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Progress Report

THE EFFECT OF VARIATIONS IN AMOUNT OF WATER ADDED TO FLY-ASH CONCRETE MIXES

ONE-YEAR REPORT

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ABSTRACT

In previous investigations of the use of Detroit Edison Company fly ashes in portland cement concrete it appeared possible that an increase in the mixing water, while producing a more fluid mix, did not produce a commensurate reduction in the compressive strength of the concrete. As a result, a study was made in which concrete mixes designed for a 4-inch slump were made with the water added as the mixer increased or decreased from the designed quantity to produce wet and dry consistency mixes. The base mixes were so selected that the concrete of a given consistency had approximately the same early compressive strength whether containing fly ash or not.

The results obtained indicate that there is no appreciable difference between the behavior of the mixes containing fly ash and the plain cement mixes with respect to added water. The addition of extra water to produce the wetter mixes was equally detrimental to the compressive strength of both the fly ash and plain cement concrete.

Mixes with higher fly ash contents did not show the expected improvement at later ages, for the dry consistency mix with respect to the medium consistency mix that would be indicated from the reduction in water. It may be that for higher fly-ash contents a certain minimum water content may be required to insure that pozzolanic activity will continue.

OBJECTIVE

The purpose of this investigation is to study the properties of fly ash and concrete containing fly ash. The specific object of the research is to determine the effect of fly ash in concrete, as indicated by compressive strength, workability, durability in freezing and thawing, flexural strength, and other measures of concrete quality.

INTRODUCTION

This progress report is one of a series on the use of fly ash from The Detroit Edison Company power stations in portland cement concrete. Presented herein are the results of a study to determine the effect of variations in the amount of water added to mixes of non-air-entrained concrete containing fly ash from the St. Clair station. The investigation was made by the Engineering Research Institute of The University of Michigan pursuant to a contract between the Institute and The Detroit Edison Company. This report covers such matters as mix design, tests on the fresh concrete, and the results of compressive strength tests through an age of one year. Some matter pertaining to test procedures which was covered in earlier reports will be omitted here to avoid repetition.

This investigation was intended to be in the nature of a pilot study making a minimum number of mixes, with the intention of extending the study if any unusual behavior were noted in the concrete containing fly ash.

The method employed in this study consisted of making concrete of three consistencies from each of three mix designs by varying the amount of water added at the mixer. This gives the effect of a mix in which part of the water is omitted, making a drier mix, and one in which extra water is accidentally or intentionally added to give a wetter consistency. These can then be compared with the batch made of average consistency.

The case with too much water is the more prevalent, particularly in transit-mix operations, where some of the wash water may not be discharged prior to charging the mixer with a new batch, or where the purchaser may direct the driver to add more water to make the concrete more fluid for easy filling of the forms.

MIX DESIGN

The "Recommended Practice for Selecting Proportions for Concrete" (ACI 613-54), the standard of the American Concrete Institute, was used as the design basis for all the mixes, with a slight modification for the mixes containing fly ash. Increased coarse-aggregate contents over those recommended by the ACI were again used in the fly-ash mixes in the amounts found to be satisfactory in previous studies using the same materials.

Three mixes were investigated, namely, 5.5 sacks of cement with no fly ash and 4.5 sacks of cement with, respectively, 100 and 200 pounds of fly ash per cubic yard of concrete. The cement and fly-ash contents were selected to yield approximately equal strengths between mixes for a given slump in the range most normally employed in construction. All mixes were designed originally for a slump of about four inches.

MATERIALS

The concrete materials were the same as those used and reported previously. The coarse aggregate was one-inch-maximum-size natural gravel, the fine aggregate was a natural sand having a fineness modulus of 3.0, the cement consisted of a blend of equal amounts of Huron, Peninsular, and Peerless brands, and the fly ash was from the St. Clair station.

Results of tests on all of these materials have been reported previously, the fly ash in Report No. 2211-8-P and the cement in Report No. 2211-10-P.

FABRICATION OF SPECIMENS AND TEST PROCEDURES

The methods of mixing, fabricating, curing, and testing were generally the same as used previously. The principal variation was in the addition of water at the mixer. Three consecutive batches were made from the same design, using the same weights of sand, gravel, cement, and fly ash. In the first batch only enough water was added to give a slump of about one inch. In the second batch, water was added to give a slump of about four inches. The third batch was made quite wet, with water being added until a slump of about eight inches was obtained. Special care was taken with the third batch to minimize segregation while molding the cylinders.

The sand was used in the moist condition in all but the last few batches of concrete made in this study. The moisture content was determined in advance of making the mixes and the batch weights were adjusted to compensate for the contained moisture.

Ten cylinders were made from each batch, and there were two repeat mixes for each cement and fly-ash combination, providing six cylinders for each age of 1, 7, 28, 90 and 365 days. These cylinders were moist-cured until time for testing.

DISCUSSION OF TEST RESULTS

A detailed tabulation of mix proportions, results of tests on fresh concrete, and compressive strengths of test cylinders is presented in Tables I-A, II-A, and III-A in the Appendix. Summaries of important aspects of these results will be presented in the body of the report.

1. CEMENT CONTENT

The mixes were designed to contain 5.5 sacks of cement per cubic yard in the concrete with no fly ash and 4.5 sacks in concrete containing fly ash. Increasing or decreasing the water from the design quantity without making compensating changes in the quantities of the other materials results in over- or under-yield and the actual cement content will be too low or too high. The quantities of sand, gravel, and water reported are based on the nominal yield, no adjustment being made for the over- or under-yield.

2. COMPRESSIVE STRENGTH

Average values of compressive strength are given in Table I. For a given slump, differences in the strength of the three mixes are not large at ages up to 28 days. At 90 days and one year there is somewhat greater variation, particularly in the mixes of medium consistency. At the later ages, the mixes with fly ash have higher strengths than the comparable mixes without fly ash but containing more cement.

At the outset of this study it was conjectured that the fly-ash mixes would not vary in compressive strength with a variation in water as much as the mixes without fly ash. Comparison can be made by determining the loss of compressive strengths between the dry and wet consistency mixes for each of the cement and fly-ash contents. These values are shown in Table II.

It appears from Table II that the fly-ash mixes are not superior to the plain cement mixes in preventing loss of strength with the addition of water. The variations in strength losses are no more than would be expected from such a variable material as concrete.

It may be noted that the concrete with 200 pounds of fly ash required slightly less water for the low slump mixes, and slightly more water for the high slump mixes, than did the concrete with no fly ash. This difference is very small, slightly more than one gallon per cubic yard of concrete.

The conclusion from this study is that the concrete producer must take as much care in controlling the water added to fly-ash concrete as he does with plain portland cement concrete unless he is willing to accept a substantial loss in strength with the wet consistency mixes.

The lack of strength improvement for the low slump, 4.5 sack mix containing 200 pounds of ash with respect to the corresponding medium slump mix at ages of 90 days and one year is perplexing. This somewhat parallels the paradoxical behavior noted in Report No. 2211-6-P wherein a diminished amount of pozzolanic strength gain was observed in the mixes rich in cement. It may be necessary to postulate for mixes having higher ash contents that a certain minimum water content may be required to insure that pozzolanic strength gain will continue.

TABLE I

SUMMARY OF RESULTS

Nominal Cement Content, sk/cu yd	Actual Cement Content, sk/cu yd	Fly Ash lb/cu yd	Net Mixing Water		Slump in.	Compressive Strength, psi				
			lb/cu yd	gal/sk		1 day	7 days	28 days	90 days	1 year
	5.47	0	234	5.11	0.8	1482	3213	4178	5238	6213
5.5	5.40	0	259	5.65	4.1	1114	2656	3562	4538	5595
	5.36	0	284	6.20	7.9	877	2133	3254	4069	5042
	4.54	100	234	6.24	0.9	1170	2963	4223	5547	6791
4.5	4.51	100	258	6.86	3.9	908	2513	3646	4933	6274
	4.44	100	288	7.68	7.8	698	1966	3188	4233	5598
	4.56	200	230	6.14	1.2	1151	2753	4243	5459	6477
4.5	4.49	200	264	7.04	4.1	853	2235	4010	5464	6375
	4.44	200	295	7.86	8.1	619	1773	2972	4541	5462

TABLE II

LOSS IN COMPRESSIVE STRENGTH OF NON-AIR-ENTRAINED PLAIN AND FLY-ASH CONCRETE DUE TO ADDED WATER

Cement Content, sk/cu yd	Fly Ash Content, lb/cu yd	Loss of Compressive Strength Between Wet and Dry Consistency Mixes, psi				
		1 day	7 days	28 days	90 days	1 year
5.5	0	605	1080	924	1169	1171
4.5	100	472	997	1035	1314	1193
4.5	200	532	980	1271	918	1015

APPENDIX

TABLE I-A

5.5—SACK REGULAR-CONCRETE DATA—LOW, MODERATE, AND HIGH SLUMPS

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content sk/cu yd	V_s**	Material Proportions lb/cu yd			W/C, gal/sk	Weight of Fresh Concrete, lb/cu ft	Slump, in.	Compressive Strength, psi				
					Sand	Gravel	Net Water				1 Day	7 Days	28 Days	90 Days	1 Year
371	3-28-56	0	5.47	0.64	1457	1815	228	4.97	149.8	1-1/4	1370	3425	4665	5740	6555
											1285	3250	4575	5565	6645
392	5-14-56	0	5.45	0.64	1481	1815	232	5.05	150.1	1/4	1570	2935	3850	5335	6200
											1580	3040	4275	5230	6115
398	5-21-56	0	5.48	0.64	1446	1815	243	5.30	150.1	1	1550	3235	3710	4945	5900
											1535	3390	3995	4610	5865
	Average	0	5.47	0.64	1461	1815	234	5.11	150.0	0.8	1482	3213	4178	5238	6213
372	3-28-56	0	5.46	0.64	1457	1815	243	5.31	150.0	5-1/4	975	2810	3920	4450	5900
											955	2630	3885	4490	6415
393	5-14-56	0	5.34	0.64	1481	1815	269	5.86	148.5	2-3/4	1140	2740	3250	4680	5425
											1125	2650	3425	4700	5245
399	5-21-56	0	5.41	0.64	1446	1815	264	5.77	149.1	4-1/4	1235	2560	3620	4610	5390
											1255	2545	3270	4295	5195
	Average	0	5.40	0.64	1461	1815	259	5.65	149.2	4.1	1114	2656	3562	4538	5595
373	3-28-56	0	5.34	0.64	1457	1815	280	6.12	148.1	8-3/4	610	1855	3320	3815	4715
											665	1875	3305	4100	4930
394	5-14-56	0	5.34	0.64	1481	1815	286	6.24	149.0	7-1/4	935	2015	3215	4185	4945
											960	2155	3270	4115	5020
400	5-21-56	0	5.41	0.64	1446	1815	286	6.24	149.9	7-3/4	1000	2455	3445	4065	5320
											1090	2440	2970	4135	5320
	Average	0	5.36	0.64	1461	1815	284	6.20	149.0	7.9	877	2133	3254	4069	5042

**Denotes volume of dry-rodded coarse aggregate per unit volume of concrete.

TABLE II-A

4.5—SACK REGULAR-CONCRETE DATA—ST. CLAIR FLY ASH—LOW, MODERATE, AND HIGH SLUMPS

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content sk/cu yd	V_s**	Material Proportions lb/cu yd			W/C, gal/sk	Weight of Fresh Concrete, lb/cu ft	Slump in.	Compressive Strength, psi				
					Sand	Gravel	Net Water				1 Day	7 Days	28 Days	90 Days	1 Year
374	4-2-56	100	4.49	0.75	1132	2126	252	6.71	150.9	3/4	1185	2970	4170	5370	6625
											1180	3200	4275	5370	6325
380	4-18-56	100	4.57	0.75	1097	2126	224	5.97	151.3	1	1100	2845	4435	5865	6875
											1075	3005	4415	5900	7210
389	5-9-56	100	4.55	0.75	1108	2126	226	6.03	150.9	1	1235	2860	3815	5405	6890
											1245	2895	4225	5370	6820
	Average	100	4.54	0.75	1112	2126	234	6.24	151.0	0.9	1170	2963	4223	5547	6791
375	4-2-56	100	4.48	0.75	1132	2126	274	7.30	151.4	4	1020	2440	3535	4680	6325
											955	2615	3695	4560	6305
381	4-18-56	100	4.54	0.75	1097	2126	243	6.47	150.7	4	820	2510	3655	4965	6360
											860	2615	3870	5055	6430
390	5-9-56	100	4.50	0.75	1108	2126	256	6.82	150.4	3-3/4	920	2510	3695	5090	5900
											875	2385	3425	5245	6325
	Average	100	4.51	0.75	1112	2126	258	6.86	150.8	3.9	908	2513	3646	4933	6274
376	4-2-56	100	4.41	0.75	1132	2126	297	7.91	149.9	7-1/4	830	2330	3550	4770*	5955
											760	2330	3285	4150	5725
382	4-18-56	100	4.48	0.75	1097	2126	275	7.34	150.0	7-3/4	550*	1835	3320	4490	5830
											660	1875	3270	4380	5655
391	5-9-56	100	4.44	0.75	1108	2126	292	7.79	149.6	8-1/4	630	1730	2825	3940	5055
											610	1695	2880	4205	5370
	Average	100	4.44	0.75	1112	2126	288	7.68	149.8	7.8	698	1966	3188	4233	5598

*Not included in average.

**Denotes volume of dry-rodded coarse aggregate per unit volume of concrete.

TABLE III-A

4.5—SACK REGULAR-CONCRETE DATA—ST. CLAIR FLY ASH—LOW, MODERATE, AND HIGH SLUMPS

Batch No.	Date Made	Fly Ash, lb/cu yd	Actual Cement Content sk/cu yd	V_s**	Material Proportions lb/cu yd			W/C, gal/sk	Weight of Fresh Concrete, lb/cu ft	Slump in.	Compressive Strength, psi				
					Sand	Gravel	Net Water				1 Day	7 Days	28 Days	90 Days	1 Year
377	4-4-56	200	4.58	0.81	824	2296	219	5.85	151.1	1-1/4	1175	2685	4400	5300	6800
											1140	2720	4505	5655	6570
383	4-30-56	200	4.55	0.81	844	2296	243	6.47	151.8	1-1/2	1085	2880	4150	5740	6235
											1135	2825	4100	5620	6235
395	5-16-56	200	4.56	0.81	835	2296	229	6.10	151.2	3/4	1165	2755	4150	4945	6500
											1205	2650	4150	5495	6520
	Average	200	4.56	0.81	834	2296	230	6.14	151.4	1.2	1151	2753	4243	5459	6477
378	4-4-56	200	4.52	0.81	824	2296	254	6.78	150.6	3-3/4	795	2525*	4240	6005	6610
											830	2175	4170	5565	6270
384	4-30-56	200	4.48	0.81	844	2296	267	7.12	150.4	4-1/4	840	2210	4010	5530	6235
											880	2365	4135	5210	6520
396	5-16-56	200	4.47	0.81	835	2296	271	7.22	149.7	4-1/4	885	1945*	3885	5230	6200
											890	2190	3620	5245	6415
	Average	200	4.49	0.81	834	2296	264	7.04	150.2	4.1	853	2235	4010	5464	6375
379	4-4-56	200	4.46	0.81	824	2296	284	7.56	149.4	8	575	1625	2860	4330	5210
											585	1645	2670	4415	5160
385	4-30-56	200	4.44	0.81	844	2296	294	7.83	149.9	7-3/4	650	1855	3180	4910	5690
											635	1835	3270	4700	5670
397	5-16-56	200	4.41	0.81	835	2296	306	8.18	149.0	8-1/2	635	1875	2740	4490	5600
											635	1800	3110	4400	5440
	Average	200	4.44	0.81	834	2296	295	7.86	149.4	8.1	619	1773	2972	4541	5462

*Not included in average

**Denotes volume of dry-rodded coarse aggregate per unit volume of concrete.