FINAL TECHNICAL REPORT
November 1, 2000 through December 31, 2001

Project Title: **FIELD EVALUATION OF PRE-CAST CONCRETE PILES USING ILLINOIS PCC COAL BY-PRODUCTS**

ICCI Project Number:	00-1/3.1B-2
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ABSTRACT

Pre-cast and pre-stressed concrete piles, approximately 12 to 18 inch diameter or side are frequently used to support heavy building and bridge structures. Use of coal combustion by-products in construction of pre-cast or pre-stressed concrete piles so far has been very limited. This is primarily due to the lack of available data demonstrating the effective use of these coal combustion residues in these piles. Therefore, the objectives of this project were to develop viable composites utilizing Illinois pulverized coal combustion (PCC) by-products, and to demonstrate their suitability for construction of pre-cast concrete piles.

The goals of the proposed study were accomplished by conducting a series of laboratory and field tests. Based on a previous study performed at Southern Illinois University – Carbondale (SIUC), two concrete composites and an equivalent conventional concrete matrix were selected to conduct further laboratory testing and construct the piles. The two concrete composites selected were: (1) 100 percent replacement of natural fine aggregate with dry PCC bottom ash; and (2) 50 percent replacement of natural fine aggregate with PCC dry bottom ash. Several samples from these concrete composites and conventional concrete were prepared and tested in the concrete laboratory. Based on the laboratory tests performed so far, the effect of replacement of natural fine aggregate with Illinois PCC dry bottom ash on long-term strength and stiffness characteristics of concrete composites is relatively insignificant.

In addition to the laboratory tests performed on concrete composites, subsurface investigation and subsequent laboratory testing on soil samples was also completed. In general, the soils at the site consisted of silty clays and clays underlain by very stiff to hard, sandy clay shale at depths of approximately 21 feet.

A total of 16 pre-cast concrete and 3 pre-stressed concrete piles were constructed and installed. All piles were 1 foot square in cross-section and varied in length from 20 to 22 feet. Piles were tested to determine their capacities to resist field loads (compression, uplift, and lateral). The field-test results show that the performance of piles made from bottom ash concrete is similar to those made from conventional concrete.

EXECUTIVE SUMMARY

The main objectives of the proposed project are to develop scientific data to demonstrate the effective coal combustion by-products from burning of Illinois coal in pre-cast piles, and to develop suitable composites containing coal combustion residues that could be used to construct pre-cast concrete piles. Although the project was intended to test pre-cast piles only, three pre-stressed concrete piles were also constructed and tested using a Pile Dynamic Analyzer (PDA).

To achieve the intended objectives, laboratory tests were performed on samples of concrete composites and a reference conventional concrete mixture, and field tests were performed on conventional reinforced concrete pre-cast piles (referred as pre-cast piles in this report) and pre-stressed concrete piles constructed using concrete composites and conventional concrete. Laboratory tests on samples included compression, split tension, and flexure at various curing ages. In addition, tests were performed to determine modulus of elasticity, Poisson's ratio, resistance to freezing and thawing, and resistance to sulphate attack. Field tests on piles were performed to determine performance of piles made with concrete composites compared to that of piles made with conventional concrete. Performance of piles was determined in terms of their capacities to resist compression, uplift, and lateral loads. Subsurface investigation and subsequent laboratory testing on soil samples was performed to determine characteristics of soils at the test site.

Within this reporting period of the project, most of the laboratory tests on concrete samples and all field tests on piles have been completed. Laboratory tests to determine resistance to freezing-thawing and sulphate attack are in progress. In addition, data interpretation from the field tests on piles is in progress and will be presented in the final report.

Laboratory Testing on Concrete Composites

Based on a previous study performed at Southern Illinois University – Carbondale (SIUC), two concrete composites and conventional concrete were selected to conduct further laboratory testing and construct the piles. The two concrete composites selected were: (1) 100 percent replacement of natural fine aggregate with PCC dry bottom ash; and (2) 50 percent replacement of natural fine aggregate with PCC dry bottom ash. Several samples were prepared and tested to determine strength, stiffness, and durability characteristics of concrete composites. Table 1 shows the mix designations with percent of different matrix constituents used to prepare the composites. Summary of laboratory test results is presented in this section.

Strength Characteristics. Strength of concrete is commonly considered its most valuable property, although, in many practical cases, other characteristics, such as durability, may in fact be more important. Nevertheless, the compressive strength test usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. Moreover, the strength of the concrete is almost invariably a vital element of structural design and is specified for compliance purposes.

Table 1: Mixture Constituents

Mixture Designation	Binders (%)		Fine Aggregates (%)		Remarks
	Portland Cement	PCC Fly Ash	PCC Dry Bottom Ash	Natural Sand	
CM	100	0	0	100	Control Mix
B50	100	0	50	50	
B100	100	0	100	0	

All matrices were prepared at a uniform water-to-cementitious ratio of 0.375 and a constant slump of 4±½ inches

Figure 1 shows the influence of curing age on compressive strength of concrete composites and conventional concrete. From Figure 1 it is clear that compressive strength of the composites increased with an increase in curing age but the rate of increase in compressive strength reduced after 28 day. Results also shows that the compressive strength of the concrete composites studied in the investigation was less than that of conventional concrete up to a curing age of approximately 60 days. However, after 90 days of curing, compressive strength of concrete composites made with Illinois PCC dry bottom ash was observed to be either higher than or equal to that of conventional concrete.

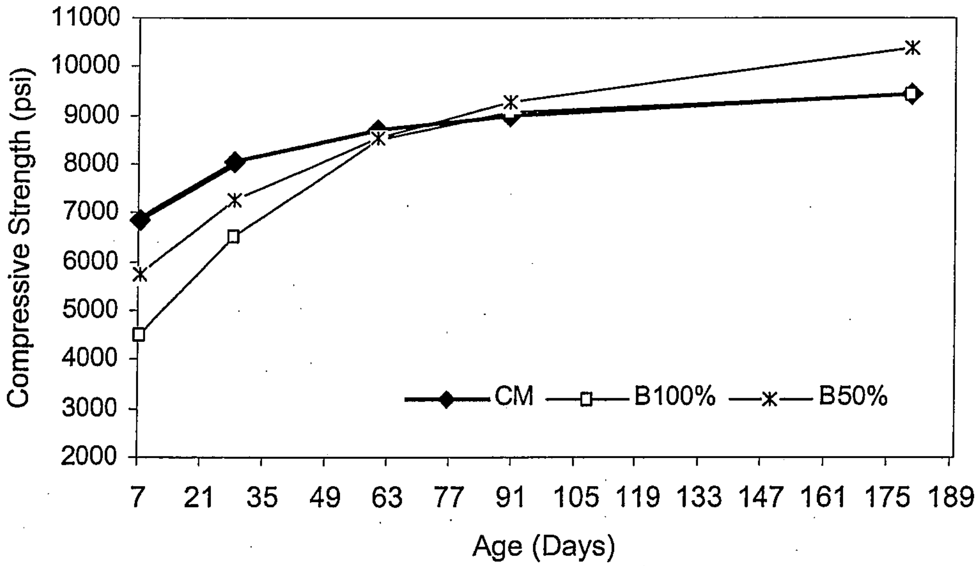


Figure 1. Influence of curing age on compressive strength of concrete composites

Before 90 days, this strength gain is attributed to continued hydration of the Portland cement to a larger extent and the pozzolanic reactions provided by the Illinois PCC dry bottom ash to a smaller extent. However, after 90 days of curing, large portion of the strength gain may be attributed to pozzolanic reactions provided by the Illinois PCC dry bottom ash. Similar trends were observed in the concrete specimens tested for splitting tensile strength and flexural strength.

Stiffness Characteristics. Stiffness characteristics for concrete composites were measured in terms of Modulus of Elasticity (MOE) and Poisson's ratio. Figure 2 shows the comparison of Modulus of Elasticity (MOE) of concrete composites with respect to conventional concrete after 28 days and 90 days of curing. Values of modulus of elasticity and Poisson's ratio are also shown in Table 2.

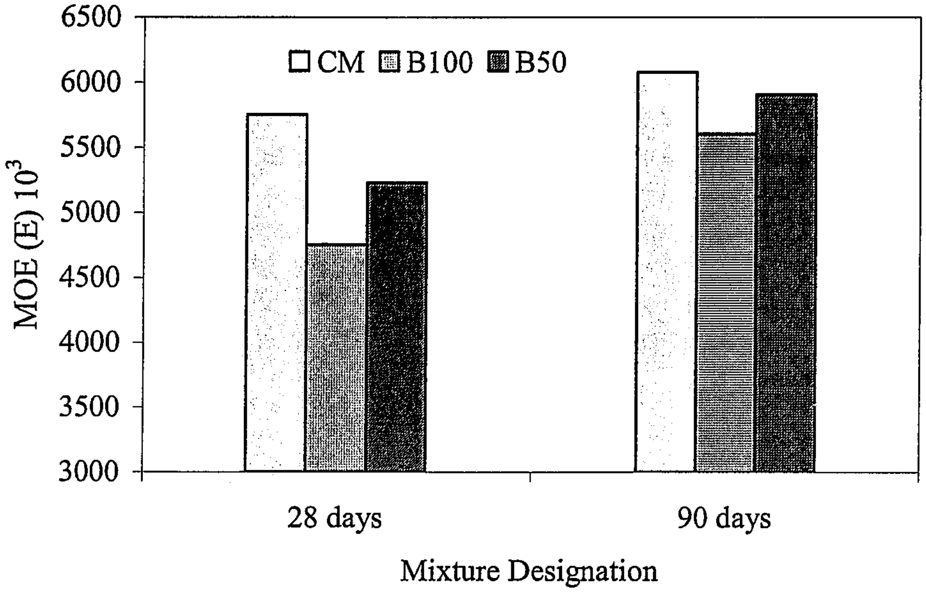


Figure 2. Comparison of Modulus of Elasticity of concrete composites

Table 2: Modulus of Elasticity (E) and Poisson's Ratio (μ) of the Concrete Composites

			Mixture Designation		
			CM	B100	B50
Average Unit Weight (psf)			155.69	147.12	151.22
fc' (psi)	Curing Age (Days)	28	8048	6514	7264
		90	8981	9055	9267
Static Modulus of Elasticity E (psi)	Curing Age (Days)	28	5.7511E+06	4.7528E+06	5.2302E+06
		90	6.0753E+06	5.6038E+06	5.9074E+06
Poisson's Ratio (μ)	Curing Age (Days)	28	0.1471	0.1663	0.1586
		90	0.1553	0.1961	0.1792

Figure 2 and Table 2 show that MOE of concrete composites (B100 and B50) is less than that of conventional concrete at both curing ages. However, the difference between MOE of concrete composites and conventional concrete is less after 90 days of curing. MOEs of concrete composites, B100 and B50, were calculated to be 17% and 9% less than that of conventional concrete, CM, after 28 days of curing, respectively. After 90 days of curing the MOE of B100 and B50 were 8% and 3% less than that of CM, respectively. The results presented show that the replacement of natural fine aggregate with Illinois PCC dry bottom ash, has insignificant effect on the higher-age modulus of elasticity of the concrete composites studied in this investigation.

Durability Characteristics. Tests on durability of concrete composites in terms of resistance to freezing and thawing and resistance to sulphate attack are in progress. Results from these tests will be presented in the final technical report.

Subsurface Investigation

Subsurface investigation at the site consisted of drilling two borings. One of the borings was drilled to a maximum depth of 25.5 feet and the other boring was drilled to a depth of 20.4 feet. The borings were drilled using a truck mounted CME 75 rotary drill. Standard Penetration Tests (SPT's) were performed using an automatic hammer. Split spoon samples and relatively undisturbed Shelby tube samples were obtained at various depths.

In general, the soil stratigraphy at the site consisted of medium stiff to stiff, brown silty clay to depths of approximately 21 feet. The silty clay is underlain by very stiff to hard, sandy clay shale to the maximum depths explored (34 feet). Both the borings were terminated at spoon refusal (more than 50 blows required to penetrate first 6 inches of the split spoon).

Construction and Testing of Piles

A total of 19 piles were constructed at the facility of Egyptian Concrete Co., in Salem, Illinois. All piles were 1 foot square in cross-section and varied in length from 20 to 22 feet. Out of the 19 piles, 16 piles were pre-cast, reinforced concrete and 3 piles were pre-stressed concrete piles. All piles were appropriately instrumented to obtain the performance data during testing. Piles were driven at the site located in the Carterville, Illinois campus of SIUC. A diesel hammer, Delmag D-15, with a rated energy of 27,100 foot-pounds was used to drive the piles. Three of the pre-cast concrete piles and all three pre-stressed concrete piles were tested during driving using Pile Dynamic Analyzer (PDA). Remainder of the pre-cast concrete piles were tested to determine performance of piles to resist compression, uplift, and lateral loads. The results from field-testing of piles show that under field loads the performance of piles made from bottom ash concrete is similar to those made from conventional concrete.

OBJECTIVES

Use of coal combustion by-products in construction of pre-cast and pre-stressed concrete piles so far has been very limited, if any. This is primarily due to the lack of technical data to convince the engineering community that coal combustion by-products could be used in pre-cast and pre-stressed concrete piles without jeopardizing long-term performance of the foundations to resist the anticipated loads. The main objectives of the proposed project are:

(1) to develop scientific data to demonstrate the effective use of coal combustion by-products from burning of coal in Illinois in pre-cast concrete piles, and

(2) to develop suitable composites containing coal combustion by-products that could be used to construct pre-cast concrete piles.

INTRODUCTION AND BACKGROUND

More than three million tons of fly ash, bottom ash, and boiler slag are currently produced annually in Illinois from coal burning power-generating plants. The largest volume of coal combustion residues in Illinois consists of fly ash and bottom ash. Typically, most of these ashes are disposed off by hauling to landfills. Because of the increasing costs associated with coal combustion ash disposal and the environmental regulations in place; the federal, state and local agencies, as well as the private sector have been taking an active part in sponsoring and promoting a growing number of programs and research studies to develop alternate methods for profitable and environmentally safe uses of these residues.

Pre-cast and pre-stressed concrete piles, approximately 12 to 18 inch diameter or side are frequently used to support heavy building and bridge structures. It is estimated that approximately ¼ million cubic feet of concrete is used in conventional, reinforced concrete, pre-cast piles (referred as pre-cast piles in this report) and pre-stressed concrete piles every year in a small region of the country comprising of Southern Illinois and St. Louis, Missouri. Use of coal combustion by-products in construction of pre-cast and pre-stressed concrete piles so far has been very limited. This is primarily due to the lack of available data demonstrating the effective use of these coal combustion residues in these types of piles.

Based on a previous study performed at Southern Illinois University – Carbondale (SIUC), two concrete composites and conventional concrete were selected to conduct further laboratory testing and construct the piles. The two concrete composites selected were: (1) 100 percent replacement of natural fine aggregate with PCC bottom ash; and (2) 50 percent replacement of natural fine aggregate with PCC bottom ash. To achieve the intended objectives, a number of laboratory tests were performed to determine index properties of raw materials and strength, stiffness, and durability characteristics of the trial composites. Laboratory tests on cylindrical and beam-shaped samples included: compression, splitting tension, flexure, elastic modulus and Poisson's ratio, resistance to freezing and thawing, and resistance to sulphate attack. Field tests on piles were performed to determine performance of piles made with concrete composites compared to that of piles made with conventional concrete. Performance of piles was determined in terms of compression, uplift, and lateral load capacities of the piles. Subsurface investigation and subsequent laboratory testing on soil samples was performed to determine characteristics of soils at the test site.

EXPERIMENTAL PROCEDURES

Material Preparation for Laboratory Test

The materials used in this investigation were Type I Portland Cement as binder, crushed limestone as a coarse aggregate, natural sand and Illinois PCC dry bottom ash as a fine aggregate, and water.

ASTM Type I Portland Cement was purchased from Lonestar made at Greencastle, Indiana through Egyptian Concrete Company located in Salem, Illinois. The cement was received in standard 94-pound bags. Each cement bag was opened and stored in sealed 55-gallon plastic drums with polyethylene liner inside. To prevent moisture infiltration, the drums containing cement were resealed after each use.

The crushed limestone coarse aggregate was obtained from a Southern Illinois quarry, Anna, Illinois. In order to remove the deleterious materials, the coarse aggregate gravels were thoroughly washed by using tap water. The washed gravels were then placed on a polyethylene sheet on the laboratory floor and air-dried by using rectangular box fans at room temperature (77 ± 3° F). The coarse aggregates were collected and stored in 55-gallon steel drums at moisture content of approximately 0.1%.

The natural siliceous fine aggregate was obtained from a Southern Illinois quarry through the Illini Ready-Mix Plant, Carbondale. The natural sand was air-dried by using box fans at room temperature (77 ± 3° F). The dry sand was collected and stored in 55-gallon steel drums, after the moisture content reached approximately 0.2%.

PCC dry bottom ash was obtained from City Water Light and Power Company (CWLPC) in Springfield, Illinois. The CWLPC uses coal from Elkhart, Illinois coal mine. Prior to use, the bottom ash was sieved, using a U.S. standard #4 sieve, and then spread inside the plastic tub to be air-dried by using box fans at room temperature (77 ± 3° F). The moisture content of the bottom ash was monitored daily until it reached 0.7%, after which the PCC bottom ash was stored and sealed in 55-gallon plastic drums. The moisture content of all raw materials was monitored biweekly except for Portland cement and PCC fly ash.

Mixing Procedure for Laboratory Tests

Mixing procedure is an important parameter of sample preparation, if overlooked, it can have an adverse affect on the strength and durability of short, and long-term characteristics of concrete. In order to obtain reproducible results, the following mixing procedure was adopted:

(1) The absorption capacity and moisture content of the raw materials were determined and accounted for in all mixture proportion designs.

(2) The specified quantities of cement, PCC bottom ash, fine and coarse aggregate, water, and WRDA 19 were weighed using electronic scale (maximum capacity of 125 lbs, accurate to 0.02lb). The batch volume of 0.6 cubic feet and water to cementitious material ratio (w/c) of 0.375 were kept constant for all mixtures.

(3) An electronically driven counter-clock revolving pan mixer was used for batch preparation. The pan was cleaned and dried prior to introduction of the raw materials. Mixing was started by placing the coarse aggregate into the rotating pan and allowing it to blend with 1/3 of the mix water for a period of 3 minutes. Subsequently, fine aggregates were slowly added and blended with another one third of the measured mix water, and mixing continued for another 3 minutes. Next, the measured cement and the remaining mix water were gradually added to the mixer. The mixing process continued for an additional 3 minutes to ensure proper blending.

(4) After mixing was completed, the slump test was performed as described by ASTM C 143 “Standard Test Method for Slump of Hydraulic Cement Concrete.” Each slump test was recorded to ensure identical consistency for the same matrix proportions used throughout the investigation. The matrix used for the slump tests was then placed back into the mixer and WRDA 19 was added to increase the slump. The blending was continued for another two minutes. The amount of WRDA was selected such that the final slump is approximately 5-inches. After checking the slump again, matrix used for the slump tests was then placed back into the mixer and continued for another one minute.

(5) The matrix prepared was used to prepare 4-inch diameter and 8-inch high samples for compression, split tension, modulus of elasticity and Poisson's' ratio, and resistance to freezing and thawing tests. Beam-shape samples of size 4x4x14 inches were prepared for flexural testing. Beam-shape samples of size 2x2x11.25 inches were prepared for resistance to sulphate attack tests.

Testing Procedure for Fresh Concrete Samples

Setting Time. The time of setting was determined using the procedure stated in ASTM C 403 "Time of Setting of Concrete Mixture by Penetration Resistance." The fresh matrix was screened through a No.4 Sieve (3/16 inch openings). The mortar of the matrix was then placed in a 6 in. (152 mm) diameter by 6 in. (152 mm) high plastic cylinder. The cylinder was filled to within 1 in. (25 mm) of the top, hand rodded 25 tamps for proper consolidation. The cylinder was then stored in a room with temperature in the range of 68 to 77° F (20 to 25° C). After approximately one hour from the initial contact between cement and water, the penetration resistance of a one-inch square needle attached to the penetrometer was recorded. Subsequent readings with smaller needles were taken at approximately 1/2 hour intervals until a penetration resistance of 4000 psi (27.6 MPa) or more was reached. The test was then terminated.

Bleeding. The bleeding test was performed in accordance with ASTM C 232 " Standard Test Methods for Bleeding of Concrete." The fresh matrix was placed into a pre-tared steel bucket in three equal layers with each layer hand rodded with 25 tamps. The top layer was troweled, the time recorded, and the filled bucket was weighed and then covered with a plastic sheet to prevent evaporation of the bleeding water. The filled bucket was stored in a room with temperature in the range of 65 to 75° F (18 to 24° C). The accumulated surface water was drawn off using pipette and placed into a sealed pre-tared beaker at approximately 10 minutes intervals during the first 40 minutes and at approximately 30 minutes intervals subsequently until bleeding ceased. Mass of the bleeded water was measured and recorded.

Testing Procedure for Hardened Concrete Samples

Tests performed to obtain the hardened characteristics of concrete consisted of compression, splitting-tensile, modulus of elasticity, Poisson's' ratio, and flexural test. The description of each testing method is given below.

Compression Test. The 4 x 8 in (101.6 x 203.2 mm) cylindrical specimens were capped with a thin layer of sulfur on both ends, as specified by ASTM C 617 “Standard Practice for capping cylindrical concrete specimens.” The reason for capping was to ensure that the ends of the specimen were plane and perpendicular to the axis of loading. To ensure the application of uniaxial compression loading, the surfaces of the upper and lower platens of the compression machine were cleaned and the specimen was placed on the hardened steel surface of the lower platen, aligning the specimen with the center of the upper spherically seated platens. Following the specification of ASTM C 39 “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.” The load was applied continuously at a rate of 22,500 lb/min until failure.

Splitting-Tensile Test. The splitting-tensile test was performed in accordance with ASTM C 496 “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.” Prior to testing, each specimen was marked with a center line for accurate positioning under center loading. The 4 x 8 inch (101.6 x 203.2 mm) cylindrical specimen was placed with axis parallel to the loading platens. Two plywood bearing strips 1/8 inches (3.2mm) thick, 1 inch (25.4mm) wide, and 10 inch (254mm) long, were placed between the specimen and the upper and lower bearing surfaces. The load was applied uniformly, at a constant rate of 7500 lb/min, along the length of the specimen. The specimen splits into two halves when failure occurred. The failure load was recorded.

Flexural Test. The flexural test followed the specification of ASTM C 78 " Standard Test Method for Flexural Strength of Concrete (using simple Beam with Third-Point Loading)." Prior to testing, each 4 x 4 x 14 in (101.6 x 101.6 x 355.6 mm) specimen was marked with four lines for accurate positioning under loading heads. The load was applied continuously at a rate of 13 lb/min until the failure occurred.

Static Modulus of Elasticity and Poisson's Ratio Test. Static modulus of elasticity test was conducted by using a combined compressometer and extensometer. The test procedure recommended by ASTM C 469 " Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression" was followed. The compressometer-extensometer consisted of three cast aluminum-magnesium alloy yokes, stainless steel control rods, and two dial indicators with a range of ± 0.2in (5.08mm), and accurate to 0.0001 of an inch (0.0025 mm). The dial indicator for the compressometer was connected to the two outside yokes hinged and pivoted on a rod at the opposite side which provided an axial gage factor of 2.0. The actual gage length was 5.5 inches (133 mm) which resulted in an effective gage length of 11 inches (279 mm). The indicator for the extensometer was connected to the two ends of the middle yoke. The compressometer-extensometer measured deformation in both axial and transverse directions. Axial deformation provides the reading for static modulus of elasticity and transverse deformation provides the reading for Poisson's' ratio.

All 4 x 8 inch (101.6 x 203.2 mm) cylindrical specimens tested for modulus of elasticity and Poisson's' ratio were capped with sulfur mortar to ensure plainness and subjected to a uniaxial compression loading. The method of loading was the same as that for the compression test, described earlier.

Resistance to Freezing and Thawing. The freezing-thawing tests to examine resistance of concrete composites with respect to freezing and thawing of subsurface applications are in progress. The procedure used is explained below.

The dry weight of the 4 x 8 inch (101.6 x 203.2 mm) cylindrical specimens for the freezing-thawing test were recorded and cured in water for 28 days before testing. The specimens were placed on top of two 1/8 in. (3 mm) diameter rods located at the bottom of steel compartments to prevent contact with the bottom of the steel compartments thus providing a uniform freezing process for each specimen. Tap water was then added into the compartments to surround the specimens by at least 1/8 in. (3 mm) on all sides. The freezer was pre-chilled to approximately -20° F (-29° C) prior to placing the test specimens. After placing the specimens in the freezer, the freezing set point was reset to 0° F (-18° C). The reasons for doing this was to verify that the temperature of air in the freezing camber reaches 0° F (-18° C) within one hour after the specimens were loaded. This temperature was then maintained throughout the freezing period. After 24 hours of freezing, the compartments were removed and stored in a room with a temperature of 77 ± 3° F for thawing for 24 hours. After every cycle, loose particles were collected and placed in an oven to dry for 24 ± 1 hours and then weighed. Mass loss was calculated as a percentage of the specimen's original dry mass. Similar cycles of freezing and thawing will be performed each day until completion of 30 to 50 cycles, or until the specimens had lost more than 1.0% of their original dry mass.

Construction of Pre-Cast and Pre-Stressed Concrete Piles

A total of 19 piles were constructed using the forms available at Egyptian Concrete in Salem, Illinois. All piles were 1 foot square in cross-section and varied in length from 20 to 22 feet. Out of the nineteen piles, 16 were pre-cast concrete piles (5 piles from each of the concrete composites and 6 piles from control mix) and 3 piles were pre-stressed concrete piles (one pile from each of the concrete composites and one pile from control mix). All piles were appropriately reinforced and instrumented to obtain the performance data during testing.

Reinforcement cages for all piles were first prepared and then instrumentation attached to the reinforcement cage. For lateral load piles, instrumentation included placement of a single inclinometer casing at the center of the pile. Seven-inch diameter O-Cells, boxed in steel cases of the same cross-section as that of piles, were used for piles to be tested using O-Cells. All piles to be tested in axial compression and axial pullout, and piles to be tested using O-Cells were instrumented with vibrating wire rebar strain meters (model 4911).

The completed reinforcement cages were placed in the forms and concrete was placed using free fall. Fresh concrete in the forms was appropriately vibrated. After two days piles were taken out of the forms stacked. Piles were allowed to cure placing plastic cover on them. All piles were then transported to the site in Carterville, Illinois. Figure 3 shows a picture of pile construction in progress.

Installation of Piles

Piles were driven at the site located in the Carterville, Illinois campus of SIUC. A single-acting diesel hammer, Delmag D15, with a rated energy of approximately 27,100 ft-lbs was used to drive the piles. Each pile was first driven two feet into the ground and then was checked for plumbness. The pile was then driven into the ground till it encountered the specified resistance. Resistance to pile driving was measured through driving of piles in terms of number of blows required to drive each of the pile. Figure 4 shows a picture of installation of piles in progress.

Figure 3. Pile construction in Progress

Figure 4. Pile Driving in Progress

Construction of Reaction Piles

A pair of reaction piles was needed to apply compressional load on pile to be tested in axial compression. After installation of test piles, two reaction piles were constructed for each of the test piles to be tested in compression. Reaction piles were installed by drilling 12-inch diameter holes to depths of 25 feet and filling the holes with concrete. Required reinforcement was lowered into the holes before placement of concrete. All holes were drilled with a high capacity, rotary drill rig CME 750 mounted on an All Terrain Vehicle (ATV). Figure 5 shows a picture of construction of reaction piles in progress.

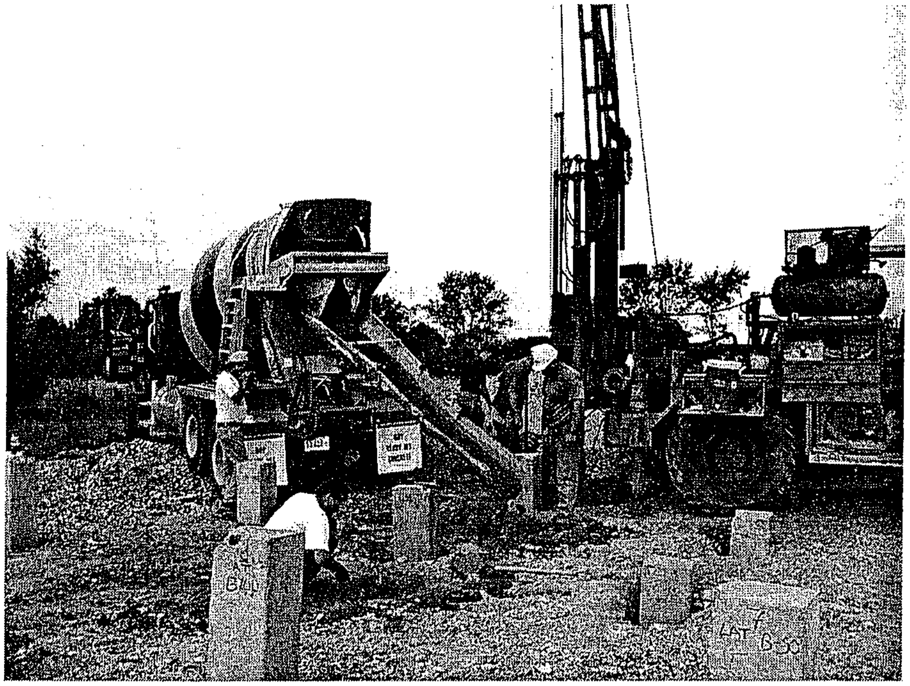


Figure 5. Construction of Reaction Piles in Progress

Field Testing of Piles

The following tests were performed on the piles. A total of 18 piles were tested.

Pre-Cast Concrete Piles

- Pile Dynamic Analyzer (PDA) testing on one pile of each concrete composite and one test on conventional concrete pile (a total of three tests)
- Osterberg Cell (O-Cell) test on one pile of each concrete composite and one test on conventional concrete pile (a total of three tests)
- Axial compression load test on one pile of each concrete composite and one test on conventional concrete pile (a total of three tests)
- Axial pull-out load test on one pile of each concrete composite and one test on conventional concrete pile (a total of three tests)

- Lateral load test on one pile of each concrete composite and one test on conventional concrete pile (a total of three tests). Load deformation characteristics of reaction pile made from conventional concrete was also measured.

Pre-Stressed Concrete Piles

Originally it was planned to construct and test only pre-cast concrete piles. Construction and testing of three pre-stressed concrete piles were added to explore possibilities of using coal combustion residues in pre-stressed concrete piles. Due to budget constraints, these piles were constructed to perform PDA testing only.

The load testing was carried out in general compliance with the pertinent ASTM Standards. O-cell and top load compression tests were carried out according to ASTM D1143 and axial tension tests were performed according to ASTM D3689. Lateral load tests were carried out in general compliance with ASTM D3966.

For all of the axial load tests (O-cell, tension and top load), each loading increment was held constant for eight minutes by manually adjusting the pressure of the loading device. Loads were removed in five decrements, each of which were held constant for four minutes.

<u>Lateral load tests.</u> A 9-inch O-cell was used to apply the loading increments for the lateral load tests. The loading increments were applied in accordance with the Standard Loading Schedule as per ASTM D3966. The applied load was determined from the cell's pressure versus load calibration. A vibrating wire load cell was also used as a check on the applied load. Reaction was provided by either a reaction shaft or by another test pile. Testing continued until the pre-determined maximum load was reached. The load was subsequently removed in four decrements, according to the Standard Loading Schedule.

<u>Axial tension tests.</u> A center-hole jack was used to apply the loading increments for the tension tests. Reaction was provided by a compound steel beam set over the test shaft and resting on wooden dunnage at each end. A Dywidag threadbar was coupled to the main reinforcing of the test shaft, passed through the reaction beam and the center-hole jack, and secured with a 2" thick steel plate and an anchor nut. The applied load was determined from the center hole jack's pressure versus load calibration. A vibrating wire load cell was also used as a check on the applied load. The load was increased until the ultimate strength of the Dywidag bar was approached.

<u>Axial compression tests.</u> A 9-inch O-cell was used to apply the loading increments for the top load tests. The applied load was determined from the cell's pressure versus load calibration. A vibrating wire load cell was also used as a check on the applied load. Reaction was provided by a compound steel beam, set over the test shaft and anchored to adjacent reaction piles on either end. The load was increased until the ultimate strength of the reaction shaft Dywidag bars were approached.

O-cell tests. O-cell tests started by pressurizing the O-cell in order to break the tack welds that hold the cell closed (for handling and construction of the shaft) and to form the fracture plane in the concrete surrounding the base of the O-cell. After the break occurs, O-cell was immediately depressurize and then loading was started. O-cell load testing was performed by pressurizing the O-cell. The applied load was determined from the cell's pressure versus load calibration. The load was increased until the ultimate capacity of the side shear resistance above the O-cell was reached and/or the maximum stroke of the O-cell was approached.

Pile Dynamic Analyzer (PDA) Tests. Dynamic measurements of strain and acceleration during PDA testing were taken two feet below the head of the test piles. Signals from these strain and acceleration signals were converted to forces and velocity by the PDA. The PDA then calculated values for the maximum transferred hammer energy, the maximum compression stress at the gage location, the maximum computed tension stresses in the piles, and approximate pile capacities. Figures 6 through 11 show pile testing in progress.

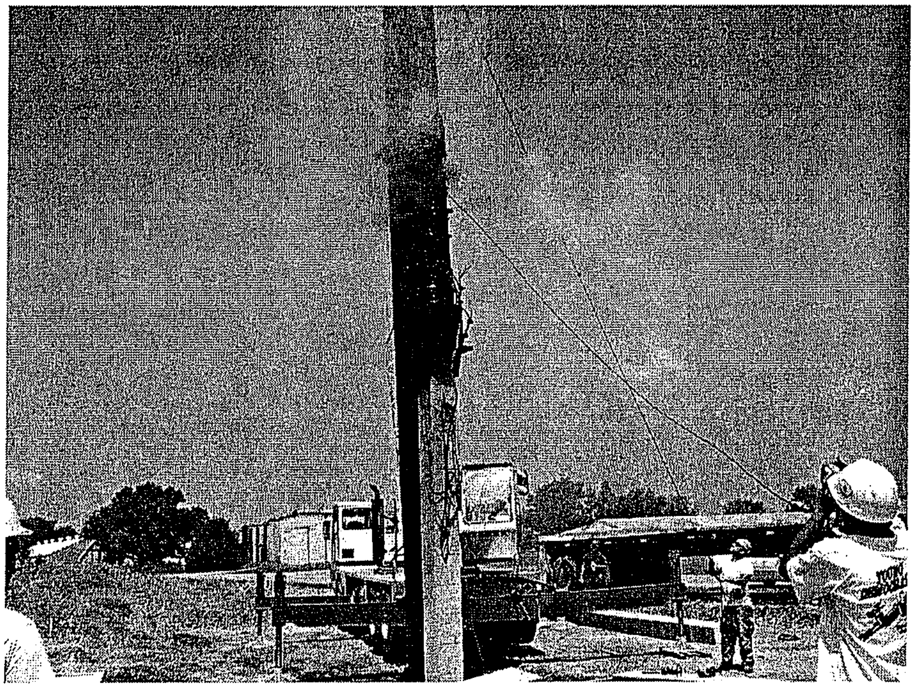


Figure 6. Pile Dynamic Analyzer (PDA) Testing in Progress

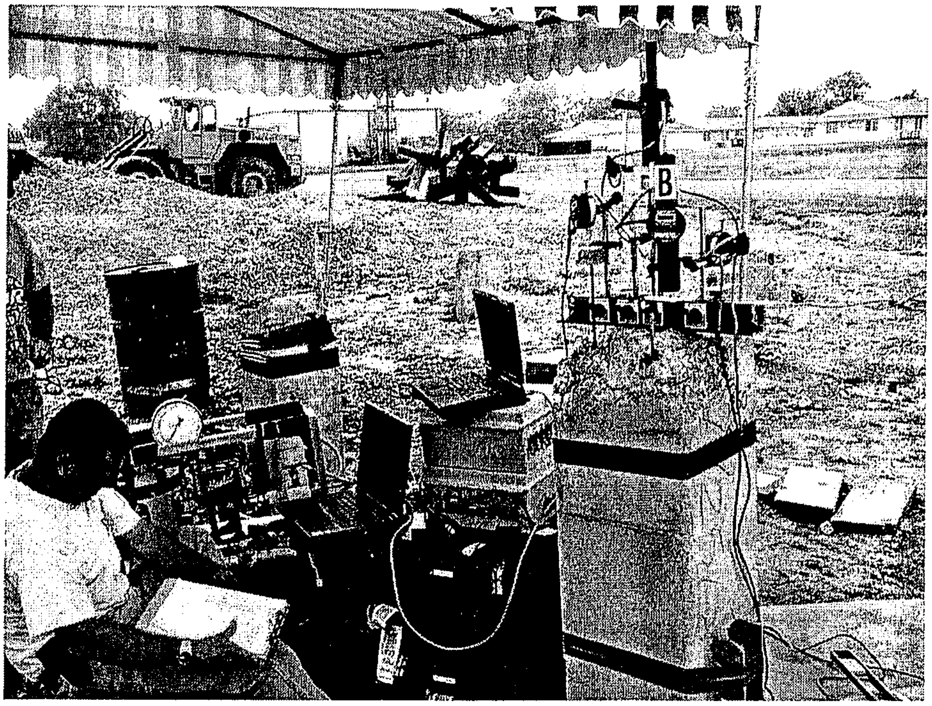


Figure 7. Osterberg Cell (O-Cell) Test in Progress

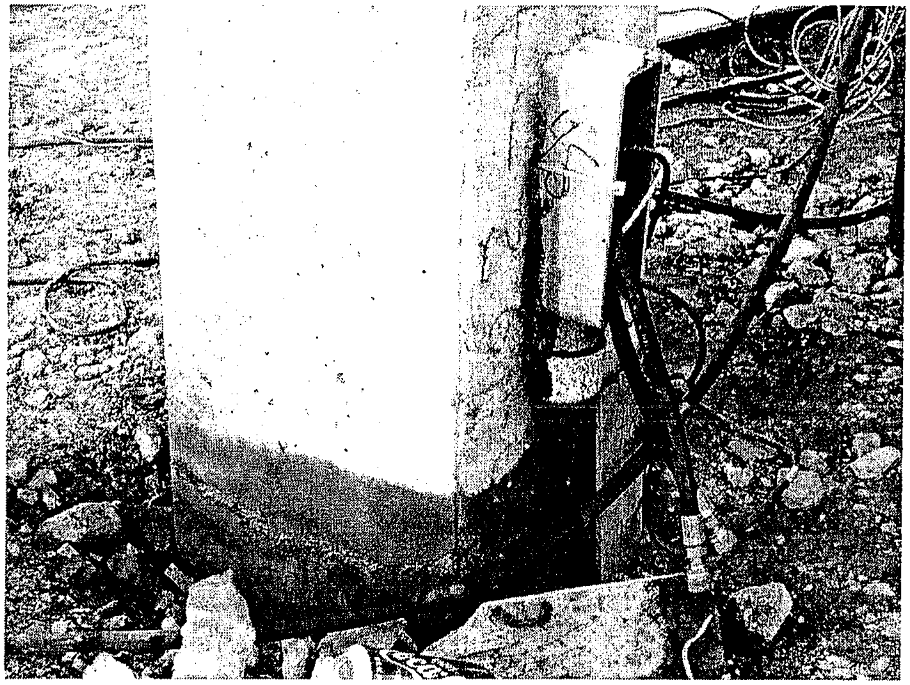


Figure 8. Pile pushed out of Ground during Osterberg Cell Test

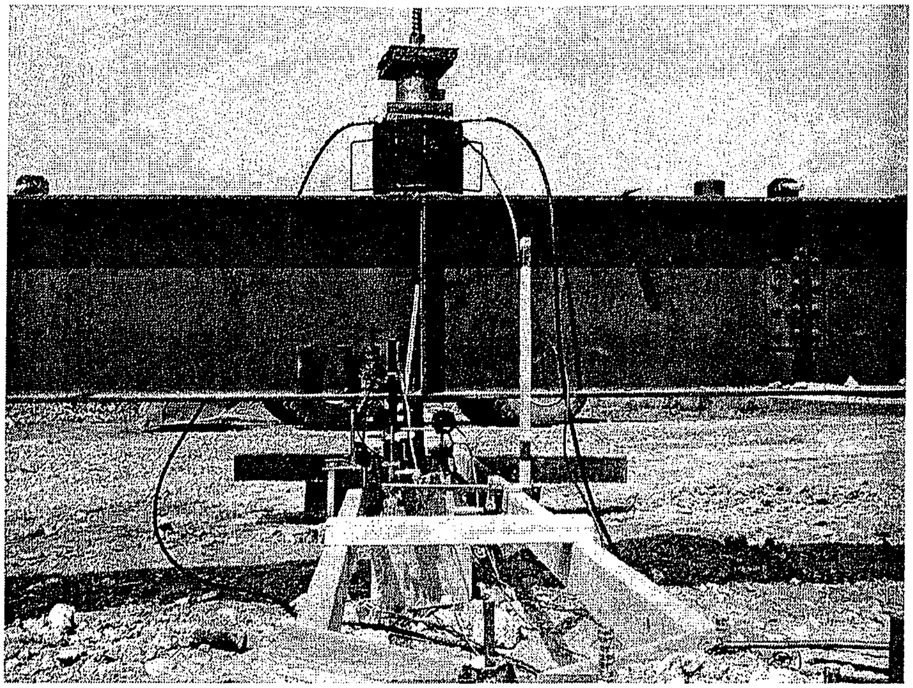


Figure 9. Axial Pull-out Test in Progress

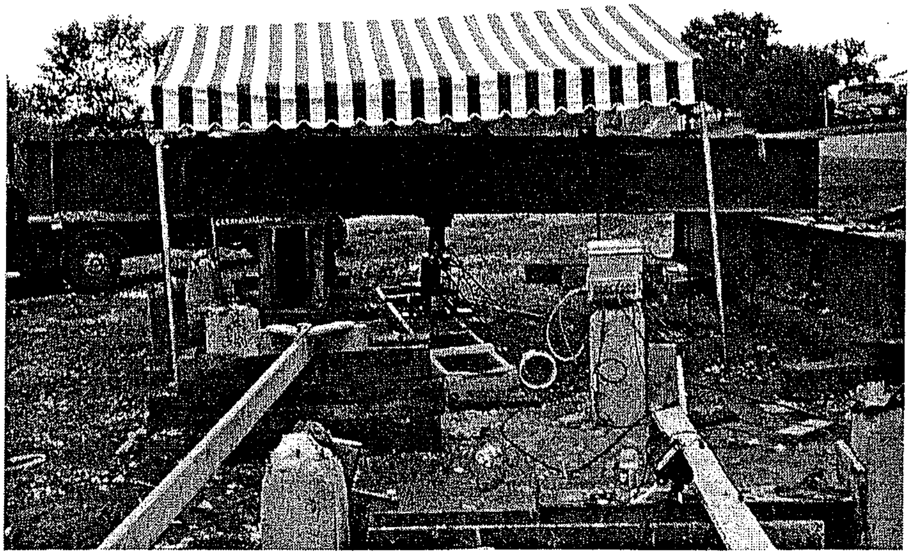


Figure 10. Axial Compression Test in Progress

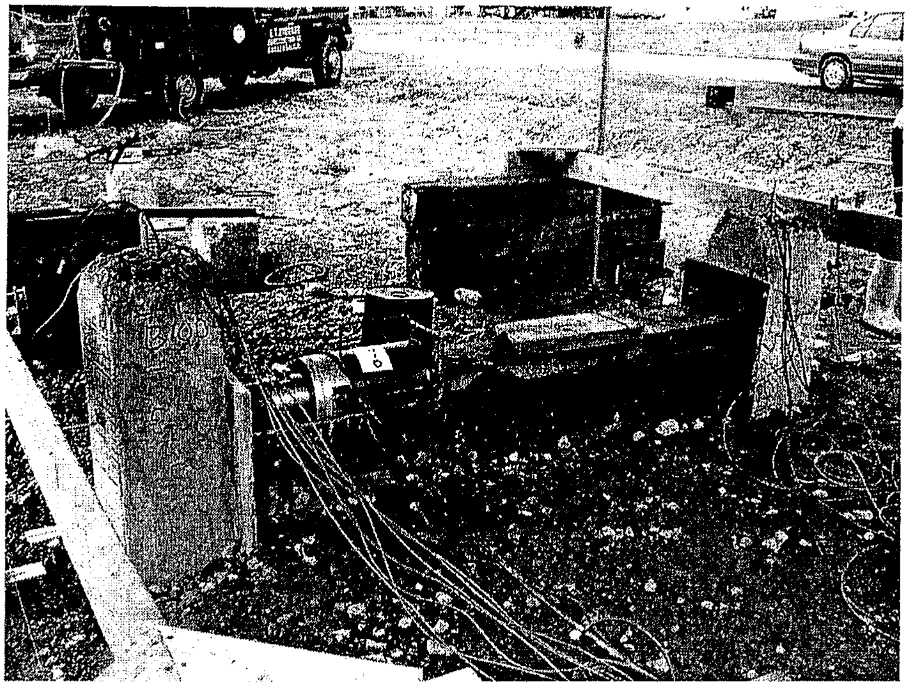


Figure 11. Lateral Load Test in Progress

RESULTS AND DISCUSSION

Laboratory Testing on Concrete Composites

A total of three Portland cement based composites having different matrix constituents and proportions were tested. Mixture designation and percent of different matrix constituents used to prepare the composites are presented in Table 1. Table 3 and 4 provide chemical composition and physical properties of Portland cement, respectively. Table 5 provides chemical composition of Illinois PCC dry bottom ash and Table 6 provides Physical Properties of dry bottom ash, natural siliceous fine aggregate, and limestone coarse aggregates.

Table 1: Mixture Constituents (The same as presented in Executive Summary)

Mixture Designation	Binders (%)		Fine Aggregates (%)		Remarks
	Portland Cement	PCC Fly Ash	PCC Dry Bottom Ash	Natural Sand	
CM	100	0	0	100	Control Mix
B50	100	0	50	50	
B100	100	0	100	0	

All matrices were prepared at a uniform water-to-cementitious ratio of 0.375 and a constant slump of 4±½ inches

Table 3: Chemical Compositions of Portland Cement

Chemical Compositions	Test Results (%)	Standard Limits (ASTM C 150)
Calcium Oxide (CaO)	62.62	None
Magnesium Oxide (MgO)	1.24	Maximum 6.0%
Sulfur Trioxide (SO3)	3.32	Maximum 4.5%
Loss on Ignition (%)	0.95	Maximum 3.0%
Tricalcium Silicate (C_3S)	56.00	None
Tricalcium Aluminate (C_3A)	10.00	Maximum 15.0%
Insoluble Residues	0.35	Maximum 0.8%
Total Alkali	0.59	None

Table 4: Physical Properties of Portland Cement

Physical Properties	Test Results	Standard Limits (ASTM C 150)
Compressive Strength (psi)		
3-day	3500	Minimum 1800
7-day	5060	Minimum 3500
Surface Area, Blaine (m^2/kg))	342	Minimum 280
Wagner (m^2/kg)	192	Minimum 160
Setting Time, minutes		
Vicat Initial	N/A	Minimum 45
Vicat Final	80	Maximum 375
Autoclave Expansion, %	0.034	Maximum 0.80%
Air content, %	8.3	Maximum 12%

Table 5: Chemical Properties of Illinois PCC Dry Bottom Ash

Chemical Composition	PCC Dry Bottom Ash (%)	Standard Limits (ASTM C 618)
Silicon Dioxide (SiO2)	46.84	---
Aluminum Oxide (Al2O3)	14.36	---
Iron Oxide (Fe2O3)	18.65	---
Total (SiO2 + Al2O3 + Fe2O3)	79.85	50% Min
Sulfur Trioxide (SO3)	0.33	5.0% Max
Calcium Oxide (CaO)	7.24	---
Magnesium Oxide (MgO)	1.04	---
Loss on Ignition	4.21	6% Max
Free Moisture	N/A	3% Max
Available Alkalies as Na2O	1.73	1.5% Max
Potassium Oxide (K2O)	1.20	---
Others (P2O5, TiO2, and etc.)	2.10	---

Table 6: Physical Properties of Dry Bottom Ash, Natural Siliceous Fine Aggregate, and Limestone Coarse Aggregates

Physical Modulus		Fine Aggregate		Coarse Aggregate
		PCC Dry Bottom Ash	Natural Sand	
Fineness Modulus		2.67	2.80	6.10
Specific Gravity	Oven Dry	2.40	2.65	2.64
	Saturated Surface Dry	2.52	2.66	2.67
Absorption (%)		10.00	0.50	0.75
Organic Impurities		None	None	---
Clay Lump & Friable Particles (%)		9.80	1.75	---
Size (inches)	Maximum	---	---	1
	Maximum Nominal	---	---	¾
Rodded Unit Weight (pcf)	Oven Dry	---	---	93.50
	Saturated Surface Dry	---	---	94.20
Void Ratio (%)		---	---	43.75

Strength of concrete is commonly considered its most valuable property, although, in many practical cases, other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, compressive strength test usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. Moreover, the strength of the concrete is almost invariably a vital element of structural design and is specified for compliance purposes.

The detailed mechanism by which concrete hardens and gains strength is not completely understood. It is generally believed that the development of strength is due to the growth of interlocking crystals and cohesion developed in a gelatinous substance that is produced during the hydration process of cementing materials. Compressive and tensile strengths of concrete are influenced by several factors, including matrix constituents (type and surface texture of aggregates), type and degree of densification, mixture proportions, and curing age. Out of these factors, mixture proportions and curing age have the largest influence on the strength properties of concrete. Influence of curing age and mixture proportions on the strength properties of concrete composites selected for this study is discussed below.

Strength Characteristics

Based on the information obtained form the manufactures of pre-cast and pre-stressed concrete piles, target compressive strength of 5000 psi was selected for all concrete composites. Quantity of cement per yard of concrete for all mixtures was kept constant at 650 lb (the same as that used by several manufactures of pre-cast and pre-stressed concrete piles). Water-to-cementitious material ratio (w/c) for all mixtures was kept constant at 0.375. In order to obtain workable concrete, water reducer (WRDA 19) was used. The amount of WRDA 19 in each mixture was selected so as to get a slump of approximately 4±½ inches inches.

Compression strength tests were performed on cylindrical samples of size 4 x 8 inches. Samples were tested at curing ages of 7, 28, 60, 90, and 180 days. Compressive strength (f_c') of concrete composites measured at various curing ages is presented in Table 7. In addition, percentage increase in compressive strength with respect to 28 days strength is presented in the table.

Table 7: Compressive Strength (f_c') of Concrete Composites

Mixture Designation		Curing Age (Days)				
		7	28	60	90	180
CM	f_c' (psi)	6840	8048	8688	8981	9452
	% Respect to 28 Days	85	100	108	112	117
B100	f_c' (psi)	4525	6514	8485	9055	9446
	% Respect to 28 Days	69	100	130	139	145
B50	f_c' (psi)	5731	7264	8537	9267	10383
	% Respect to 28 Days	79	100	118	128	143

Figures 1 and 12 show the compressive strength of the design matrices at different curing ages. Figures 1 and 12 show that the compressive strength of the concrete composites increased with an increase in curing age but the rate of increase in compressive strength reduced after 28 days (4 weeks) of curing. After 7 days of curing, strength gain in control mix (CM) was 85% of its 28 days strength compared to 69 and 79% for PCC concrete composites, B100 and B50, respectively. Rate of strength gain beyond 28 days of curing was observed to be significantly higher in PCC concrete composites compared to that in control mix. At 60 days of curing, additional strength gain (with respect to 28 days strength) in control mix (CM) was 8% compared to 30 and 18% in PCC concrete composites, B100 and B50, respectively. Results on samples tested after 90 and 180 days of curing also show that additional strength gain (with respect to 28 days strength) is higher in PCC concrete composites compared to control mix.

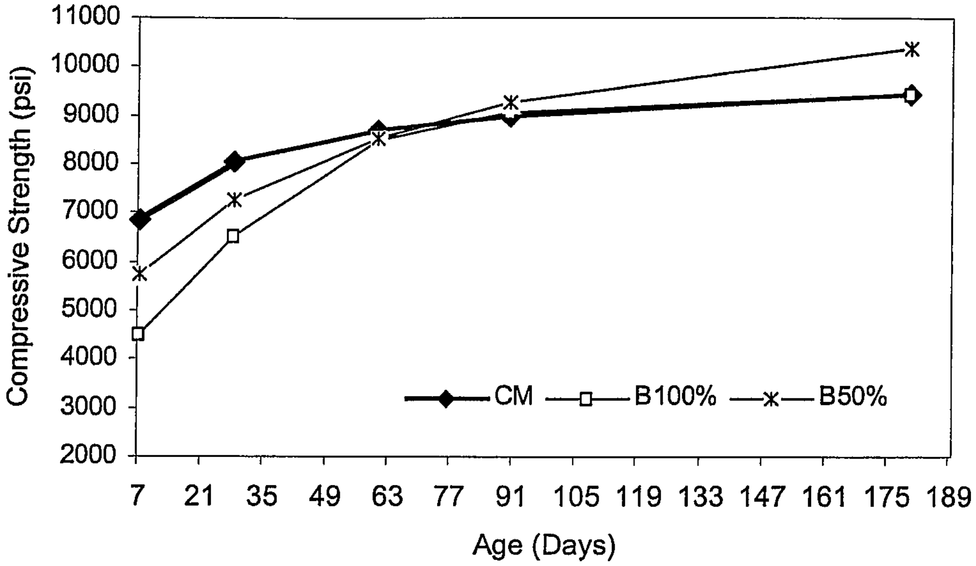


Figure 1. Influence of curing age on compressive strength of concrete composites (The same as presented in Executive Summary)

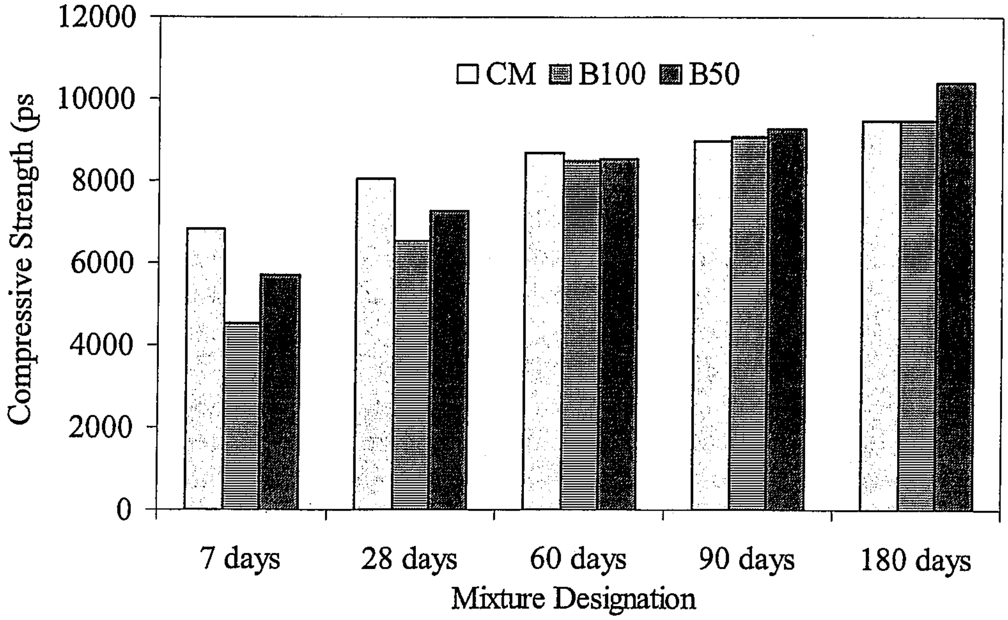


Figure 12. Compressive Strength of Composites for Various Curing Ages

Similar observations were made from splitting tensile and flexural strength tests. Table 8 and Figures 13 and 14 present the results of splitting tensile strength test. Table 9 and Figures 15 and 16 present results of flexural strength tests.

Table 8: Splitting Tensile Strength (f_t') of Concrete Composites

Mixture Designation		Curing Age (Days)				
		7	28	60	90	180
CM	f_t' (psi)	601	651	706	740	790
	% Respect to 28 Days	92	100	108	114	121
B100	f_t' (psi)	480	592	658	733	771
	% Respect to 28 Days	81	100	111	124	130
B50	f_t' (psi)	547	613	683	745	843
	% Respect to 28 Days	89	100	111	122	138

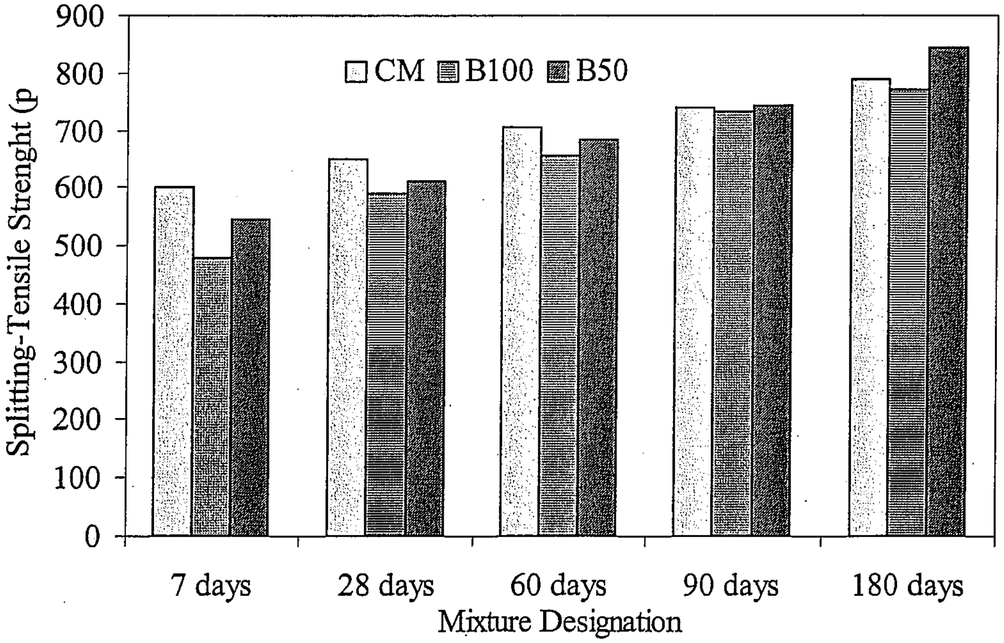


Figure 13. Splitting-Tensile Strength of Composites for Various Curing Ages

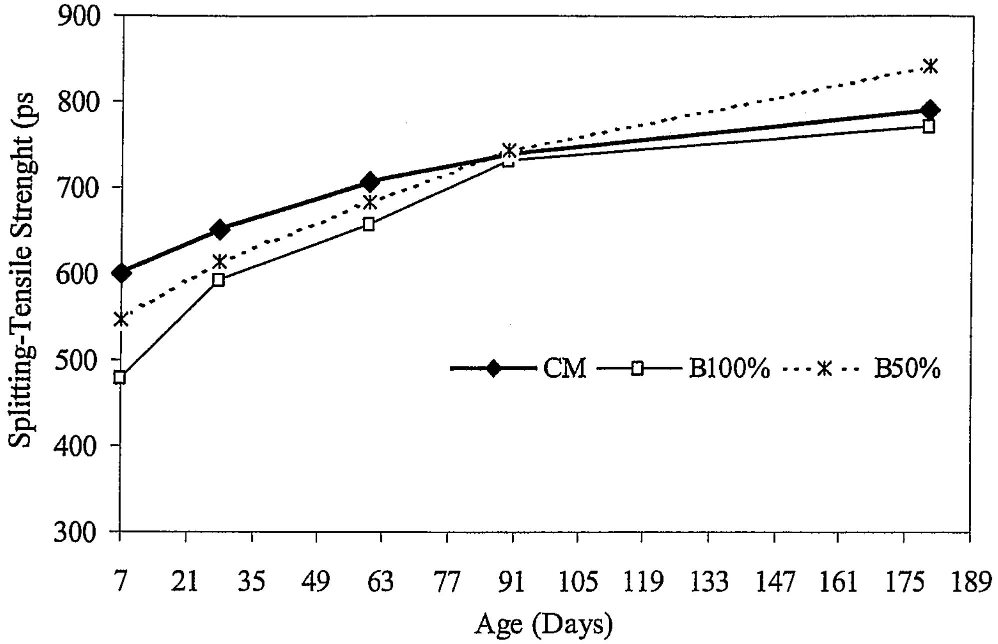


Figure 14. Influence of Curing Age on Splitting-Tensile Strength

Table 9: Flexural Strength (f_r') of Concrete Composites

Mixture Designation		Curing Age (Days)				
		7	28	60	90	180
CM	f_r' (psi)	955	1055	1146	1174	1200
	% Respect to 28 Days	91	100	109	111	114
B100	f_r' (psi)	907	1047	1097	1116	1226
	% Respect to 28 Days	87	100	105	107	117
B50	f_r' (psi)	1023	1077	1124	1159	1286
	% Respect to 28 Days	95	100	104	108	119

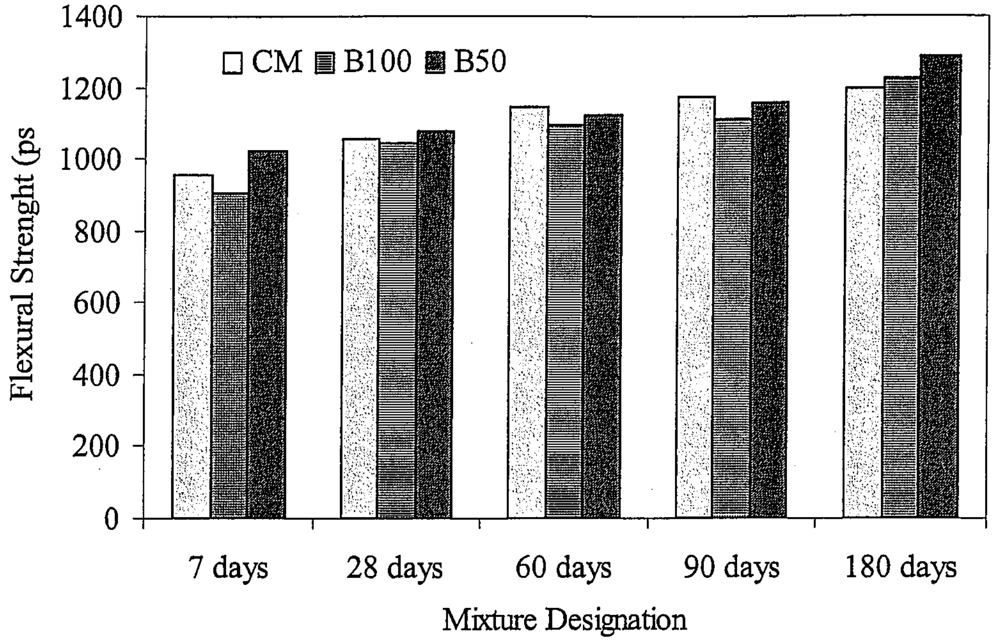


Figure 15. Flexural Strength of Composites for Various Curing Ages

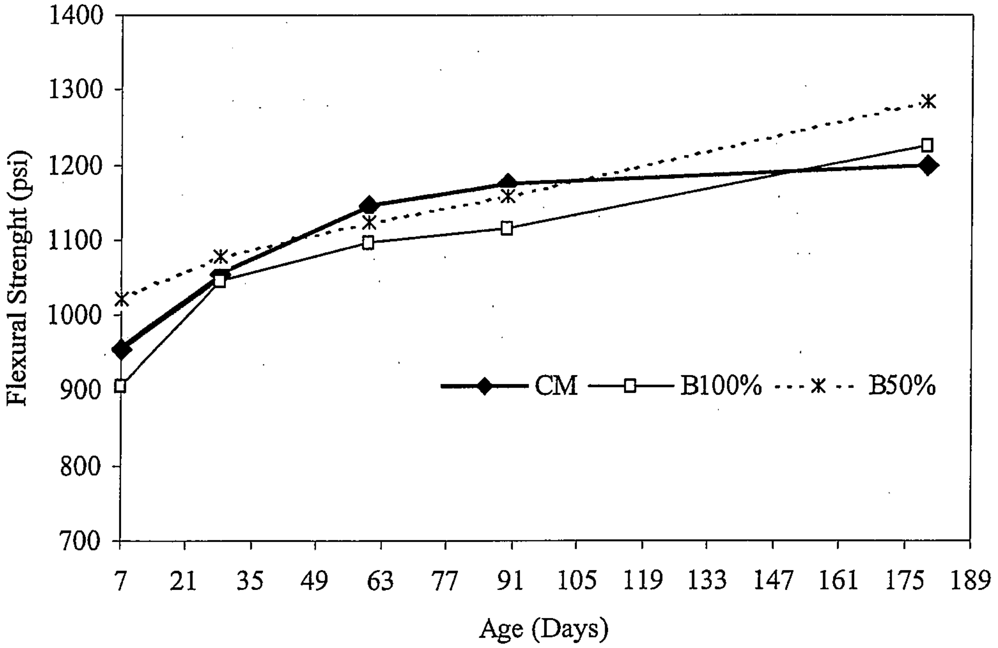


Figure 16. Influence of Curing Age on Flexural Strength

From the results on strength characteristics of concrete composites presented, it was concluded that long-term strength of the selected concrete composites made with Illinois PCC dry bottom ash is likely to be either higher or equal to that of control concrete.

Stiffness Characteristics

Stiffness characteristics for concrete composites were measured in terms of Modulus of Elasticity (MOE) and Poisson's ratio. Results from these tests are presented in this section.

Modulus of Elasticity (MOE). Modulus of elasticity is a measurement of the stiffness of a material. Cylindrical specimens of size 4 x 8 inches (102 x 204 mm) were tested to determine the static modulus of elasticity. The static modulus of elasticity was calculated from the stress-strain response of specimens. Since the stress-strain curve for concrete is nonlinear, three methods for computing the MOE are available. *Tangent modulus* is given by the slope of the line drawn tangent to the stress-strain curve at any point on the curve. *Secant modulus* is given by the slope of the line drawn from the origin to a stress corresponding to 40 percent of the failure stress. *Chord modulus* is given by a slope of line drawn between the stresses corresponding to longitudinal strain of 50 x 10^{-6} and 40 percent of the failure stress. American Concrete Institute (ACI) recommends the use of chord modulus for determination of modulus of elasticity of concrete. Therefore, Chord modulus was used for determination of modulus of elasticity of concrete in this investigation.

Static elastic modulus tests were performed on specimens cured for 28 days and 90 days. The unit weight, compressive strength, and the 28 days and 90 days modulus of elasticity of the PCC concrete composite and control mix, are presented in Table 2. Figure 2 shows the static modulus of elasticity at 28 and 90 days of curing.

Table 2: Modulus of Elasticity (E) and Poisson's Ratio (μ) of the Concrete Composites (The same as presented in Executive Summary)

			Mixture Designation		
			CM	B100	B50
Average Unit Weight (psf)			155.69	147.12	151.22
fc' (psi)	Curing Age (Days)	28	8048	6514	7264
		90	8981	9055	9267
Static Modulus of Elasticity E (psi)	Curing Age (Days)	28	5.7511E+06	4.7528E+06	5.2302E+06
		90	6.0753E+06	5.6038E+06	5.9074E+06
Poisson's Ratio (μ)	Curing Age (Days)	28	0.1471	0.1663	0.1586
		90	0.1553	0.1961	0.1792

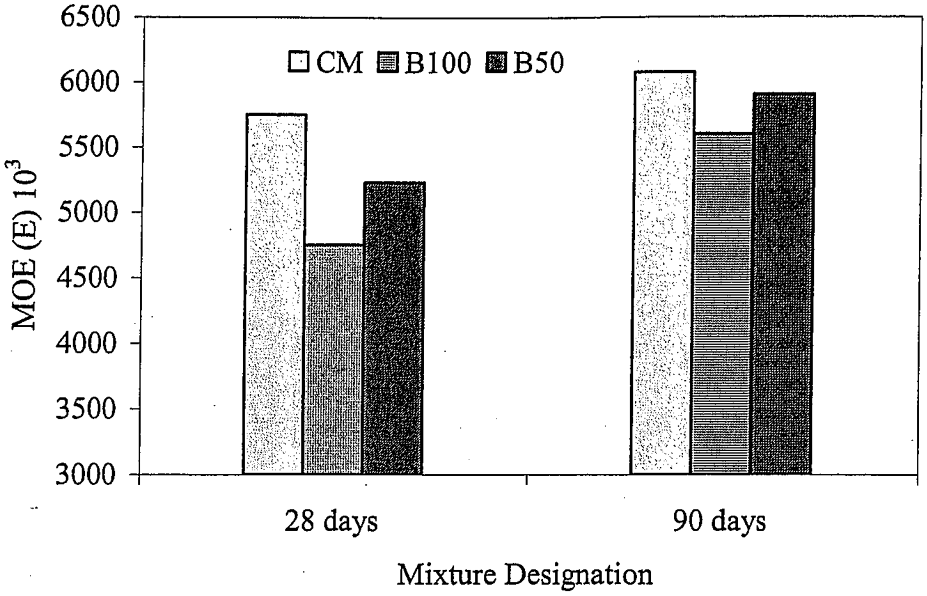


Figure 2. Comparison of Modulus of Elasticity of concrete composites (The same as presented in Executive Summary)

Test results presented in Table 2 show that the unit weight of PCC concrete composites, B100 and B50, and control mix, CM, are 147.12, 151.22, and 155.69, respectively. Unit weight of PCC concrete composites B100 and B50 is 5.5 and 3 percent less than that of control mix, CM, respectively. Results show that replacement of natural sand with Illinois PCC dry bottom ash has insignificant effect on unit weight of concrete composites.

The modulus of elasticity was observed to increase with the curing age. After 28 days of curing, the MOE of PCC concrete composites, B100 and B50, was observed to be 17 and 9% lower than that of the control mix, CM, respectively. However, after 90 days of curing, MOE of PCC concrete composites, B100 and B50, was observed to be 8 and 3% lower than MOE observed for control mix, CM, respectively. The results presented show that the replacement of natural fine aggregate with Illinois PCC dry bottom ash, has insignificant effect on the long term modulus of elasticity of the concrete composites studied in this investigation.

Poisson's Ratio. For a material subjected to simple axial load, the ratio of the lateral strain to the axial strain, within the elastic range of the material, is called Poisson's ratio. In general, values of Poisson's ratio for concrete vary between 0.15 and 0.20.

The tests for determining Poisson's ratio of the PCC concrete composites and control concrete were conducted on the same samples used for the modulus of elasticity test. The values of Poisson's ratio at 28 days and 90 days of curing, are presented in Table 2 and

Figure 17. Poisson's ratio of PCC concrete composites, B100 and B50, and control concrete, CM, after 28 days curing were 0.1663, 0.1586, and 0.1471, respectively. After 90-day of curing, the Poisson's ratio of PCC concrete composites, B100 and B50, and control concrete, CM, were 0.1961, 0.1792, and 0.1553, respectively.

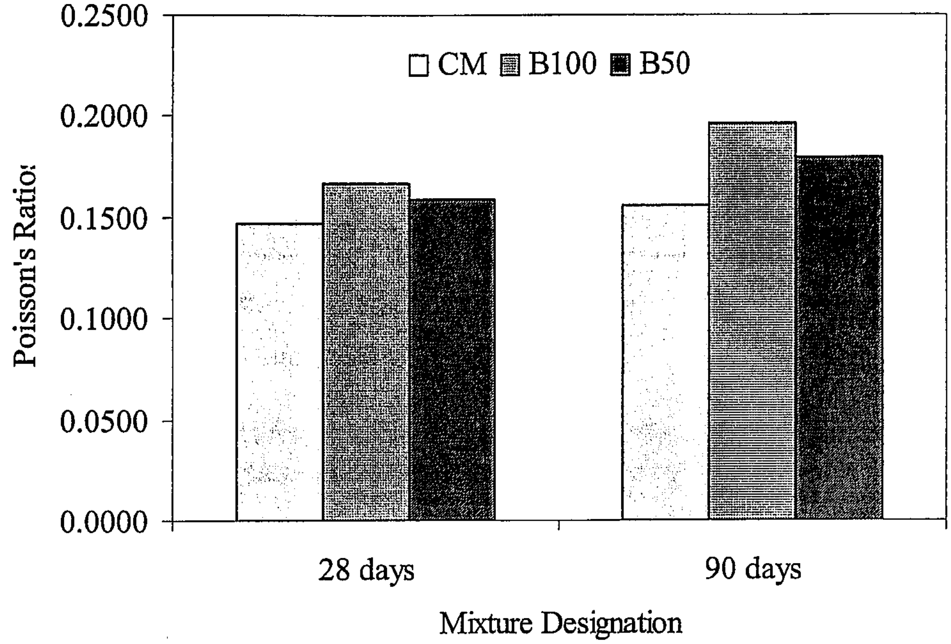


Figure 17: Poisson's Ratio of Concrete Composites for Various Curing Ages

Similar to the observation made from the MOE tests, test results presented in Table 2 and Figure 17 show that for the concrete composites studied in this investigation, the Poisson's ratio increased with the curing age. The results presented show that the replacement of natural fine aggregate with Illinois PCC dry bottom ash has higher influence on Poisson's ratio compared to the effect on modulus of elasticity of the concrete composites studied in this investigation.

Durability Characteristics

Tests on durability of concrete composites in terms of resistance to freezing and thawing and resistance to sulphate attack are in progress. Results from these tests will be presented in the final technical report.

Fresh Properties of Composites

Consistency/workability. Workability of concrete is defined as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity. Consistency is used as a simple index for mobility or flowability of fresh concrete. There is no single test available to measure workability of concrete. The most universally used test is the slump test, which measures only the consistency of concrete. Therefore, consistency/workability characteristics of the matrices were measured using the slump test. All matrices had a constant w/c of 0.375. In order to achieve a slump of approximately 4±½ inches, water reducer WRDA 19 was used. The amount of WRDA 19 used for each matrix is presented in Table 10. The results show that addition of Illinois PCC bottom ash resulted in an increase of water demand. This may be attributed to higher absorption and porous nature of particles of bottom ash.

Table 10: Water-to Cementations Materials Ratio, Water, Admixtures, Bleeding, and Setting Times of Design Matrices

Mixture Designation	W/C (%)	Water (Lb)	Admixture WRDA-19 (Oz)	Bleeding (%)	Initial Setting (min)	Final Setting (min)
CM	0.375	5.66	15	0.16	90	240
B100	0.375	8.26	17	0.3	120	210
B50	0.375	7.00	15	0.35	90	180

Bleeding. As shown in Table 10, all PCC dry bottom ash concretes exhibited bleeding results higher than that of the reference mixture.

Time of settling. The initial and final time of setting results are presented in Table 10. The initial and final time of setting of the concrete composites marginally changed when natural fine aggregate was replaced (fully or partially) with the Illinois PCC dry bottom ash. In general, it was concluded that replacement of natural fine aggregate with Illinois PCC dry bottom ash is not likely to delay construction activities for sub-surface and on-surface applications.

Subsurface Investigation

Subsurface investigation at the site consisted of drilling two borings. One of the borings was drilled to a maximum depth of 25.5 feet and the other boring was drilled to a depth of 20.4 feet. The borings were drilled using a truck mounted CME 75 rotary drill. Standard Penetration Tests (SPT's) were performed using an automatic hammer. Split spoon samples and relatively undisturbed Shelby tube samples were obtained at various depths.

In general, the soil stratigraphy at the site consisted of medium stiff to stiff, brown silty clay to depths of approximately 21 feet. The silty clay is underlain by very stiff to hard, sandy clay shale to the maximum depths explored (25.5 feet). Both the borings were terminated at spoon refusal (more than 50 blows required to penetrate first 6 inches of the split spoon).

Laboratory testing was performed on the soil samples to estimate pertinent engineering and index properties of the soil. Moisture contents were determined for cohesive samples and Atterberg limit tests were accomplished on selected samples. Unconfined compression tests were performed on selected Shelby tube samples. The results of field and laboratory testing indicate that the compressive strength of the silty clay generally range between 0.75 to 1.75 ton per square foot (tsf). The moisture content of the silty clay generally varies between 15 and 29 percent.

Field Testing on Piles

Field-testing on piles consisted of testing 12 pre-cast concrete piles to determine compression, uplift, and lateral load capacities of the piles, and 3 pre-cast concrete and 3 prestressed concrete piles to determine pile-driving stresses and to assess pile structural integrity using Pile Dynamic Analyzer (PDA). Tets results obtained from these tests are presented below. The PDA tests were performed by Goble Rausche Likins and Associates, Inc. (GRL) and all other tests were performed by Load Test, Inc (LTI).

PDA Tests. The main purposes of PDA tests were to estimate pile-driving stresses and assess pile structural integrity. For each hammer blow during driving of piles, the maximum pile head compression stress was calculated by the PDA using the average signal from the two strain transducers. At the end of driving, the average pile head compression stress ranged from 2.24 to 3.10 ksi. These stresses are within typicals for concrete piles. The maximum computed tension stress from any blow during pile driving ranged from 0.08 to 0.28 ksi. These maximum tension stress levels are below typical tension stress limits for either prestressed of pre-cast, reinforced concrete piles.

During data acquisition, high strain force and velocity records from PDA were evaluated by GRL for indications of pile damage below the gauge location, which was typically 2 feet below the top of the piles. In addition, low strain integrity test records of pile top velocity versus time were obtained using a Pile Integrity Test (PIT) Collector for all the piles tested using PDA. These records were obtained before and after pile driving. Based on GRL's interpretation of these records, no significant impedance reduction or cracking occurred during driving of the prestressed concrete piles. In the pre-cast, reinforced concrete pile constructed using concrete composite, B100, and one of the pre-cast pile constructed using concrete composite, B50 (referred to as dummy pile), the records indicate micro cracking after pile driving. driving, micro cracking after driving. Records of the pre-cast concrete pile constructed using conventional concrete, CM, and the other pile constructed using concrete composite, B50, indicate that more significant minor cracks occurred during driving of these piles.

Based on the test results discussed above, it was concluded that the precast or prestressed concrete piles constructed using concrete composites developed in this study performed similar to the piles constructed using conventional concrete.

Axial Compression Tests. Figure 18 shows the top of shaft movements in conventional axial compression tests on piles constructed from concrete composites and conventional concrete. Figure 19 shows, shaft compression in the axial compression tests. Based on the results presented in Figures 18 and 19, it was concluded that the piles constructed with concrete composites will provide resistance similar to the piles constructed using conventional concrete, provided the piles made with concrete composites are constructed and installed in a manner similar to the conventional concrete piles.

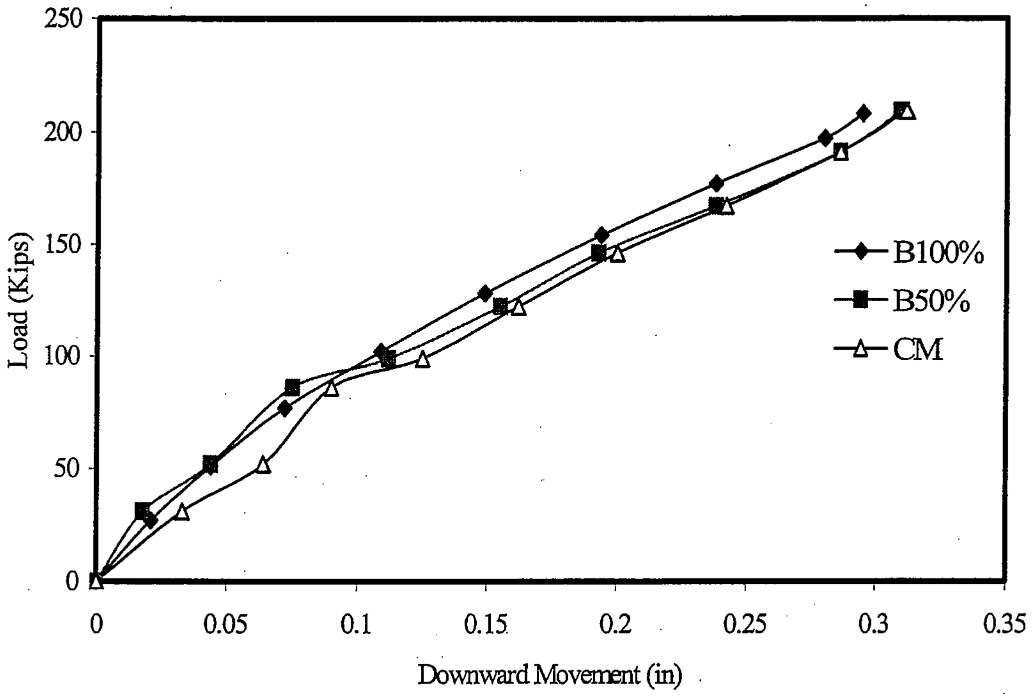


Figure 18: Load versus Downward Top of Shaft Movement

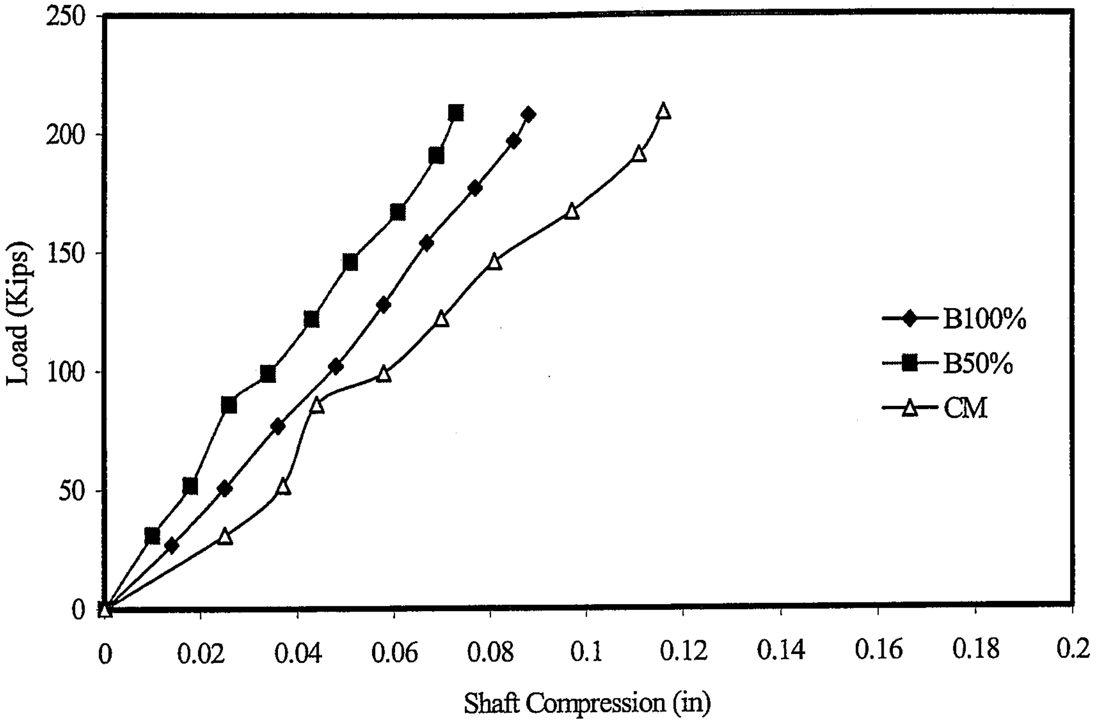


Figure 19: Load versus Shaft Compression

<u>O-cell Tests</u>. In the O-cell tests, the upward shaft movement provides information about frictional resistance between the concrete and the surrounding soil whereas the downward O-cell movement only provides information on the capacity of the soil/rock to resist pressure applies. Therefore, only upward shaft movement results are provided. Figure 20 shows response of load versus upward movement at the O-cell level for three piles tested using O-cell. This figure shows that performance of the piles constructed with concrete composites is similar to that of the piles constructed using conventional concrete

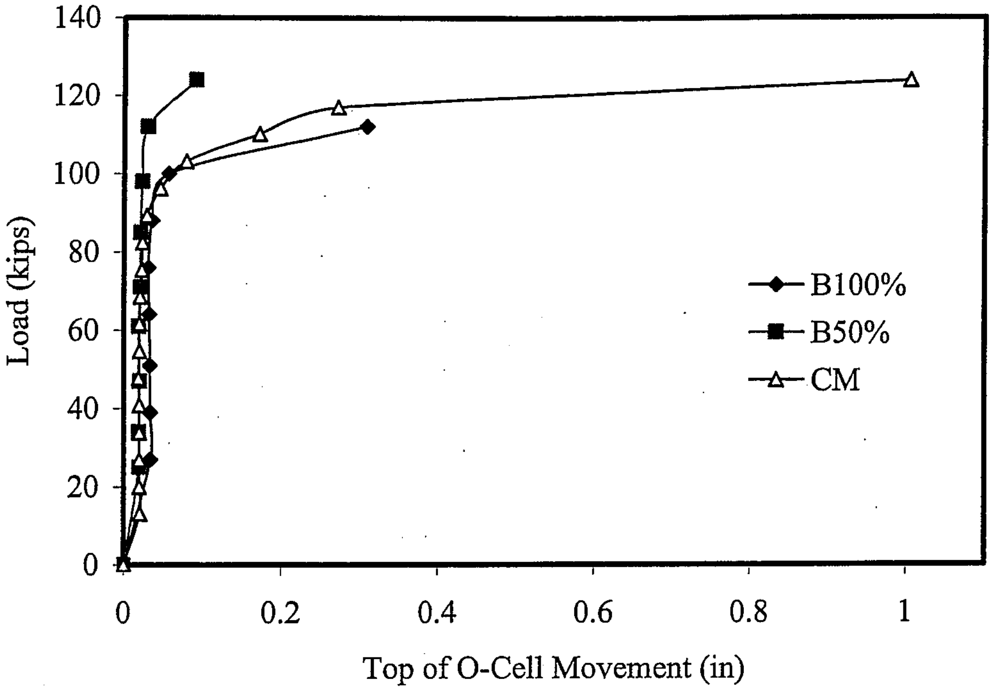


Figure 20: Load versus Upward Movement at O-Cell Level

Lateral Load Tests. Figure 21 shows the results of lateral load tests on piles constructed from concrete composites and conventional concrete. Based on the test results presented on Figure 21, it is clear that, in general, the lateral load – deflection response of piles constructed using concrete composites is similar to that of a pile constructed using conventional concrete. Although, all three piles were constructed in a similar manner, and had similar cross-section and reinforcement, the piles constructed with 'B50' mix and 'CM' mix were not exactly perpendicular to the loading axis. This will result in slightly bigger 'effective' width of these piles, which in turn will result in slightly higher resistance. Therefore, it was concluded that slightly higher resistance observed in the pile constructed with concrete composite 'B50' and conventional concrete 'CM' is due to slightly bigger "effective" width of these piles.

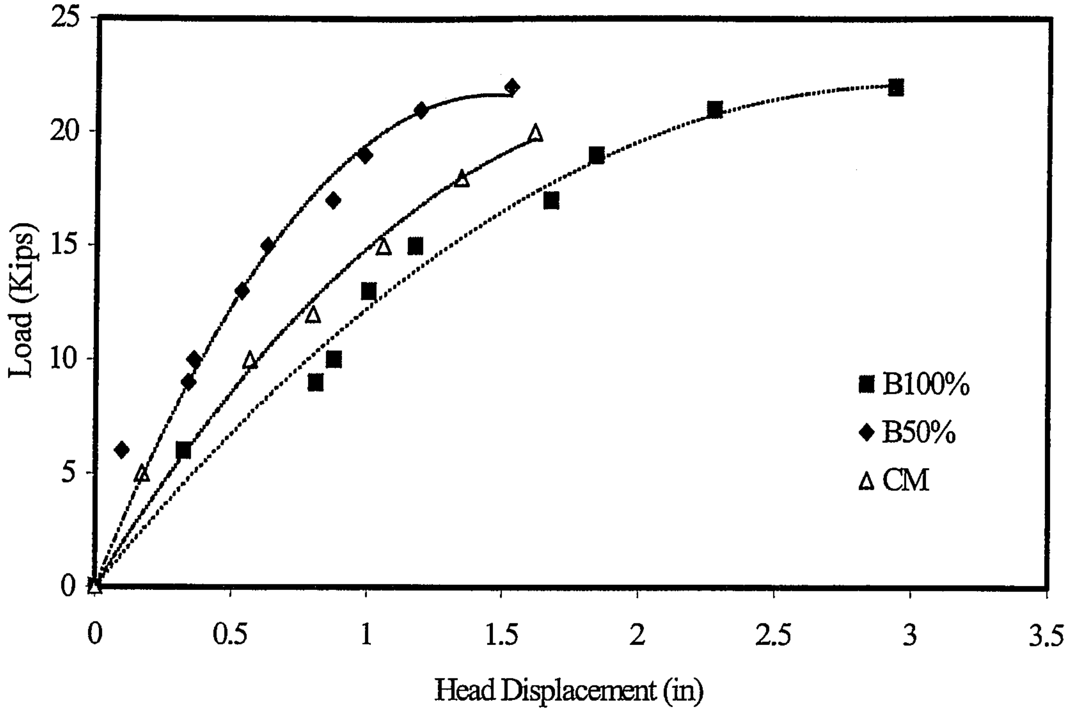
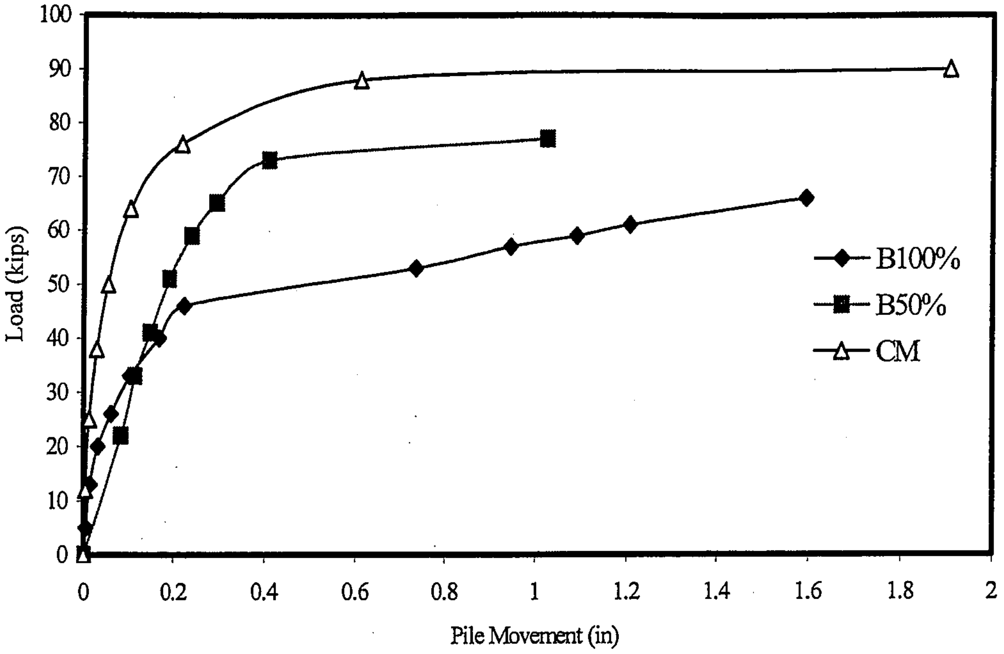


Figure 21: Lateral Load versus Head Movement

Axial Pull-out Tests. The results of axial pull-out tests on piles constructed from concrete composites and conventional concrete are presented in Figure 22. From this figure it appears that the piles constructed using conventional concrete, CM, and concrete composite, B50, provided higher resistance compared to the pile constructed using concrete composite, B50. It is important to note that Piles constructed with concrete composites B100 and B50 could not be driven straight into the ground because of limitations of the driving equipment. This could result in loss of frictional resistence between the pile and the surrounding soil. Therefore, if all the piles are constructed and installed in a similar manner, performance of piles constructed with concrete composites and conventional concrete will be similar. The test results from the axial compression and O-Cell tests support this argument since results from both of these tests show that the frictional resistance between all piles and surrounding soil is similar.



From the field observations made during installation of piles and data presented in Figures 18 through 21, it was concluded that the piles constructed using concrete composites will show the behavior similar to the piles constructed using conventional concrete, provided they are constructed an installed in a similar manner.

CONCLUSIONS

- Based on the laboratory tests performed on the samples prepared and cured in laboratory, it was concluded that for all practical purposes, replacement of natural fine aggregate with Illinois PCC dry bottom ash has a slight effect on short-term strength and stiffness characteristics of concrete composites tested in this investigation. The effect of replacement of natural fine aggregate with Illinois PCC dry bottom ash on long-term strength and stiffness characteristics of concrete composites is relatively insignificant.

- Based on the data collected on pile tests, it appears that the performance of piles made with Illinois PCC dry bottom ash is similar to that of piles made with conventional concrete. Data interpretation from the full-scale pile load tests is in progress. Final conclusions on data from pile load tests will be presented in the final report.

- Tests performed on piles under actual field conditions show that the response of piles constructed using selected concrete composites is similar to the response of piles constructed using conventional concrete.

- Concrete composites developed in this investigation can be used to construct precast and prestressed concrete piles without jeopardizing performance of the piles under the field loads.

DISCLAIMER STATEMENT

This report was prepared by Sanjeev Kumar, Southern Illinois University - Carbondale with support, in part by grants made possible by the Illinois Department of Commerce and Community Affairs through the office of Coal Development and the Illinois Clean Coal Institute. Neither the authors nor any of its subcontractors nor the Illinois Department of Commerce and Community Affairs, Office of Coal Development, Illinois Clean Coal Institute, nor any person acting on behalf of either:

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