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FINAL REPORT

84-1

EVALUATION OF AIR-VOID SYSTEM IN PCCP WITH DIFFERENT NOMINAL SIZES OF COARSE AGGREGATE

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16. Abstract

Air-void system characteristics were determined for six sections of PCCP. Each section had a different concrete mix design, including those recently adopted for areas of the state with D-cracking problems. Maximum size of coarse aggregate and percentage of sand were major variables. Average air-void spacing factors were greater than ACI recommendations of less than 0.008 inches in all test sections. Low air content of fresh concrete and consolidation problems with mixes having fineness modulus of combined aggregate below 5.0 were main reasons for high spacing factors. A laboratory study to confirm proposed mix design changes has recently been completed. After this data is analyzed and reported, proposed changes in concrete mix design and consolidation practices will be submitted to the Design Committee for implementation. Test sections will be observed periodically in an attempt to correlate concrete air-void system characteristics and/or laboratory freeze-and-thaw durability data with performance of PCCP.

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EVALUATION OF AIR-VOID SYSTEM IN PCCP WITH DIFFERENT NOMINAL SIZES OF COARSE AGGREGATE

FINAL REPORT

STUDY NO. 84-1

Prepared By

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

DIVISION OF MATERIALS AND RESEARCH

MAY, 1987

In Cooperation With

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

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LIST OF ABBREVIATIONS

Abbreviation	Name
ACI	American Concrete Institute
PCA	Portland Cement Association
Cyl	Cylinder(s)
In	Inch(es)
Mpsi	Million Pounds Per Square Inch
PCCP	Portland Cement Concrete Pavement
Pcf	Pounds Per Cubic Foot
Psi	Pounds Per Square Inch

DEFINITION OF TERMS

Term	Definition
Durability Factor	Relative modulus multiplied by number of cycles and divided by specified cycles for termination of test. (AASHTO T161)
Dynamic Modulus	Modulus of elasticity of a concrete beam as determined by fundamental frequency of transverse vibration, beam dimensions, and weight. (ASTM C215)
Fineness Modulus	Summation of percentage retained on a series of screens then divided by 100.
Modulus	Same as dynamic modulus.
Relative Modulus	Dynamic modulus at any cycle as a percentage of initial dynamic modulus. (AASHTO T161)
Spacing Factor	Maximum distance from any point in cement paste to periphery of an air void as determined by linear traverse of a polished surface. (ASTM C457)

INTRODUCTION

Concrete pavement durability characteristics have been the subject of many studies by this and other agencies. Air entrainment of concrete utilizing durable aggregates has been beneficial in increased durability in freezing and thawing environments. The size of and spacing of bubbles created by air entrainment are two of several factors contributing to the effectiveness of air entrainment in concrete. ACI and PCA literature indicate an adequate air-void spacing factor has been considered to be less than 0.008 inch. PCA indicates about 90% of entrained air bubbles are 0.004 inch or less in diameter and 60% are less than 0.0008 inch in diameter.

Regardless of air entrainment, durability of concrete pavement in Northern and Western Missouri is often reduced by D-cracking distress. D-cracking is normally associated with the use of marginal limestone coarse aggregate in concrete subjected to freeze-and-thaw cycles while critically saturated. In 1967, various steps were taken to alleviate the problem of D-cracking. Some changes included reducing the maximum size of coarse aggregate from two inches to one inch and reducing the quantity of coarse aggregate required by the mix proportions.

While the changes appeared to be beneficial, D-cracking continued to cause increased maintenance and reduced service life.

Since 1967, the air-void system of concrete in the D-cracked area of the state had not been documented. In 1983, two paving projects in the D-cracked areas were selected for detailed study of further reduction in maximum size of coarse aggregate and increased percent fine aggregate. Both projects were located on Route I-435,

Clay County. The paving projects provided an opportunity to determine the air-void system characteristics of concrete with different mix proportions. Six test sections were selected with variables for each section as follows:

Test Section I

Coarse Aggregate (CA) - Burlington Limestone
CA - 100 percent passing - 1 1/2 inch sieve
Percent Fine Aggregate: 39

Test Section II

Coarse Aggregate (CA) - Bethany Falls Limestone
CA - 100 percent passing - 1 inch sieve
Percent Fine Aggregate: 45

Test Section III

Coarse Aggregate (CA) - Bethany Falls Limestone
CA - 100 percent passing - 3/4 inch sieve
Percent Fine Aggregate: 45

Test Section IV

Coarse Aggregate (CA) - Bethany Falls Limestone
CA - 100 percent passing - 3/4 inch sieve
Percent Fine Aggregate: 50

Test Section V

Coarse Aggregate (CA) - Bethany Falls Limestone
CA - 100 percent passing - 3/4 inch sieve
Percent Fine Aggregate: 50

Test Section VI

Coarse Aggregate (CA) - Bethany Falls Limestone
CA - 100 percent passing - 1/2 inch sieve
Percent Fine Aggregate: 50

Type I cement from Missouri Portland Cement Company, Sugar Creek, Missouri, was used in all test sections except Test Section V. Type I cement from Lone Star Cement Company, Bonner Springs, Kansas, was used in Test Section V.

Burlington Limestone was selected to be used in one test section because it had no known history of D-cracking. A local river sand was used as fine aggregate in all test sections. All air-entraining agent was Carter-Waters AdAire Extra Strength. Slump of less than 2 1/2 inches, cement factor of 6.1 sacks per cubic yard, and air content of 5 1/2 $\pm$ 1 1/2 percent were specifications common to all sections. Test section layout is shown in Figure 3.

Air-void system characteristics were determined on hardened concrete from each test section. Particular emphasis was made to determine the amount of air from bubbles less than 0.006 inches in diameter.

The results of this study will be used in conjunction with another study entitled "Influence of Design Characteristics on Concrete Durability".

CONCLUSIONS

Major conclusions reached in this study were based on characteristics of fresh and hardened concrete with specific mix designs, aggregates, cement, and additives included in this study. Since different sampling plans were utilized for determining characteristics of fresh and hardened concrete, relationships are general in nature. Generalizations beyond the stated conditions may not be warranted. A recently completed laboratory study has refined the relationships noted between design variables and air-void system characteristics.

1. Average air-void spacing factor in all sections exceeded the upper limit of 0.008 inches recommended by ACI and PCA.

2. Air-void spacing factors and consolidation problems both increased as fineness modulus of combined aggregate decreased.

3. Air content of fresh concrete should be increased when fineness modulus of combined aggregate decreases to provide adequate spacing factors.

4. Consolidation of PCCP should be studied to determine the level of dependency on vibrator characteristics and fineness modulus.

IMPLEMENTATION

Monitoring of PCCP sections with various mix designs should be continued in an effort to correlate air-void system characteristics and design factors with pavement durability.

A study entitled "Influence of Design Characteristics on Concrete Durability" is currently being conducted in the laboratory to more accurately evaluate the mix design variables.

Results of this study will be considered in the continuous process of updating specifications and mix design guidelines.

DISCUSSION

General

Eight sets of samples were obtained from each of six PCCP sections while paving was in progress. Each set consisted of slump, percent air by pressure meter, compressive strength cylinder, flexural strength beam, and laboratory freeze-and-thaw beam.

Beam modulus, density, and flexural strength were determined at 35 days of age. Cylinder modulus, density, and compressive strength (ASTM C 22) were determined at 28 days of age.

Laboratory freeze-and-thaw durability factors shown were computed after relative modulus dropped to 70 percent or after 100 weeks of one freeze cycle (in air) per week and storage in room temperature water when not in a freeze cycle. Table 1 includes a summary of cylinder, beam, and fresh concrete tests from this study. Relationships between most variables discussed are graphically illustrated in Figures 1 and 2.

Air-void characteristics were determined on 10 thickness cores from each test section of PCCP. All thickness cores available from each section were tested for density and dynamic modulus of elasticity. Three high density, three low density, and four average density cores were selected from each section to comprise the lot of pore structure cores. Cores were sawed, polished, and traversed. Traversing was completed by sets of six cores, consisting of one core from each section, in order to eliminate operator bias with time in favor of any design variable.

Air-void parameters determined by linear traverse methods (ASTM C457) were printed for each core as it was tested. Air-void spacing

factor, total air in concrete, total air in mortar, distribution of voids sizes, air in mortar composed of bubbles less than 0.006 inches in diameter, and mortar content were among items printed in the data sheet for each core. An example printout is included as Table 3. Core data discussed in this report is included in Tables 1 and 2. Relationships between most variables discussed are graphically illustrated in Figures 1 and 2.

Study Findings

Correlations between several individual air-void system parameters and design factors were tested for significance. While several correlations were good, standard errors of estimate were generally too high for reliable predictions. Examination of raw data plots indicated the same cores were not outliers on all correlations.

Fineness modulus of combined aggregate was computed as a replacement for both maximum size of coarse aggregate and percentage of sand in the mix.

Consolidation of PCCP varied from section to section as shown in Table 1 and Figures 1 and 2. Differences between air content in fresh concrete and air content in hardened concrete ranged from 0.2 to 1.3 percent. Corresponding differences between densities of beams and cores ranged from 1.2 to 3.2 pounds per cubic foot. Changes in air and density both show consolidation problems increased as fineness modulus decreased. Reasons for the relationship between consolidation and fineness modulus could not be determined from factors included in this study.

While there was substantial compliance with specifications for air content (5 1/2% with 1 1/2% operating tolerances), the measured air in the fresh concrete was not sufficient to provide recommended air-void spacing factors of 0.008 inches or less in the hardened concrete. Studies conducted several years ago indicated 5.5 percent air produced satisfactory spacing factors for mixes with fineness modulus of 5.5 or higher. When fineness modulus is decreased by reducing maximum size of coarse aggregate and/or increasing percentage of sand, it is reasonable to assume specified air content should be increased.

Air content of hardened mortar from small bubbles (less than 0.006 inch) remained relatively uniform for all values of fineness modulus. All small bubbles in the hardened mortar could reasonably be assumed to have been entrained in the fresh concrete.

Durability factors shown in Table 1 and Figure 2 are from laboratory freeze-and-thaw cycling of beams molded in the field. These factors apparently indicate reduced fineness modulus may provide additional pavement life.

It should be noted in Table 1 that durability factor of concrete using Coarse Aggregate Code B was very low. The coarse aggregate was Burlington Limestone and when used in PCCP has an excellent pavement service life. It is believed low quality and size of chert in the limestone with respect to size of beams was responsible for the low durability. The chert content in the coarse aggregate was within the allowable specification limits.

EQUIPMENT AND PROCEDURES

Linear Traverse Equipment

A binocular microscope at 72X magnification was used to examine a plane surface which had been sawed perpendicular to the PCCP surface. A modified lathe bed provided a means for moving each core laterally and transversely under the microscope.

A distance pulse generator attached to the modified lathe bed provided 100,000 pulses per inch of traverse to a counter bank in a microprocessor. A remote keypad allowed the operator to indicate boundaries between aggregate, paste, and voids. Data consisting of chord length and material type was saved on floppy disks at the end of each line of traverse. Air-void system parameters for all data from a core were computed and printed.

Miscellaneous equipment used to prepare cores for microscopic examination included a water-cooled saw with diamond-tipped blade, surface-grinding machine, and lapping machine with various sizes of abrasive grit.

Testing Procedures

All thickness determination cores available from each section were tested for dynamic modulus of elasticity and density prior to linear traverse testing. Cores for air-void system determinations were selected to represent the full range of densities from each section of PCCP.

Cores were then sawed into slabs with a diamond-tipped blade and ground plane with a surface grinder. A lapping machine with progressively finer sizes of abrasive grit (#120 to #1000) provided a polished plane.

Approximately 100 inches of line were traversed for each core. Ten lines, uniformly spaced over the polished surface, provided the required total line length for examination.

Table 1

SUMMARY OF CONCRETE PROPERTIES AND MIX CHARACTERISTICS
by Average and Standard Deviation

Coarse Aggregate Code	B	A	A	A	A	A
Aggr. Size (in)*	1 1/2	1	3/4	3/4	3/4	1/2
Percent Sand	39	45	45	50	50	50
Cement Code	A	A	A	A	B	A
Water-Cement Ratio (gal/sk)	4.9	4.9	4.9	5.3	5.3	5.4
Slump (in)	1.7 (0.3)	1.6 (0.6)	1.6 (0.4)	1.1 (0.3)	1.3 (0.7)	1.2 (0.4)
Air (%): Fresh; Total; All Bubbles	4.4 (0.3)	4.7 (0.9)	5.5 (0.6)	4.9 (0.4)	5.6 (0.8)	5.5 (0.4)
Hard; Total; All Bubbles	4.6 (0.6)	5.0 (0.4)	6.1 (1.1)	6.2 (0.8)	6.3 (0.7)	6.7 (0.8)
Hard; Mortar; All Bubbles	8.1 (1.0)	8.1 (0.6)	9.7 (1.7)	9.6 (1.2)	9.6 (1.0)	10.2 (1.1)
Hard; Mortar; Bubbles < 0.006"	2.34 (0.51)	2.09 (0.37)	2.66 (0.27)	2.44 (0.48)	1.92 (0.29)	2.42 (0.27)
Air Void Spacing Factor (in)	0.0094 (0.0012)	0.0100 (0.0013)	0.0091 (0.0012)	0.0099 (0.0011)	0.0118 (0.0013)	0.0104 (0.0009)
Fineness Modulus	5.49	5.13	4.82	4.66	4.56	4.42
Strength (psi): Beams Flexure	1079 (49)	915 (67)	907 (36)	920 (42)	908 (64)	903 (39)
Cyl.; Compr.	5420 (200)	4830 (360)	4910 (310)	4840 (350)	4400 (240)	4920 (340)
Density (psf): Beams	149.3 (0.7)	147.1 (1.8)	145.7 (1.0)	146.1 (0.8)	145.2 (1.1)	144.9 (1.1)
Cyl.	148.6 (0.5)	146.0 (1.9)	144.6 (0.9)	145.3 (0.8)	144.3 (1.3)	144.0 (0.8)
Cores	148.1 (1.1)	145.8 (1.1)	143.1 (0.7)	142.9 (1.3)	143.6 (0.7)	142.1 (1.3)
Modulus (mpsi): Beams	6.25 (0.16)	5.97 (0.30)	5.65 (0.14)	5.76 (0.12)	5.68 (0.17)	5.57 (0.22)
Cyl.	6.14 (0.18)	5.82 (0.28)	5.56 (0.16)	5.63 (0.15)	5.56 (0.16)	5.47 (0.16)
Cores	5.79 (0.20)	5.12 (0.16)	4.74 (0.07)	4.83 (0.20)	4.89 (0.12)	4.65 (0.18)
Lab. Freeze-and-Thaw Durability Factor	29.1 (7.8)	39.3 (4.7)	53.5 (18.1)	55.0 (12.7)	51.4 (14.9)	77.4 (14.4)

NOTES:

1. Standard deviations are shown in brackets.
2. Ten cores, eight cylinders, eight beams, eight slump tests, or eight fresh concrete air tests constituted a sample for any concrete design.
3. Coarse Aggregate Code; A = Bethany Falls Ls., B = Burlington Ls.
4. Cement Code; A = Missouri Portland, B = Lone Star

* Coarse Aggregate 100% Passing

Table 2

CONCRETE PROPERTIES AND MIX CHARACTERISTICS

Coarse Aggr Code	Max. Size	Sand (%)	Cem Code	Density (pcf)	Dynamic Modulus (mpsi)	Air (%) From Bubbles Of All Sizes Conc.	Mortar	<0.006" Mortar	Air Void Spacing Factor (In)
B	1 1/2	39	A	147.7	5.61	4.2	7.5	2.68	0.0077
				146.8	5.50	5.6	9.7	3.05	0.0081
				150.1	6.04	3.4	6.2	1.45	0.0115
				149.2	6.00	5.1	8.7	1.86	0.0106
				148.5	5.90	4.6	7.8	NA	0.0101
				148.8	5.96	4.0	7.4	2.45	0.0081
				147.3	5.70	5.0	8.7	2.64	0.0093
				147.8	5.79	4.6	7.7	1.90	0.0102
				146.7	5.54	4.7	8.6	2.68	0.0087
				148.1	5.89	5.2	8.4	2.38	0.0095
Average				148.1	5.79	4.6	8.1	2.34	0.0094
Standard Deviation				1.1	0.20	0.6	1.0	0.51	0.0012
A	1	45	A	147.8	5.37	4.8	7.7	1.82	0.0106
				144.3	5.01	5.5	8.6	2.19	0.0096
				145.3	5.01	4.9	7.9	1.99	0.0099
				146.6	5.27	4.9	7.8	1.84	0.0112
				144.7	4.97	5.4	9.1	2.75	0.0082
				145.9	5.02	5.0	8.0	2.49	0.0084
				145.4	5.08	4.9	8.1	2.32	0.0088
				147.1	5.19	4.2	6.8	1.46	0.0117
				145.2	4.96	5.5	8.8	2.15	0.0100
				145.7	5.37	4.9	7.8	1.89	0.0118
Average				145.8	5.12	5.0	8.1	2.09	0.0100
Standard Deviation				1.1	0.16	0.4	0.6	0.37	0.0013
A	3/4	45	A	142.2	4.80	7.5	12.2	2.46	0.0110
				144.3	4.86	4.3	7.0	2.79	0.0081
				143.1	4.69	7.6	11.9	2.25	0.0114
				142.4	4.75	6.8	11.0	2.91	0.0088
				143.5	4.73	6.4	10.2	2.59	0.0093
				143.6	4.68	6.2	9.7	3.22	0.0080
				142.6	4.75	5.8	9.1	2.42	0.0087
				142.5	4.62	5.2	8.4	2.59	0.0088
				143.5	4.73	4.9	7.8	2.71	0.0078
				143.0	4.76	6.5	9.8	2.67	0.0094
Average				143.1	4.74	6.1	9.7	2.66	0.0091
Standard Deviation				0.7	0.07	1.1	1.7	0.27	0.0012

Table 2 (Continued)

CONCRETE PROPERTIES AND MIX CHARACTERISTICS

Coarse Aggr Code	Coarse Aggr Max. Size	Sand (%)	Cem Code	Density (pcf)	Dynamic Modulus (mpsi)	Air (%) From Bubbles Of All Sizes Conc.	Air (%) From Bubbles Of All Sizes Mortar	Air (%) From Bubbles <0.006" Mortar	Air Void Spacing Factor (In)
A	3/4	50	A	144.1	5.00	6.4	9.5	2.07	0.0108
				141.5	4.61	6.2	9.5	2.66	0.0099
				142.6	4.83	6.1	9.6	2.24	0.0099
				141.4	4.66	7.4	11.0	3.26	0.0080
				142.5	4.79	6.9	10.5	2.41	0.0103
				141.7	4.56	5.9	9.1	2.35	0.0099
				145.2	5.19	4.4	6.8	1.80	0.0104
				143.1	4.77	7.0	11.0	2.44	0.0101
				144.6	5.05	6.0	9.5	1.96	0.0115
				142.5	4.83	6.2	9.5	3.16	0.0081
Average				142.9	4.83	6.2	9.6	2.44	0.0099
Standard Deviation				1.3	0.20	0.8	1.2	0.48	0.0011
A	3/4	50	B	142.9	4.91	7.4	11.3	1.48	0.0142
				144.5	4.98	6.0	9.2	1.87	0.0120
				143.6	4.96	6.6	9.9	2.05	0.0111
				142.8	4.86	6.5	10.0	2.20	0.0106
				144.3	4.83	4.8	7.4	1.48	0.0122
				143.6	4.94	6.7	10.5	2.12	0.0116
				143.6	5.02	6.4	9.6	1.69	0.0135
				142.5	4.65	5.9	8.9	2.31	0.0098
				144.3	5.01	6.6	10.2	2.09	0.0116
				143.4	4.75	6.1	9.3	1.87	0.0116
Average				143.6	4.89	6.3	9.6	1.92	0.0118
Standard Deviation				0.7	0.12	0.7	1.0	0.29	0.0013
A	1/2	50	A	140.4	4.47	7.5	11.1	2.57	0.0106
				144.2	4.79	5.9	8.9	2.20	0.0107
				141.2	4.51	6.6	10.5	2.83	0.0089
				141.0	4.36	7.0	10.6	2.65	0.0088
				141.3	4.74	7.1	10.5	2.16	0.0109
				143.9	4.96	5.5	8.5	2.04	0.0112
				142.5	4.68	6.0	9.0	2.63	0.0100
				142.9	4.72	6.9	10.6	2.18	0.0116
				142.1	4.70	6.6	10.2	2.33	0.0110
				141.3	4.55	8.1	12.1	2.61	0.0104
Average				142.1	4.65	6.7	10.2	2.42	0.0104
Standard Deviation				1.3	0.18	0.8	1.1	0.27	0.0009

Table 3

Summary of TRAVERSE Results for FD0459 Prepared on 5/3/84

Length = 93.38852 Percent AIR = 4.93 Average Air Void =0.00691 Standard Dev. of Air Void Sizes =0.01714

Voids Per Inch = 7.13 Spacing Factor* =0.01176 Specific Surface =578.86 Void / Paste Ratio =0.085

Percent Paste =57.85 Paste / Void Ratio =11.74 Frequency Distribution of Air Voids (In Distance Pulse Counts) Follows

Lower	- Upper		No.	Pct.	Lower	- Upper		No.	Pct.	Lower	- Upper		No.	Pct.	Lower	- Upper		No.	Pct.
0	- 49	=	24	3.60	50	- 99	=	99	18.47	100	- 149	=	86	31.68	150	- 199	=	61	40.84
200	- 249	=	75	52.10	250	- 299	=	35	57.36	300	- 349	=	34	62.46	350	- 399	=	30	66.97
400	- 449	=	30	71.47	450	- 499	=	22	74.77	500	- 549	=	6	75.68	550	- 599	=	10	77.18
600	- 649	=	8	78.38	650	- 699	=	11	80.03	700	- 749	=	3	80.48	750	- 799	=	9	81.83
800	- 849	=	5	82.58	850	- 899	=	7	83.63	900	- 949	=	4	84.23	950	- 999	=	4	84.83
1000	- 1049	=	6	85.74	1050	- 1099	=	2	86.04	1100	- 1149	=	2	86.34	1150	- 1199	=	5	87.09
1200	- 1249	=	5	87.84	1250	- 1299	=	5	88.59	1300	- 1349	=	4	89.19	1350	- 1399	=	4	89.79
1400	- 1449	=	4	90.39	1450	- 1499	=	4	90.99	1500	- 1549	=	0	90.99	1550	- 1599	=	1	91.14
1600	- 1649	=	4	91.74	1650	- 1699	=	2	92.04	1700	- 1749	=	2	92.34	1750	- 1799	=	0	92.34
1800	- 1849	=	2	92.64	1850	- 1899	=	1	92.79	1900	- 1949	=	2	93.09	1950	- 1999	=	3	93.54
2000	- 2499	=	9	94.89	2500	- 2999	=	5	95.65	3000	- 3499	=	6	96.55	3500	- 3999	=	3	97.00
4000	- 4499	=	2	97.30	4500	- 4999	=	3	97.75	5000	- 5499	=	2	98.05	5500	- 5999	=	1	98.20
6000	- 6499	=	0	98.20	6500	- 6999	=	2	98.50	7000	- 7499	=	2	98.80	7500	- 7999	=	1	98.95
8000	- 8499	=	0	98.95	8500	- 8999	=	2	99.25	9000	- 9499	=	2	99.55	9500	- 9999	=	0	99.55
10000	- 10499	=	1	99.70	10500	- 10999	=	0	99.70	11000	- 11499	=	0	99.70	11500	- 11999	=	0	99.70
12000	- 12499	=	0	99.70	12500	- 12999	=	0	99.70	13000	- 13499	=	0	99.70	13500	- 13999	=	0	99.70
14000	- 14499	=	0	99.70	14500	- 14999	=	0	99.70	15000	- 15499	=	0	99.70	15500	- 15999	=	0	99.70
16000	- 16499	=	1	99.85	16500	- 16999	=	0	99.85	17000	- 17499	=	0	99.85	17500	- 17999	=	0	99.85
18000	- 18499	=	0	99.85	18500	- 18999	=	0	99.85	19000	- 19499	=	0	99.85	19500	- 19999	=	0	99.85
20000	- 20499	=	0	99.85	20500	- 20999	=	0	99.85	21000	- 21499	=	0	99.85	21500	- 21999	=	0	99.85
22000	- 22499	=	0	99.85	22500	- 22999	=	0	99.85	23000	- 23499	=	0	99.85	23500	- 23999	=	0	99.85
24000	- 24499	=	0	99.85	24500	- 24999	=	0	99.85	25000	- 25499	=	0	99.85	25500	- 25999	=	0	99.85
26000	- 26499	=	0	99.85	26500	- 26999	=	0	99.85	27000	- 27499	=	1	100.00					

	Total	Bubbles <600	Bubbles >=600	Ratio
Percent Air in Concrete	4.93	1.18	3.74	.240323
Percent Air in Mortar	7.85	1.89	5.96	

*Air Void Spacing Factor

Figure 1

Air Content of Mortar and Concrete Vs. Fineness Modulus

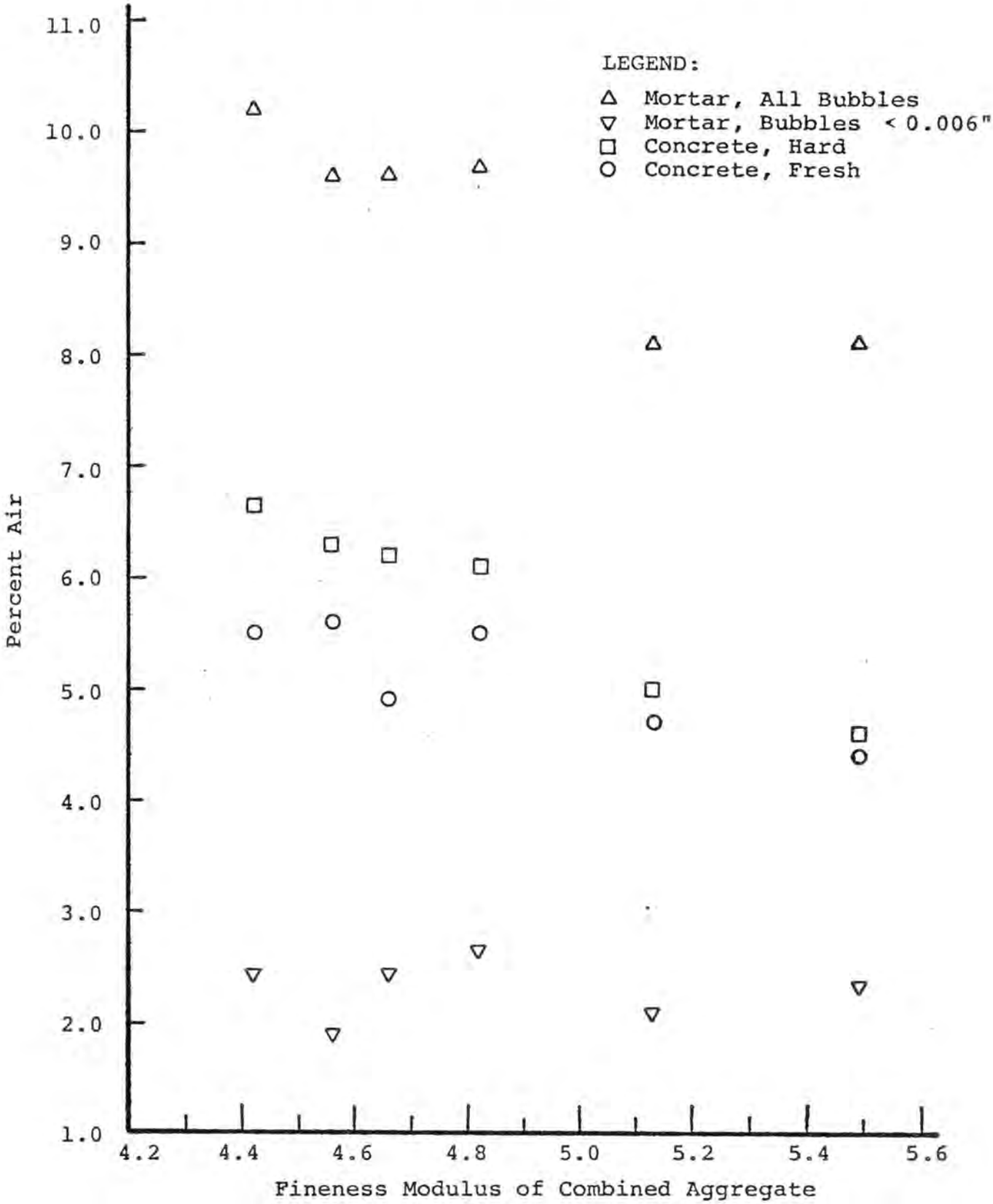


Figure 2

Density, Durability, and Air Void Spacing Factor Vs. Fineness Modulus

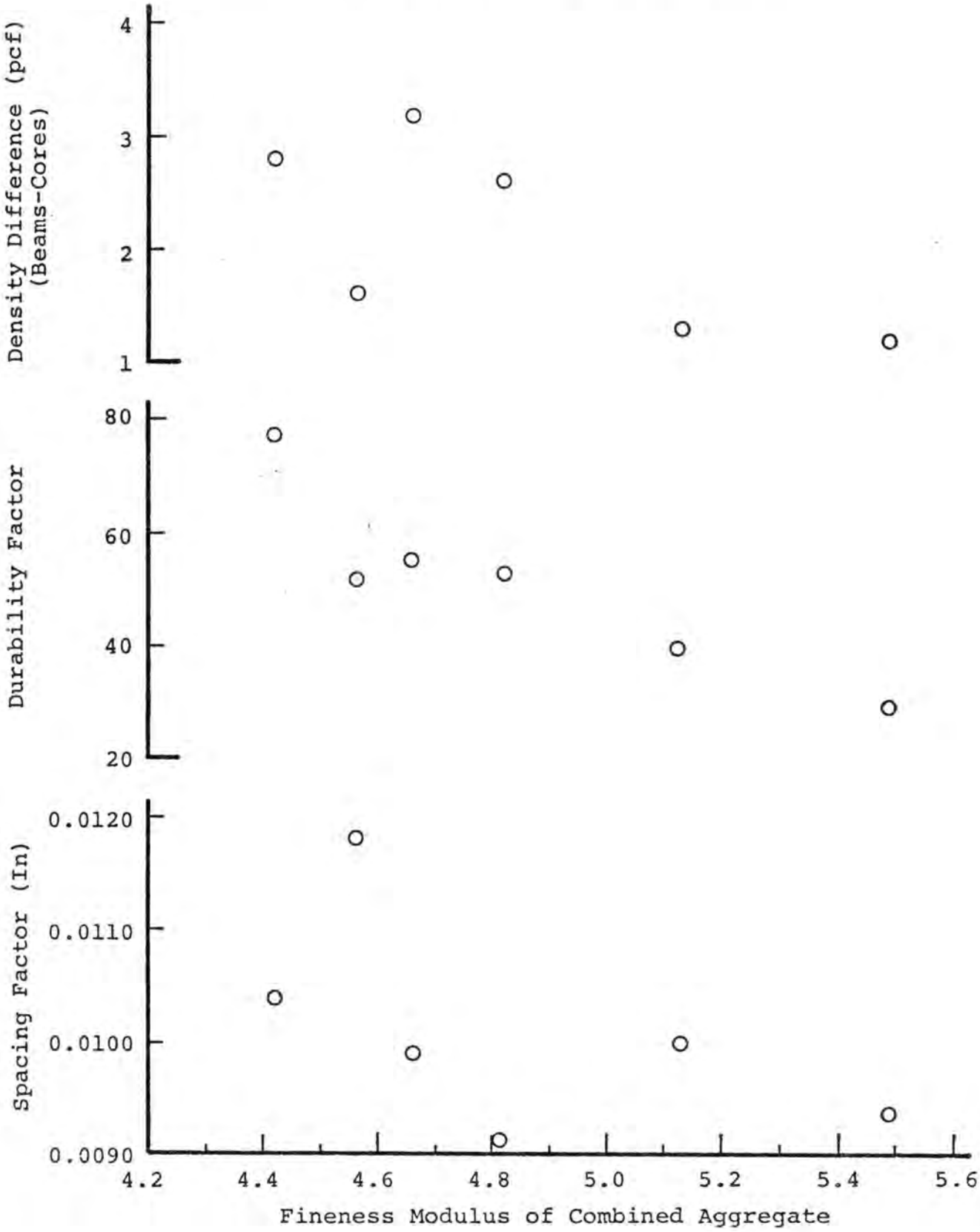


Figure 3

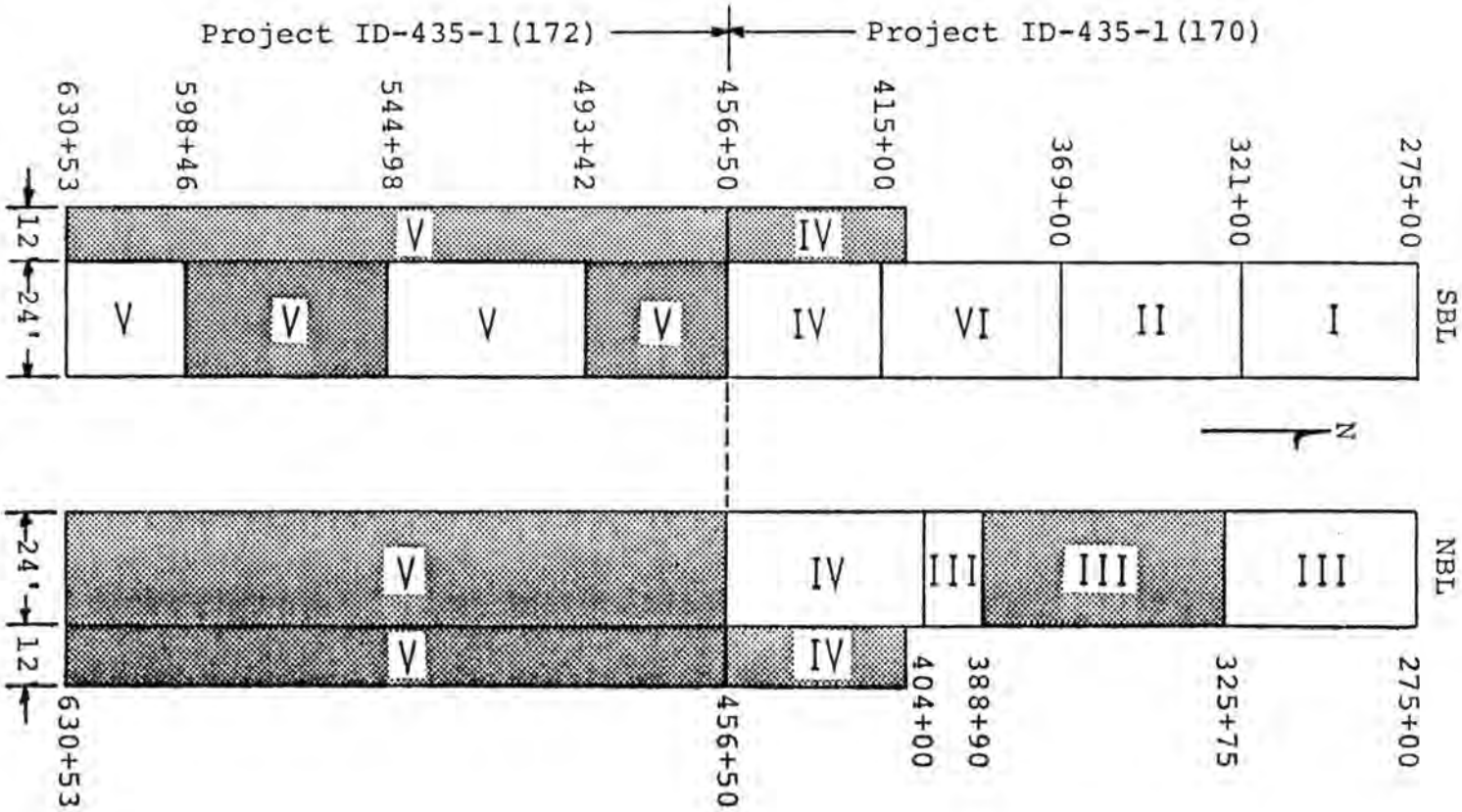
Physical Layout of Test Sections

Route I-435, Clay County

Key:

Area	I	II	III	IV	V	VI
Coarse Aggr. Code	B	A	A	A	A	A
Coarse Aggregate 100% Passing (in.)	1 1/2	1	3/4	3/4	3/4	1/2
Percent Sand	39	45	45	50	50	50
Cement Code	A	A	A	A	B	A
Fineness Modulus	5.59	5.13	4.82	4.66	4.56	4.42

Coarse Aggregate Code: A = Bethany Falls Ls., B = Burlington Ls.
Cement Code: A = Missouri Portland, B = Lone Star



NOTE: Shaded areas indicate pavement placed on dates when no samples were taken.

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