0.8	16.0	2.7	2.6	0.1	2.7
Specific surface (mm-1)	26.9	26.7	0.1	0.5	16.5	29.0	8.8	**38.9**	13.9	18.1	3.0	18.6
Spacing factor (mm)	0.218	0.211	0.005	2.3	0.318	0.224	0.066	**24.5**	0.492	0.400	0.065	14.6
Notes	Air content out of range	Air content out of range			Air content out of range	Air content out of range			Air content out of range	Air content out of range		

Mixture Properties			
LTRC Lab. No.	**Trial Mix #8**	**Trial Mix #9-A**	**Trial Mix #9-B**
Date Made	4/10/2007	4/17/2007	4/17/2007
0754 Holcim Type I Portland Cement (lbs/yd³)	560	560	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1440	1440	1440
#67 Limestone, AB29 Martin Marietta (lbs/yd³)	1607	1607	1607
% by volume Fine Aggregate	47.8	47.8	47.8
% by volume Coarse Aggregate	52.2	52.2	52.2
Water (lbs/yd³)	245.0	245.0	245.0
Water Cement Ratio	0.438	0.438	0.438
Admixture	Daravair 1000	Daravair AT30	Daravair AT30
Dosage (oz/100ct)	0.50	0.25	0.25
Admixture	WRDA 35	WRDA 35	WRDA 35
Dosage (oz/100ct)	8.00	8.00	8.00
ASTM C 1064 Air Temperature (°F)	69.0	70.0	70.6
ASTM C 1064 Concrete Temperature (°F)	70.6	71.3	71.5
ASTM C 143 Slump (inches)	3.00	1.00	1.25
ASTM C 231 Pressure Air Content (%)	8.0	5.6	5.7
ASTM C 173 Volumetric Air Content (%)	7.9	5.6	5.9
ASTM C 138 Unit Weight (lbs/ft³)	142.0	145.6	146.8

Air Void Analyzer (AVA) Test Properties												
LTRC Lab. No.	**Trial Mix #8**				**Trial Mix #9-A**				**Trial Mix #9-B**			
	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.
Chord Length	< 2 mm				< 2 mm				< 2 mm			
Air - % concrete	5.6	2.6	2.1	**51.7**	4.1	2.2	1.3	**42.7**	2.3	2.6	0.2	8.7
Air - % paste	22.1	10.0	8.6	**53.3**	15.9	8.4	5.3	**43.6**	8.9	10.2	0.9	9.6
Air - % putty	18.1	9.1	6.4	**46.8**	13.7	7.8	4.2	**38.8**	8.2	9.2	0.7	8.1
Chord Length	< 0.35 mm				< 0.35 mm				< 0.35 mm			
Air - % concrete	1.2	0.9	0.2	**20.2**	1.3	1.0	0.2	18.4	0.6	1.1	0.4	**41.6**
Air - % paste	4.7	3.5	0.8	**20.7**	5.2	3.8	1.0	**22.0**	2.3	4.1	1.3	**39.8**
Air - % putty	3.8	3.2	0.4	12.1	4.5	3.5	0.7	17.7	2.1	3.7	1.1	**39.0**
Specific surface (mm-1)	8.3	12.3	2.8	**27.5**	14.4	28.9	10.3	**47.4**	10.3	23.2	9.1	**54.5**
Spacing factor (mm)	0.532	0.507	0.018	3.4	0.355	0.234	0.086	**29.1**	0.639	0.268	0.262	**57.8**

Notes			
Notes	Air content out of range	Temperature out of range; Air content and Temp. out of range	Air content and Temp. out of range; Air content out of range

Mixture Properties

LTRC Lab. No.	Trial Mix #10	Trial Mix #11	C-2826
Date Made	4/24/2007	5/1/2007	5/22/2007
0754 Holcim Type I Portland Cement (lbs/yd³)	560	560	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1440	1440	1437
#67 Limestone, AB29 Martin Marietta (lbs/yd³)	1607.0	1607.0	
#57 Limestone, AB29 Martin Marietta (lbs/yd³)			1607.0
% by volume Fine Aggregate	47.8	47.8	47.8
% by volume Coarse Aggregate	52.20	52.20	52.20
Water (lbs/yd³)	245.00	245.00	274.00
Water Cement Ratio	0.4	0.4	0.5
Admixture	Daravair AT60	Daravair AEA ED	Daravair 1400
Dosage (oz/100ct)	0.25	0.25	0.50
Admixture	WRDA 35	WRDA 35	WRDA 35
Dosage (oz/100ct)	8.00	8.00	2.00
ASTM C 1064 Air Temperature (°F)	69.0	70.9	71.0
ASTM C 1064 Concrete Temperature (°F)	71.5	71.1	72.4
ASTM C 143 Slump (inches)	1.75	2.00	6.75
ASTM C 231 Pressure Air Content (%)	6.8	6.2	6.5
ASTM C 173 Volumetric Air Content (%)	6.8	6.3	6.6
ASTM C 138 Unit Weight (lbs/ft³)	144.4	144	140.8

Air Void Analyzer (AVA) Test Properties

LTRC Lab. No.	**Trial Mix #10**				**Trial Mix #11**				**C-2826**			
	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.
Chord Length	< 2 mm				< 2 mm				< 2 mm			
Air - % concrete	3.4	2.6	0.6	18.9	2.2	3.1	0.6	**24.0**	2.6	6.1	2.5	**56.9**
Air - % paste	13.0	9.7	2.3	**20.6**	8.2	11.8	2.5	**25.5**	9.3	23.1	9.8	**60.2**
Air - % putty	11.5	8.9	1.8	18.0	7.6	10.5	2.1	**22.7**	8.5	18.8	7.3	**53.4**
Chord Length	< 0.35 mm				< 0.35 mm				< 0.35 mm			
Air - % concrete	1.8	1.0	0.6	**40.4**	0.8	2.1	0.9	**63.4**	1.0	1.9	0.6	**43.9**
Air - % paste	7.0	3.8	2.3	**41.9**	2.9	8.0	3.6	**66.2**	3.8	7.3	2.5	**44.6**
Air - % putty	6.2	3.5	1.9	**39.4**	2.6	7.2	3.3	**66.4**	3.5	5.9	1.7	**36.1**
Specific surface (mm-1)	27.2	24.9	1.6	6.2	13.8	39.6	18.2	**68.3**	15.0	12.1	2.1	15.1
Spacing factor (mm)	0.204	0.253	0.035	15.2	0.492	0.146	0.245	**76.7**	0.430	0.361	0.049	12.3

Notes	Air content out of range	Air content and Temp. out of range			Air content out of range	Air content out of range			Air content out of range			

Mixture Properties

LTRC Lab. No.	**C-2827**	**C-2828**	**C-2844**
Date Made	5/23/2007	5/23/2007	6/26/2007
0754 Holcim Type I Portland Cement (lbs/yd³)	475	475	475
Sand, A133 TXI Dennis Mills (lbs/yd³)	1133	1174	1131
#57 Limestone, AB29 Martin Marietta (lbs/yd³)		2109	
Grade B Gravel, A133 TXI Dennis Mills (lbs/yd³)	2030		2032
% by volume Fine Aggregate	35.0	36.3	35.0
% by volume Coarse Aggregate	65.0	63.7	65.0
Water (lbs/yd³)	265.0	214.0	214.0
Water Cement Ratio	0.476	0.451	0.451
Admixture 1	Daravair 1400	Daravair 1400	Daravair 1400
Dosage (oz/100ct)	0.50	0.50	0.50
Admixture 2	WRDA 35	WRDA 35	WRDA 35
Dosage (oz/100ct)	2.00	2.00	2.00
ASTM C 1064 Air Temperature (°F)	69.0	70.0	70.3
ASTM C 1064 Concrete Temperature (°F)	72.3	70.6	72.8
ASTM C 143 Slump (inches)	4.00	4.00	1.75
ASTM C 231 Pressure Air Content (%)	5.0	5.6	4.8
ASTM C 173 Volumetric Air Content (%)	5.0	5.5	4.8
ASTM C 138 Unit Weight (lbs/ft³)	142.0	145.6	142.4

Air Void Analyzer (AVA) Test Properties

LTRC Lab. No.	**C-2827**				**C-2828**				**C-2844**			
AVA Test	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.
Chord Length	< 2 mm				< 2 mm				< 2 mm			
Air - % concrete	4.5	2.8	1.2	**32.9**	1.5	2.6	0.8	**37.9**	3.8	1.7	1.5	**54.0**
Air - % paste	20.5	12.4	5.7	**34.8**	6.7	11.7	3.5	**38.4**	17.4	7.8	6.8	**53.9**
Air - % putty	17.0	11.0	4.2	**30.3**	6.3	10.5	3.0	**35.4**	14.8	7.2	5.4	**48.9**

Chord Length	< 0.35 mm				< 0.35 mm				< 0.35 mm			
Air - % concrete	2.3	1.0	0.9	**55.7**	0.7	1.2	0.4	**37.2**	1.5	0.9	0.4	**35.4**
Air - % paste	10.6	4.7	4.2	**54.5**	3.2	5.2	1.4	**33.7**	6.9	4.2	1.9	**34.4**
Air - % putty	8.8	4.2	3.3	**50.0**	3.0	4.6	1.1	**29.8**	5.9	3.9	1.4	**28.9**
Specific surface (mm-1)	18.5	27.9	6.6	**28.7**	30.9	16.0	10.5	**44.9**	14.4	26.4	8.5	**41.6**
Spacing factor (mm)	0.247	0.205	0.030	13.1	0.241	0.366	0.088	**29.1**	0.341	0.264	0.054	18.0
Notes		Air content out of range			Air content and Temp. out of range	Air content and Temp. out of range				Air content out of range		

Mixture Properties

LTRC Lab. No.	**C-2845**	**Trial Mix #17**
Date Made	6/27/2007	08/08/07
0754 Holcim Type I Portland Cement (lbs/yd³)	475	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1134	1160
#67 Limestone, AB29 Martin Marietta (lbs/yd³)		1921
#57 Mexican Limestone (lbs/yd³)	2037	
% by volume Fine Aggregate	35.1	38.2
% by volume Coarse Aggregate	64.9	61.8
Water (lbs/yd³)	214.0	245.0
Water Cement Ratio	0.451	0.438
Admixture	Daravair 1400	Daravair 1000
Dosage (oz/100ct)	0.50	0.50
Admixture	WRDA 35	ADVA 170
Dosage (oz/100ct)	3.00	3.00
ASTM C 1064 Air Temperature (°F)	70.0	70.0
ASTM C 1064 Concrete Temperature (°F)	71.2	71.8
ASTM C 143 Slump (inches)	1.75	1.5
ASTM C 231 Pressure Air Content (%)	7.5	3.6
ASTM C 173 Volumetric Air Content (%)	7.4	3.9
ASTM C 138 Unit Weight (lbs/ft³)	135.2	148.8

Air Void Analyzer (AVA) Test Properties

LTRC Lab. No.	**C-2845**				**Trial Mix #17**					
	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	Test 3	Test 4	St.Dev.	%C.V.
Chord Length	< 2 mm				< 2 mm					
Air - % concrete	0.7	1.3	0.4	**42.4**	4.1	2.7	1.7	2.2	1.0	**38.7**
Air - % paste	3.0	5.7	1.9	**43.9**	15.9	10.2	6.6	8.4	4.0	**39.2**
Air - % putty	2.9	5.4	1.8	**42.6**	13.8	9.3	6.2	7.8	3.3	**35.3**
Chord Length	< 0.35 mm				< 0.35 mm					
Air - % concrete	0.4	0.9	0.4	**54.4**	1.2	1.9	0.8	0.8	0.5	**44.2**

Air - % paste	1.6	3.9	1.6	**59.1**	4.6	7.1	2.9	3.2	1.9	**43.0**
Air - % putty	1.5	3.7	1.6	**59.8**	4.0	6.5	2.7	3.0	1.7	**42.6**
Specific surface (mm-1)	16.8	41.6	17.5	**60.1**	16.5	43.0	18.5	13.1	13.7	**60.0**
Spacing factor (mm)	0.622	0.192	0.304	**74.7**	0.309	0.144	0.405	0.513	0.157	**45.7**
Notes	Air content out of range	Air content out of range			Temp. out of range	Air content and Temp. out of range	Air content out of range	Air content out of range		

Mixture Properties			
LTRC Lab. No.	**Trial Mix #18**	**Trial Mix #19**	**Trial Mix #20**
Date Made	8/29/2007	10/3/2007	10/3/2007
0754 Holcim Type I Portland Cement (lbs/yd³)	560	560	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1159	1159	1159
#67 Limestone, AB29 Martin Marietta (lbs/yd³)	1920	1920	1920
% by volume Fine Aggregate	38.2	38.2	38.2
% by volume Coarse Aggregate	61.8	61.8	61.8
Water (lbs/yd³)	245.0	245.0	245.0
Water Cement Ratio	0.438	0.438	0.438
Admixture	Daravair 1000	Daravair 1000	Daravair 1000
Dosage (oz/100ct)	1.00	1.00	1.25
Admixture	ADVA 170	ADVA 170	ADVA 170
Dosage (oz/100ct)	4.00	4.00	3.50
ASTM C 1064 Air Temperature (°F)	71.5	71.5	71.5
ASTM C 1064 Concrete Temperature (°F)	71.5	71.3	70.0
ASTM C 143 Slump (inches)	4.00	8.00	3.25
ASTM C 231 Pressure Air Content (%)	4.0	3.4	4.9
ASTM C 173 Volumetric Air Content (%)	5.0	3.4	4.9
ASTM C 138 Unit Weight (lbs/ft³)	148.0	148.2	145.6

Air Void Analyzer (AVA) Test Properties												
LTRC Lab. No.	**Trial Mix #18**				**Trial Mix #19**				**Trial Mix #20**			
	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.	Test 1	Test 2	St.Dev.	%C.V.
Chord Length	< 2 mm				< 2 mm				< 2 mm			
Air - % concrete	0.5	4.0	2.5	**110.0**	3.8	2.5	0.9	**29.2**	4.2	2.0	1.6	**50.2**
Air - % paste	1.7	15.7	9.9	**113.8**	14.6	9.5	3.6	**29.9**	16.5	7.6	6.3	**52.2**
Air - % putty	1.7	13.6	8.4	**110.0**	12.7	8.7	2.8	**26.4**	14.2	7.0	5.1	**48.0**
Chord Length	< 0.35 mm				< 0.35 mm				< 0.35 mm			
Air - % concrete	0.4	1.2	0.6	**70.7**	1.7	1.0	0.5	**36.7**	1.6	1.3	0.2	14.6
Air - % paste	1.7	4.5	2.0	**63.9**	6.8	3.7	2.2	**41.8**	6.4	4.9	1.1	18.8
Air - % putty	1.6	3.9	1.6	**59.1**	5.9	3.4	1.8	**38.0**	5.4	4.6	0.6	11.3

Specific surface (mm-1)	81.1	12.8	48.3	**102.9**	15.2	12.4	2.0	14.3	16.6	26.9	7.3	**33.5**
Spacing factor (mm)	0.162	0.399	0.168	**59.7**	0.348	0.514	0.117	**27.2**	0.303	0.262	0.029	10.3
Notes	Air content and Temp. out of range				Temp. out of range	Air content out of range			Temp. out of range	Air content out of range		

Mixture Properties

LTRC Lab. No.	**Trial Mix 1d**	**Trial Mix 2b**	**C-2672**	**C-2675**	**C-2699**
Date Made	12/7/2005	12/9/2005	1/24/2006	2/14/2006	5/11/2006
0754 Holcim Type I Portland Cement (lbs/yd³)	475	500	600	560	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1108	1542	1211	1436	1436
#8 Limestone, AB29 Martin Marietta (lbs/yd³)	460				
#11 Limestone, AB29 Martin Marietta (lbs/yd³)	412				
#67 Limestone, AB29 Martin Marietta (lbs/yd³)	1197	1708	1833	1595	1595
% by volume Fine Aggregate	35.3	48.0	40.3	47.9	47.9
% by volume Coarse Aggregate	64.7	52.0	59.7	52.1	52.1
Water (lbs/yd³)	250	250	264	245	245
Water Cement Ratio	0.526	0.500	0.440	0.438	0.438
Admixture1	Darex II	Darex II	Darex II	Daravair 1000	Daravair 1000
Dosage (oz/100ct)	0.75	1.50	0.75	1.00	1.00
Admixture2	ADVA 170				
Dosage (oz/100ct)	5.00				
ASTM C 1064 Air Temperature (°F)	70.6	70.0	71.0	70.0	72.8
ASTM C 1064 Concrete Temperature (°F)	69.7	68.9	70.1	69.9	71.8
ASTM C 143 Slump (inches)	2.00	5.50	1.00	1.25	3.50
ASTM C 231 Pressure Air Content (%)	6.8	8.3	4.9	5.40	6.10
ASTM C 173 Volumetric Air Content (%)	6.8	8.2	5.0	5.50	6.30
ASTM C 138 Unit Weight (lbs/ft³)	143.6	140.0	142.7	146.4	143.2

Air Void Analyzer (AVA) Test Properties

LTRC Lab. No.	**Trial Mix 1d**	**Trial Mix 2b**	**C-2672**	**C-2675**	**C-2699**
	Test 1	Test 1	Test 1	Test 1	Test 1
Chord Length	< 2 mm	< 2 mm	< 2 mm	< 2 mm	< 2 mm
Air - % concrete	7.5	7.6	6.0	0.9	temp.out

Air - % paste	30.1	30.6	23.6	3.5	of range
Air - % putty	23.1	23.4	19.1	3.4	
Chord Length	< 0.35 mm	< 0.35 mm	< 0.35 mm	< 0.35 mm	< 0.35 mm
Air - % concrete	4.6	4.0	3.7	1.0	Air content
Air - % paste	18.4	16.3	14.7	3.7	out of
Air - % putty	14.2	12.5	11.9	3.6	range
Specific surface (mm-1)	21.9	19.3	24.0	66.7	
Spacing factor (mm)	0.149	0.166	0.170	0.145	
Notes	No Comment	Temperature out of range.	Air Content out of range	Air Content out of range	

Mixture Properties

LTRC Lab. No.	**C-2707**	**C-2708**	**C-2709**	**C-2718**	**C-2737**
Date Made	5/18/2006	5/23/2006	5/26/2006	6/27/2006	9/26/2006
0754 Holcim Type I Portland Cement (lbs/yd³)	560	560	560	560	560
Sand, A133 TXI Dennis Mills (lbs/yd³)	1444	1444	1444	1375	1449
#67 Limestone, AB29 Martin Marietta (lbs/yd³)	1609	1609	1609	n/a	1619
Grade A Gravel, A133 TXI Dennis Mills (lbs/yd³)	n/a	n/a	n/a	1532	n/a
% by volume Fine Aggregate	47.9	47.9	47.9	46.4	47.8
% by volume Coarse Aggregate	52.1	52.1	52.1	53.6	52.2
Water (lbs/yd³)	245	245	245	266	266
Water Cement Ratio	0.438	0.438	0.438	0.474	0.474
Admixture1	Daravair 1000	Daravair 1000	Daravair 1000	Daravair 1000	Darex II AEA
Dosage (oz/100ct)	1.00	0.50	1.00	0.50	0.50
Admixture2	ADVA 170	ADVA 170	WRDA 35	WRDA 35	ADVA 170
Dosage (oz/100ct)	3.00	3.00	2.00	4.00	3.00
ASTM C 1064 Air Temperature (°F)	71.0	75.5	73.5	71.2	67.1
ASTM C 1064 Concrete Temperature (°F)	72.5	74.6	74.1	74.3	71.3
ASTM C 143 Slump (inches)	6.50	7.00	1.75	5.00	7.50
ASTM C 231 Pressure Air Content (%)	14.00	9.80	7.30	7.20	9.60
ASTM C 173 Volumetric Air Content (%)	>9.00	9.00	7.80	7.60	9.50
ASTM C 138 Unit Weight (lbs/ft³)	130.8	137.2	141.6	137.6	138.4

Air Void Analyzer (AVA) Test Properties

LTRC Lab. No.	**C-2707**	**C-2708**	**C-2709**	**C-2718**	**C-2737**
	Test 1	Test 1	Test 1	Test 1	Test 1
Chord Length	< 2 mm	< 2 mm	< 2 mm	< 2 mm	< 2 mm
Air - % concrete	7.3	3.8	2.1	5.0	8.7
Air - % paste	29.4	14.5	8.0	18.6	34.3

Air - % putty	22.7	12.7	7.4	15.7	25.5
Chord Length	< 0.35 mm	< 0.35 mm	< 0.35 mm	< 0.35 mm	< 0.35 mm
Air - % concrete	4.6	1.2	1.3	3.3	5.0
Air - % paste	18.6	4.6	5.0	12.3	19.8
Air - % putty	14.4	4.1	4.6	10.4	14.7
Specific surface (mm-1)	19.5	11.0	26.4	24.8	21.5
Spacing factor (mm)	0.176	0.482	0.260	0.192	0.141
Notes			Air Content out of range	Temperature out of range.	

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