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IOWA STATE HIGHWAY COMMISSION

MATERIALS DEPARTMENT

Special Investigations Section

FINAL REPORT FOR R-252

A STUDY
OF THE RELIABILITY
OF THE ASTM C-666
FREEZE-THAW TEST

September 20, 1972

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A STUDY OF THE RELIABILITY OF THE ASTM C-666 FREEZE-THAW TEST OF CONCRETE

September 20, 1972

by
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A STUDY OF THE RELIABILITY OF THE ASTM C-666 FREEZE-THAW TEST OF CONCRETE

1.0 INTRODUCTION

The Iowa State Highway Commission purchased a Conrad automatic freeze and thaw machine and placed it in operation during October 1961. There were a few problems, but considering the many electrical and mechanical devices used in the automatic system it has always functioned quite well.

Rapid freezing and thawing of 4"x4"x18" concrete beams has been conducted primarily in accordance with ASTM C-291 (now ASTM C-666 procedure B) at the rate of one beam per day. Over 4000 beams have been tested since 1961, with determination of the resulting durability factors. Various methods of curing were used and a standard 90 day moist cure was selected. This cure seemed to yield durability factors that correlated very well with ratings of coarse aggregates based on service records.[1] Some concrete beams had been made using the same coarse aggregate and the durability factors compared relatively well with previous tests.

Durability factors seemed to yield reasonable results until large variations in durability factors were noted from beams of identical concrete mix proportions in research projects R-234 and R-247. This then presents the question "How reliable is the durability as determined by ASTM C-666?"

This question became increasingly more important when a specification requiring a minimum durability factor for P.C. concrete made from coarse aggregates was incorporated into the 1972 Standard Specification for coarse aggregates for concrete.

2.0 PURPOSE

The purpose of this study is to determine the reliability of concrete durability factors by investigating the variables of air contents and fabrication methods. Variations within concrete batches and from batch to batch will also be studied.

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[1] R-11-Z "A Study of Curing Methods and Type II Cements on the Durability of Concrete" by Vernon J. Marks & Ronald E. Grubb, June 17, 1969.

3.0 SCOPE

The specimens for the studies were:

1. Air content

   Three series each containing five sets of 3-4"x4"x18" beams were made.

2. Vibration

   One set of 3-4"x4"x18" beams was molded by vibrating two lifts ten seconds each. Two sets were made from another concrete mix with one set being vibrated ten seconds per lift and the other twenty seconds per lift. On a third mix three sets were made and vibrated ten seconds per lift on one set, twenty seconds per lift on another and thirty seconds per lift on the last.

3. General mixing variation

   One set of 3-4"x4"x18" beams were made from each of six identical mixes during one day.

4. General batch variation

   Ten 4"x4"x18" beams were made from one batch of concrete.

4.0 MATERIALS

The cement was a blend of Type I (R-11 blend) from seven different companies that produce for Iowa construction (Lab. No. ACO-149).

The fine aggregate was from Hallett's Ames Pit complying with Section 4110 of the Standard Specifications (AAS1-58).

Coarse aggregate for concrete, meeting the AASHO 57 grading, was crushed limestone from the following sources:

1. Variation in air content

   B.L. Anderson - Garrison Quarry - AAC1-266 & AAC1-603

   B.L. Anderson Montour Quarry - AAC1-615

2. Vibration study

   B.L. Anderson Montour Quarry - AAC1-431

3. Mix variation study

   B.L. Anderson Montour Quarry - AAC1-579

4. Individual beam variation study

   B.L. Anderson Montour Quarry - AAC1-579

The air agent was Ad-Aire produced by Carter Waters of Kansas City, Missouri.

5.0 PROCEDURE

The mix proportion for all concrete was C-3 from the standard specifications. The coarse aggregate was soaked for a minimum of 20 hours before being brought to a saturated surface dried condition. The fine aggregate was dried and assumed to have an absorption of 0.5% on the basis of previous testing. The mixing procedure was:

1. Proportion fine aggregate
2. Proportion cement
3. Mix for one minute
4. Proportion coarse aggregate
5. Mix for one minute
6. Mix for three minutes while dispensing the air agent in approximately one half of the required water and then adding water to yield a slump of 2-1/2" ± 1/2". The air was 6 ± 1% except when studying the variation in air content.

The molding procedure was as follows except for variation in time of vibration in that study:

1. Fill the mold half full and consolidate for ten seconds on a platform vibrator.
2. Fill the mold level full with concrete while consolidating for an additional ten seconds on the platform vibrator.
3. Strike off the excess concrete and finish with a steel trowel.

The specimens were cured for 20 to 24 hours in the molds covered with polyethylene film. They were then carefully removed from the molds and stored in a moist room (ASTM C-511) for 89 days before being transferred to a 40°F. water bath for one day.

Freeze and thaw testing was conducted in accordance with ASTM C-666 procedure B except that:

1. The beams were 18" in length
2. The beams were not weighed

6.0 INTERPRETATION OF RESULTS

1. Air content (Table I - Mix Nos. 218-222, 257-261, 262-266)

Air content of the plastic concrete made with coarse aggregate from B.L. Anderson's Garrison Quarry varied from 3.3% to 8.3% (Figure 1). The durability increased with air content up to between 7 and 8% air where it seemed to level off. One mix increased from a durability of 75% at 5% air content to 91% at 7% or a 16% increase. The other mix increased from 56% at 5% to 89% at 7% or a 33% increase. This points out the fact that if durability is to be used for a coarse aggregate specification, the air content would have to be controlled closer than 5-7% which is the present practice. The growths in Figure 2 show supporting information as they decrease with increasing air.

The concrete made with B.L. Anderson Montour Quarry showed lower durabilities (Figure 3) on air contents ranging from 2.9 to 8.3%. The durability increased from 39% at 5% to 63% at 7% or a difference of 24%. There was no apparent optimum concrete air content at which the durability factors stabilized as was the case with concrete containing aggregate from the Garrison Quarry. This would tend to indicate that the air content of concrete to obtain the maximum durability may be a function of the quality of the coarse aggregate.

2. Vibration (Table I - Mix Nos. 241, 242, 243)

The durabilities for sets of beams vibrated 10 seconds per lift were 76, 74, and 76. The 20 second vibrations were 76 and 79 while the 30 second vibration was 83. There is no signifigant difference exhibited here due to variation in vibration time.

3. General mixing variation (Table I - Mix Nos. 248-253)

The standard deviation using the average of six sets of beams was 1.71% durability factor. The standard deviation of these same 18 individual beams is 5.17%. This points out the improved probability of a more correct answer using an average of a set of three beams.

4. General batch variation (Table I - Mix No 254)

The standard deviation of the ten beams from one mix was 6.00% durability.

7.0 SUMMARY

From this project, we can conclude that:

1. The air content greatly affects the resulting durability factor and if it is to be used for a coarse aggregate specification it will have to be controlled or interpolated closer than 5-7% which is the present practice. More study should be conducted to determine if our 5-7% air in concrete is right for all coarse aggregates (R-258 is an additional study in this area).

2. Vibration with the laboratory facilities shows little affect on durability so a 10 second per lift standard should be continued.

3. The standard deviation of "sets" of beams is far lower than that for individual beams so durabilities should be determined for sets only. The standard deviation of individual beams was too much and more study should be conducted to determine ways to improve this (R-258 which is in progress will be an additional study in this area).

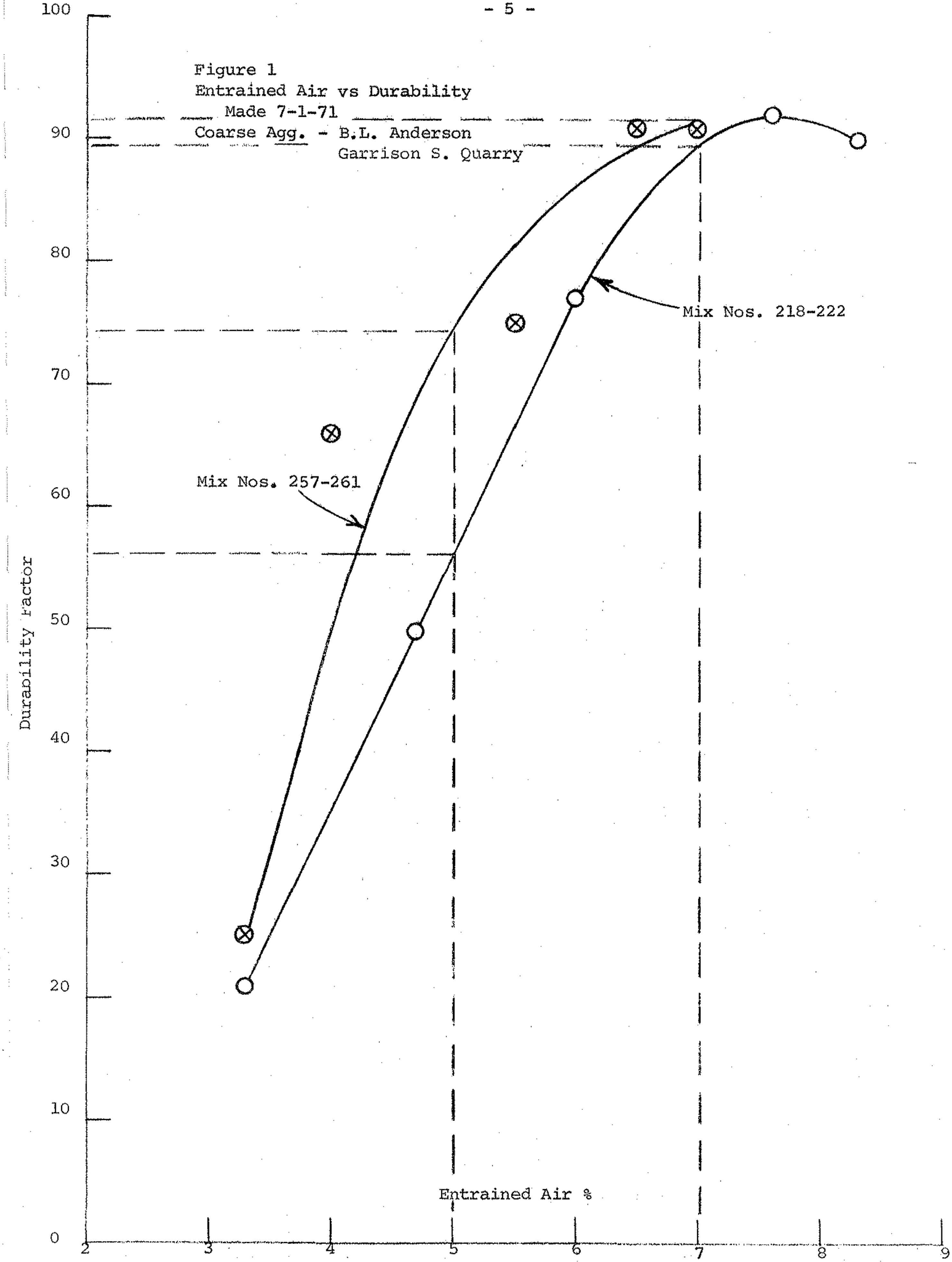
Figure 1
Entrained Air vs Durability
Made 7-1-71
Coarse Agg. - B.L. Anderson
Garrison S. Quarry
Mix Nos. 218-222
Mix Nos. 257-261
Durability Factor
Entrained Air %
100
90
80
70
60
50
40
30
20
10
0
2
3
4
5
6
7
8
9

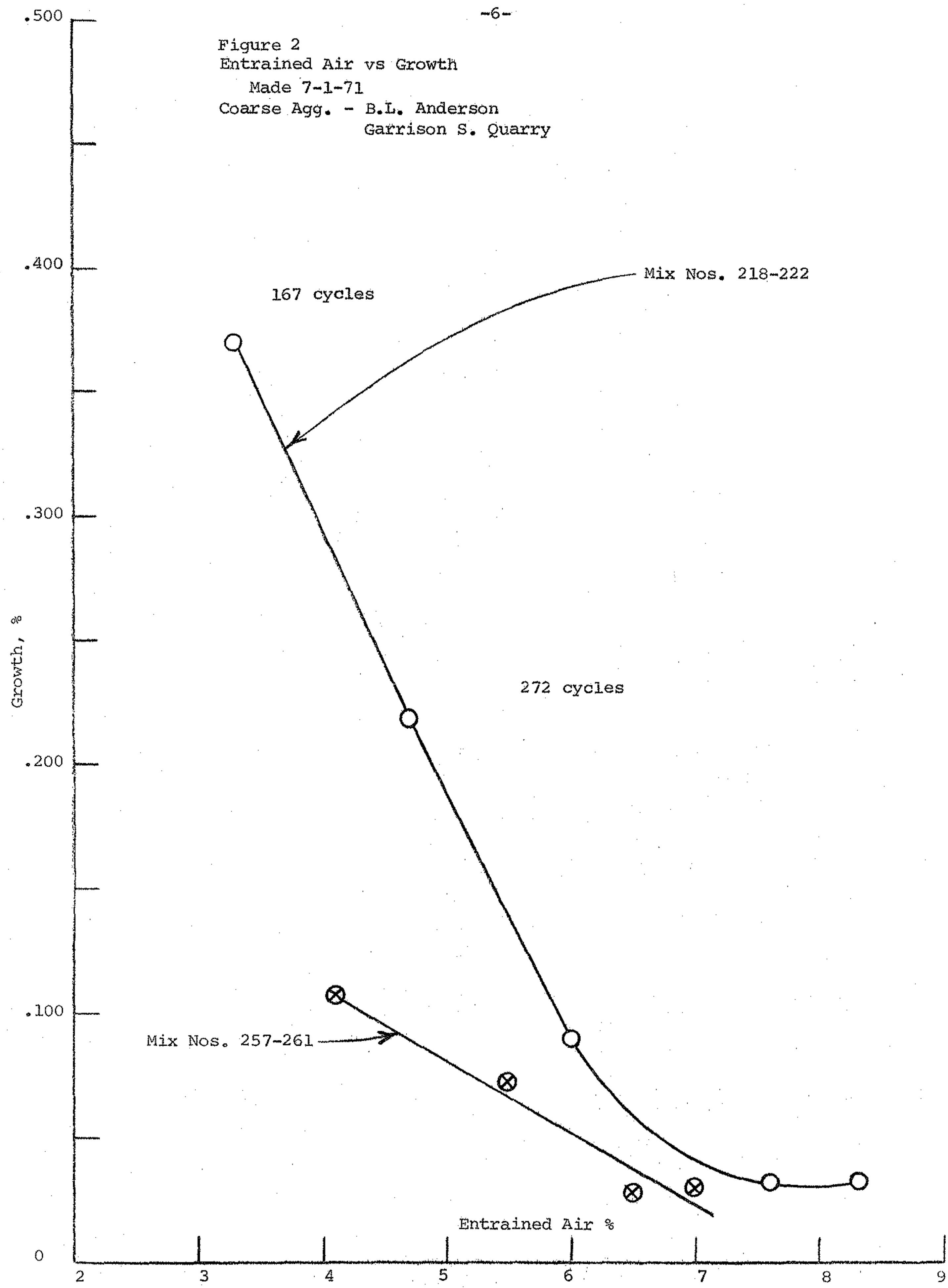
Figure 2
Entrained Air vs Growth
Made 7-1-71
Coarse Agg. - B.L. Anderson
Garrison S. Quarry
.500
.400
.300
.200
.100
0
Growth, %
167 cycles
Mix Nos. 218-222
272 cycles
Mix Nos. 257-261
Entrained Air %
2
3
4
5
6
7
8
9

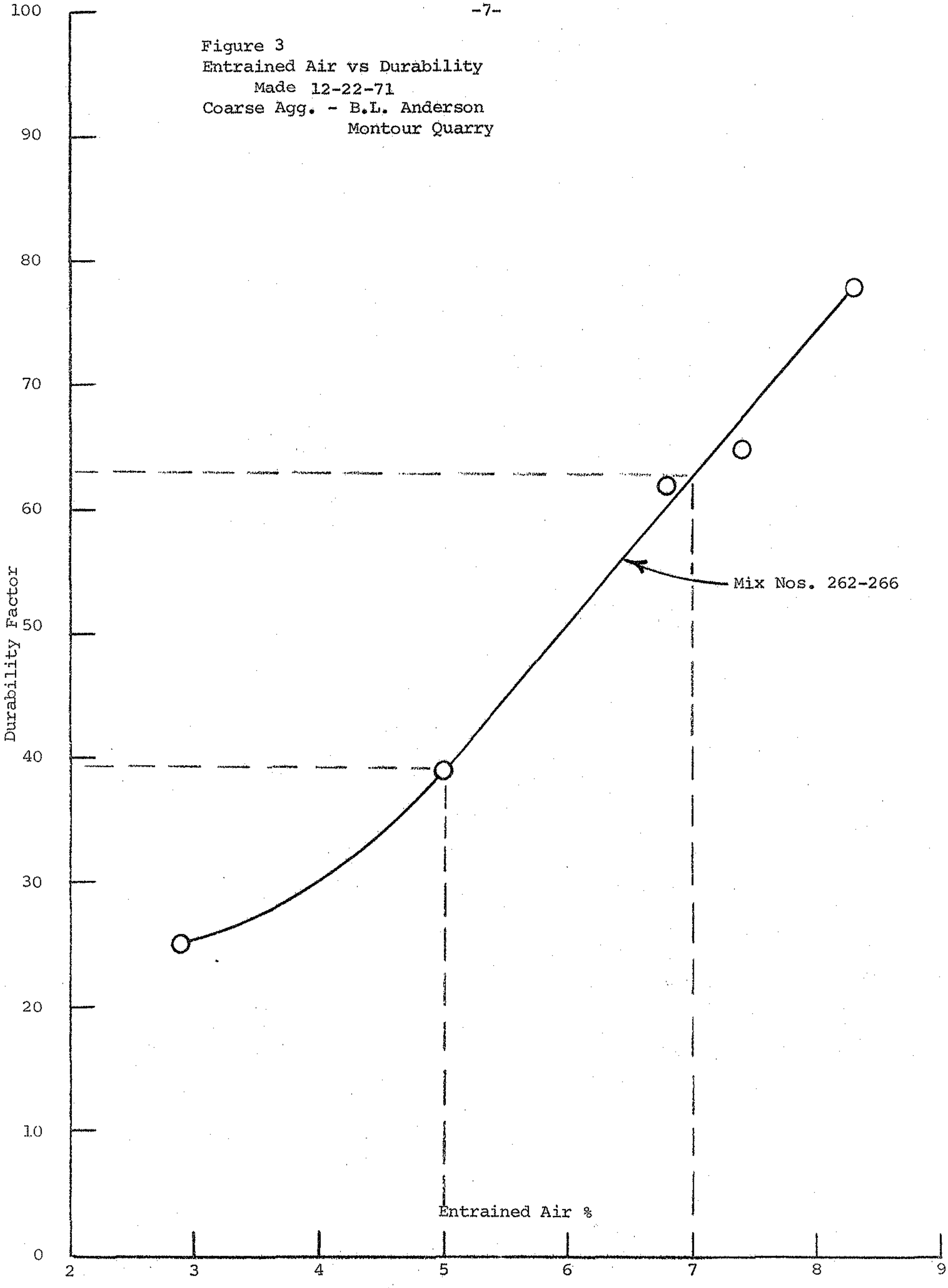
Figure 3
Entrained Air vs Durability
Made 12-22-71
Coarse Agg. - B.L. Anderson
Montour Quarry
Mix Nos. 262-266
Durability Factor
Entrained Air %
100
90
80
70
60
50
40
30
20
10
0
2
3
4
5
6
7
8
9

TABLE I

Mix No.	Air Plas.	Air H.P.	Slump	w/c Ratio	Vibration Seconds	D.F. %	Growth %	Final Cycles	Final Growth
218-1	3.3	2.3				19	-	167	.410
-2	3.3	2.1				18	-	167	.361
-3	3.3	1.8				25	-	167	.342
218-Avg.	3.3	2.1	2.5	.468	10	21	-	167	.371
219-1	4.7	3.1				54	-	272	.172
-2	4.7	3.4				53	-	272	.182
-3	4.7	3.3				42	-	272	.300
219-Avg.	4.7	3.3	2.25	.429	10	50	-	272	.219
220-1	6.0	4.8				78	.078	-	-
-2	6.0	4.9				73	.097	-	-
-3	6.0	5.2				81	.093	-	-
220-Avg.	6.0	5.0	2.50	.436	10	77	.090	302	-
221-1	7.6	6.3				93	.030	-	-
-2	7.6	6.3				92	.034	-	-
-3	7.6	6.8				91	.031	-	-
221-Avg.	7.6	6.5	2.75	.436	10	92	.032	431	
222-1	8.3	6.9				88	.044		
-2	8.3	7.4				92	.026		
-3	8.3	7.6				90	.033		
222-Avg.	8.3	7.3	2.00	.410	10	90	.034	321	
241-1	6.3	5.9				71	.123		
-2	6.3	5.8				77	.153		
-3	6.3	5.7				79	.098		
241-Avg.	6.3	5.8	2.75	.484	10	76	.125	377	
242-1	7.0	6.0				71	.172		
-2	7.0	6.3				77	.146		
-3	7.0	5.7				78	.132		
242-A Avg.	7.0	6.0	2.50	.459	10	74	.150	377	
242-4	7.0	5.8				77	.120		
-5	7.0	5.6				74	.085		
-6	7.0	5.4				77	.130		
242-B Avg.	7.0	5.6	2.50	.459	20	76	.111	377	
243-1	6.6	6.7				73	.118		
-2	6.6	6.4				70	.125		
-3	6.6	7.1				90	.105		
243-A Avg.	6.6	6.7	2.50	.433	10	76	.116	365	
243-4	6.6	6.7				78	.166		
-5	6.6	6.5				78	.142		
-6	6.6	6.6				82	.105		
243-B Avg.	6.6	6.6	2.50	.433	20	79	.138	365	

TABLE I
(cont.)

Mix No.	Air Plas.	Air H.P.	Slump	w/c Ratio	Vibration Seconds	D.F. %	Growth %	Final Cycles	Final Growth
243-7	6.6	6.0				77	.144		
-8	6.6	6.4				84	.136		
-9	6.6	6.0				87	.149		
243-C Avg.	6.6	6.1	2.50	.433	40	83	.143	365	
248-1	6.0	7.0				64	.145		
-2	6.0	6.3				70	.100		
-3	6.0	6.6				78	.127		
248-Avg.	6.0	6.6	2.50	.459	10	71	.124	321	
249-1	6.4	7.1				70	.127		
-2	6.4	6.4				78	.080		
-3	6.4	6.6				65	.122		
249-Avg.	6.4	6.7	2.50	.459	10	72	.111	321	
250-1	6.3	6.3				69	.142		
-2	6.3	6.8				71	.106		
-3	6.3	6.8				75	.186		
250-Avg.	6.3	6.6	2.75	.459	10	71	.144	321	
251-1	6.1	6.6				77	.135		
-2	6.1					70	.148		
-3	6.1	6.1				73	.147		
251-Avg.	6.1	6.4	2.75	.459	10	73	.144	321	
252-1	6.0	6.7				80	.127		
-2	6.0	6.4				65	.186		
-3	6.0	6.5				71	.131		
252-Avg.	6.0	6.5	2.50	.459	10	72	.149	376	
253-1	6.3	6.6				82	.098		
-2	6.3	6.7				70	.113		
-3	6.3	6.8				77	.099		
253-Avg.	6.3	6.7	2.75	.459	10	76	.104	376	
254-1	6.7	7.2				69	.156		
-2	6.7	7.4				68	.128		
-3	6.7	7.4				82	.139		
-4	6.7	7.4				79	.133		
-5	6.7	7.3				79	.089		
-6	6.7	7.1				76	.133		
-7	6.7	7.2				72	.194		
-8	6.7	7.2				61	.272		
-9	6.7	7.4				73	.167		
-10	6.7	7.7				77	.111		
254-Avg.	6.7	7.3	2.75	.464	10	73	.152	342	
257-1	3.3	2.7				22		272	.632
-2	3.3					26		272	.582
-3	3.3	2.8				27		272	.457
257-Avg.	3.3	2.8	3.00	.468	10	25		272	.556

TABLE I
(cont.)

Mix No.	Air Plas.	Air H.P.	Slump	w/c Ratio	Vibration Seconds	D.F. %	Growth %	Final Cycles	Final Growth
258-1	4.1	4.4				70			
-2	4.1	3.4				68			
-3	4.1	3.0				62			
258-Avg.	4.1	3.6	2.00	.429	10	66	.106	366	
259-1	5.5	3.9				78			
-2	5.5	4.4				76			
-3	5.5	4.3				71			
259-Avg.	5.5	4.2				75	.072	421	
260-1	7.0	5.9				93			
-2	7.0	5.6				89			
-3	7.0	5.9				89			
260-Avg.	7.0	5.8				91	.029	421	
261-1	6.5	6.0				89			
-2	6.5	7.1				93			
-3	6.5	6.0				92			
261-Avg.	6.5	6.4				91	.028	421	
262-1	2.9	4.1				18		192	
-2	2.9	3.8				27		192	
-3	2.9	3.8				52		192	
262-Avg.	2.9	3.9				35		192	.461
263-1	5.0	5.4				39			
-2	5.0	5.2				40			
-3	5.0	6.5				38			
263-Avg.	5.0	5.7				39	.379	311	
264-1	6.8	6.6				64			
-2	6.8	6.8				59			
-3	6.8	6.3				64			
264-Avg.	6.8	6.6				62	.150	311	
265-1	7.4	7.5				65			
-2	7.4	8.9				67			
-3	7.4	8.0				61			
265-Avg.	7.4	8.1				65	.150	311	
266-1	8.3	8.6				84			
-2	8.3	8.6				78			
-3	8.3	8.9				73			
266-Avg.	8.3	8.7				78	.075	366	