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"Experimental Use of Fly Ash Concrete in Prefabricated Bridge Deck Slabs"

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Abstract

Hydraulic cement concretes with and without fly ash were investigated to assess the suitability of using fly ash in bridge-deck concrete. Eight prefabricated concrete slabs were prepared: four were control and the remaining contained fly ash. They were used for widening two bridge structures.

Slump, air content, and unit weight were determined on the freshly mixed concrete; compressive strength, permeability, absorption, freezing and thawing durability, and the air void system were determined for the hardened concrete. Depth of cover over the reinforcing steel was measured. After three winters of exposure, slabs were surveyed visually for cracks, scaling, and spalls. Half-cell readings were taken, and chloride samples obtained and tested.

Fly ash concretes required a larger amount of air-entraining admixture than the controls to achieve the required air content. Although the 28-day strength tests showed that three of the four fly ash concretes did not achieve the required strength of 4,000 psi, the strength of all concretes exceeded 4,800 psi at 6 months when moist cured. The field evaluation after 3 years of winter exposure indicates that all concretes with fly ash are performing satisfactorily.

SI CONVERSION FACTORS

To Convert From	To	Multiply By
Length:		
in	cm	2.54
in	m	0.025 4
ft	m	0.304 8
yd	m	0.914 4
mi	km	1 . 609 344
Area:		
in^2	cm^2	6.451 600 E+00
ft^2	m^2	9.290 304 E-02
yd^2	m^2	8.361 274 E-01
mi^2	Hectares	2.589 988 E+02
acre (s)	Hectares	4.046 856 E-01
Volume:		
oz	m^3	2.957 353 E-05
pt	m^3	4.731 765 E-04
qt	m^3	9.463 529 E-04
gal	m^3	3.785 412 E-03
in^3	m^3	1.638 706 E-05
ft^3	m^3	2.831 685 E-02
yd^3	m^3	7.645 549 E-01
Volume per Unit Time:	NOTE: $1m^3$ = 1,000 L	
ft^3/min	m^3/sec	4.719 474 E-04
ft^3/s	m^3/sec	2.831 685 E-02
in^3/min	m^3/sec	2.731 177 E-07
yd^3/min	m^3/sec	1.274 258 E-02
gal/min	m^3/sec	6.309 020 E-05
Mass:		
oz	kg	2.834 952 E-02
dwt	kg	1.555 174 E-03
lb	kg	4.535 924 E-01
ton (2000 lb)	kg	9.071 847 E+02
Mass per Unit Volume:		
lb/yd^2	kg/m^2	4.394 185 E+01
lb/in^3	kg/m^3	2.767 990 E+04
lb/ft^3	kg/m^3	1.601 846 E+01
lb/yd^3	kg/m^3	5.932 764 E-01
Velocity: (Includes Speed)		
ft/s	m/s	3.048 000 E-01
mi/h	m/s	4.470 400 E-01
knot	m/s	5.144 444 E-01
mi/h	km/h	1.609 344 E+00
Force Per Unit Area:		
lbf/in^2 or psi	Pa	6.894 757 E+03
lbf/ft^2	Pa	4.788 026 E+01
Viscosity:		
cS_t	m^2/s	1.000 000 E-06
P	Pa·s	1.000 000 E-01

Temperature: $(°F-32)^5/9$ = °C

FINAL REPORT

EXPERIMENTAL USE OF FLY ASH CONCRETE IN PREFABRICATED BRIDGE-DECK SLABS

by

Celik Ozyildirim
Research Scientist

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

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CONCRETE RESEARCH ADVISORY COMMITTEE

ABSTRACT

Hydraulic cement concretes with and without fly ash were investigated to assess the suitability of using fly ash in bridge-deck concrete. Eight prefabricated concrete slabs were prepared: four were control and the remaining contained fly ash. They were used for widening two bridge structures.

Slump, air content, and unit weight were determined on the freshly mixed concrete; compressive strength, permeability, absorption, freezing and thawing durability, and the air void system were determined for the hardened concrete. Depth of cover over the reinforcing steel was measured. After three winters of exposure, slabs were surveyed visually for cracks, scaling, and spalls. Half-cell readings were taken, and chloride samples obtained and tested.

Fly ash concretes required a larger amount of air-entraining admixture than the controls to achieve the required air content. Although the 28-day strength tests showed that three of the four fly ash concretes did not achieve the required strength of 4,000 psi, the strength of all concretes exceeded 4,800 psi at 6 months when moist cured. The field evaluation after 3 years of winter exposure indicates that all concretes with fly ash are performing satisfactorily.

PURPOSE AND SCOPE

The purpose of the study was to evaluate the properties of bridge deck concretes containing fly ash and to observe their performance in the field over a three-year period. Eight concrete slabs measuring 4 ft by 22 ft 4 in and 1 ft 6 in deep, half with and the remaining without fly ash were fabricated and then placed on two bridge structures carrying Rte. 340 over Mine Branch and Stull Run in Augusta County, Virginia, for bridge widening. The slabs were alternated in the two decks as shown in Figure 1 to minimize differences in exposure.

The tests conducted at the fresh and hardened stages and in the field after three years of winter exposure are given in Table 1.

Seventy two 4 in by 8 in cylinders were prepared for compressive strength tests; 16 4 in by 8 in cylinders were prepared for permeability tests; 24 3 in by 4 in by 16 in beams were prepared for freeze-thaw tests; and 8 3 in by 4 in by 16 in beams for the air void system tests.

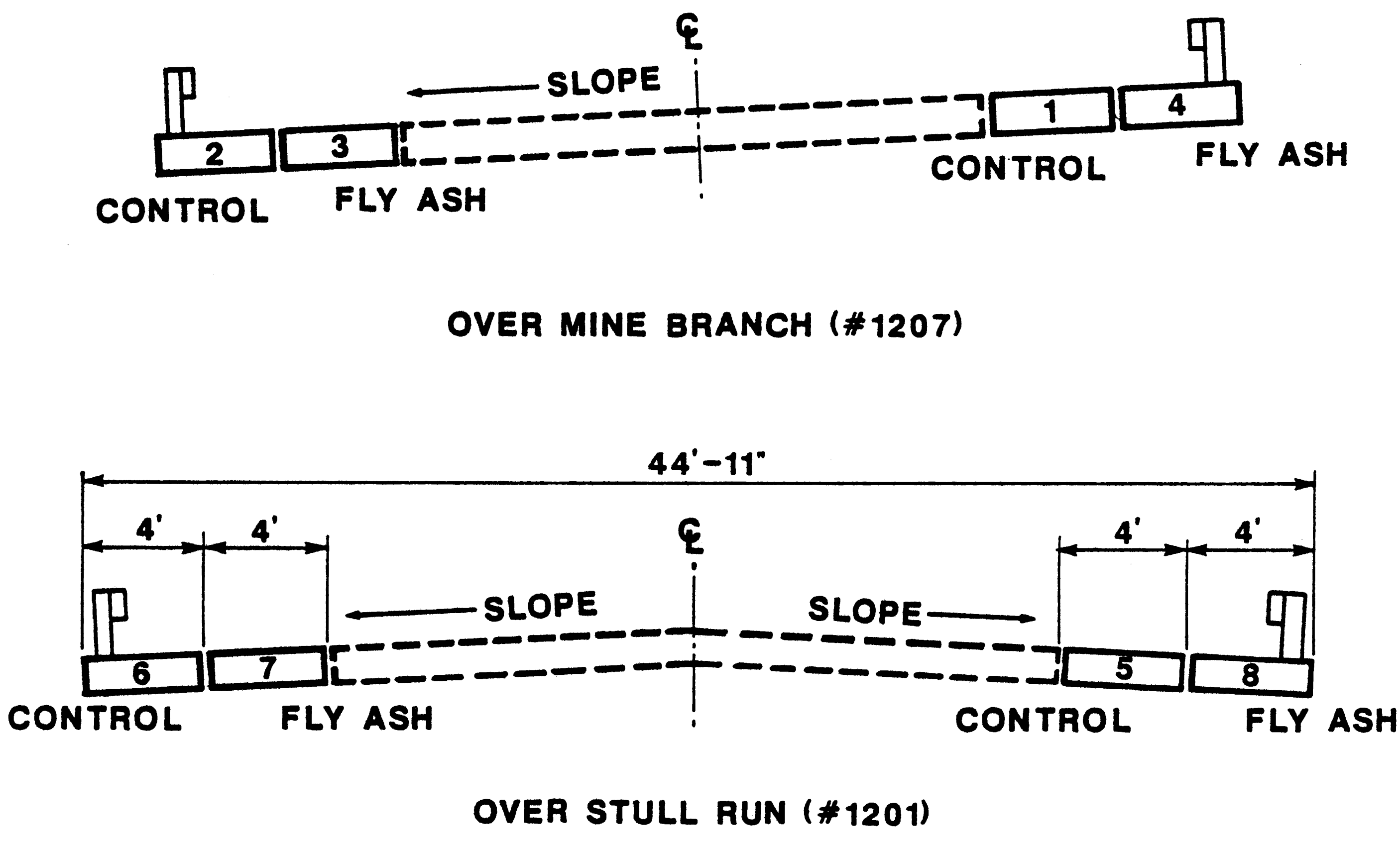

Figure 1. Transverse section of decks. The numbers on slabs show the sequence of fabrication.

FINAL REPORT

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INTRODUCTION

Fly ash is a by-product produced in abundant quantities in electric power plants that use pulverized coal. It consists mostly of small spheres of glass of complex composition including silica, ferric oxide, and alumina. These occur in forms that react with lime in the presence of water to form cementitious reaction products. Thus it can be used in portland cement concrete to supplement its strength developing properties (1,2,3). Its use in concrete can be either as an admixture added to the mixture or as an interground blend produced at the plant. The former use is desirable since it enables the adjustment of the amounts of cementitious materials; this makes it possible to produce concretes with properties suitable for different applications. ASTM C 618 is a specification for fly ash for use as a mineral admixture in portland cement, and it is widely used by the state highway agencies, except that lower limits on loss on ignition (indicative of the carbon content) are generally required. Higher amounts of carbon could cause problems in uniformity, especially in the achievement of the desired entrained air content. In our region, Type F fly ash described in ASTM C 618 is widely available. It is a pozzolanic material, and if used properly, it can improve workability, increase strength and resistance to alkali-silica and sulfate reactions, reduce permeability, and reduce temperature increases in large masses of concrete (1). When fly ash is used, proper precautions must be taken to assure the desired air content and to avoid adverse effects from low early strength.

Use of fly ash is warranted in those instances in which it is shown to be technically feasible since it can lead to improved properties at maturity and possible reductions in cost. Also, the use of fly ash is consistent with the national goals of energy conservation and by-product disposal. Therefore, after extensive laboratory work at the Research Council that yielded satisfactory results (3), a field evaluation of bridge deck concretes containing fly ash was initiated and conducted as described in this report.

TABLE 1

Tests Conducted

Concrete	Test	Method
Freshly mixed	Air content	ASTM C 231
	Slump	ASTM C 143
	Unit weight	ASTM C 138
Hardened	Compressive strength	AASHTO T 23[a]
	Permeability	AASHTO T 277
	Absorption	ASTM C 642
	Freeze-thaw durability	ASTM C 666[b]
	Air void system	ASTM C 457
	Cover depth	c
Field	Visual observation	d
	Delamination	e
	Half-cell potential	ASTM C 876
	Chloride content	AASHTO T 260

[a] Neoprene pads in steel end caps were used for capping

[b] Procedure A except 2 weeks moist and one week dry cured and tested in 2% NaCl solution

[c] Magnetic device senses the location of rebars and gives the depth of cover

[d] Cracks, scaling, spalls

[e] Chain drag

MATERIALS AND MIXTURE PROPORTIONS

Type II cement and fly ash with a low carbon content (approximately 1%) were used as the cementitious material. The fly ash met the requirements of ASTM C 618 (class F), and it had a specific gravity of 2.30. The fine aggregate was a siliceous sand with a specific gravity of 2.59 and a fineness modulus of 2.90. The coarse aggregate was crushed limestone with a specific gravity of 2.71 and a dry rodded unit weight of 95.8 lb/ft^3. The mixtures contained an air entraining admixture and a retarder.

The four control slabs contained class A4 concrete, which was required by the Department's specifications at the time of construction. Table 2 summarizes these specifications.

TABLE 2

Class A4 Bridge Deck Concrete Specifications

Min. 28-day compressive strength	4,000 psi
Aggregate size number	57
Nominal maximum aggregate size	1 in
Minimum cement content	635 lb/yd^3
Maximum water-cement ratio	0.47
Slump	2 - 4 in
Air Content	6½ ± 1½%

The experimental mixtures containing fly ash were required to meet the class A4 specifications, except that minimum portland cement content was reduced 15%, and 18% of weight of fly ash was added. The amount of fine aggregate was adjusted in accordance with ACI 211. The mixture proportions are given in Table 3.

TABLE 3

Mixture Proportions, lb/yd^3

Ingredient	Control	Fly Ash Concrete
Cement	635	540
Fly ash	---	114
Fine aggregate	1,167	1,116
Course aggregate	1,707	1,707
Water, max.	295	295

PROCEDURE

The concrete slabs were prepared in the casting yard at the District Office in Staunton during the summer of 1982. The top mat of reinforcing steel consisted of longitudinal uncoated #4 reinforcing bars. Ready-mixed concrete from one truckload was used for each slab. About two cubic feet of concrete from the initial portion of the load were used for tests for air content, slump, and unit weight. Specimens for tests on the hardened concrete were prepared using the ASTM C172 sampling procedure that requires that samples be taken from the middle portion of the load. Also an air content determination was made on concrete from the middle portion. Tests were made to determine compressive strength, permeability, absorption, freeze-thaw durability, and the air void system. After the concretes hardened in the structure, the depth of cover was measured using a magnetic device.

After aging approximately 10 months, the prefabricated slabs were placed on both sides of the existing bridge decks as shown in Figure 1 in the spring of 1983. In the fall of 1986, after three winter exposures, the sites were visited and visual observations of the slabs, chain soundings for delaminations, and half-cell readings were taken. From each slab at one location, a chloride sample was obtained at each of two depth levels (1/4 in to 3/4 and 1 1/2 in to 2 in).

RESULTS

Freshly Mixed Concrete

The characteristics of the freshly mixed concretes are summarized in Table 4. Mixtures meeting the specifications were obtained, except that the third slab had a slightly low air content of 4.8%, and the fourth slab had a high slump of 5 in. The measured air content from the middle portion of concrete was similar to that obtained from the initial portion. The differences ranged from 0.2% to 1.1%. The unit weights ranged from 138.1 lb/yd^3 to 147.8 lb/yd^3.

To meet the specifications, the concretes containing fly ash required about 50% to 100% more air-entraining admixture than did the controls.

TABLE 4

Characteristics of the Freshly Mixed Concretes

Slab[a]	Variable[b]	Slump in.	Air %[c]	Air %[d]	Unit Weight lb/ft^3
1	C	3.0	6.0	4.9	147.8
2	C	3.5	6.5	5.6	144.8
3	F	3.5	4.8	4.0	--
4	F	5.0	5.2	5.0	144.4
5	C	4.0	7.0	7.8	143.2
6	C	3.2	5.5	6.2	146.4
7	F	3.8	8.0[e]	8.7	138.1
8	F	3.5	6.6	6.8	--

[a] See Figure 1.

[b] C = control, F = fly ash.

[c] From the initial portion of the batch.

[d] From the middle portion of the batch.

[e] Water was added after this reading. From the middle portion, slump was 4.5 in.

Hardened Concrete

Compressive Strength

The compressive strengths were determined in accordance with AASHTO T 23 using 4 in by 8 in cylinders, except that neoprene pads in steel end caps were used for capping. The results of tests at 14, 28 days, and 6 months are summarized in Table 5. The results indicate that all of the control mixtures met the 28-day strength requirements. In the mixtures with fly ash, one met the criterion and the remaining three failed (two of these were below 3,200 psi). However, at 6 months, all the strengths were in excess of 4,800 psi when moist cured, which is considerably above the 4,000 psi required at 28 days. Although there were only a few samples, a statistical analysis based on an estimate of average and standard deviation values indicates that ultimate fly ash strengths would be sufficient even though lower than the controls. The average value for the four control batches at 6 months was 6,530 psi with a standard deviation of 441 psi; for the fly ash batches, the average was 5,740 psi with a standard deviation of 820 psi.

TABLE 5

Strength Data
(Average of Three Specimens)

Slab	Variable[a]	Compressive Strength, psi 14 Days	28 Days	6 Months
1	C	3,460[b]	4,303	6,310
2	C	3,810[b]	4,680	6,480
3	F	3,530[b]	4,290	6,720
4	F	3,110	3,700	6,020
5	C	3,870	4,490	6,160
6	C	4,600	5,440	7,160
7	F	2,530	2,850	4,810
8	F	2,440	3,190	5,400

[a] C = control, F = fly ash

[b] 11 days

Permeability and Absorption

The permeability to chloride ions of the mixtures was determined using AASHTO T 277. This test measures the quantity of electricity, which is expressed as coulombs, that passes through the test specimens in six hours. In this test concretes are rated as follows:

Coulombs		Permeability
>4,000	-	high
2,000-4,000	-	moderate
1,000-2,000	-	low
100-1,000	-	very low
<100	-	negligible

The test specimens, which are 2-in thick, were obtained from the top of 4 in by 8 in cylinders that were moist cured for 1 month and then air dried. The tests were made 6 weeks to 14 weeks after fabrication because of malfunctioning equipment. The total charge in coulombs transmitted during a 6-hr period is summarized in Table 6.

The lower portion of the cylinders from which the permeability specimens were removed were subjected to the absorption test described in ASTM C 642. The absorption test results are also given in Table 6.

TABLE 6

Permeability and Absorption Data
(Average of Two Specimens)

Slab	Variable	Coulombs	Absorption
1	C	4,670	5.2
2	C	2,350	5.5
3	F	1,030	5.4
4	F	2,240	5.5
5	C	4,560	4.9
6	C	3,870	4.6
7	F	4,322	5.2
8	F	4,955	5.9

The results of the permeability test indicate considerable variation in the coulomb values. The controls ranged from 2,350 to 4,670 coulombs. The fly ash concrete coulomb values ranged from 1,030 to 4,955 coulombs. The significance of the variation is not clear from the limited data available. However, it appears to be similar in both concretes and cannot be attributed to fly ash only. The absorption values varied between 4.9% and 5.9%. The controls had an average value of 5.1%, and the fly ash specimens 5.5%. There was essentially no correlation between the permeability and the absorption values. The calculated coefficient was 0.184.

Freezing and Thawing

The resistance of concretes to damage from cycles of freezing and thawing was determined using ASTM C 666 Procedure A with two modifications: (1) specimens were moist cured for 2 weeks and air dried for 1 week, and (2) 2% NaCl was added to the test water.

The Research Council's acceptance criteria require that at 300 cycles the average weight loss (WL) be 7% or less, the durability factor (DF) be 60 or more, and the surface rating (SR) be 3% or less. The surface rating was determined by estimating the proportion of the surface having ratings given in ASTM C 672. The top surface was rated separately from the molded surfaces. The final rating for each beam was calculated by averaging the weighted ratings computed for the top and molded surfaces separately.

The WL, DF, and SR values at 300 cycles are summarized in Table 7. These indicate that all the mixtures fulfill the acceptance criteria, and comparable results were obtained in both the controls and the fly ash mixtures.

Air Void System

The air void system in the hardened concrete was determined using the linear traverse method of ASTM C 457. The specimens were moist cured for at least a month and then a slab was cut and lapped for the linear traverse analysis. The values for small, large, and total voids, specific surface and spacing factor are summarized in Table 8.

TABLE 7

Freeze-Thaw Data at 300 Cycles
(Average of Three Specimens)

Slab	Variable	W.L.,%	D.F.	S.R.
1	C	6.5	95	2.0
2	C	4.9	99	1.2
3	F	5.7	97	1.4
4	F	5.3[a]	98[a]	1.4[a]
5	C	1.8	100	1.0
6	C	2.2	102	0.9
7	F	4.1	95	1.6
8	F	2.4	100	1.0

[a] Average of 2 beams since one of the specimens was damaged.

TABLE 8

Air Void System of Hardened Concrete

Slab	Variable	Void Content >1mm	Void Content <1mm	Void Content Total	Specific Surface in^{-1}	Spacing Factor in
1	C	1.9	4.3	6.2	833	0.0052
2	C	1.0	5.0	6.0	890	0.0049
3	F	1.3	3.5	4.8	829	0.0059
4	F	2.0	4.6	6.6	674	0.0060
5	C	2.1	8.0	10.1	636	0.0040
6	C	1.2	3.7	4.9	811	0.0060
7	F	1.3	7.6	8.9	1,053	0.0028
8	F	0.9	8.7	9.6	1,140	0.0024

The air content ranged from 4.8% to 10.1%. Five values were outside the specifications, three of the values exceeded the upper limit of 9%. There was a good correlation between the air content measured at the fresh stage and at the hardened stage. The correlation coefficient was 0.79.

The specific surface values ranged from 636 in^{-1} to 1,140 in^{-1}, and the spacing factors 0.0024 in to 0.0060 in. These values satisfied the generally accepted limits for satisfactory performance recommended by Mielenz et al. which are 600 in^{-1} or more for the specific surface values and 0.008 in or less for the spacing factors (4). The satisfactory air void system is consistent with the freeze-thaw data, which indicated satisfactory resistance to cycles of freezing and thawing.

Depth of Cover

The concrete cover over the top reinforcement was determined using a portable battery-operated magnetic device. Table 9 summarizes the cover depths and the standard deviations. The results indicate average depths ranging from 2.7 to 3.8 in, which is above the specified limit of 2.5 in.

TABLE 9

Depth of Cover Data

Slab	Variable	Depth	Standard Deviation
1	C	3.1	0.2
2	C	3.2	0.3
3	F	2.7	0.2
4	F	3.1	0.2
5	C	3.4	0.5
6	C	3.8	0.4
7	F	3.8	0.4
8	F	3.3	0.2

Field Data

Visual Survey and Delaminations

There were no cracks on the deck surface of the slabs. However, serious cracking and spalling originating from anchor locations has occurred at the outside edge of the exterior slabs. It appears that water in bolt holes that expanded during freezing caused the resulting distress. Also, one of the interior control slabs (number 1) had an epoxy patch measuring approximately 4 ft by 17 in at the surface and spanning the whole width of the slab. The cause of the patch is not known. However, it is attributed to a handling or transportation problem rather than an environmental effect. Other than this patching the slab was in very good condition. Soundings by chain drag revealed no delaminations in any of the slabs.

The surfaces of the slabs were rated in accordance with ASTM C 672 rating scale. Most of the values were 0 and all were below 1 (See Table 10). The former value indicates no scaling and the latter very slight scaling.

TABLE 10

Scaling Data

Slab	Variable	Rating
1	C	0.3
2	C	0
3	F	0.9
4	F	0
5	C	0
6	C	0
7	F	0
8	F	0.3

Half-Cell Potentials

Twenty-one electrical half-cell potential readings were taken on each of the slabs. The values ranged between 0 and -0.10 VCSE, all of which were less than the ASTM limit of -0.20 V CSE; this indicates that there is a greater than 90% probability that no corrosion was occurring in the reinforcing steel at the time of measurement.

Chloride Content

Chloride samples from each slab at two depths (1/4 in to 3/4 in and 1 1/2 in to 2 in) were tested. The chloride content (corrected for the base chloride levels) is summarized in Table 11.

TABLE 11

Chloride Content, lb/yd^3

Slab	Variable	1/4-3/4 in.	1 1/2-2 in.
1	C	1.02	0.04
2	C	0.40	0.00
3	F	0.38	0.04
4	F	0.41	0.04
5	C	1.21	0.01
6	C	0.28	0.04
7	F	0.59	0.00
8	F	1.20	0.00

The results show that even for the 1/4-in to 3/4-in depth the chloride content was below the threshold level of 1.27 lb/yd^3 (5). At depths of 1 1/2 to 2 in, all the values were negligible or undetectable, indicating that chlorides are not present in amounts that could initiate or accelerate corrosion.

When the chloride content at the 1/4-in to 3/4-in depth are correlated to coulomb values, the line of best fit shows a correlation coefficient of 0.73, which indicates a general relationship of lower salt content with lower coulomb values.

SUMMARY OF RESULTS AND CONCLUSIONS

The following conclusions are based on the laboratory tests and field evaluations.

1. Concretes with fly ash had lower 28-day compressive strengths than the controls and did not meet specifications in three of the four batches at 28 days. However, at 6 months all the concretes exhibited satisfactory levels of strength (all values exceeded 4,800 psi).

2. Mixtures with fly ash required a larger amount of air-entraining admixture than the controls to achieve the specified air content.

3. The coulomb values for all concretes with and without fly ash exhibited considerable variation, but were generally in the same range, indicating similar permeability.

4. The specific surface and spacing factor of all the mixtures were satisfactory, and the resistance to cycles of freezing and thawing were satisfactory and similar in both the controls and the fly ash concrete mixtures.

5. Field data indicate that slabs are in very good condition, and chlorides are not penetrating in quantities sufficient to cause corrosion in the steel, even to a depth of 1/4 to 3/4 in.

6. In summary, concretes with and without fly ash are performing satisfactorily and are expected to continue to do so.

RECOMMENDATION

It is recommended that concretes containing fly ash continue to be used in highway structures, provided that quality materials and fly ash meeting ASTM C 618 are used, the desired air content system is achieved, and the proper construction practices are followed. Special attention should be given to proportioning fly ash concretes to achieve the required strengths at early ages and at 28-days. However, if strength at early ages is not important, consideration can be given to meeting specifications on the basis of tests made at later ages.

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REFERENCES

1. Halstead, W. J., "Use of Fly Ash in Concrete," NCHRP Synthesis 127, Transportation Research Board, Washington, D. C., 1986.

2. Abdun-Nur, E. A., "Fly Ash in Concrete," HRB Bulletin 284, Highway Research Board, Washington, D. C., 1961.

3. Ozyildirim, H. C., "Alternatives to Type II Cement," VHTRC 79-R3, Virginia Highway & Transportation Research Council, Charlottesville, Virginia, 1978.

4. Mielenz, R. C., V. E. Woldokoff, J. E. Backstrom, and R. W. Burrows, "Origin, Evolution, and Effects of the Air Void System in Job Concrete," ACI Journal, American Concrete Institute, Detroit, Michigan, October 1958.

5. Clear, K. C., "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs," Vol. 3, FHWA-RD-76-70, Federal Highway Administration, Washington, D. C., 1976.