

Center for By-Products Utilization

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By Tarun R. Naik and Bruce W. Ramme

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**Department of Civil Engineering and Mechanics
College of Engineering and Applied Science
THE UNIVERSITY OF WISCONSIN - MILWAUKEE**

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Synopsis: This investigation was conducted to review the state-of-the-art information on permeable base road pavements. A construction project was carried out to demonstrate use of fly ash in manufacture of permeable base concrete pavement.

Past investigations have indicated that adequate drainage is required in producing durable pavements, especially when it is subjected to heavy traffic loads. Pumping is reported to be one of the primary causes of pavement distress and generally occurs in undrained pavement. To help solve this problem, permeable base pavements are used. A properly designed and constructed permeable base eliminates pumping, faulting, and cracking. A permeable base pavement is composed of three components: an open-graded permeable base, a separator layer, and an edge drainage system. The base is designed to have adequate permeability and stability. It is estimated that the use of a permeable base would add to pavement service life by 33% and 50%, for asphaltic and portland cement concrete pavements, respectively.

The demonstration project completed in this investigation indicated that fly ash can be used in the manufacture of permeable base concrete pavements. The use of fly ash resulted in a reduced cost of the pavement without compromising its performance.

ACI Fellow **Tarun R. Naik** is Director of the Center for By-Products Utilization and Associate Professor of Civil Engineering at the University of Wisconsin-Milwaukee. He is a member of ACI Committees 201, Durability of Concrete; 232, Fly Ash and Natural Pozzolans in Concrete; 123, Research; 214, Evaluation of Results of Tests Used to Determine Strength of Concrete; and others.

ACI member **Bruce W. Ramme** is the Manager of Combustion By-Products Utilization for the Wisconsin Electric Power Company, Milwaukee. He is Vice President of ACI Wisconsin Chapter; Chairman of ACI Committee 229, Controlled Low Strength Materials and ACI Subcommittee 213C, By-Product Lightweight Aggregate; Member of ACI Committee 213, Lightweight Aggregate and Lightweight Aggregate Concrete; Associate member of ACI Committee 232, Fly Ash and Natural Pozzolans.

INTRODUCTION

For a long time, the presence of water under hard surface pavements has been identified as a major cause of pavement distress. Water can enter pavement through its top, bottom, and sides. Extended exposure to water can lead to premature oxidation, pumping, D-cracking, faulting, frost action, shrinkage, cracking, and potholes (1). Of these, pumping is known to be a major mechanism of pavement distress.

The infiltrated water is trapped in the pavement structure due to slow draining capabilities of the dense-graded base of pavements and the impermeability of surrounding soils. When high pressure is applied to these pavements from heavy traffic loads, pumping occurs in the presence of water. This causes erosion of the base as fines along with water are pumped out. Consequently, a loss in pavement support occurs, leading to early failure of pavement. In order to avoid this, an open-graded permeable base is used to allow rapid drainage of the water (1-15). A permeable base pavement system consists of three elements: permeable base, separator layer, and edge drainage system. Adequate design of these components is essential to obtaining the desired performance.

This investigation was undertaken to present the state-of-the-art information on permeable base pavements, and to demonstrate the application of fly ash in manufacture of permeable base concrete pavements. A demonstration project was designed to use an off spec ASTM C 618 Class F fly ash in the base course and an ASTM C 618 Class C fly ash in the concrete pavement of a loop road that was reconstructed at the Port Washington Power Plant of Wisconsin Electric Power Company, Port Washington, WI.

REVIEW OF LITERATURE

Permeable bases are divided into two classes: treated and untreated. A treated permeable base employs a binder which would typically consist of either cement (119-178 kg/m³) or asphalt

(2 to 5% by weight). An untreated subbase contains more smaller size particles in order to provide stability through aggregate interlock. A permeable base must be capable of maintaining both permeability and stability. In order to have improved stability, an untreated subbase should contain 100% crushed aggregate (2). Although aggregate gradations vary among users, the two most commonly used gradations are AASHTO NO. 57 and NO. 67 (Tables 1 and 2). The coefficient of permeability for treated base depends upon several factors such as aggregate gradation and binder content. Due to the coarse gradation and small amount of binder used in manufacture of treated base, they are by design quite porous and permeable. The coefficient of permeability for untreated permeable base is normally lower when compared to treated permeable base materials due to their greater amount of fines (Tables 1 and 2).

A permeable base system is composed of three major elements: permeable base, separator or filter layer, and edge drain system. A typical cement-treated permeable base is composed of 86% aggregate, 10% cement, and 4% water (4). Information on design, construction, and material requirements are available in the literature (2,4,13,14,15,16,17). Although the thickness of permeable bases generally varies between 75 to 150 mm, a 100 mm thickness of the permeable base is most commonly used (13-15).

The importance of adequate pavement drainage has been identified since the early days of road construction (5). To help solve drainage problems, open-graded permeable materials have been used in portland cement pavements since the beginning of pavement construction. To handle heavy traffic loads, the trend of using dense-graded materials dominated during the middle of this century which resulted in decreased use of the permeable materials (5). However, a renewed interest in the use of permeable materials for pavement construction has occurred during the last two decades. In a survey conducted by the National Asphalt Institute, 30 states indicated use or planned use of asphalt-treated permeable base materials under pavement (13). A number of investigations (10,11) have supported the use of open-graded permeable bases for efficient drainage. Crovetti and Dempsey (5) showed that various parameters such as cross slope, longitudinal grade, and drainage layer width and thickness can influence the permeability performance of open-graded permeable materials (OGPM).

In 1988, the Federal Highway Administration (18) surveyed ten different states which had installed permeable base pavements. Of these, the most experienced states were: California, Michigan, New Jersey, and Pennsylvania. The remaining six were Iowa, Kentucky, Minnesota, North Carolina, West Virginia, and Wisconsin. These states developed their design data largely based upon the information of the four most experienced states. Out of the 10 states surveyed, seven states used untreated permeable base and the remaining three (California, North Carolina, and West Virginia) used treated permeable base. Five of the seven states using untreated permeable base had dense-graded materials with reduced amounts of fines. The other two states, Wisconsin and Kentucky, employed larger AASHTO NO. 57 or an equivalent size which resulted in higher permeability of the base.

Grogan (16) reported that subsurface pavement layers are virtually impermeable in the case of dense-graded materials. When these layers become saturated, they remain saturated for the majority of the pavement life. These saturated layers cause pumping, erosion, subgrade

weakening, and freezing/thawing damage. Use of properly designed and constructed permeable bases reduces or practically eliminates these problems thus improving pavement performance. The improved performance will translate into dollar savings through increased life and reduced maintenance requirements for the pavement. Based on investigations (17,18) in California, a minimum life increase was estimated to be 33% for asphaltic concrete pavement and 50% for portland cement concrete pavements incorporating permeable bases compared to undrained pavements. Hall (19) reported that factors such as cement content, truck traffic, sublayer stability, segregation, and surface irregularities are important in affecting performance of the permeable material.

Studies conducted by several state agencies were summarized by Munn (20). Two eight-year-old pavements on permeable bases in California did not exhibit any cracking, whereas corresponding undrained pavements showed 18% and 47% cracking. Non-destructive testing of permeable base pavements in Iowa revealed a greater support relative to undrained pavements. The increased support is equivalent to a thickness of 75 to 125 mm of additional pavement. In Michigan, permeable base test sections built in 1975 did not show any faulting or cracking and had less D-cracking compared to control sections of bituminous and dense-graded sections. In Minnesota, a jointed reinforced concrete pavement on permeable base built in 1983 experienced only one mid-panel crack in its 59 panels, while undrained sections adjacent to either end showed 50% mid-panel cracks. Performance of Pennsylvania's permeable base sections built in 1979-80 were rated much better than that of dense-graded aggregate sections. In Pennsylvania, a permeable base between portland cement concrete pavement and the dense-graded aggregate subbase was standardized in 1983. Wisconsin (20) estimates that the use of a cement stabilized base would add 25% more service to concrete pavements. Recent nondestructive testing in Iowa (21) have shown excellent performance of permeable base pavements. New Jersey (15) found similar rutting for permeable base pavements constructed in 1979-1980 having either thicker or thinner sections. Also, there was less deflection, no faulting or pumping, and reduced frost penetration on concrete pavements. In 1990, permeable base PCC pavement became standard in nine different states (4). The use of permeable bases is rapidly increasing in the USA.

Kozeliski (22) reported successful application of open-graded cement treated base material in the construction of a parking lot for an office building, the driveway of a home, and a ground cover of a refinery. Kuenner (23) described construction of a high-quality, high-durability, drainable PCC pavement incorporating 18% fly ash of total cementitious materials.

DEMONSTRATION PROJECT

A project was designed to demonstrate the use of fly ash in the construction of an open-graded permeable base course concrete pavement at the Port Washington Power Plant of Wisconsin Electric Power Company.

Port Washington Power Plant Roadway Design and Construction

Wisconsin Electric's (WE's) Port Washington Power Plant has been in service for the generation of electricity from the combustion of coal since 1935 and is located on the west shore of Lake Michigan approximately 50 kilometers north of Milwaukee, Wisconsin. The existing plant roadway consisted of crushed stone placed over a variety of old fill, silty sand, and clay soils. The power plant is located in downtown Port Washington, Wisconsin and one of the major benefits of paving included a reduction in fugitive dust produced from plant truck traffic. Material was removed from the existing roadway to make room for the open graded cement treated base coarse and high-volume fly ash concrete pavement to be placed. A plan view of the Port Washington Power Plant loop roadway is shown in Fig. 1. The roadway cross section (Fig. 2) consisted of an initial layer of filter fabric which was installed to prevent fines from the subgrade working their way up and blocking drainage in the base course covered by a 150 mm thick layer of open-graded base course and a 250 mm thick high-volume fly ash concrete. The loop roadway had a 6 m width which was expanded as needed at the loading dock and lay down areas at both the north and south ends of the plant. Construction began in the fall of 1993 and was completed in the spring of 1994. The work was performed in stages to accommodate other plant renovation construction work that was already in progress. The pavement was designed to comply with the State of Wisconsin Standard specification for Road and Bridge Construction with the exception of the mixture proportions used for the open-graded base and high volume fly ash containing concrete pavement. A highway paving contractor was selected to perform the work so that work would proceed in a manner typical of local and state paving practice. The contractor provided a portable batch plant that had been used for airport and highway construction projects and it was set up on the plant's coal dock. Ready-mixed concrete trucks were loaded with a high LOI (over 10%) off spec ASTM C 618 Class F fly ash at the power plant's ash silo and then proceeded for loading of the stone, and portland cement. The fly ash used was off spec because of the high LOI content. A 30.5 m test section of open-graded base course was constructed using the same off spec high LOI fly ash. This fly ash was produced in electric generation units with advanced sulfur removal equipment. These units inject baking soda to remove SO₂ from the flue gas and thus the fly ash contained sodium sulfate. The test section was constructed to see if the long-term expansive effects of the sulfate containing fly ash would cause any expansive heave problems in the open-graded base course and thus lift the pavement. It was expected that the expansive hydration product crystals would have a place to grow in the multitude of voids provided in the open-graded base. To date (1997) there has been no heaving of this concrete pavement section. Mixing of the materials was accomplished in the ready-mixed concrete trucks and they proceeded to place the open-graded base course material directly on top of the filter fabric. The filter fabric was unrolled as the truck moved forward to avoid damage to the fabric material. The open graded base material was then graded with a standard highway grader, and rolled with a smooth drum vibrating compactor. Under drains, manholes, and storm sewer piping were also installed as a part of this project to ensure yard drainage and treatment of yard runoff. Concrete for the high-volume fly ash concrete pavement was also produced at the portable batch plant located on the power plant property. Portland cement, WE's Pleasant Prairie ASTM Class C fly ash, water, sand, and stone aggregates were all added to the ready-mixed concrete trucks and mixed as

required per ASTM C 94 (32). The concrete was placed on top of the open graded base course by a standard highway slip form paver set for the 6 m pavement width. The roadway sections were pitched as required to maintain site drainage. The concrete was sprayed with a curing compound and contraction joints were saw cut at 6 m intervals after the concrete had reached the desirable strength for saw cutting. The road was opened to traffic within 10 days of paving completion and has been providing very good service without significant defects through three Wisconsin (northern United States) winters. The only significant comment from the contractor was that the open-graded base course mixture used was easier to work with than the standard State of Wisconsin Department of Transportation mix. The contractor also stated that their company would have no reservations using either mixture if specified for future work.

An economic analysis was conducted to evaluate cost-effectiveness of the 50% Class C fly ash concrete. Cost of fly ash to a concrete producer varies depending upon transportation cost, cost of storage, additional hardware needed at the ready-mixed plant, etc. For this investigation, the market cost of Class C fly ash was \$25 per tonne. Cost of cement was \$85 per tonne; on an average it varies between \$70 and \$90 per tonne. The result indicated a material cost saving of about \$9 per cubic yard for the 50% fly ash mixture, compared to concrete containing portland cement only.

Materials

A Type I cement was used in this project. An off specification Class F fly ash with a high LOI was used in construction of the permeable base as a replacement of cement. ASTM Class C fly ash was used in the manufacture of paving concrete. The properties of cement and fly ashes used are shown in Table 3. The fine aggregate was natural sand, and natural gravel was used as the coarse aggregate. Both fine and coarse aggregates were obtained from local sources. Two sizes of coarse aggregates (19 mm and 38 mm) were used. The coarse, as well as fine, aggregates met the grading requirements for Test Method for Sieve Analysis of Fine and Coarse Aggregates (ASTM C 136). An air-entraining admixture was used to entrain air in the concrete mixture.

Mixture Proportions

Two mixtures, one for an open-graded base course and the other for concrete pavement, were proportioned. The mixture proportion for the open-graded base course was composed of 95 kg/m³ cement, 74 kg/m³ fly ash, 48 kg/m³ water, and 1543 kg/m³ 19 mm coarse aggregate. The water to cementitious materials ratio was at about 0.28. The mixture proportions for the high-volume fly ash concrete pavement included: 178 kg/m³ cement, 178 kg/m³ Class C fly ash, 131 kg/m³ water, 712 kg/m³ sand, 573 kg/m³ 19 mm aggregate, and 573 kg/m³ 38 mm coarse aggregate. The water to cementitious materials ratio was kept at about 0.37.

Field and Laboratory Testing

Field testing was performed during the placement of the open-graded base course and high-volume fly concrete pavement. A sample of fresh concrete from each batch of base course mixture was taken for measurement of slump (ASTM C 143). For each batch of concrete mixture, samples were also taken to measure slump (ASTM C 143), air content (ASTM C 231), and temperature (ASTM C 1064).

For measurement of compressive strength, a set of four cylinders were cast in accordance with ASTM C 31 on selected batches of base course and paving slab concrete mixtures. The cylinders were typically cured one to three days in the field. The cylinders were then transported to Midwest Engineering Services, Inc. (MES) Laboratory for curing and testing. The cylinders were cured in the MES Laboratory in their molds at room temperature. Each cylindrical specimen was tested for compressive strength in accordance with ASTM C 39. Compressive strength data were generally recorded at 3, 7, 28, and 56 days.

RESULTS AND DISCUSSION

The test results derived from testing of the base course and concrete mixtures are described in the following sections.

Base Course Material

The compressive strength data are shown in Table 4 and Fig. 3. The permeable base course was designed to have a 28-day compressive strength in the range of 3.4 to 6.8 MPa. The mixture met the design strength as it achieved a compressive strength of 4.6 MPa at the 28-day age. At 56 days, a compressive strength of 5.6 MPa was observed for this mixture. Because of pozzolanic contributions of fly ash, this mixture is expected to have a higher rate of compressive strength gain compared to a base treated with a cement binder only.

Fly Ash Concrete Pavement

Numerous investigations by Naik and associates (24-31) were carried out to develop good quality structural, paving, and high-strength concrete mixtures using the same Class C fly ash as that used in the present investigation. These investigations have substantiated that a high quality

structural-grade and paving quality concrete can be manufactured using large amounts of fly ash. The results of the research projects in 1984 using 20%, 40%, 50% and 60% fly ash as a replacement of cement have shown that compressive strength typically exceeds 34 MPa at 28 days for mixtures using an equivalent six-bag cement mixture (25). Flexural strength at the 28-day age ranged from 4.1 to 5.4 MPa, and splitting tensile strength ranged from 2.7 to 3.4 MPa for these mixtures (31). All mixtures passed freezing and thawing resistance requirements in accordance with ASTM C 666, Procedure A. Results of the de-icing salt scaling tests performed according to ASTM C 672 were rated between zero and two with zero being the highest and 5 being the lowest resistance to salt scaling. Chloride permeability determined in accordance with ASTM C 1202 exhibited a value of 391 coulombs for the 50% fly ash mixture and 188 coulombs for the 40% fly ash mixture (31). These mixtures also showed high abrasion resistance in accordance with the ASTM requirement.

The mixture used in the present investigation was selected based on strength and durability data obtained in the above investigations. Since the past investigations showed a high correlation between compressive strength and durability-related properties for similar mixtures, it was decided to measure only compressive strength of the paving mixture used in the present investigation. It was assumed that a mixture meeting air content and strength requirements would also meet durability requirements. Visual observations are being made and recorded to determine performance of this concrete pavement with respect to cracking, surface deterioration due to deicer salt scaling and abrasion, etc.

Test data on the high-volume fly ash concrete mixture used for the paving is shown in Table 4 and Fig. 4. The mixture showed a compressive strength of 33.6 MPa at the 28-day age which was about 20% higher than the design strength of 28 MPa. Visual observation has revealed no major cracks or other pavement distress during the past three years of service. Since the fly ash is significantly less costly than portland cement, the use of the 50% fly ash in the mixture resulted in a material cost saving of \$9 per cubic yard, compared to concrete made with portland cement only.

SUMMARY AND CONCLUSION

This work was conducted to review the state-of-the-art information on permeable base pavements, and to demonstrate the application of fly ash in the manufacture of no-fines concrete permeable base, as well as portland cement concrete pavement.

Past investigations have shown that pumping is one of the primary mechanisms of pavement failures. Several factors that can cause pumping include heavy traffic loads, curled pavement slabs, presence of fines in the base, and free water and voids under and around pavement slabs (2). These conditions are encountered in the majority of hard surface pavements. In order to avoid pumping, permeable bases are designed with adequate permeability and strength.

Drained pavements are composed of a permeable base, a separator layer, and an edge drainage system. Each of these components should be designed to avoid pumping. A permeable base is composed of open-graded material with or without a stabilizer. A stabilized base material

uses portland cement or asphalt as a binder to obtain desired levels of stability, whereas unstabilized base materials use more fines to obtain the desired stability through good mechanical interlock of the aggregates.

Most investigations have indicated improved performance of drained pavements over undrained pavements. It was estimated that the use of an open-graded permeable base would increase service life by 33% and 50% for asphaltic concrete pavement and portland cement concrete pavement, respectively.

The demonstration project completed in the present investigation indicated that a treated permeable base can be made using an off spec ASTM C 618 Class F fly ash as a replacement for cement without compromising its performance. The paving concrete mixture made with 50% Class C fly ash as a replacement of cement showed excellent performance. It showed a compressive strength of 34 MPa at 28 days, approximately 20% higher than the design strength. Visual observations show no obvious pavement distress during the past three years of service. Additionally, use of ASTM C 618 Class C fly ash as a replacement of cement reduced the cost of the paving mixture compared to concrete mixture containing portland cement only. Based on the results obtained, it was concluded that high-volume of ASTM C 618 Class C fly ash can be used in the manufacture of excellent quality concrete pavements; and no-fines permeable base can be constructed with off spec ASTM C 618 Class F fly ash.

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Table 1: Untreated Permeable Subbase Gradations and Permeabilities (3,15)

Sieve Size	Percent Passing						
	IA	KY	MI	MN	NJ	PA	WI
50 mm (2 in.)	--	--	--	--	--	100	--
38 mm (1½ in.)	--	100	100	--	100	--	--
25 mm (1 in.)	100	95-100	--	100	95-100	--	100
19 mm (¾ in.)	--	--	--	65-100	--	52-100	90-100
12.7 mm (½ in.)	--	25-60	0-90	--	60-80	--	--
9.5 mm (3/8 in.)	--	--	--	35-70	--	35-65	20-55
No. 4	--	0-10	0.8	20-45	40-55	8-40	0-10
No. 8	10.35	0-5	--	--	5-25	--	0-5
No. 10	--	--	--	8-25	--	--	--
No. 16	--	--	--	--	0-8	0-12	--
No. 30	--	--	--	--	--	0-8	--
No. 40	--	--	--	2-10	--	--	--
No. 50	0-15	--	--	--	0.5	--	--
No. 200	0.6	0.2	--	0-3	--	0-5	--
Coefficient of Permeability m/s (ft per day)	18×10 ⁻⁴ (500)	706×10 ⁻⁴ (20,000)	35×10 ⁻⁴ (1000)	7×10 ⁻⁴ (200)	71×10 ⁻⁴ (2000)	35×10 ⁻⁴ (1000)	635×10 ⁻⁴ (18,000)

Table 2: Treated Permeable Subbase Gradations and Permeabilities (3)

Sieve Size	Percent Passing				
	No. 57 AC/PC Stabilized	California		WI PC Stabilized	New Jersey AC Stabilized
		AC Stabilized	PC Stabilized		
38 mm (1½ in.)	100	--	100	--	--
25 mm (1 in.)	95-100	100	86-100	--	100
19 mm (¾ in.)	--	90-100	X ± 22	90-100	95-100
12.7 mm (½ in.)	25-60	35-65	--	--	85-100
9.5 mm (3/8 in.)	--	20-45	X ± 22	20-55	60-90
No. 4	0-10	0-10	0-18	0-10	15-25
No. 8	0-5	0-5	0-7	0-5	2-10
No. 10	--	--	--	0-5	--
No. 16	--	--	--	--	2-5
No. 200	0-2	0-2	--	--	*
Coefficient of Permeability m/s (ft/day)	706×10 ⁻⁴ (20,000)	529×10 ⁻⁴ (15,000)	141×10 ⁻⁴ (4,000)	350×10 ⁻⁴ (10,000)	35×10 ⁻⁴ (1,000)

AC = Asphalt; PC = Portland cement

"X" is the gradation that the contractor proposes to furnish for the specific sieve size.

* Add 2% mineral filler.

Table 3: Properties of Cement and Fly Ashes Used

Chemical Composition (%)	Cement Type I	ASTM C 150, Type I	Class F Fly Ash	Class C Fly Ash	ASTM C 618, Class F	ASTM C 618, Class C
Silicon dioxide, SiO ₂	20.0	-	36.5	35.4	-	-
Aluminum oxide, Al ₂ O ₃	4.3	-	16.0	23.3	-	-
Ferric oxide, Fe ₂ O ₃	2.5	-	7.0	5.6	-	-
Total, SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃	26.8	-	61.5	64.3	70.0 min	50.0 min
Sulfur trioxide, SO ₃	2.3	3.0 max	1.5	2.4	5.0 max	5.0 max
Calcium oxide, CaO	65.0	-	2.1	36.7	-	-
Magnesium oxide, MgO	2.0	6.0 max	-	-	5.0 max	5.0 max
Available alkali	0.3	-	0.7		1.5 max	1.5 max
Moisture content	-	-	1.2	0.13	3.0 max	3.0 max
Loss on ignition	2.0	3.0 max	31.5	0.6	6.0 max	6.0 max
Physical Properties of Cement						
Air content (%)	9.5	12 max			-	-
Fineness (m ² /kg)	351	280 min			-	-
Autoclave expansion (%)	-0.02	0.8 max			-	-
Specific gravity	3.16	-			-	-
Compressive strength (MPa)						
1-day	13.7	-			-	-
3-day	24.1	12.3 min			-	-
7-day	29.2	19.2 min			-	-
28-day	37.4	-			-	-
Vicat time of initial Set (min)	145	45 min 375 max			-	-
Physical Properties of Fly Ashes						
Fineness retained on No. 325 sieve (%)	-	-	25.5	19.4	34 max	34 max
Pozzolanic activity index with cement (% of control)						
7-day	-	-	64	92.5	75 min	75 min
28-day	-	-	73	99.5	75 min	75 min
Water requirement (% of control)	-	-	112	93.0	105 max	105 max
Autoclave expansion (%)	-	-	-0.02	0.01	0.8 max	0.8 max
Specific gravity	-	-	2.02	2.62	2.68	-

Table 4: Open-Graded Base Course Test Results

Test	No. of Tests	Average
Slump	91	178 mm
Compressive Strength (MPa)		
3-day	59	2.0
7-day	59	2.9
28-day	59	4.6
56-day	59	5.6

Table 5: Fly Ash Concrete Test Results

Specified Strength: 28 MPa at 28-Day Age

Test	No. of Tests	Average
Slump (mm)	174	3.0
Air Content (%)	170	6.0
Concrete Temperature (°C)	174	13.9
Compressive Strength (MPa)		
3-day	62	15.0
7-day	62	22.9
28-day	62	33.6
56-day	62	38.3

**List of figure captions for the Manuscript entitled:
"Roller Compacted No-Fines Concrete Containing
Fly Ash for Road Base Course," by Naik et al.**

Fig. 1: Port Washington Power Plant Loop Roadway Plan View

Fig. 2: Port Washington Power Plant Typical Loop Road Cross Section

Fig. 3: Compressive Strength as a Function of Age for Open-Graded Base Material - Average of 59 Sets of Test Data

Keywords: Permeable base; concrete; no-fines concrete, fly ash, edge drainage