Order Number 9510625

Sludge ash utilization and hydroplaning on concrete and asphalt pavements

Afshari-Tork, Shahriar, Ph.D.

City University of New York, 1994

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

SLUDGE ASH UTILIZATION AND HYDROPLANING ON CONCRETE AND ASPHALT PAVEMENTS

BY

SHAHRIAR AFSHARI-TORK

A dissertation submitted to the Graduate Faculty in Engineering in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

1994

This manuscript has been read and accepted for the Graduate Faculty in Engineering in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

August 18, 1994
Date

Professor Reza M. Khanbilvardi
Chair of Examining Committee

8/23/94
Date

Professor Gerald G. Lowen
Executive Officer

Professor John Fillos

Professor Charles Miller

Professor Lin Ferrand

Dr. Paul Grosser

Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

Abstract

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by

Shahriar Afshari-Tork

Advisor: Professor Reza M. Khanbilvardi

A study was performed on samples of sludge ash taken from the Bergen Point Wastewater Treatment Plant to determine its utilization as an aggregate to be used in concrete and asphalt mixtures. The results of physical analyses indicated that the particle size distribution of ash resembles an aggregate comprised of approximately 60% sand and 40% silt. The ash has a low permeability, a relatively high shrinkage limit, and is free of organic matter. TCLP and EP-toxicity tests on ash samples showed that ash collected from Bergen Point is a non-hazardous material. Based on these results it was concluded that although the ash alone may not be a desirable construction material, blending it with other construction materials, such as concrete or asphalt, could reduce the adverse effects of the ash without diminishing the design properties of the concrete or asphalt mixes.

Laboratory scale tests were conducted on specimens with different percentage of ash as a partial replacement of the fine aggregates in both concrete and asphalt mixes. The results indicated that ash can replace fine aggregate up to 30% in concrete and up to 15% in asphalt mixes, without a significant adverse effect on strength, durability, and skid resistance of the product.

A hydroplaning study was also conducted on both ash-concrete and ash-asphalt pavements using a rainfall simulator. The results were compared with those for control no-ash mixes. No significant difference was found between hydrological parameters of ash-mixtures and those of the conventional mixes. In fact the introduction of ash into the asphalt and concrete mixes appeared to somewhat improve the process of surface water drainage. Runoff samples proved to be non-hazardous whether or not deicing material was used.

A field scale test was also conducted on ash-mix pavement sections and the results were compared with those for similar control no-ash mixes. Each pavement section was exposed to natural precipitation for a period of six months. The field study data supported the laboratory scale test results.

Analysis of the runoff-leachate samples from all pavement sections, with or without ash present, indicated compliance with current EPA groundwater standards.

ACKNOWLEDGEMENTS

The author would like to express his sincere thanks to his mentor Professor Reza M. Khanbilvardi, for his support, encouragement, and advice during the course of the study. His advice convinced me, after a long time that I was away from the academic environment, that I should pursue a Master and a Ph.D. degree at CUNY. It was Prof. Khanbilvardi who initiated the present investigation and encouraged me to work on this research.

I also wish to thank the other members of my dissertation committee (Lin A. Ferrand, John Fillos, Charles A. Miller, and Paul W. Grosser) for the time and effort they have spent on this matter. I wish...

To thank Prof. Ferrand for her kind guidance with respect to data analysis of the hydroplaning section of this dissertation.

To thank Prof. Fillos whom I owe my Environmental Engineering knowledge to and for his constructive comments on chemical analysis involved in this project and his helpful suggestions in preparation of this dissertation.

To thank Prof. Miller for his advice on the matters relating to concrete and its properties as incorporated in this dissertation.

To thank Dr. Grosser for his input on the hydraulic aspects of my dissertation.

Grateful acknowledgement is due to the employees of the Public Works Department of Suffolk County who extended assistance and gave important suggestions which contributed significantly to the successful completion of this study. In this regard special recognition must be given to Richard Carioto, Edwin Cohen P.E., and Madeline Jubenville.

Acknowledgement and appreciation also must be expressed for the support provided by the laboratory technicians namely Robert Suhoke Jr., Thomas Sedlacek and Edward Robles.

Acknowledgement is also due to the Pave Asphalt Co. which kindly provided us with the required asphalt and ash-asphalt mixes.

Funding for this project was provided by the Suffolk County Department of Public Works, The New York State Energy Research and Development Authority and the City College of the City University of New York. Their support is gratefully appreciated.

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CHAPTER 1. INTRODUCTION

1.1 MOTIVATION FOR THE RESEARCH AND BACKGROUND

Disposal of sludge from sewage treatment plants presents a rapidly growing problem in metropolitan areas in the United States. About 1,000 dry tons of sludge per day are disposed of in New York State alone. Due to the large volumes of sludge, the recent ban on sludge disposal in the ocean, the lack of or inappropriate land application alternatives, and the scarcity of suitable landfill space, municipalities are considering, and in some cases have on line, incineration as a means of handling the ever increasing volumes of sludge. Even though the final ash remaining after the burning process occupies considerably less volume than the original sludge, a significant amount of ash still remains to be disposed. An important obstacle to implementing incineration may be the long term management of the residual ash. In some areas, as for example Long Island, in addition to the lack of new landfill sites, the law mandates the closing of existing landfills during a specified period of time (V. Breslin, 1990). Currently many urban areas are forced to transport ash long distances, to other states, where land is available. This has caused disposal to become an expensive process with the cost rising to as high as the annual costs for wastewater treatment (Campbell and Bridle, 1985). In addition to high costs, transportation and disposal of sludge and sludge ash may have an adverse environmental impact.

Many researchers have been attempting to solve the problem by studying the use of sludge ash in construction materials. A study was carried out to add sludge ash as a filler for portland cement (Tay, 1987, Ref. 30). The result of this study indicated that sludge ash could replace up to 10% of cement in concrete and the strength developed was still well within the range of normally required. For 20% of cement replaced, however, more than 30% decrease in 28 day compressive strength was observed. Fly ash was also used in soil stabilization (Tay & Goh 1991). The result showed that fly ash could be used as an admixture in the stabilization of soft soil. The clay samples treated with fly ash, for a 10% fly ash mix, showed substantially improved shear strengths and lower compressibility.

Breslin, et. al. (1988) successfully used stabilized incinerator residue in the Long Island marine environment. Duedall et. al., (1983) and later Woodhead et. al., (1985) successfully stabilized coal ash, while Shieh et. al., (1988) reported satisfactory utilization of oil ash for the construction of artificial coastal reefs. Tay (1987, Ref. 30) reported successful results in the use of sludge ash in the manufacturing of concrete bricks, and finally Tay et. al., (1989) has concluded that sludge ash manifests the basic attributes required for light-weight aggregates in the production of light-weight concrete. The resulting light-weight concrete satisfies the physical requirements in terms of weight, strength, heat-insulating properties and fire resistance.

1.2 OBJECTIVES OF THIS RESEARCH

Utilization of ash, until now, has been limited to its application in low strength concrete elements such as lightweight concrete and some kinds of concrete blocks. Therefore, there is a need to study the possible use of ash as an aggregate in higher strength concrete. Similarly, the use of ash as an asphalt aggregate has not been investigated. Due to the wide application of asphalt as a roadway pavement material, it is of major interest to study the merits of using ash as an aggregate.

In this study, sludge incineration residues, collected from the Bergen Point Wastewater Treatment Plant, were stabilized within an ash matrix by adding: (a) portland cement to form solid concrete and (b) to form an ash-mixed asphaltic material. Laboratory analysis, including leachate studies, comprehensive strength testing, asphalt testings, rainfall runoff testing and others were conducted to demonstrate the viability and advantages of these ash stabilization alternatives.

The objectives of this study are summarized as:

1. Determine the physical and chemical characteristics of the sludge ash generated at the Bergen Point Wastewater Treatment Plant.
2. Confirm the utilization of the stabilized mixes for suitability (i.e., strength, durability, and skid resistance properties) as construction and roadway paving materials.
3. Confirm that ash-asphalt and ash-concrete mixtures are non-hazardous.
4. Evaluate the performance of the stabilized mixes with respect to hydrological and hydroplaning aspects such as runoff, infiltration, and hydraulic flow resistance.
5. Evaluate the economical benefits associated with the use of ash as an aggregate in concrete and asphalt mixes.

1.3 SUITABILITY OF ASH STABILIZED MIXES

It is proposed that ash be used to replace a portion of the aggregate in concrete or asphalt. The term "aggregate" is used to describe the gravel, crushed stone, sand or other materials which are mixed with Portland cement or asphalt cement to make concrete or asphalt, respectively. As aggregates form the bulk of the volume of concrete and asphalt, the selection of suitable material is extremely important. Essential characteristics of aggregates include the following:

Aggregate should be hard and should not contain materials that are likely to decompose or change in volume when exposed to the weather and water, to chemically interact with the cement paste or asphalt or to affect the reinforcement, for the case of concrete. Examples of undesirable materials are coal, pyrites and clay: coal may swell, pyrites may cause stains and clay softens and so form weak pockets. Aggregates should also be clean and free from organic impurities.

The term "fine aggregate" is used to describe the natural sand, crushed stone sand, crushed gravel sand or other material that mainly passes through a No. 4 sieve. "Coarse aggregate" is the term used to define materials such as natural gravel, crushed gravel, or crushed stone that is mainly retained on a No. 4 sieve.

The proportions of the different sizes of particles making up the aggregate are found by sieving and are known as the "grain size distribution" or "grading" of the aggregate: the grading is usually given in terms of the percentage by weight passing the various sieves. For aggregates to be used in concrete or asphalt, their grading has to comply with the specifications as set forth by standards.

To employ ash for use in concrete as an aggregate, the mix should be checked for physical strength. The following tests should be conducted to establish reasonable estimates of the materials physical characteristics: compressive test, tensile splitting, bending strength, creep test, and bond strength test. Also included should be the tests which measures or indicates the durability of concrete, like resistance to the cycles of freezing and thawing and the differential scanning calorimetry (DSC) test. These tests will be described in detail in Chapter 3.

Since the ash-mixed asphalt binder behaves as a viscoelastic material from a materials point of view, the following information needs to be obtained:

1. Marshall Test results on the asphalt materials. The Marshall test is a mix design procedure used to establish proper proportion of aggregates and asphalt cement to meet New York State Department of Transportation standards (N. Y. S. D. O. T. 1981). The Marshall test and its requirements will be discussed later in Chapter 3.
2. The asphalt durability can be evaluated with a test known as thermo-mechanical test. This test evaluates the response of the ash-asphalt to temperature change between -50 to 50°C. A detailed description of the test will follow in Chapter 3.

Stability for driving and drivers safety, under dry weather condition, is highly dependent on the skid resistance of the pavement surface against vehicular tire. Under the wet weather situation, these factors are reflected in part by the surface roughness that may be measured by the hydraulic resistance. The hydraulic resistance is a function of the material, the aggregate size and surface finish. The depth of runoff produced during the storm events is of particular importance to drivers safety. The ash-concrete and ash-asphalt pavements, therefore, have to be studied for skid resistance and runoff hydraulic resistance during rainfall events.

The new ash-asphalt and ash-concrete material should not adversely affect the environment by producing either leachate or surface runoff contaminated with heavy metals and/or other pollutants. Runoff from the roadway and highway right-of-way are normally discharged to a variety of watersheds. The runoff may be contaminated with suspended solids, heavy metals, nutrients, oil and grease, bacteria and other pollutants (Kerri, et. al., 1984). Furthermore, the application of road deicing agents such as sodium chloride, NaCl, could contribute to roadway runoff pollution. The quantity and quality of pollutants from roadways and highways are dependant on the location of the site, adjacent land use, volume of traffic, and pavement material (Maestri, et. al., 1987). It is important to identify and evaluate the potential pollutants from a roadway surface paved with an ash-mixed asphalt or concrete and attempt to identify those contaminants that may be contributed from the ash alone or as a result of the ash-asphalt/ash-concrete mixtures.

CHAPTER 2. PLANT DESCRIPTION AND ASH CHARACTERISTICS

2.1 TREATMENT PLANT OPERATIONS

The ash material studied in this project is the end product of the sludge incinerators at the Bergen Point Wastewater Treatment Plant Facility located on Bergen Avenue in Babylon, Suffolk County. Suffolk County is the eastern 2/3 of Long Island, New York. The service area of Suffolk County's sanitary sewer system is divided into 18 districts. The subject facility, which processes all public sewage collected in District No.3, presently serves approximately 155,000 customers and has ultimate service capacity for 240,000 customers.

The Bergen Point Waste Water Treatment Plant, owned and entirely operated by Suffolk County Department of Public Works, has a design flow of 30 MGD. At present, the facility using the activated sludge process treats an average flow of 24 MGD.

There are three types of sludge to be processed which originate from primary treatment, secondary activated sludge treatment, and the scavenger waste. These three types of sludge are blended and thickened to 2-4% solids. The blended sludge is composed of 45% primary sludge, 35% secondary sludge and 20% scavenger waste that is trucked to the plant.

Potassium permanganate and polymer are added to the blended sludge prior to dewatering. The sludge is then pumped to the belt filter press which produces a filter cake at 24% solids which is conveyed to the incinerators for burning.

2.2 SOLID PROCESSING SYSTEM

Presently, solids which are burned in the incineration system can be traced to five sources within the plant. These are: grit chambers and primary settling tanks (from primary treatment), waste activated sludge floatation thickeners and scum separation tank (from secondary treatment), and the scavenger waste settling tanks. Screenings during primary treatment are currently disposed off-site except for influent screenings which are returned to the flow and mostly are included with primary sludge.

All sludge processed at the Bergen Point Wastewater Treatment Plant passes through a blending tank designed to blend the different waste sludges and scum into a homogeneous mixture. The blended mixture is pumped to belt filter presses for dewatering. The estimated quantity of sludge cake generated, as calculated from plant records, is approximately 267,000 lbs./day wet weight at 24% solids. Sludge cake beyond the capacity of the incinerator is landfilled directly.

The volume of grit generated at the plant during the primary treatment process, recorded by plant personnel, is

26,300 lbs./day wet weight at 50% solids.

The increase in solids quantities generated at the Bergen Point Sewage Treatment Plant will be in direct proportion to increases in influent raw wastewater and scavenger waste. The ultimate increase in wastewater flow is expected to be approximately 33% since the plant is currently processing 24 MGD and is designed for 30 MGD. Approximately 0.3 MGD of scavenger waste is currently being processed and, according to County sources, will be limited to 0.5 MGD in the future. Provided in Table 2.1 is a summary of the present solids quantities and a calculation of the projected quantities.

2.3 DESCRIPTION OF INCINERATION SYSTEM

The existing sludge incineration system consists of two 18-foot 9-inch diameter seven hearth furnaces (Fig. 2.1). Each furnace's capacity is 120 tons per day (240,000 lbs/day) of wet material of approximately 24% solids that is fed from the belt filter presses. The sludge, fed into the first hearth, is dried, burned, and cooled as it passes downward through the furnace. If necessary, a supplemental fuel system can feed No.2 fuel oil to burners located in hearth No.3, No.4, and No. 6. Temperature sensors at each hearth, monitored in a control room, control hearth temperature for proper burning. Normally the first two hearths are used as a drying zone.

TABLE 2-1: PROJECTED SOLIDS QUANTITIES

Presented Solids Quantities (Dry) From Plant Data

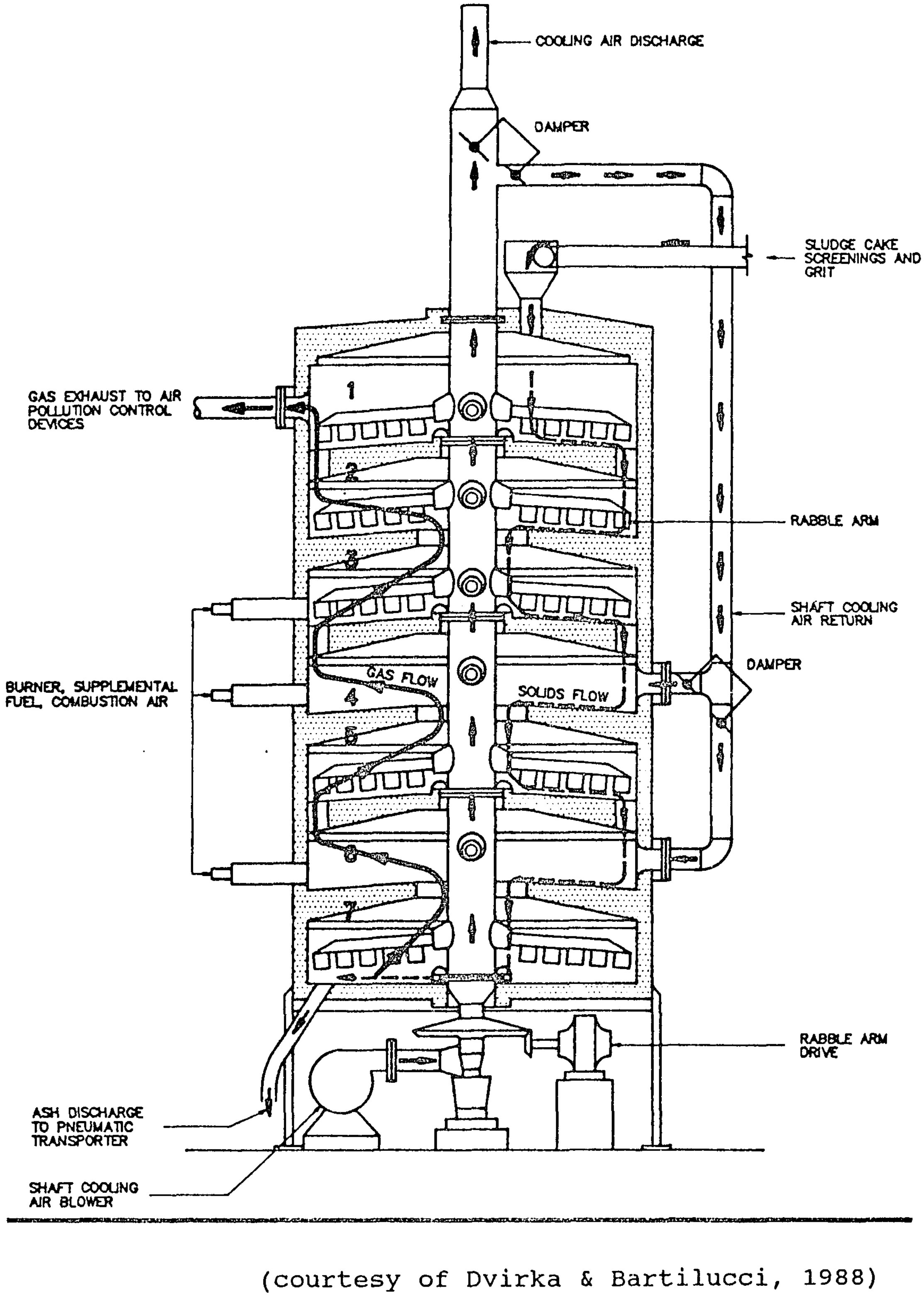
Material	Quantity (lbs/day)	
Primary Sludge	20,000	
Waste Activated Sludge	30,700	
Scum	2,800	
Grit	13,150	
Screenings	1,870	
Sub-Total at 20 MGD		68,520 lbs/day
Scavenger Sludge	10,500	
Screenings from Chemical Sludge	540	
Sub-Total		11,040 lbs/day
Total Present Solids Quantity		79,560 lbs/day

Projected Future Solids Quantities (Dry)

Solids at 30 MGD = 68,520 x 1.5 =	102,780 lbs/day
Scavenger Sludge = 11,040 x 5/3 =	18,400 lbs/day
TOTAL	121,180 lbs/day

(Dvirka & Bartilucci, September 1988)

FIGURE 2-1 : MULTIPLE HEARTH FURNACE



(courtesy of Dvirka & Bartilucci, 1988)

Hearth #3 and Hearth #4 are the primary burning zones. The remaining Hearths (#5, #6, and #7) gradually cool the material. After cooling, the ash is discharged into a hopper located under the furnace. A vacuum periodically draws the ash from the hopper and conveys it to an ash storage silo located external to the sludge disposal building. The ash is eventually disposed of off-site. The temperature of the exhaust gas from the furnace (Hearth No.1) generally varies between 1200 °F and 1300 °F. After exiting the furnace the gas passes through an oil fired afterburner designed to increase the temperature of the gas to 1400 °F. The exhaust gas from the afterburner enters the waste heat boiler where it gives up its heat and the gas temperature is reduced to 121 °F. The gas, cleaned and cooled in the venturi and impingement tray scrubbers, is discharged to the atmosphere.

2.4 INCINERATION OPERATION

The dewatered sludge cake is plowed into the drop chute by a plate. When enough sludge falls into the drop chute to outweigh the damper weights, the sludge falls onto the inner part of hearth No.1. The sludge is dried on hearths No.1 and No.2 at temperatures ranging from 1200-1300 F. As the sludge moves across hearth No.3, it begins to burn and continues to burn across hearth No.4. After hearth No.4, the sludge gradually cools until it exits the furnace through the bottom of hearth No.7. A data sheet for the system equipment is provided in Appendix 2-A (Dvirka and Bartilucci, 1988).

The normal exhaust gas temperature for a multiple hearth furnace, which is operating efficiently, is between 800-900 °F. At present operation the hearth temperatures are maintained at:

Hearth 1 (exhaust)	1200-1300°F
Hearth 2	1300-1400°F
Hearth 3	1400-1600°F
Hearth 4	900-1100°F
Hearth 5	400- 600°F
Hearth 6	200- 400°F
Hearth 7	200- 300°F

The exhaust gas temperature is held at 1200-1300 °F because of the variable characteristics of the feed sludge. When the concentration of waste activated sludge is more difficult to dewater, the feed to the furnace becomes wetter. Since it is difficult to foresee this change with the current system, the operators keep the temperatures high in anticipation of the wet sludge.

The ash hauling system consists of a hopper under the furnace, a vacuum-assisted removal system and an ash storage silo located outside the west wall of the sludge disposal building. Steam from the waste heat boiler is utilized to induce the vacuum in the ash removal duct. Ash is removed from the hopper once a day. The ash builds up in the silo and is periodically dropped into a truck and disposed of off-site. Ash is removed from the silo several times per month, depending on how much sludge is burned and then disposed of at a local landfill.

2.5 WASTE HEAT BOILER

The waste heat boiler is capable of producing 11,900 lbs. of steam per hour at 425 psig and 454 °F. In addition to powering the ash removal system, the steam is used for heat in the winter and air conditioning in the summer. The steam's pressure is regulated and maintained by an automatic damper which distributes the waste heat to the boiler or the scrubbing system.

2.6 AIR POLLUTION CONTROL EQUIPMENT

After passing through the afterburner, the exhaust gas is ducted, as needed, to the waste heat boiler or the scrubbing system. The gas is distributed by an automatic damper that is controlled by the boiler pressure. On entering the scrubbing system, the gas is precooled by a water spray and drawn through a venturi and an impingement tray scrubber. Flue gas, generated by the incineration process, is drawn from the furnace through the venturi scrubber and impingement scrubber by the I. D. fan and is then finally exhausted from the stack. Particulate matter entrained in the flue gas is separated from the gas as it passes through the venturi and impingement scrubber. These devices operate on the principle of conditioning the particulate and disengaging it from the flue gas. Particulate matter leaving the furnace varies in size, ranging from the submicron particle to the relatively large 10 micron and above.

As hot gases enter the venturi, they are conditioned (wetted) by a central vertical spray and four impingement sprays just prior to the venturi throat. Adjustment of the venturi blade angle varies the pressure drop across the scrubber. Increasing the pressure drop increases the removal efficiency of the smaller sized particles. Further improvement of collection efficiency can be achieved by increasing the pressure and quantity of water being supplied to the sprays.

As the pressure drop across the venturi increases, the pressure drop across the inlet damper should be correspondingly decreased if the I.D. fan is to operate at constant static pressure.

Flue gas entering the impingement scrubber is laden with moisture and water droplets, many of which contain particulate matter. As the flue gas travels through a series of impingement baffle plates, it is directed to a target plate and dispersed. The particulate is left behind in the water bath and is subsequently removed. For the impingement scrubber to be effective, the water level must be above the target plate.

Draft in the furnace is maintained between -0.2 and -0.3 inches WC. The pressure drop across the venturi scrubbing system of Furnace No. 2 is currently varying between 5 and 10 inches WC. The exhaust gas temperature is currently averaging approximately 70°F.

Fly ash (or scrubber ash) is captured in the scrubber water. The scrubber water with the ash goes to the beginning of the plant for processing with the influent wastewater.

2.7 HISTORICAL DATA

Incinerator ash data from Bergen Point collected since 1988, are shown in Table 2-2 through Table 2-4. These data include Sieve Analysis, EP-Toxicity analysis, and TCLP.

The results of sieve analysis, as performed in five different occasion by SCDPW and shown in Table 2-2, are not consistent. Since the SCDPW sampling strategy is not known, further comments on the distribution of ash particle size from the existing data is not possible.

The results of EP-Toxicity and TCLP tests on ash, as performed previously by SCDPW, are tabulated in Tables 2-3 and 2-4.

The Extraction Procedure (EP) Toxicity Test is used to determine if a waste exhibits the characteristics of EP toxicity. The procedure consists of placing 100 grams of the ash sample in the extractor and adding 1600 grams of distilled water to it. The pH is adjusted to 5.2 with acetic acid. The sample is placed in agitator for 24 hours and then is removed and filtered with 0.45 um membrane filters and prefilters. The sample is finally placed in proper containers and is analyzed. The extract concentrations are compared to the maximum contamination limits listed in 40 CFR- 261.24. If the extract concentration is less than the limits, the waste is then considered to exhibit the characteristic of extraction procedure toxicity. This procedure may be used to simulate the leaching that a waste may undergo in a sanitary landfill.

The Toxicity Characteristic Leaching Procedure (TCLP) Test is used to evaluate the leaching potential of hazardous substances. In this test the liquid portion is separated first by filtration and the remaining solid phase is leached with extraction fluid. The liquid portion is combined with the leachate for analysis.

As it is seen from Tables 2-3 and 2-4, all tests passed the existing EPA standard limits (as shown later in Table 2-11). It is worth to mention that the EP-Toxicity test of 01/24/1989 was the only analysis that showed pesticides, Lindane and α-BHC as marked with * and yet below the standard limits, in the ash. In all other tests, whether performed by SCDPW in the past or during this study, the amount of these parameters fell well below the detectable limits.

For comparison with ash values from another wastewater treatment plant with a multiple hearth incinerator available data from the wastewater treatment plant in Orangetown, Rockland County, New York was obtained. A description of the plant together with available existing data are shown in Appendix 2-B. It appears that the ash materials from the Orangetown plant are a little bit finer than the ash materials from the Bergen Point plant (see Table Appx 2-B-2).

TABLE 2-2: HISTORICAL DATA ON SIEVE ANALYSES FOR ASH SAMPLE FROM BERGEN POINT WASTEWATER TREATMENT PLANT

		% Finer				
Classi-fication	Sieve No.	1989 Sample A	1988 Sample B	1988 Sample C	1988 Sample D	1988 Sample E
Gravel	#4	96	95	85	95	
	#8	95	92	82	95	
Coarse sand	#16	91	91	92	95	
	#20	90	91	82	95	
	#30	87	90	81	95	100
Medium sand	#40	83	88	79	93	99
	#50	76	85	77	90	97
	#80	66	81	72	82	90
Fine sand	#100	63	80	71	79	88
	#200	49	50	63	71	79
Coarse silt	#270		36	62	71	79
F.M.*		0.92	0.67	1.22	0.51	0.15

* Fineness Modulus: The fineness modulus is calculated for cumulative % retained on sieves #4, #8, #16, #30, #50 and #100.

TABLE 2-3 : HISTORICAL EP-TOXICITY ANALYSIS DATA FOR ASH

EP-Toxicity Test	Sample collection date			
Parameters	1985 ug/l	1988 ug/l	1989 ug/l	1990 ug/l
Endrin	<10	<.05	<.05	<.05
Lindane	<10	<.05	* 52.3	<.05
Methoxychlor	<10	<.05	<.05	<.05
Toxaphene	<10		<.05	<.05
2,4-D	<10	<.05	<.05	<.05
2,4,5-TP (Silvex)	<10		<.05	<.05
α-BHC		<.05	* 83.3	
β-BHC		<.05	<.05	
Heptachlor		<.05	<.05	
P,P'-DDE		<.05	<.05	
Dieldrien		<.05	<.05	
P,P'-DDD		<.05	<.05	
δ-BHC		<.05		
P,P'-DDT		<.05		
Endrin Aldehyde		<.05		
Silvex		<.05		
Endosulfane I			<.05	
OP-DDT			<.05	
Endosulfan Sulfat			<.05	
Endosulfan II			<.05	
Heptachlor Epoxide		<.05	<.05	
Aldrin		<.05	<.05	

TABLE 2-3 : (CONTINUED)

Metals EP-Toxicity	Max. Cont. Level mg/l	Sample collection date			
		1985 mg/l	1988 mg/l	1989 mg/l	1990 mg/l
Arsenic	5	0.03	0.03	< 0.01	0.023
Barium	100	0.23	<0.05	<0.05	0.283
Cadmium	1	<0.01	0.002	0.002	0.002
Chromium	5	<0.01	<0.02	<0.02	0.055
Lead	5	<0.03	<0.01	<0.01	<0.01
Mercury	0.2	<0.01	<0.001	<0.001	0.001
Selenium	1	0.04	<0.01	<0.01	0.046
Silver	5	<0.01	<0.02	<0.02	<0.02

TABLE 2-4: HISTORICAL TCLP-TOXICITY ANALYSIS DATA FOR ASH

Date received: 08/13/90
Date analyzed: 08/20/90

TCLP METALS

Parameters	**Maximum Contaminant Level (mg/l)**	**Result (mg/l)**
Arsenic	5.0	<0.05
Barium	100.0	<5.0
Cadmium	1.0	<0.05
Total chromium	5.0	<0.05
Lead	5.0	<0.05
Mercury	0.2	<.005
Selenium	1.0	<0.05
Silver	5.0	<0.05

TABLE 2-4 : HISTORICAL TCLP-TOXICITY ANALYSIS DATA FOR ASH (CONTINUED)

<u>TCLP VOLATILES</u>

Parameters	**EPA Maximum mg/l**	**Result ug/l**
Acrilonitrile	5.0	<0.5
Benzene	0.07	<5.0
Carbon Disulfide	14.4	<5.0
Carbon Tetrachloride	0.07	<5.0
Chlorobenzene	1.4	<5.0
Chloform	0.07	<5.0
1,2-Dichloroethane	0.4	<5.0
1,1-Dichloroethylene	0.1	<5.0
Isobutanol	25.0	<5.0
Methylene Chloride	8.6	1.2
Methyle Ethyl Ketone	7.2	<5.0
1,1,1,2-Tetrachloroethane	10.0	<5.0
1,1,2,3-Tetrachloroethane	1.3	<5.0
Tetrachloroethylene	0.1	<5.0
Toluene	14.4	35.7
1,1,1-Trichloroethane	25.0	<5.0
1,1,2-Trichloroethane	1.2	<5.0
Trichloroethylene	0.07	<5.0
Vinyl Chloride	0.05	<10.0

TABLE 2-4 : HISTORICAL TCLP ANALYSIS DATA FOR ASH (CONTINUED)

TCLP SEMIVOLATILES

Parameters	**EPA Maximum ug/l**	**Result (ug/l)**
Di-N-Butyl Phthalate	-	<10.0
Fluoranthene	-	<10.0
Benzidene	-	<80.0
Pyrene	-	<10.0
Butyl Benzyle Phthalate	-	<10.0
2,4-Dichlorophenol	-	<10.0
1,2,4-Trichlorobenzene	-	<10.0
Naphthalene	-	<10.0
Hexachlorobutadiene	-	<10.0
2,4,6-Trichlorophenol	-	<10.0
2-Chloroaphthalene	-	<10.0
Dimethyl Phthalate	-	<10.0
Acenapthylene	-	<10.0
Acenapthene	-	<10.0
2,4-Dintrophenol	-	<50.0
4-Nitrophenol	-	<50.0
2,4-Dinitrotoluene	-	<10.0
2,6-Dinitrotoluene	-	<10.0
3,3-Dichlorobenzidine	-	<20.0
Benzo(a) Antracene	-	<10.0
bis (2-Ethylhexyl) Phtalat	-	<10.0
Chrysene	-	<10.0

TABLE 2-4 : HISTORICAL TCLP ANALYSIS DATA FOR ASH (CONTINUED)

TCLP SEMIVOLATILES

Parameters	EPA Maximum ug/l	Result (ug/l)
Di-N-Octyl Phtalate	-	<10.0
Benzo(b) Fluoranthene	-	<10.0
Benzo(k) Fluoranthene	-	<10.0
Benzo(a) Pyrene	-	<10.0
Indeno(1,2,3,cd) pyrene	-	<10.0
Dibenzo (a,h) Anthracene	-	<10.0
Benzo(g,h,i) Perylene	-	<10.0
Phenol	-	<10.0
bis(2-Choloroethyl) ether	-	<10.0
2-Chlorophenol	-	<10.0
1,3-Dichlorobenzene	-	<10.0
1,4-Dichlorobenzene	7,500	<10.0
1,2-Dichlorobenzene	-	<10.0
Uis(2-Chloroisopropyl)ethe	-	<10.0
N-Nitroso-Di-N-Propylamine	-	<10.0
Hexachloroethane	3,000	<10.0
N-Nitrosodimethylamine	-	<10.0
Nitrobenzene	2,000	<10.0
Isophorone	-	<10.0
2-Nitrophenol	-	<10.0
2,4-Dimethyl Phenol	-	<10.0
bis(2-Chloroethoxy)Methane	-	<10.0

TABLE 2-4 : HISTORICAL TCLP ANALYSIS DATA FOR ASH (CONTINUED)

TCLP SEMIVOLATILES

Parameters	**EPA Maximum ug/l**	**Result ug/l**
Diethyl Phthalate	-	<10.0
4-Chlorophenyl-Phenyl Ether	-	<10.0
Fluorene	-	<10.0
4,6-Dinitro-2-Mehtyl Phenol	-	<50.0
N-Nitrosodiphenylamine	-	<10.0
4-Bromophenyl-Phenylether	-	<10.0
Hexachlorobenzene	130	<10.0
Pentachlorophenol	100,000	<50.0
Phenanthrene	-	<10.0
Anthracene	-	<10.0

HERBICIDES AND PESTICIDES

Parameters	**EPA Maximum ug/l**	**Result (ug/l)**
Endrin	20	<0.006
Lindane	400	<0.004
Methoxychlor	10,000	<0.126
Toxaphene	500	<0.240
2,4-D	10,000	<1.200
2,4,5-T(silvex)	1,000	<0.170
Chlordane	30	<0.014
Heptachlor	8	<0.003

In Table 2-4, the detectable limit for some pollutants subtitled: TCLP VOLATILES, was higher than the standard threshold making it impossible to compare the actual concentration of these parameters with the standard limits.

2.8 SAMPLING STRATEGY

Following a site reconnaissance two locations, one from hearth No.7 of each incinerator, were selected for sampling the bottom ash from the two incinerators at the Bergen Point plant. Fly ash is being captured within the scrubber water, and there is no mechanism for retrieving this ash. Considering the small amount of fly ash generated at Bergen Point in relation to incinerator ash and the difficulties with collecting samples, only the bottom ash from both incinerators was collected.

The bottom ash samples were extracted using a shovel. Ash samples were taken at 15 minutes intervals from each hearth. Subsequently, sixteen incremental samples were combined and mixed together to form a 40 pound gross sample to represent the ash collected over a four hour period (peak flow time). Additionally, 4.5 tons of material per load were collected from the ash silo and stored on three trucks parked at the facility. Two trucks each containing 4.5 tons of ash and one compartmented truck containing 9 tons (4.5 ton in each compartment) of ash were stored for future study. These loads were carefully protected from the weather with plastic liners and covers. The combined 40 pound ash samples were placed in plastic bags which were tied and labelled with time and date of sampling activity. The bags were then put in 5 gallon plastic containers, and transported to the laboratory at the City College of the City University of New York (CCNY). The ash samples were collected on 11-27-90, 11-29-90, 12-04,90 and 12-21-90. During the ash sampling, a number of treatment plant operating parameters were obtained and recorded as shown in Table 2-5.

2.9 LABORATORY WORKS

Physical and chemical analyses were conducted to characterize the ash samples collected on these four sampling dates. The following subsections describe the results.

2.9.1 PHYSICAL ANALYSIS

Table 2-6 lists the physical parameters, with the corresponding ASTM procedure used to test each sample. All of these analyses, except for the shrinkage and permeability tests, were conducted in the Soils Laboratory at CCNY. The shrinkage and the permeability tests were conducted at the Suffolk County Department of Public Works' Laboratory in Yaphank, New York.

TABLE 2-5: OPERATION DATA MONITORED DURING SAMPLING PERIOD AT BERGEN POINT WASTEWATER TREATMENT PLANT

		sample 1	sample 2	sample 3	sample 4
collection date		11/27/ 1990	11/29/ 1990	12/4/ 1990	12/21/ 1990
wastewater flowrate MGD*	Min	13.84	14.0	15.97	14.42
	Avg	23.58	23.5	25.52	23.92
	Max	34.92	28.98	36.41	32.53
sludge production rate	liquid M gal**	0.307	0.293	0.238	0.321
	wet cake tons	177	182	127.4	195
	dry cake tons	33.6	41.4	28.8	41.5
ash generation rate cuyd/day		14	14	7	14

Notes:

- MGD = million gallons per day

- M gal = million gallons

Table 2-7 shows the results of the sieve analysis while Table 2-8 presents all the other physical characteristics of the ash samples. Two test runs on each sample were conducted for each parameter. The numbers shown in these tables are the averages of two test runs.

TABLE 2-6 : PHYSICAL TEST REFERENCES

TEST	REFERENCE
Sieve Analysis	ASTM C136
Organic Impurities	ASTM C40
Fine Materials	ASTM C117
Clay lumps	ASTM C142
Permeability	ASTM D2434
Specific Gravity	ASTM C128
Moisture Content	ASTM D2216
Shrinkage limit	ASTM D427

TABLE 2-7 : SIEVE ANALYSIS FOR ASH SAMPLES

Sieve No.	Sample No.1			Sample No.2		
	% Finer			% Finer		
	Test-1	Test-2	Mean	Test-1	Test-2	Mean
#4	100.0	100.0	100.0	100.0	100.0	100.0
#8	97.8	98.4	98.1	98.3	97.8	98.0
#16	93.0	93.1	93.0	91.3	92.5	91.9
#20	89.0	87.3	88.2	85.0	87.7	86.4
#30	84.2	80.9	82.6	78.5	82.1	80.3
#40	78.0	73.1	75.6	71.6	74.6	73.1
#50	70.5	65.9	68.2	64.6	67.0	65.8
#80	62.2	56.5	59.4	57.5	57.8	57.7
#100	58.6	53.8	56.2	54.5	54.9	54.7
#200	44.0	39.8	41.9	41.6	41.0	41.3
#270	27.9	24.7	26.3	28.9	18.7	23.8
#500	0.9	0.7	0.8	0.8	0.5	0.7

TABLE 2-7 : SIEVE ANALYSIS FOR ASH SAMPLES (Continued)

Sieve No.	Sample No.3			Sample No.4		
	% Finer			% Finer		
	Test-1	Test-2	Mean	Test-1	Test-2	Mean
#4	100.0	100.0	100.0	100.0	100.0	100.0
#8	98.7	99.3	99.0	97.8	98.4	98.1
#16	89.2	94.3	91.8	92.7	93.1	92.9
#20	79.6	89.5	84.6	87.7	87.4	87.6
#30	70.8	84.6	77.7	82.1	81.2	81.7
#40	62.2	79.1	70.7	74.6	73.2	73.9
#50	52.4	73.1	62.8	66.2	64.7	65.5
#80	43.8	63.5	53.7	56.5	53.9	55.2
#100	40.5	60.1	50.3	52.6	50.7	51.6
#200	28.3	41.3	34.8	38.0	36.2	37.1
#270	18.5	9.5	14.0	24.7	15.8	20.3
#500	0.6	0.3	0.5	0.9	0.6	0.8

TABLE 2-8 : PHYSICAL TEST ANALYSIS FOR ASH SAMPLES

Sample No.	Fine mat. C117* %			Clay lumps C142* %			Organic Impurities C40* %		Sp.Gr. Bulk C128*		
	Test1	Test2	Mean	Test1	Test2	Mean	Test1	Test2	Test1	Test2	Mean
1	37.03	40.51	38.77	36.13	34.11	35.12	Lighter	Lighter	2.00	1.96	1.98
2	44.36	38.94	41.65	55.16	53.66	54.41	Lighter	Lighter	1.67	1.79	1.74
3	38.79	40.11	39.45	45.92	41.32	43.62	Lighter	Lighter	1.73	1.81	1.77
4	39.85	42.05	40.95	41.96	46.92	44.44	Lighter	Lighter	1.78	1.86	1.82
Mean			40.20			44.40					1.83

Notes:

* : C117, C142, C40, D2434, C128, D2216 and D427 are all ASTM standards.

- For the Organic Impurities test the term "lighter" refers to the color of the sample being lighter than the color of a standard solution as recommended in the test procedure in ASTM C40.

TABLE 2-8 : PHYSICAL TEST ANALYSIS FOR ASH SAMPLES (Continued)

Sample No.	Permeability D2434* cm/s			Water Content D2216* %			Shrinkage Limit D427 %		
	Test1	Test2	Mean	Test1	Test2	Mean	Test1	Test2	Mean
1	0.000700	0.000391	0.000533	0.14	0.16	0.15	66	54	60
2	0.000132	0.000312	0.000222	0.21	0.17	0.19	61	63	62
3	0.000399	0.000241	0.000320	0.34	0.32	0.33	40	46	43
4	0.000532	0.000508	0.000520	0.49	0.41	0.45	31	41	36
Mean			0.000400			0.28			50.2

Notes:

*: C117, C142, C40, D2434, C128, D2216 and D427 are all ASTM standards.

The sieve analyses data of the four samples of ash obtained for this project show the grain size distributions to be quite consistent with each other. According to the sieve analyses data in Table 2-7, the ash sample particle size distribution resembles an aggregate comprised of approximately 60% sand and 40% silt. Comparing these particle distributions with the ASTM C-33 requirements for fine aggregate reveals that pure ash does not fall within the required range for fine aggregate used in concrete mixes.

The other physical properties of the ash materials in the latest tests are as follows:

(a) Organic impurities (Table 2-8) are less than the standard limit, indicating that the ash is an inorganic material.

(b) The permeability results (Table 2-8) are within the inorganic-silt range and much higher than clay for which permeability is greater than 10^{-6} cm/s.

(c) The average shrinkage limit of ash is about 50% (Table 2-8) which is appreciably higher than is normally encountered for non-clay inorganic fine soils. The water content of the samples (Table 2-8) were well below their shrinkage limits. This can be an advantage in certain engineering designs where little or no volume change is required. However, it can be undesirable in terms of a high rate of water absorption during concrete mixing which can alter the design water-to-cement ratio. In order to keep the water/cement ratio at its design value, it is appropriate to dry up ash first. Then mix other aggregates, including cement, with ash when they are still dry. After a uniform dry mixture of all aggregates and cement is reached then add enough water as designed. In this way the water will be given a chance to react with cement before getting absorbed by ash. Even in the conventional concrete practice, the aggregates and cement are first mixed dry, to maintain a uniform mixture in the mixer, then water is added.

(d) The fine material test covers determination of the amount of material finer than a No. 200 (75-μm) by washing. clay particles and other aggregate particles that are dispersed by the wash water will be removed from the aggregate during the test. For ash, with 40% Fine material as shown in Table 2-8, there is no chance to be considered as a fine aggregate by itself. Blending it with sand, to an extent which reduces the fine material of the over all sand-ash composition to below the standard limit, however, may give a suitable fine aggregate for concrete and asphalt.

(e) The Clay Lumps test covers the approximate determination of friable particles in aggregate. For usual aggregates the value of this test directly indicates the amount of clay particles present. Our study shows that even though the ash material is free of organic matters but contains a 44 percent clay lumps. The presence of clay lump will adversely affect the strength of concrete. Although ash is not a clay soil, but presence of about 40% friable material in ash can reduce the strength of ash-concrete as well as ash asphalt. Once again the proportions of ash in the mix is found to be critical in a sense that the clay lump percent of the overall sand-ash should be kept below the standard limits.

(f) Bulk specific gravity of ash was found to be 1.83 (Table 2-8). Bulk specific gravity is a measure of the specific gravity of a particle that includes the volume occupied by the interparticle pore space. As a result, for a soil matrix, the larger the interparticle pore space the lower its bulk specific gravity would be when compared to the true specific gravity of the matrix.

2.9.2 CHEMICAL ANALYSIS

All of the ash samples were sent to the H2M Laboratory, a New York State Certified Laboratory, for analysis of the parameters shown in Table 2-9. Each sample was tested twice and the results of the chemical analyses as shown in Tables 2-10 and 2-11 are the average of the two tests. A separate sample was prepared by mixing an equal amount of ash from the four ash piles stored at Bergen Point. This mixed sample was then tested for all of the parameters and is also reported in Tables 2-10 and 2-11. Finally a TCLP test was performed on the composite ash sample and the result is tabulated in Table 2-12.

TABLE 2-9 : CHEMICAL TEST REFERENCES

TEST	REFERENCE
Heavy Metals	SW-846
Chloride	SW-846
Sulfate	SW-846
Phosphate	SW-846
Toxicity	EP Tox., and TCLP

TABLE 2-10 : HEAVY METAL ANALYSIS FOR THE ASH SAMPLES

Collection Date	Sample No	Constituents, mg/kg					
		Silver	Arsenic	Barium	Cadmium	Chloride	Chromium
11-27-90	1	124	20.0	1220	12.0	50	166
11-29-90	2	130	29.4	1560	13.4	70	186
12-04-90	3	120	16.36	1220	10.2	220	136
12-21-90	4	136	8.34	1260	13.8	210	146
Mean		127.5	18.52	1315	12.35	137.5	158.5
Composite Sample*		138	11.36	1320	15.6	150	150

Sample No	Constituents, mg/kg							
	Mercury	Lead	Total Phos. (As P)	Sele-nium	Sulfate	Total Solid %	Zinc	Copper
1	0.10	704	70	30.6	5210	99.8	1900	3690
2	<0.10	766	50	54.4	7550	100	2440	4080
3	<0.09	548	70	25.6	13000	100	2080	3000
4	0.10	584	70	42.8	11753	100	1880	3020
Mean		650.5	65	40.4	9378		2075	3447
Comp.* Sample	<.09	580	56	5.78	9018	99.8	2000	3490

Note: Heavy metals obtained through digestion procedure.

* Composite (Comp.) sample was prepared by mixing equal amount of ash from sample #1, #2, #3 and #4.

TABLE 2-11 : EP-TOXICITY TEST RESULT FOR THE ASH SAMPLES

Collection Date	Sample No mg/l	METALS Silver ug/l	Arsenic ug/l	Barium ug/l	Cad-mium ug/l	Chro-mium ug/l	Mercury ug/l	Lead ug/l	sele-nium ug/l
11-27-90	1	0.02	172	0.33	244	<.01	<.20	49	175
11-29-90	2	0.01	166	0.29	7	0.03	<.20	33	117
12-04-90	3	<.01	76	<.20	28	0.03	<.20	<55	118
12-21-90	4	0.02	<72	0.26	26	<.01	<.20	<55	95
Composite Sample*		<.01	160	<.20	60	<.01	<.20	100	190
EPA Standard		5.0 mg/l	5.0 mg/l	100 mg/l	1.0 mg/l	5.0 mg/l	0.2 mg/l	5.0 mg/l	1.0 mg/l

Collection Date	Sample No	PESTICIDE, ug/l Lindane	Endrin	Methoxy-chlor	Toxaphene	HERBICIDE, ug/l 2,4, D	2,4,5 T Silvex
11-27-90	1	<.50	<1.0	<5.0	<10	<2.0	<0.5
11-29-90	2	<.50	<1.0	<5.0	<10	<2.0	<0.5
12-04-90	3	<.50	<1.0	<5.0	<10	<2.0	<0.5
12-21-90	4	<.50	<1.0	<5.0	<10	<2.0	<0.8
Composite Sample		<.50	<1.0	<5.0	<10	<2.0	<0.5
EPA Standard		400 ug/l	20 ug/l	10,000 ug/l	500 ug/l	10,000 ug/l	1,000 ug/l

Note: Composite sample was prepared by mixing equal amount of ash from sample #1, #2, #3 and #4.
Comment: No parameter exceeds EPA "hazardous wastes" standard.

TABLE 2-12 : TCLP TEST RESULT FOR THE COMPOSITE ASH SAMPLE

Composition		Quantity	EPA standard
Ag	mg/l	<0.01	5.0
As	mg/l	0.12	5.0
Ba	mg/l	<0.20	100.0
Cd	mg/l	0.16	1.0
Cr	mg/l	0.01	5.0
Hg	mg/l	<0.20	0.2
Pb	mg/l	<0.05	5.0
Se	mg/l	<0.07	1.0
TCLP PESTICIDES:			
Lindane	μg/l	<10.0	400.0
Heptachlor	μg/l	<0.5	8.0
Heptachlor- Epoxide	μg/l	<0.5	
Endrin	μg/l	<0.5	20.0
Methoxychlor	μg/l	<100.0	10,000.0
Toxaphene	μg/l	<10.0	500.0
Chlordane	μg/l	<10.0	30.0
TCLP HERBICIDES:			
2, 4 -D	μg/l	<100.0	10,000.0
2,4,5-TP(Silvex)	μg/l	<10.0	1000.0
TCLP SEMIVOLATILES:			
1,4-Dichlobenzene	μg/l	<10.0	7500.0
Hexachloroethane	μg/l	<100.0	3000.0
1,2-Dichlorobenzene	μg/l	<10.0	
Nitrobenzene	μg/l	<10.0	2000.0
Hexachlorobutadiene	μg/l	<10.0	
2,4 Dinitrotoluene	μg/l	<10.0	130.0
Hexachlorobenzene	μg/l	<10.0	130.0
2,4,6-Trichlorophenol	μg/l	<10.0	2000.0
Pentachlorophenol	μg/l	<5.0	100,000.0
2-Methyphenol	μg/l	<10.0	
2,4,5-Trichlorophenol	μg/l	<10.0	
4-Methylphenol	μg/l	<10.0	
3-Methylphenol	μg/l	<10.0	
Pyridine	μg/l	<100.0	5000.0

TABLE 2-12 : TCLP TEST RESULT FOR THE COMPOSITE ASH SAMPLE (CONTINUED)

Composition		Quantity	EPA standard
TCLP VOLATILES:			
Vinyl Chloride	μg/l	<10.0	200.0
1,1-Dichloroethene	μg/l	<10.0	
Chloroform	μg/l	<10.0	6000.0
1,2-Dichloroethene	μg/l	<10.0	500.0
Carbon Tetrachloride	μg/l	<10.0	500.0
Trichloroethene	μg/l	<10.0	
Benzene	μg/l	45.0	500.0
Tetrachloroethene	μg/l	<10.0	
Chlorobenzene	μg/l	<10.0	100,000.0
2-Butanone (Mek)	μg/l	<10.0	

Test results of the four ash samples (Tables 2-10 and 2-11) show that the concentrations of heavy metals, pesticides and herbicides are considerably less than the Maximum Contaminant Levels. The composite ash sample results (Tables 2-11 and 2-12) indicate the same quality of EP-Toxicity and heavy metals when compared to the individual ash samples. The composite sample TCLP results indicate that the concentrations are less than the Maximum Contaminant Levels.

2.10 CONCLUSION

(1) The ash material is non hazardous.

(2) The ash consists predominantly of sand and silt sized particles with about 40% of the material finer than the #200 sieve.

(3) With Organic Impurities less than the standard limit the ash may be considered an inorganic material.

(4) The permeability and bulk specific gravity results are within the range of inorganic silt.

(5) The ash alone is not a desirable material as a construction aggregate, but blending with a coarse material may yield a suitable aggregate.

CHAPTER 3: EVALUATION OF ASH-CONCRETE AND ASH-ASPHALT

3.1 INTRODUCTION

Based on the result of the physical tests it was found that the ash was generally similar to inorganic silt in terms of sieve analysis grading and permeability. The ash sample was also found to be free of both organic matter and clay particles. It was postulated that if the ash is used as a fraction of the fine aggregate in either asphalt or concrete mixes, the physical properties of either mix would not be changed dramatically . The results of the chemical analysis conducted on ash samples confirmed that the ash was not toxic according to the standards established by U.S. Environmental Protection Agency for "hazardous Waste".

3.1.1 CONCRETE CHARACTERISTICS

The general characteristics of good concrete are considered to be:

- Strength
- Workability
- Durability

When cement is mixed with water to form a soft paste, it gradually stiffens until it becomes a solid. This process is known as "setting" and "hardening". For complete hydration of a given amount of cement, according to Winter & Nilson, 1979, an amount of water equal to 25% of that of cement, by weight, is needed chemically. An additional 10 to 15 percent must be present, however, to provide mobility for the water in the cement paste during the hydration process so that it can reach the cement particles. This gives a minimum water/cement ratio of 0.35 to 0.40 by weight. Addition of more water tends to reduce the strength of concrete by producing pores in the cement paste. In practice, however, larger water/cement ratios are taken to provide the necessary workability for the concrete mix.

The type and proportioning of aggregate have major effect on the strength, and durability of concrete. The coarse aggregate has to be made of strong and non deterioring rocks. The fine aggregate has to be sound and free of organic and plastic soils. Clay particles have adverse effect on both strength and surface texture and for this reason the common design standards, e.g. ASTM C-33, limit the percentage of fine aggregate which is finer than 0.15 mm to 10 percent or less. Chloride content of aggregate, if in excess of 0.15, significantly reduces concrete durability by corroding reinforcement steel if the pH of concrete falls below 11.

Using the physical characteristics of ash, as discussed in previous chapter, the ash content of concrete should be chosen such that the grain size distribution for the combined ash-sand does not violate the above standards. Also the chloride concentration of the whole mix should be kept below 0.15 percent. Some environmental factors, such as spread of deicing material, could worsen the situation by increasing the concentration of chloride ion around the concrete.

The high water content of ash also may adversely affect the strength of concrete in two ways: 1- by increasing the water/cement ratio if it is not accounted for in the mix proportioning; 2- even if the ash water is accounted for, the entrapped water in the ash matrix may not find sufficient time to get in contact with cement paste and react during limited mixing period. In order to keep the water/cement ratio at its design value, it is appropriate to dry up ash first. Then mix other aggregates, including cement, with ash when they are still dry. After a uniform dry mixture of all aggregates and cement is reached then add enough water as designed. In this way the water will be given a chance to react with cement before getting absorbed by ash. Even in the conventional concrete practice, the aggregates and cement are first mixed dry, to maintain a uniform mixture in the mixer, then water is added.

Although the ash samples are bottom ash they may still contain some fraction of very fine, i.e. fly ash, particles which have proved to act as a cementing agent and may in turn improve the strength of concrete, though in a longer setting time.

3.1.2 ASPHALT CHARACTERISTICS

Asphalt, the residual matter in the processing of crude petroleum oil, is a mixture of high molecular weight compounds, namely asphaltenes and maltenes. The asphalt mixture behaves as a viscoelastic material and thus amenable to characterization procedures applicable to polymeric materials. Viscoelastic materials are subject to creep and do not fully recover after the removal of an applied stress.

The serviceability of asphalt pavements depend on a number of characteristics. Particular characteristics of these materials are their denseness, imperviousness, strength and durability. Utilization of ash with asphalt could affect these properties. Depending on the ratios of ash being mixed with asphalt the range and variation in these parameters could become critical. Therefore, all these properties must be studied when different ratios of ash are being mixed with asphalt.

Several methods are available for evaluating the stability properties of asphalt. The Marshall test is the most widely used approach today. In the Marshall test, aggregates are selected on the basis of specification. Specimens of the aggregate and asphalt cement mix are compacted in the laboratory, utilizing varying amount of asphalt cement. The density and voids of compacted specimen are established and the specimen then heated to 140° F for the Marshal stability and flow tests. Load is applied to the specimen at a prescribed rate. The maximum load registered during the test, in pounds, is designated as the Marshall Stability of the specimen. The amount of movement, or strain, occurring between no load and the maximum load, in units of 0.01 inch is the flow value of the specimen.

Although there are many forms of distress associated with asphalt pavements, three significant distress modes have received a great deal of attention, (a) repetitive (fatigue) cracking of the asphalt layer, (b) permanent deformation (rutting), and low-temperature cracking (thermal cracking).

It is well known that the asphalt stiffness has a significant influence upon the low temperature cracking distress. Obviously, the lower the stiffness, the more probable is the possibility of not obtaining thermal cracking. However, reducing stiffness has consequences upon permanent deformation, referred to as rutting. It is obvious that the two design asphalt cement contents for each distress mode are in conflict with each other. Moreover, it is also known that the optimum asphalt cement content for maximum fatigue life is generally greater than that required for stability (rutting). Therefore mix design based upon fundamental distress modes must result in a compromise to satisfy all the potential distress mechanisms.

3.1.3 SCOPE OF THE WORK

The remainder of this chapter covers the methodology used to assess the performance of ash in mixes of concrete and asphalt. The following tasks were performed:

(i) create a relatively uniform composite ash from the four different stockpiles.

(ii) replace a portion of the fine aggregate in mixes for concrete and asphalt and conduct laboratory scale tests on formed concrete and asphalt specimens. The specimens should differ from each other only by the amount of ash they contained, since all other parameters remain the same.

(iii) Prepare various concrete mixes and produce concrete specimens in terms of cylinders, cubes, beams, and slabs and perform the following tests:

- compressive strength test (ASTM C39)
- creep test (ASTM C512)
- bond test (ASTM C234)
- flexural strength (ASTM C78)
- splitting tensile strength (ASTM C496)
- skid resistance (ASTM E303)
- resistance to freeze and thaw (ASTM C666)
- durability test, using differential scanning

calorimetry (Wendlandt, 1986)

(iv) Prepare various asphalt mixes and produce cylinders and slabs, and perform the following tests:

- compressive strength (ASTM D1074/Marshall Test)
- resistance to plastic flow (ASTM D1559/Marshall Test)
- durability test, using thermal analysis (Wendlandt, 1986)

3.2 COMPOSITE ASH

The four existing ash stockpiles at Bergen Point Wastewater Treatment Plant were used to create a relatively uniform composite ash. A flat indoor area within the Bergen Point Wastewater Treatment plant facility was selected for this operation. A 500 pound portion of ash was brought from each of the four ash stockpiles to the indoor area where each portion was first individually mixed by shovel. Then the four 500 pound loads were mixed together to create a uniform single stockpile of composite ash. When, by visual observation, the mixture was deemed a uniform mix, the composite ash was put in plastic containers and transported to the Suffolk County Department of Public Works' Laboratory in Yaphank, New York, where most of the work for this Task was done. Prior to transport, four random samples of 20 pound each were collected from the combined ash pile and placed in plastic bags and tied. These bags were sent to H2M labs. Inc. for chemical analysis. In addition, a particle size distribution check was conducted on the composite sample for quality control. Figure 3-1 shows that the composite ash particle size distribution follows the values previously reported for each individual ash stockpile. One half of the composite ash (about 1000 lbs) was used for mixing with portland cement, and the other half was used for mixing with asphalt material.

3.3 CONCRETE PROPERTY TESTS

3.3.1 MIX DESIGN

Four separate concrete batches were prepared. One batch had no ash while in the other three batches 10, 20, and 30 percent (by weight) of the fine (sand) aggregate was replaced with ash. The amount of the other constituents, namely the coarse aggregate, portland cement, and water remained the same. The coarse aggregate used was crushed stone with a grading as shown in Figure 3-2. The sand used was beach sand with a grading as shown in Figure 3-2. The portland cement used was Type 2. The control mix (concrete mix with no ash) was designed to have an ACI (American Concrete Institute) mix design specification for 3000 psi compressive strength at 28 days and a slump of 2" to 3". Cylinders, beams, and cube specimens were prepared from all batches and the following

Figure 3-1 : SIEVE ANALYSIS FOR THE COMPOSITE ASH SAMPLE FROM BERGENPOINT WASTEWATER TREATMENT PLANT

Sieve No.	Percent Finer
#4	100
#8	98.3
#16	92.4
#20	86.7
#30	80.6
#40	73.3
#50	65.6
#80	56.5
#100	53.2
#200	38.8

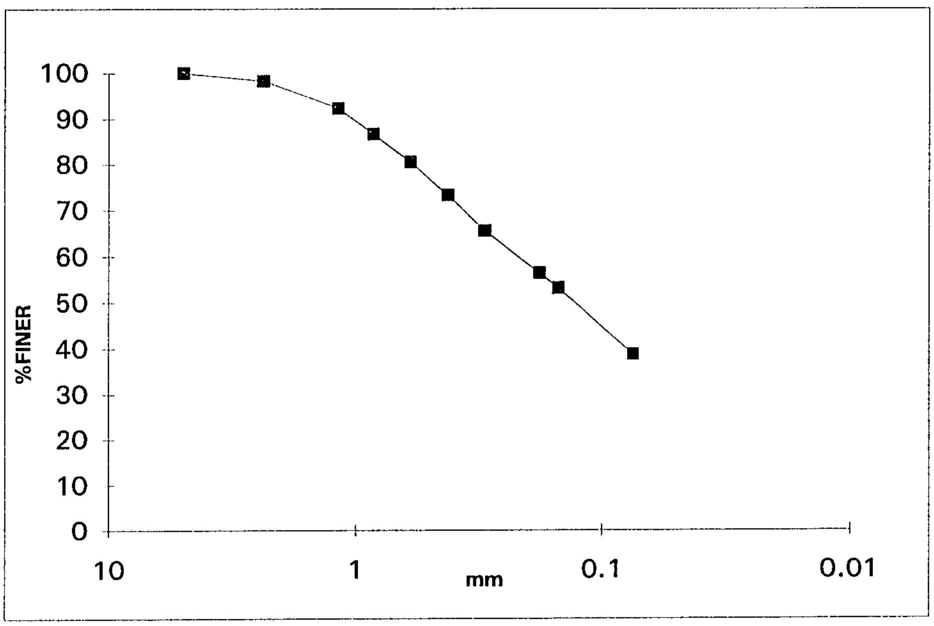
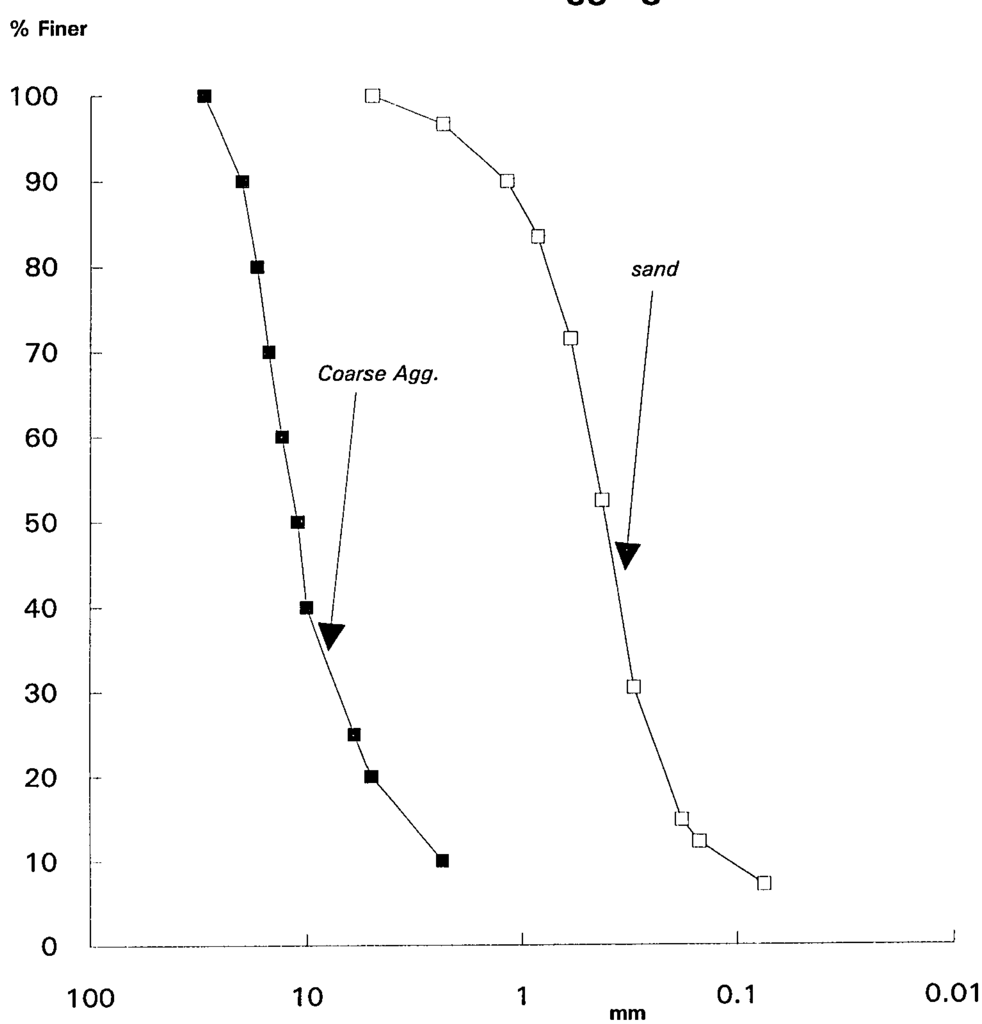


Figure 3-2: Grain Size Disrtribution of Sand and Coarse Aggregate



physical tests were run:

1. Compressive Strength Test (ASTM C39)
2. Creep Test (ASTM C512)
3. Bond Test (ASTM C234)
4. Flexural Strength Test (ASTM C78)
5. Splitting Tensile Strength (ASTM C496)

The ash-concrete specimens taken from the batch mix which gave the highest ash content along with satisfactory strength and other test results, based on these tests, was selected for slab testing. Prior to testing, moisture in ash was determined to be 28 percent. Since ash was stored in sealed container, it was assumed that ash moisture content would not alter significantly during the few days of batching process. A final water content measurement, which took place after all tests were completed, confirmed this assumption.

Based on current ACI standards, the concrete mixture was designed for f'_c = 3000 psi and a slump of 3 inch. The mix constituents and the resulting slump values are tabulated in Table 3-1. Mixing was accomplished by using a mechanical concrete mixer into which the appropriately weighed materials were placed. After about 15 to 20 minutes, for mixing to be completed, the fresh concrete was removed, tested for slump, and placed in cylinder and beam molds.

The following samples were prepared from each batch:

3 cylinders for compressive strength, 3 cylinders for splitting tensile strength; 4 cylinders for creep test; 3 cubes for bond test; and 3 beams for flexural strength. An additional set of samples consisting of 9 different cylinders were also prepared. The samples differed from each other only by their ash content. The ash content used were 10, 20, 30, 35, 40, 45, 50, 55, and 60 percent by weight of the fine aggregate. These samples, used to provide a tentative estimate of the 7-day compressive strength, were for comparison purposes only. The test cylinders were to provide an indication of the extent to which the ash fraction might be increased without a dramatic fall or change in strength.

TABLE 3-1: MIX DESIGN OF CONCRETE TEST SPECIMENS

Mix No.	% Ash*	Water #	Cement #	Fine Agg. #	Ash #	Coarse Agg. #	Slump inch
1	0	250	500	1380	-	1900	2.7
2	10	250	500	1242	138	1900	2.5
3	20	250	500	1104	276	1900	4.0
4	30	250	500	966	414	1900	2.5

Notes:
* % of fine aggregate.
\# all in terms of pound per cubic yard

All specimens were held in the mold for 24 hours, then unmolded and transferred to the curing room to cure. The nine special cylinders were cured for 7 days while all other specimens were held for 28 days.

3.3.2 COMPRESSIVE STRENGTH

This is the most important test for the design of concrete structures. Concrete is designed to sustain loads that structural members carry as axial compressive loads, as for example in columns. The results of other concrete tests, such as flexural and tensile strength, are correlated and defined in terms of the 28-day compressive strength.

The compressive strength tests were conducted in accordance with ASTM C39. Three samples, collected from each batch, were placed in standard cylinder molds (6" diameter, 12" high), unmolded after 24 hours and stored in the curing room under standard humid condition for the required interval of time. The cured cylinders were placed in the compression testing machine and an increasing vertical axial load was applied until failure occurred. The load at failure, the ultimate load, divided by the circular surface area of the cured cylinder is defined as the compressive strength of the concrete.

A 7 days compressive strength test was run on the prepared concrete cylinder specimens that contained different ash content. The ash content and corresponding compressive strength test results for each cylinder are tabulated in Table 3-2 and Figure 3-3. These test values would give an indication of the ash content to choose such that the concrete mix would not loose considerable strength. A sharp reduction in compressive strength occurs beyond 35% ash. Another criteria for choosing ash content was to make sure that the particle size distribution of the combined ash-sand would still satisfy the ASTM C-33 standard.

TABLE 3-2: 7-DAY COMPRESSIVE STRENGTH TEST RESULT FOR DIFFERENT ASH CONTENT

Mix. No.	% Ash*	Compressive Strength (psi)
1	10	2575
2	20	2043
3	30	2118
4	35	2125
5	40	1747
6	45	1721
7	50	1588
8	55	1541
9	60	1432

Figure 3-3 : 7day Compressive Strength For Different Ash Content

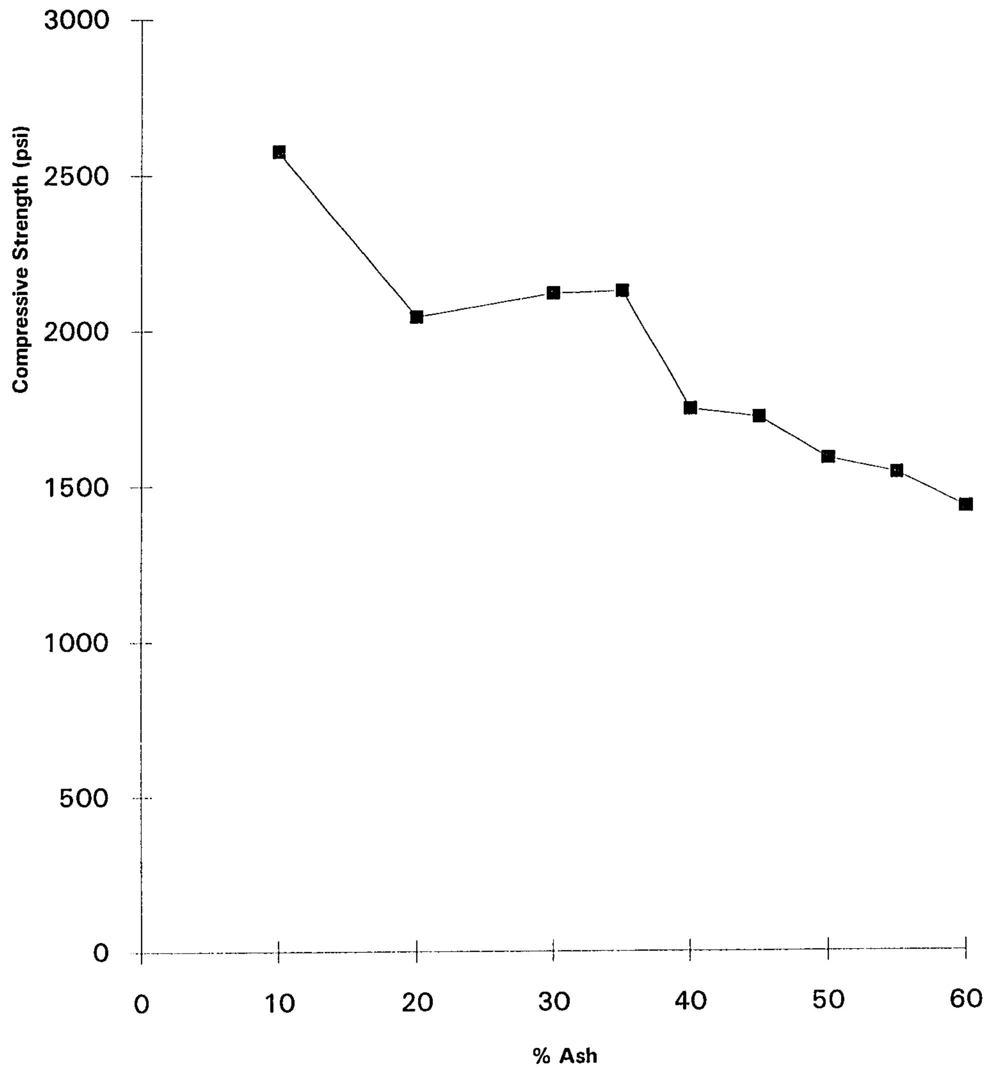


Table 3-3 shows the results of the nonslab concrete tests based on the average values obtained from 3 samples of each different mix. These results are compared with the typical anticipated values based on 3000 psi design compressive strength. The major design parameter in a concrete mix is its 28 days compressive strength. In this experiment the minimum target value for the control specimen, the mix with no ash, was 3000 psi. The 28 day compressive strength for the no ash specimen was 4225 psi. The sample with 10% ash showed a 15% drop in the compressive strength. However the further drop in the compressive strength was not more than 7% as the ash content increased from 10 % to 30%. The compressive strength for the sample with 20% ash was lower than that of the one with 30% ash. The reason for this discrepancy is likely to be due to excess water of the wetted aggregate, exposed to a rainfall event which occurred the night before batching took place. The consequence of this excess moist is also reflected in the slump value, i.e. 4 inch as shown in Table 3-1, for the batch with 20% ash replacement. More tests are required to establish a reliable correlation, if any, between ash content and strength reduction. However, based on the data from this experiment, it can be said that by increasing the amount of ash replacement to 30% of the sand content, some 20% reduction in compressive strength would be expected. This reduction of strength for the ash contained mixes may be due to the following reasons:

- The original high water content of ash which might have not gotten a chance to react with cement during the mixing period.
- It is also possible that fly ash fraction of the ash matrix, which has cementing property, follows a longer setting time duration, as compared with the setting time for regular cement, and therefore the full strength of ash-concrete specimens have not yet been reached within 28 day.

It should be noted that the compressive strength of all four mixes was still higher than the minimum target value of 3000 psi. This indicates that by using a properly designed and controlled mix for ash-concrete, or by raising 20% the target strength, the design value is attainable.

3.3.3 BOND TEST

For a reinforced concrete element, the load is transferred through the concrete to the reinforcement through a bonding action. There is a limit for this bond force beyond which interaction between concrete and steel no longer exists and the structural element fails to carry the design load. The bond strength test was conducted according to ASTM C234. Samples, collected from each batch, were placed in standard cubic molds (6"X6"X6"), and a 15" long #6 re-bar was inserted vertically into the fresh concrete at the center of the top face. The specimen were unmolded after 24 hours and placed in the curing room for 28 days. The cured specimens were inserted into the tension testing apparatus where the surrounding concrete was firmly held while a load was increasingly applied to the #6 bar in such a way that it would produce shear between the bar and the surrounding concrete. The load increased at a standard rate until failure occurred by splitting the specimen into two halves. The bond strength was calculated by dividing the ultimate load by the circumferencial area of the #6 bar embedded in the concrete. The results of bond test are tabulated in Table 3-3. They too are all above the minimum design levels.

3.3.4 FLEXURAL STRENGTH

Flexural elements, such as beams, experience tension in the lower half of their sections at midspan and in the upper half of their sections at supporting points. This type of loading is obviously different from axial tension and, therefore, requires ultimate flexural tension strength to be evaluated separately.

The flexural strength test was conducted according to ASTM C78. Samples, collected from each batch were placed in standard beam molds (6"X6"X20"). The specimens were unmolded after 24 hours and placed in the curing room for 28 days. The cured specimens were placed in the appropriate apparatus, resting on two points located at one third and two third of the length of the specimen. An increasing load was applied at the center of the specimen until failure occurred. The flexural strength was calculated by dividing the ultimate moment at midspan by the section modulus. The results of flexural strength test are also tabulated in Table 3-3. They too are all above the minimum design levels.

3.3.5 SPLITTING TENSILE STRENGTH

This is an indirect way to measure the strength of the concrete with respect to the tensile stress. According to the theory of elasticity a stress applied in one direction will also produce a stress in the lateral direction. The magnitude of this lateral stress is less than 50% of its main stress. The tensile strength of concrete is much less than 50% of its compressive strength. Therefore a vertical compressive load applied to a concrete cylinder lying horizontally should develop a horizontal tensile stress producing tensile failure prior to reaching the ultimate compressive strength.

The splitting tensile strength test was conducted according to ASTM C496. Samples, collected from each batch were placed in standard cylindrical molds (6" diameter by 12" high) The specimens were unmolded after 24 hours and placed in the curing room for 28-days. The cured specimens were placed in the appropriate compressive apparatus, lying longitudinally while a vertical load was applied along its longitudinal axis. The vertical compressive load was increased until lateral tension failure occurred, splitting the specimen. The splitting tensile strength of concrete was calculated from equation:

$$f_t(psi) = 2P/(\ DL),$$

where

P= Ultimate load applied, lb

D= Diameter of the cross section of the cylinder, 6"

L = Height of the cylinder, 12"

The results of splitting tensile test are also tabulated in Table 3-3. They too are all above the minimum design levels.

As can be seen in Table 3-3 and for all strength parameters the 20% ash sample exhibits a lower strength value when compared with the similar value for the sample with 30% ash except for bond test in which the sample with 20% ash shows a higher bond stress. Since the values presented in Table 3-3 are the average of three test runs, a review of the raw data confirmed that one of the three values obtained for bond stress of the 20% ash specimens was significantly different from the other two. The three readings for bond test on 20% ash-concrete were 773, 797, and 1024. The last reading differs from the average value more than 18%. If the last reading is discarded then the average value for bond test of the 20% ash-concrete reduces to 785 which then becomes consistent with the results of other tests.

TABLE 3-3: TEST RESULTS FOR CONCRETE SPECIMENS HAVING DIFFERENT ASH CONTENT

% Ash	28 days Compress. Strength psi	Splitting Tensile strength psi		Bond Strength psi		Flexural Strength psi	
	Test Result	Test Result	Typical Design Value	Test Result	Typical Design Value	Test Result	Typical Design Value
0	4225	467	328	1047	815	645	493
10	3594	370	328	905	815	587	493
20	3188	322	328	865	815	518	493
30	3299	344	328	817	815	548	493

Design 28 day compressive strength (f'_{cd}) = 3000 psi.

Criteria used for typical design values:
1. Split Cylinder Strength, $f'_{sp} = 6(f'_{cd})^{1/2}$
2. Flexural Strength, $f_r = 7.5(f'_{cd})^{1/2}$
3. Ultimate avg. Bond force, $U_n = 35(f'_c)^{1/2}$
Bond Stress = $U_n/2.35$ psi per inch of bar length.

Figures 3-4 through 3-7 show the results of the above mentioned non-slab concrete tests. Comparing the results with the control sample, there was a rapid fall of all different strength parameters, i.e. compressive, tensile, bond and flexural strength, for the sample with 10% ash, but after this point the reduction in strength became moderate. Results for the 20% ash sample showed slightly inconsistency, i.e. less strength, when compared with the 30 percent ash. This controversy, as mentioned before, might have been caused by some excess moisture in the aggregates due to the rainfall on the day prior to the test.

3.3.6 CREEP TEST

Creep is a phenomenon in which deformation occurs under constant loads. Excessive deformation is harmful to any type of structure and an estimate of ultimate deformation under certain loading patterns is, therefore, very important in the design of concrete structures. The creep test consists of placing the cured concrete cylinder in a machine where the specimens are subjected to a constant load and their deformations measured. Figures 3-8 and 3-9 show the results of the creep test performed on two different sets of specimens derived from the same batch. The vertical axis represents the ratio of strain at different times to the initial strain. There is no significant difference in creep pattern between the ash-concrete specimens and the no-ash concrete control specimen. Likewise the strength tests results, the creep test indicates a lower deformation for 0% ash specimen and a higher deformation for the 20% ash-concrete when compared with 30% ash-concrete.

Figure 3-4 : Effect of Ash Content on 28 Day Compressive Strength for Concrete Cylinders

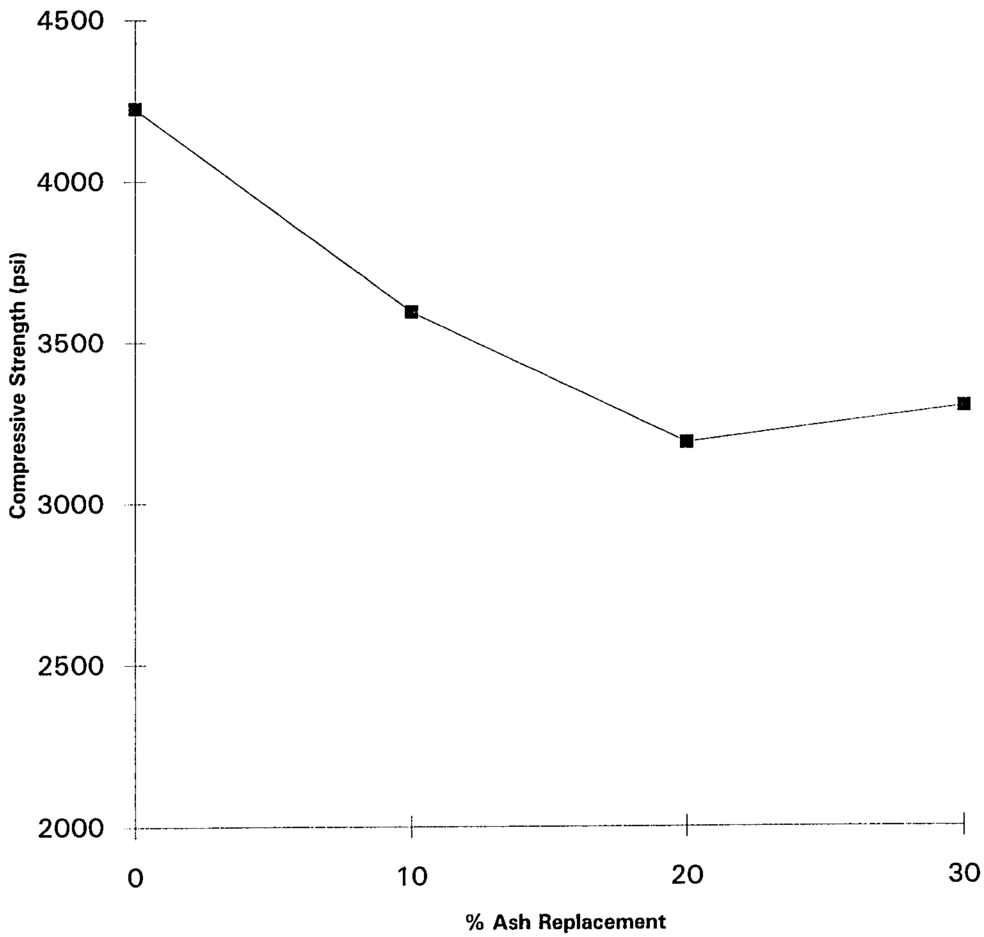


Figure 3-5 : Effect of Ash Content on 28Day Splitting Tensile Strength for Concrete Cylinders

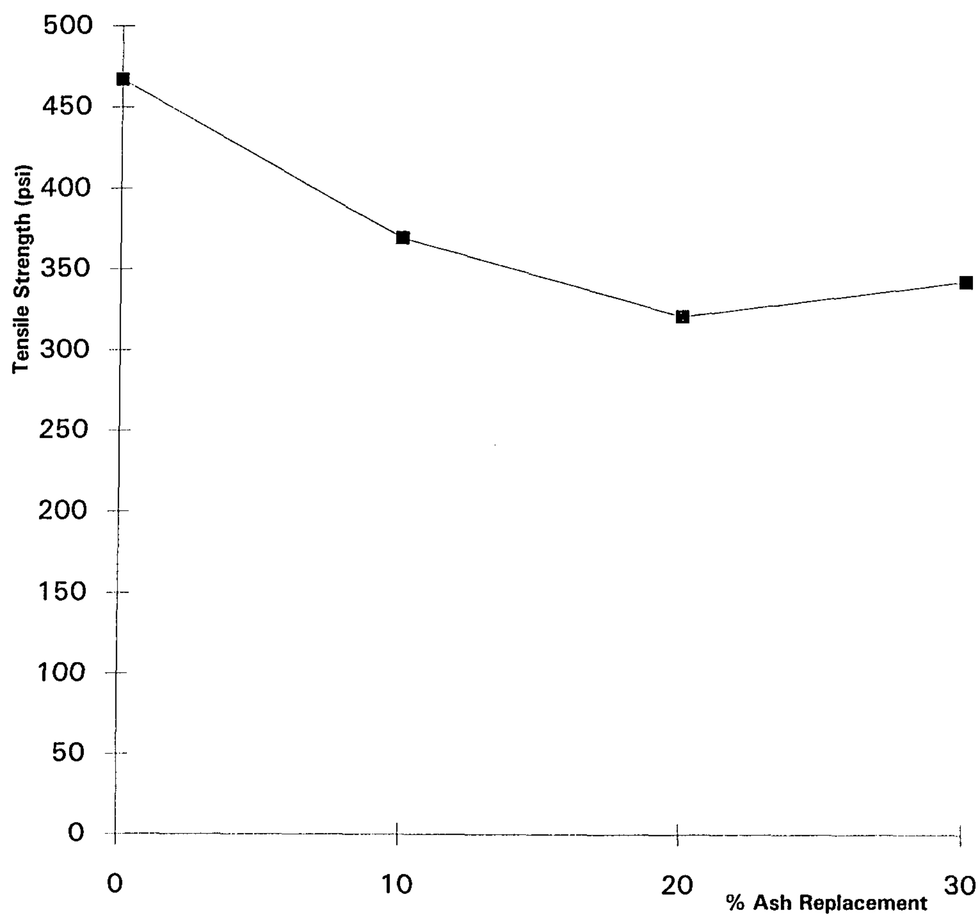


Figure 3-6 : Effect of Ash Content on 28Day Bond Stress for Concrete Cylinders

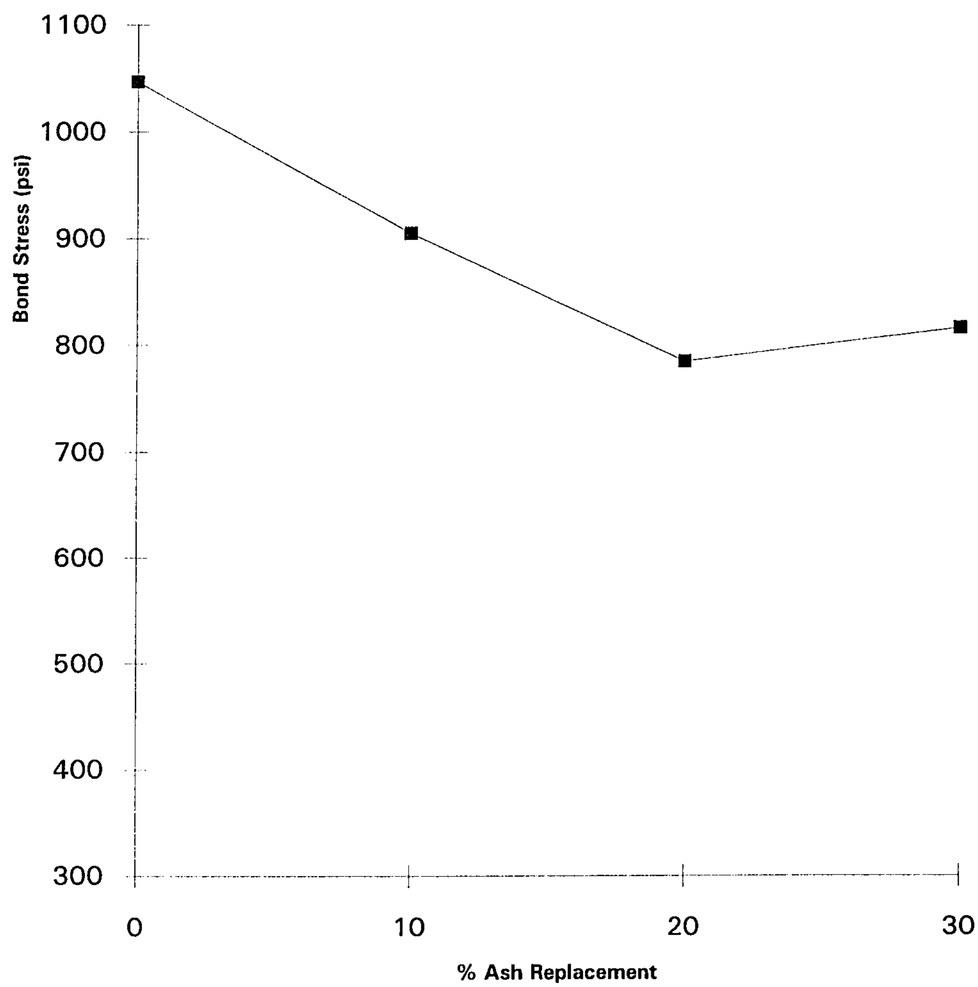


Figure 3-7 : Effect of Ash Content on 28Day Flexural Strength for Concrete Cylinders

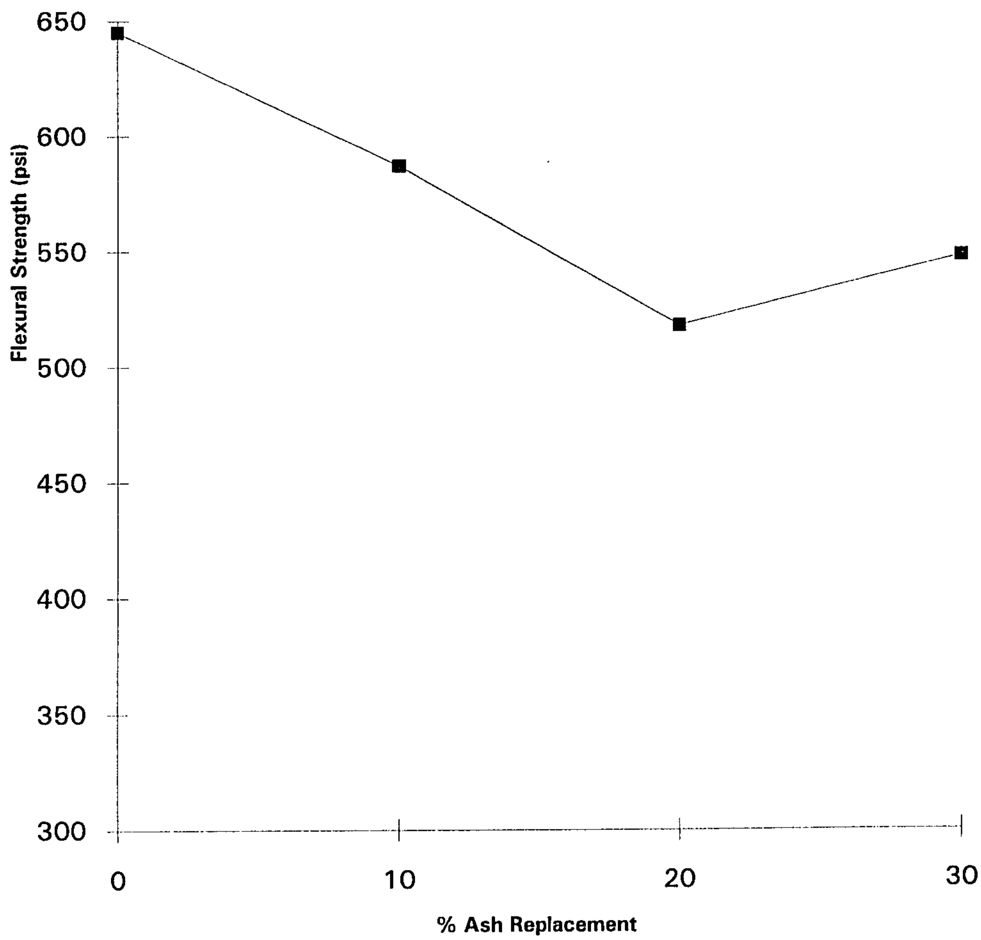


Figure 3-8 : Creep Test Results for the Set Up No. 1

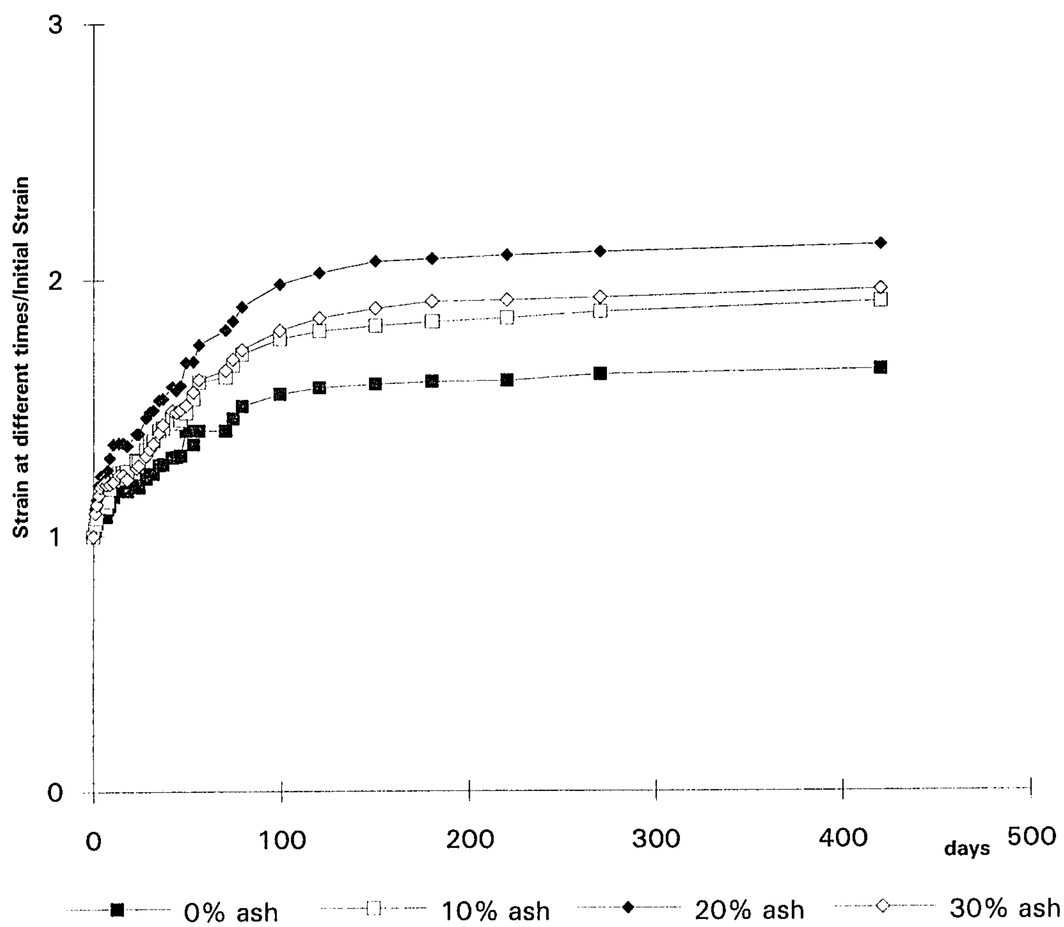
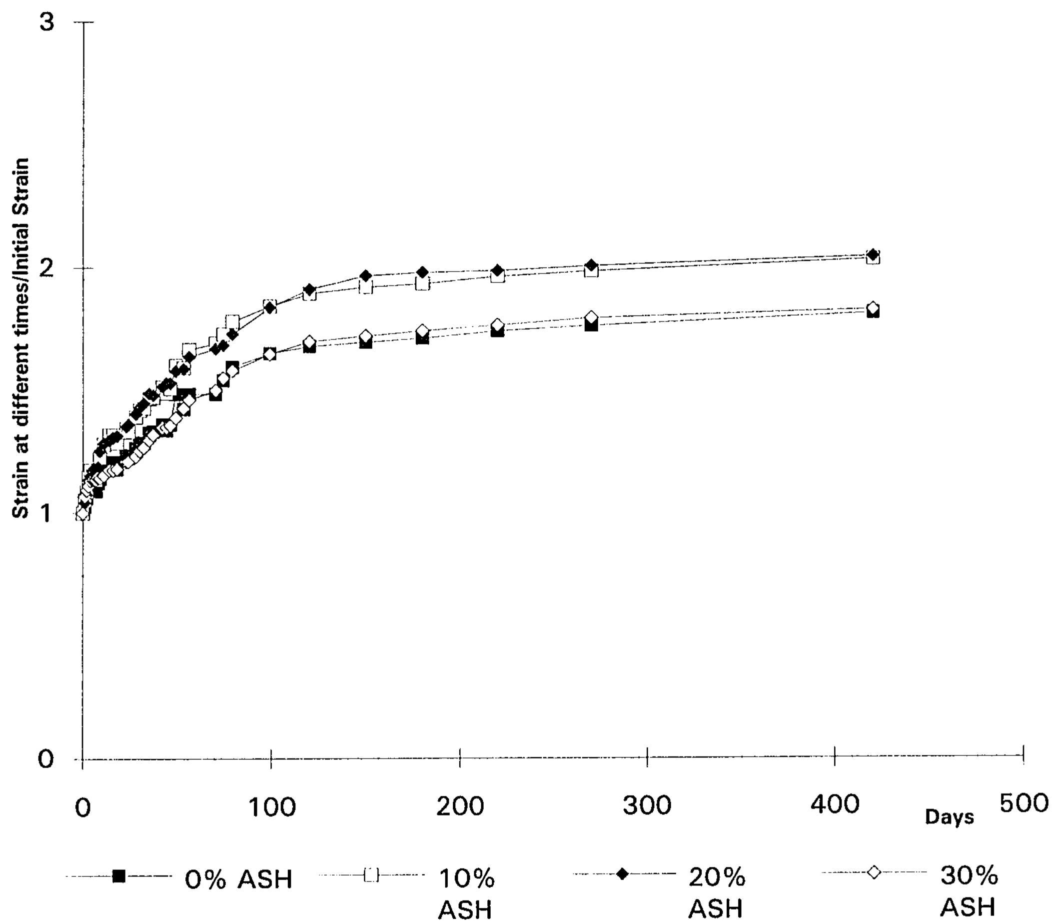


Figure 3-9 : Creep Test Results for the Set Up No. 2



3.4 SKID RESISTANCE OF CONCRETE SLABS

Based on the result of the concrete tests described in the above, a 30% replacement of sand by ash was taken as the median point for the concrete slabs. Four different slabs each 3'-0"X4'-0"X4" were prepared. Each slab had a different percent of the fine aggregate replaced with ash while coarse aggregate, water content, and cement remained unchanged. The slabs were 25%, 30%, 35% and 40% ash replacement. In addition one control slab having no ash in the mix and one slab with vitrified ash, instead of the bottom ash replacing 30% (by weight) of the fine aggregate were prepared. These slabs were tested for the skid resistance.

The ash vitrification took place in the Chemical Engineering Department Laboratory. The ash, placed in special containers, was placed in an oven at 1950° F, for a period of 60 minutes. The vitrified ash taken from the special containers, was crushed to a particle size of less than one millimeter prior to its introduction into the concrete mix.

The design mix for the concrete slabs was exactly the same as for the non slab mixes. A mechanical concrete mixer was used, and each of concrete mixes with a different ash content were placed within the slab forms and the surface was finished. The slabs, placed outdoor, were left for 28 days of curing.

The frictional properties of a surface have a major effect on driving safety. For concrete pavements, it has been found that the skid resistance depends mostly on the quality of the fine aggregates. The British Pendulum Tester is the most popular procedure for the laboratory measurement of surface frictional properties. The test is performed in accordance with ASTM E303. The apparatus consists of a swinging arm with a rubber slider provided at the free end. The slider is set on the surface of the specimen whose skid resistance is to be measured, and the arm is released from a specified elevated position. As the released arm swings, the slider touches the surface at the vertical position and it arcs up some distance before swinging back in the reverse direction. The maximum rise of the arm, monitored by a pointer, is recorded by a number shown on the apparatus. The limiting values, as taken from ASTM E303, are shown in Table 3-4.

TABLE 3 - 4 : SUGGESTED VALUES OF 'SKID RESISTANCE' FOR USE WITH PORTABLE TESTER

Skid resistance on wet surface	Standard of skidding resistance represented
Above 65	'Good': fulfilling the requirements even of fast traffic and making it most unlikely that the road will be the scene of repeated skidding accidents
Above 55	'Generally satisfactory': meeting all but the most difficult conditions encountered on the roads
Above 45	'Satisfactory only in favorable circumstances'
Below 45	'Potentially slippery'

The results of the skid resistance test (Table 3-5 and Figure 3-10) show a satisfactory skid resistance for all samples. The introduction of ash into a concrete mix will apparently have no adverse effect on the skidding property of the concrete surface. In fact according to Figure 3-10, replacing 30% of the fine aggregates with ash appears to result in about a 25% improvement in the skid resistance property of the concrete.

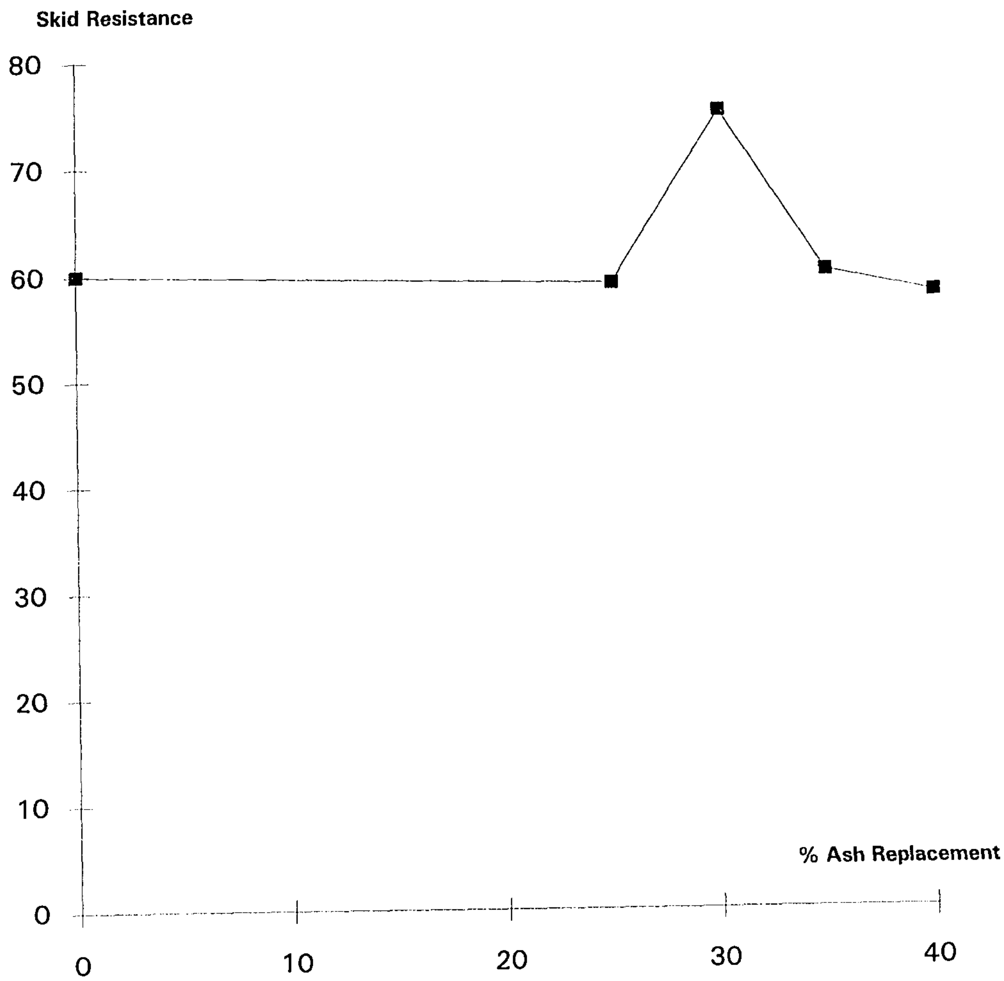
TABLE 3-5: RESULTS OF SKID RESISTANCE TEST ON CONCRETE SLABS

Mix n	% Ash*	Skid Resistance	Minimum Allowable
1	0	60	55
2	25	59	55
3	30	75	55
4	35	60	55
5	40	58	55
6	30**	67	55

* % of fine aggregate.
** Vitrified ash was used.

Note:
Five tests were done on each slab and the average skid resistance are given in the table.

Figure 3-10 : Ash Content vs Skid - Resistance for concrete slabs



3.5 RESISTANCE OF CONCRETE TO RAPID FREEZING AND THAWING

This test determines the resistance of concrete specimens to repeated cycles of freezing and thawing in air. It must be noted that this test is not intended to provide a quantitative measure of the length of service that may be expected from a specific type of concrete.

3.5.1 TEST SPECIMENS

The test specimens were prisms (3" x 3" x 14") cut from the hardened concrete slabs. The specimens were stored in the curing chamber at the Laboratory of the Department of Public Works, Suffolk County (SCDPW's Laboratory), until testing. Testing was done at the City College using an apparatus for determining the Fundamental Transverse Frequencies and a chamber unit for applying cycles of freezing-and-thawing to the test specimens.

3.5.2 FUNDAMENTAL TRANSVERSE FREQUENCIES

This test method is employed primarily for detecting significant changes in the dynamic modulous of elasticity of a test specimen that is undergoing exposure to weathering or other types of potentially deteriorating influences. The apparatus for this test consists of a driving circuit, a pick up circuit, and a specimen support. The driving circuit consists of a variable frequency audio oscillator, an amplifier, and a driving unit to create vibration on the specimen. The pick up circuit consists of a pick up unit, an amplifier and an indicator. The function of the pick up unit is to generate a voltage proportional to the amplitude of the vibrating test specimen. The test specimen is supported in such a way that it is permitted to vibrate without significant restriction.

The test specimen was placed on the support in such a manner that it might vibrate without significant reaction in a free transverse mode. The driving force was applied on a vertical face of the specimen at a point near one end of the specimen. The pick up unit was placed against the top surface and near the other end of the specimen. The specimen was then forced to vibrate at varying frequencies. The frequency of the test specimen that resulted in a maximum indication, having a well - defined peak on the indicator, was recorded as the "fundamental transverse frequency".

3.5.3 APPARATUS FOR FREEZING - AND - THAWING TEST

The freezing-and-thawing apparatus is composed of a chamber in which the specimen could be subjected to a specified freezing-and-thawing cycle, together with the necessary refrigeration and heating equipment with their controls to automatically produce continuously reproducible cycles within the specified temperature requirements. Temperature measuring equipment, consisting of thermometers and thermocouples capable of measuring the temperature at various points within the specimen chamber, were provided on the apparatus. The freezing-and-thawing cycle consisted of alternately lowering the temperature of the specimen from 40°F to 0°F and raising it from 0°F to 40°F in two hour periods. The cycle started by lowering the temperature of the specimen from 40° to 0° F in a 1/2 hour. The specimen was kept at 0° F for a 1/2 hour and then the temperature was brought back to 40° F in a 1/2 hour where the specimen was kept for a 1/2 hour. Thereafter the cycle was repeated as discussed above.

Immediately after the specimen was brought out of the curing chamber, it was weighed and tested for fundamental transverse frequency. The freezing-and-thawing test started immediately after the specimen was placed inside the freezing-and-thawing chamber. At intervals equal to 30 cycles of exposure to the freezing-and-thawing, the specimen was brought out of the chamber, in the thawed condition at 40°F, and tested for fundamental transverse frequency, at a temperature of 42$\pm$ °F, weighed and returned to the freezing-and-thawing apparatus. The test was continued until the relative dynamic modulus of elasticity of each specimen reached 60 percent of the initial modulus.

The relative dynamic modulus of elasticity was calculated using the following equation:

$$P_c = (n_1^2 / n^2) \times 100$$

where

P_c = relative dynamic modulus of elasticity, after "c" cycle of freezing and thawing, percent.

n = fundamental transverse frequency at zero cycles of freezing and thawing, and

n_1 = fundamental transverse frequency after "c" cycles of freezing and thawing.

Weighing the specimen at each interval, was to ensure that the weight of the specimen remained constant during the test.

The results of the "resistance to rapid freezing-and-thawing" test is shown in Table 3-6. The durability factor (the last column) is calculated as follows;

$$DF = PN/300$$

where

DF = durability factor of the test specimen

P = relative dynamic modulus of elasticity at "N" cycles, percent.

N = number of cycles at which "P" reached the specified minimum value of 60 percent of the initial value.

The tabulated results indicate that all specimens showed an almost similar response to the cycles of rapid freezing-and-thawing. The durability factor (DF) for the specimen with 25% ash content was about fifteen percent lower than for the rest of the specimens. Since all specimens with more than 25% ash showed a DF value close to that of the no-ash control concrete specimen, it could be presumed that the drop of the DF value for the 25% ash specimen might have been caused by other factors, such as improper batching or some failure during placement, rather than the presence of the ash. The specimen with 30% ash, taken as the optimum ash content for the preceding tasks, showed results satisfactorily close to those for the no-ash specimen. Therefore, it can be concluded that the replacement of fine aggregate in concrete with ash would not adversely affect the behavior of concrete with respect to the cycles of freezing - and - thawing.

Table 3-6: RESULTS OF THE TEST FOR "RESISTANCE TO RAPID FREEZING-AND-THAWING"

%ASH	NUMBER OF CYCLES FOR "P" TO REACH 60% OF ITS INITIAL VALUE, "N"	n	n1	Pc	DF
0	108	240	186	0.60	21.6
25	87	229	177	0.60	17.4
30	107	233	180	0.60	21.4
35	102	279	216	0.60	20.4
40	113	278	215	0.60	22.6
vitri-fied	100	238	184	0.60	20.0

Note:
n = fundamental transverse frequency at 0 cycles of freezing and thawing
n1= fundamental transverse frequency after 'c' cycles of freezing and thawing
Pc= relative dynamic modulus of elasticity, after 'c' cycles of freezing and thawing,
$Pc = (n1/n)^2 \times 100$

3.6 DURABILITY (DSC) TEST

Differential Scanning Calorimetry (DSC) is a technique in which the difference in energy inputs into a substance and a reference material is measured as a function of temperature or time while the substance and the reference material are subjected to a controlled temperature program. In this test, the recorded output is the heat flow, derived from the temperature difference between the sample and reference, as a function of temerature. Because of the various factors which affect DSC curve of a sample, the peak temperatures and the shape of the peak are rather empirical. The areas enclosed by the curve peaks can be related to heats of reaction, transition, polymerization, fusion, and so on. The type of phenomena happening to a sample under DSC test may be inferred by investigating the origins of the endothermic or exothermic curve peaks. DSC can be used as a control for comparing similar but not identical materials. In this study the DSC test was used to study the role of sludge ash in the microstructure of concrete and its potential impact on the durability of product. Impurities, which may affect durability of product, can be detected by subjecting the ash-concrete samples to the DSC test and comparing the results with that for the control no-ash concrete.

Figures 3-11 through 3-16 show the results of the Differential Scanning Calorimetry (DSC) test relating to the durability of the concrete samples. The rate of heat flow in Watts per gram needed to withdraw the water from the pores is higher for higher ash contents. This implies that there is more water present in the microscopic pores of ash-contained concrete than in the control. However, the DSC result for the sample containing vitrified ash remained almost the same as the control. The interpretation may be that the microscopic pore water in the ash-concrete samples may have been due to the relatively high original water content of 24% in the ash prior to mixing. If this is the case, then the ash-concrete would be more durable if the ash is dried out prior to being introduced into the mix.

Figure 3-11 : DSC Test Result For No-Ash Concrete

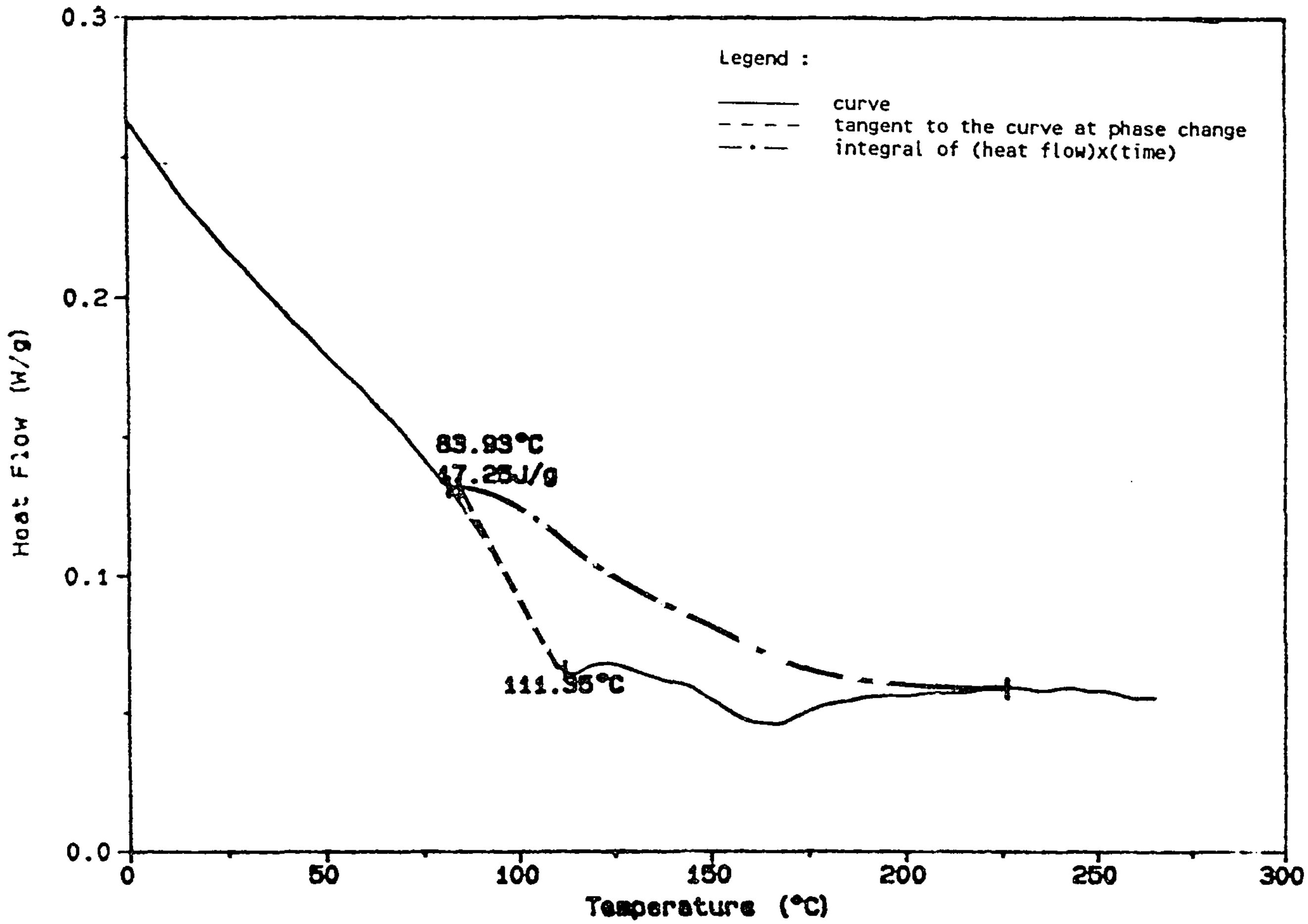


Figure 3-12 : DSC Test Result For 25% Ash Replacement Concrete

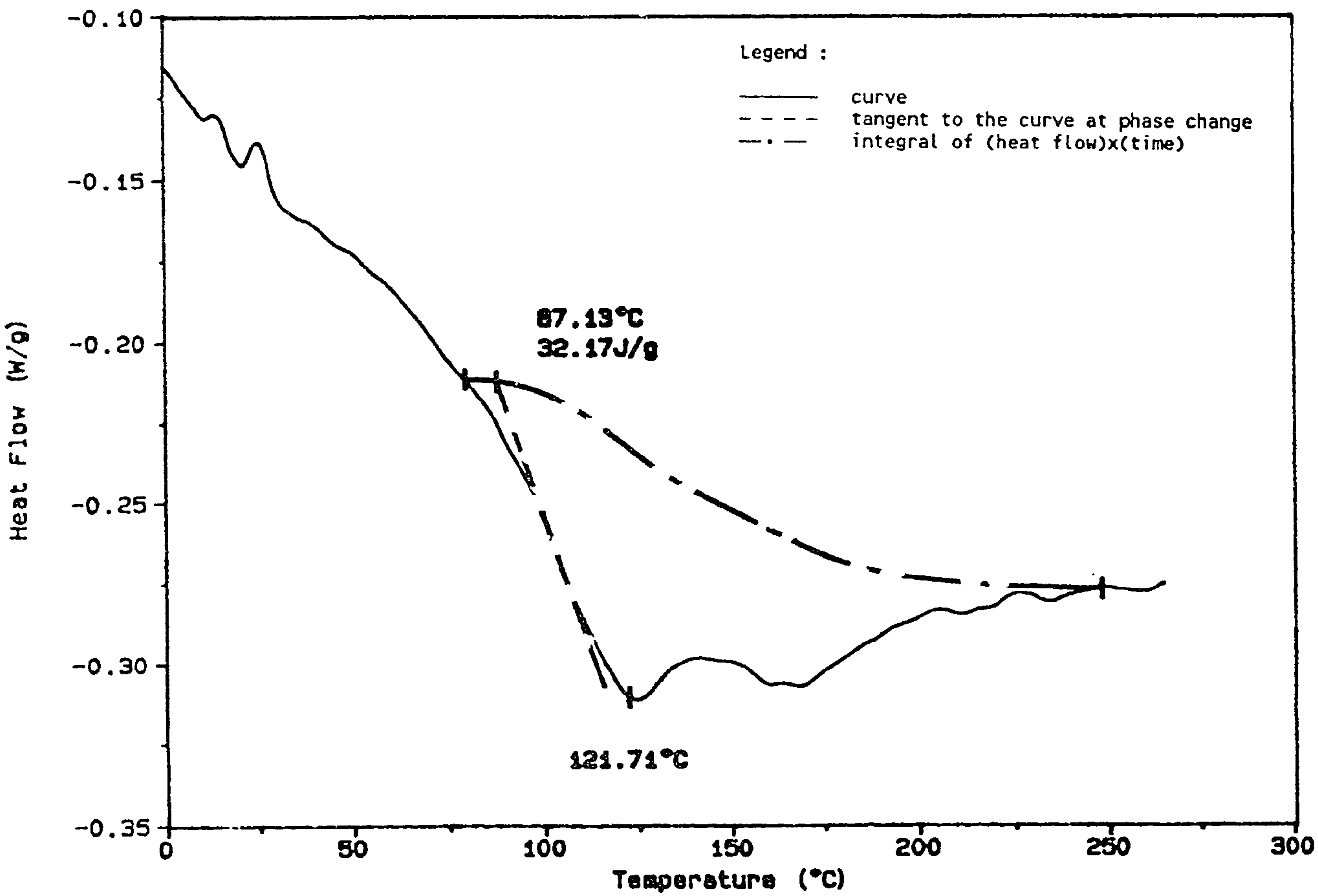


Figure 3-13 : DSC Test Result For 30% Ash Replacement Concrete

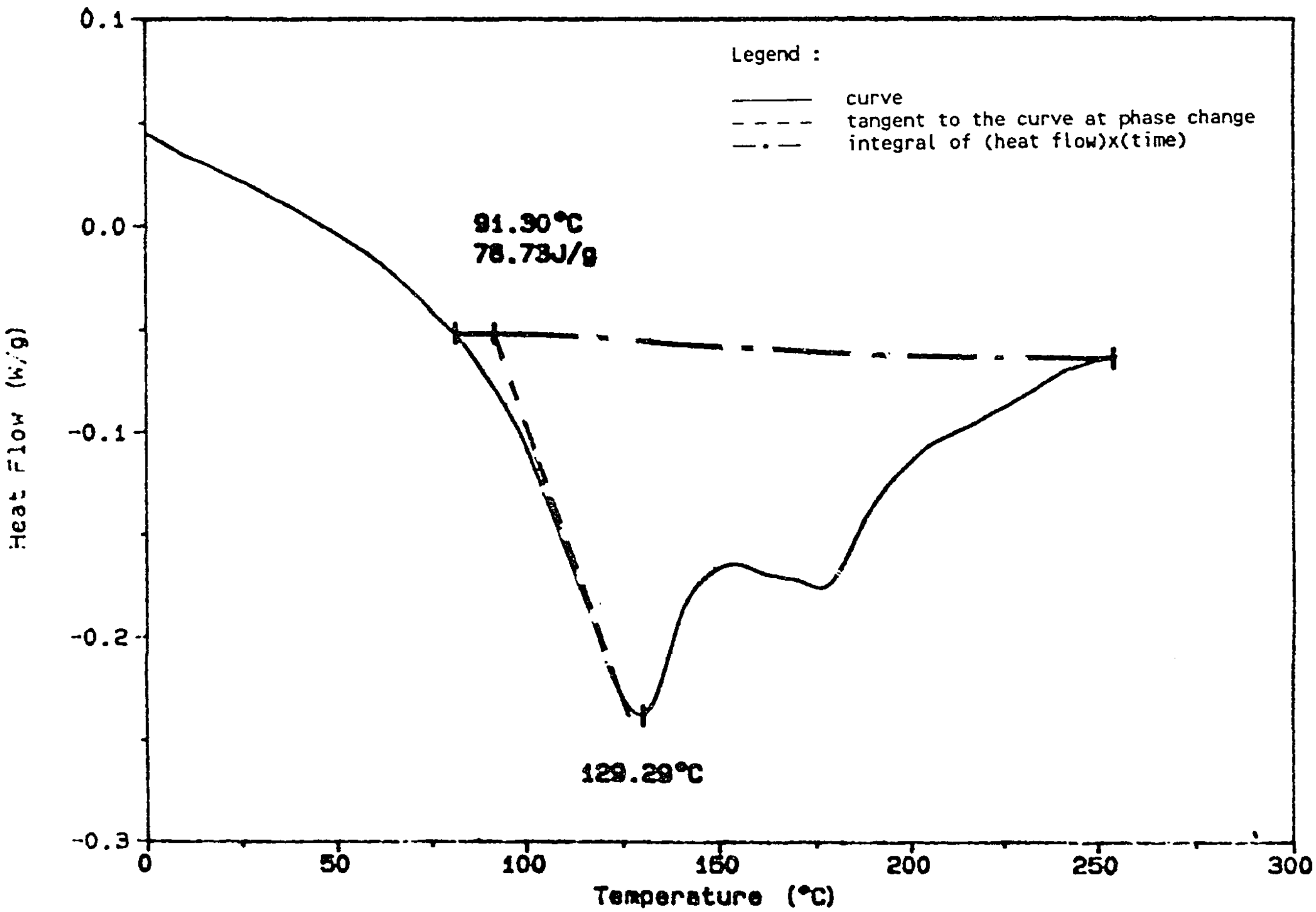


Figure 3-14 : DSC Test Result For 35% Ash Replacement Concrete

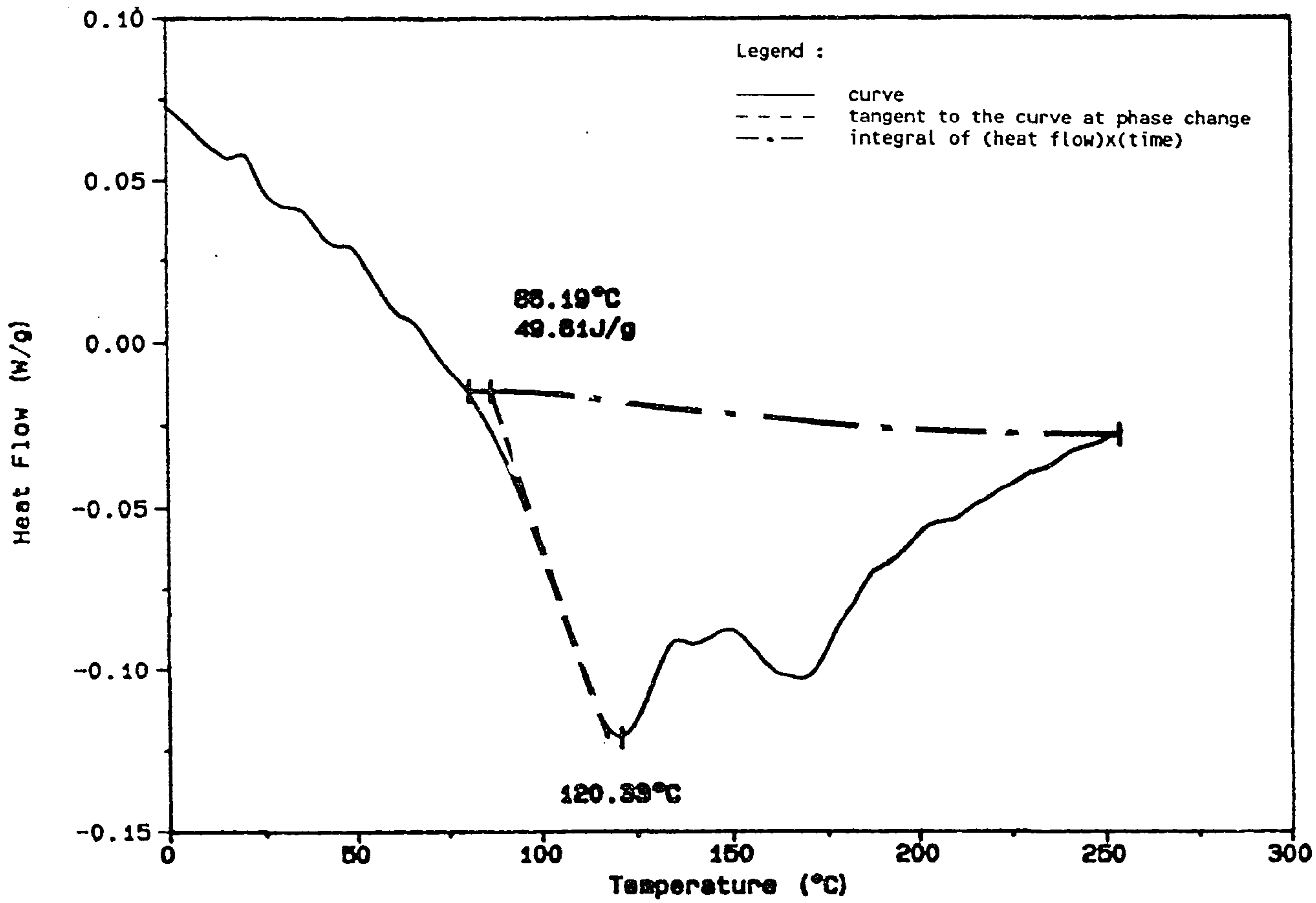


Figure 3-15 : DSC Test Result For 40% Ash Replacement Concrete

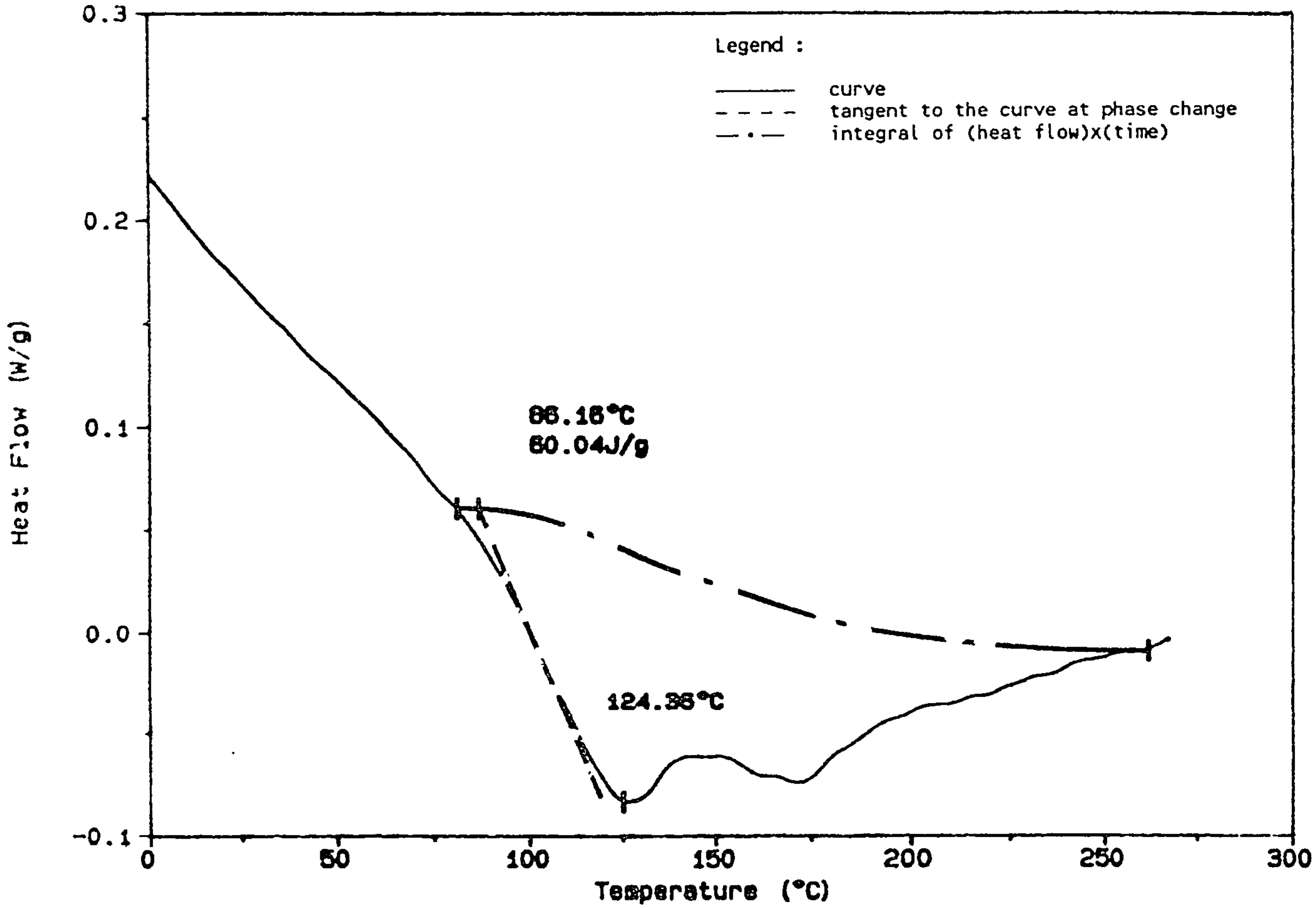
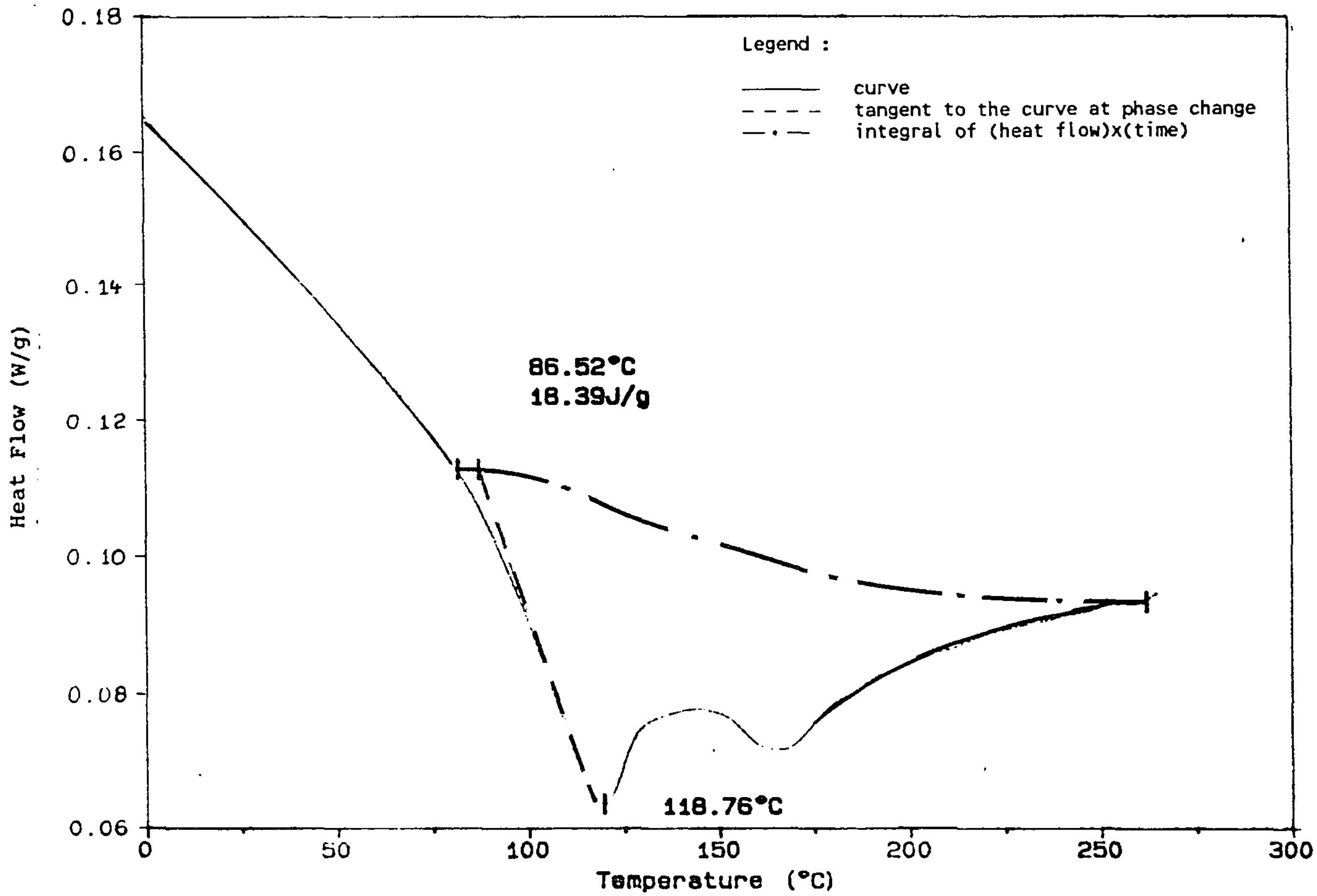


Figure 3-16 : DSC Test Result For 30% Vitrified Ash Replacement Concrete



3.7 ASPHALT MIXES

Four different asphalt batches were prepared in SCDPW's Laboratory. One contained no ash and in the other three batches, 10, 20 and 30 percent of the fine aggregate was replaced with ash. The amount of other materials in the mixes, namely bitumens and coarse aggregate remained the same for all of the batches. The control batch, the batch with no ash, was prepared according to the specification set by the Marshall Mix Design Method and approved by New York State. These requirements are presently used by Suffolk County and are shown in Table 3-7.

Table 3-7: MARSHALL REQUIREMENTS

Mix Property	Mix Criteria
Stability, lb, min	1500
Flow, 0.01 in.	8-18
Air Voids, %	2.0-4.0

Specimens collected for each batch were tested for all the above Marshall parameters. Based on the results obtained from these tests and according to the criteria described in Table 3-7, four slabs (about 3'-0" X 4'-0" X 4") with 11, 13, 15 and 17 percent ash (as percent of fine aggregate by weight) were prepared. In addition one control slab with no ash and one slab using vitrified ash material were prepared. These slabs were used for the following tests,

1. Durability Tests
2. Skid resistance.

3.8 ASPHALT CYLINDER MIX PREPARATION

Four separate asphalt batches were prepared in the SCDPW's Laboratory. One contained no ash while in the other three batches, 10, 20 and 30 percent of the fine aggregate (sand) was replaced by ash. The quantity and quality of the other components of the mix remained unchanged. All mix designs were prepared in accordance with the approved Marshall Mix Design. From each batch, 6 cylinders were prepared to conduct the Marshall Test.

3.9 ASPHALT CYLINDER TESTS

Asphalt mixes were prepared in the laboratory according to the mix designs shown in Table 3-8. Each mix was placed in an oven and, after reaching a temperature specified by ASTM D1074 and ASTM D1559 was poured into 6 standard cylindrical molds, each 4 inch diameter and 2.5 inches high. Each cylinder was subjected to 50 blows by a standard mechanical hammer and left for 24 hours to cool down. After 24 hours, the specimens were unmolded and again placed in an oven to maintain 140 F temperature prescribed by the ASTM standard. Once the specimen reached 140 °F, it was removed from the oven and placed in the Marshall test apparatus. Here a vertical load was applied diagonally on the specimen at a specified rate. The specimen started to deform until failure occurred. The deformation in 0.01 inches of the flow value caused by the compressive load was recorded by the apparatus.

TABLE 3-8: BATCH MIX FOR MARSHALL TEST SPECIMENS

% Ash*	Aggregate (% by weight)				Filler % by weight	Asphalt Cement % by weight
	Ash	sand	1/4"	3/8"		
0	0	36.75	23.5	30	3.76	6
10	3.67	33.10	23.5	30	3.76	6
20	7.35	29.40	23.5	30	3.76	6
30	11.03	25.72	23.5	30	3.76	6

3.10 OPTIMUM ASPHALT CEMENT CONTENT

Optimum asphalt cement (AC) content is found by constructing a set of curves which show variations of the

Marshall test parameters of Stability, Flow, Density, and Voids, against changes in A/C content. The optimum asphalt cement content will be based upon the average of the percent asphalt cement corresponding to the peak of the stability and density curves, provided the requirements for voids and flow are met.

The optimum asphalt cement content for two sets of asphalt mixes were attempted. One set had pure fine aggregate while the other set had ash replacing 15% of its fine aggregate. For each of the two sets, four different batches, each differing from each other only in their asphalt cement content were prepared. The Marshall test parameter values for each of them were determined. The percent asphalt cement used for the ash-asphalt samples were 5, 6, 7, and 8% and those used for the control samples with no ash were 4, 5, 6, and 7%. Greater asphalt cement percentages were used for the ash asphalt samples since it was not possible to prepare workable ash-asphalt mixes with an asphalt cement percentage less than 5%. The test results are shown in Figure 3-17 though Figure 3-3-20. It is seen from these figures that the optimum asphalt content for both mixes, according to the New York State criteria defined in Table 3-7 (section 3.8), is 6%.

Figure 3-17 : Variation of Density with Asphalt Cement

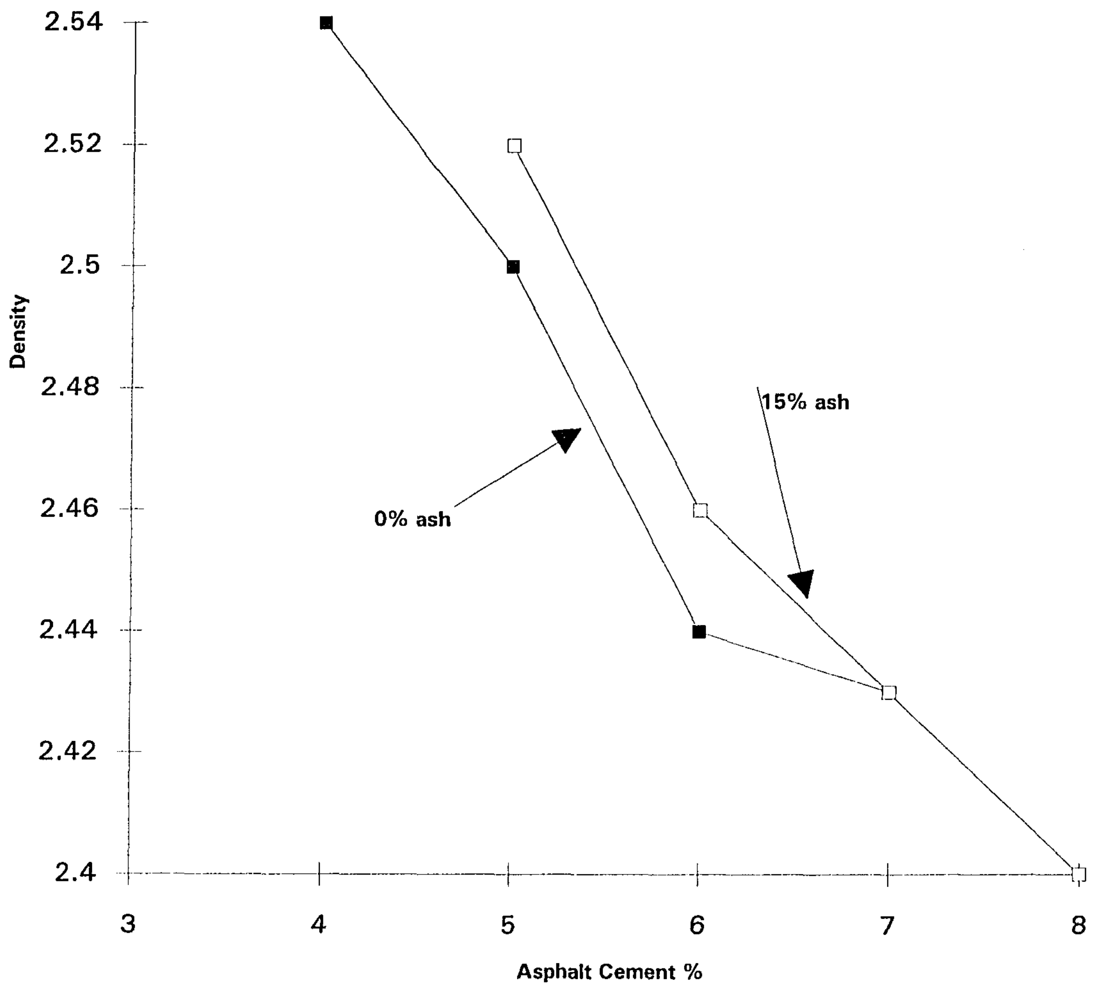


Figure 3-18 : Variation of Air Voids with Asphalt Cement

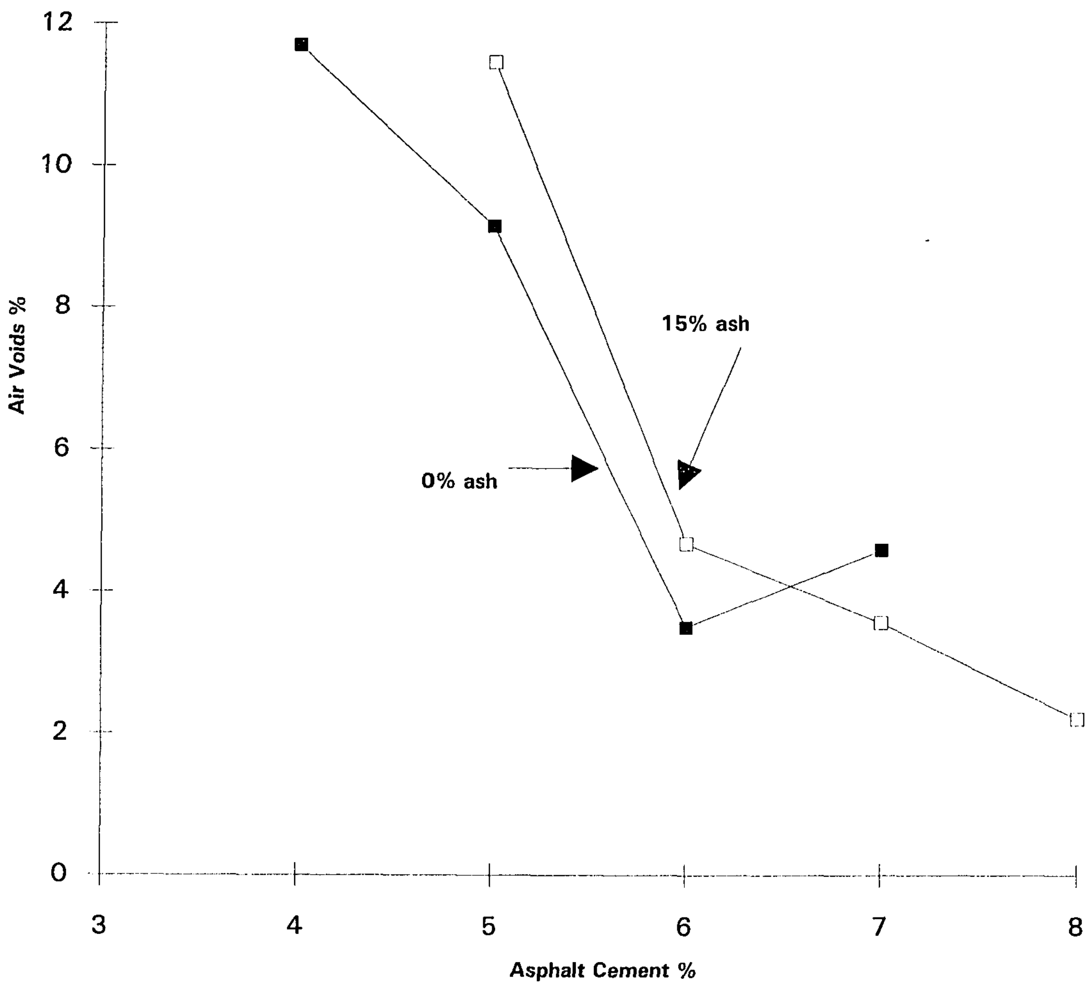


Figure 3-19 : Variation of Stability with Asphalt Cement

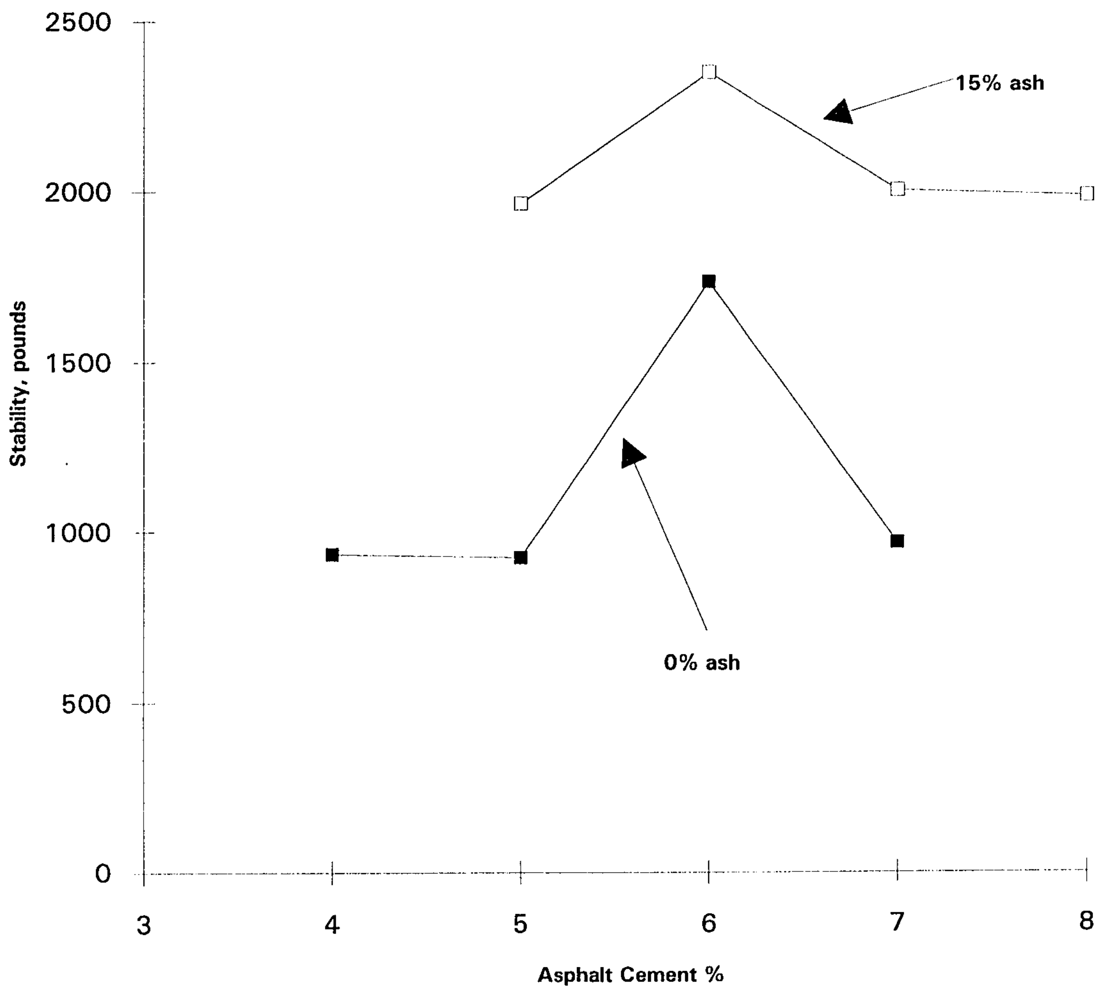
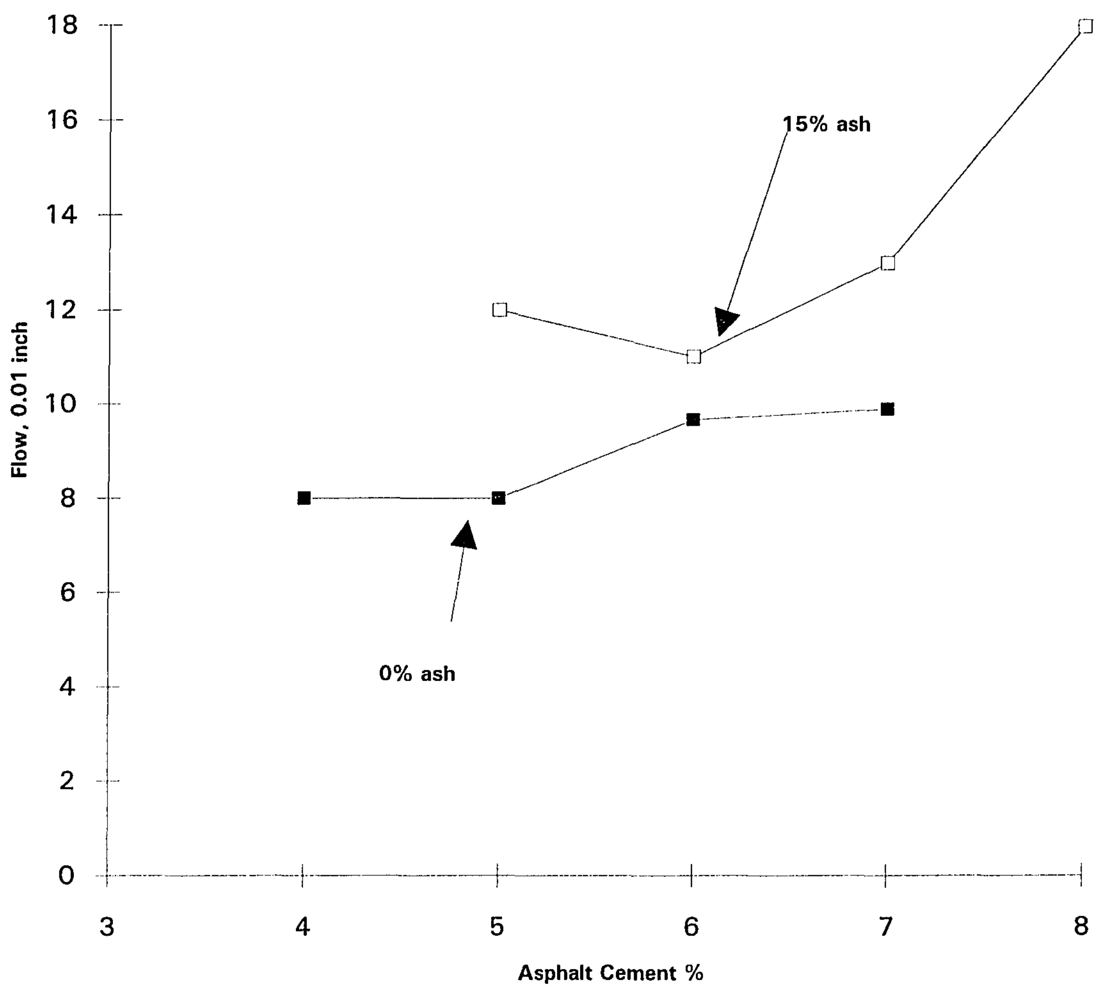


Figure 3-20 : Variation of Flow with Asphalt Cement



The results of the tests on the asphalt cement cylinders are shown in Table 3-9, while Figure 3-21 through Figure 3-23 show the variations of Marshall Test parameters versus ash contents. Table 3-9 shows the values obtained from tests on samples containing different amount of ash within the asphalt mix. The stability values, a measure of the strength of asphalt, increased by increasing the ash content while the flow did not change significantly. However a third criteria, percent voids, which can be as important as stability and flow, became the critical factor. First the voids were reduced from 3.5% for the ash-free control sample to 2.68% for the one with 10 percent ash, implying a more desirable situation. Increasing the ash increment another 10 percent of the sand replacement, increased the voids value to 6.7%, or about 50 percent more than the standard limit. Based on the test results it was assumed that a 15 percent substitution of sand by ash would be the optimum which the slab in the next stage should be designed for. This was the primary reason for preparing the asphalt mix for the slabs with 11, 13 , 15 and 17 percent ash.

TABLE 3-9: TEST RESULTS OF ASPHALT CEMENT CYLINDERS

Mix No.	% Ash*	Stability lb.		Flow		Void %	
		Test Result	Min. Limit	Test Result	Limit	Test Report	Limit
1	0	1736	1500	9.67	8 to 18	3.50	2 to 4
2	10	2203	1500	11.00		2.68	
3	20	2496	1500	10.67		6.70	
4	30	2896	1500	11.67		13.90	

* % of Fine Aggregate by weight

Note:
(1) All the test results are the average of six test samples
(2) The limits are approved by New York State according to Marshall Mix Design.

Figure 3-21 : Variation of Flow with Ash Content (Asphalt Cylinders)

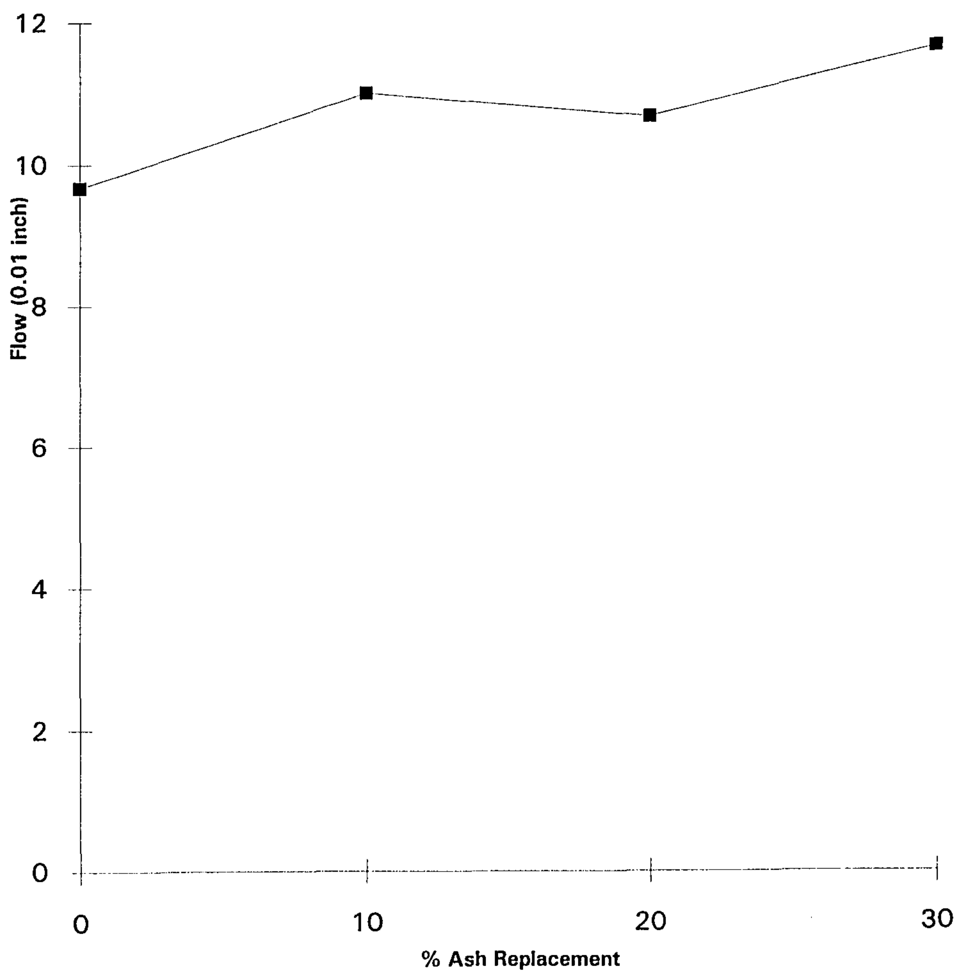


Figure 3-22 : Variation of Stability with Ash Content (Asphalt Cylinders)

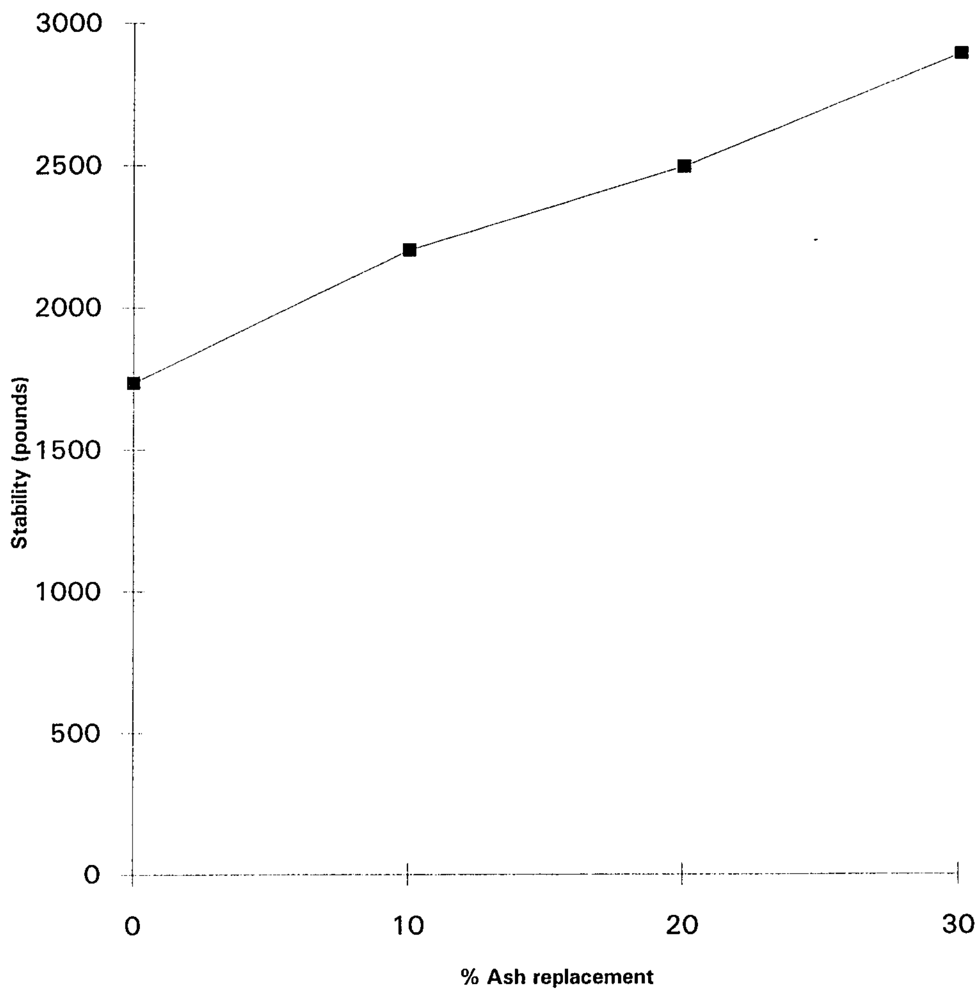
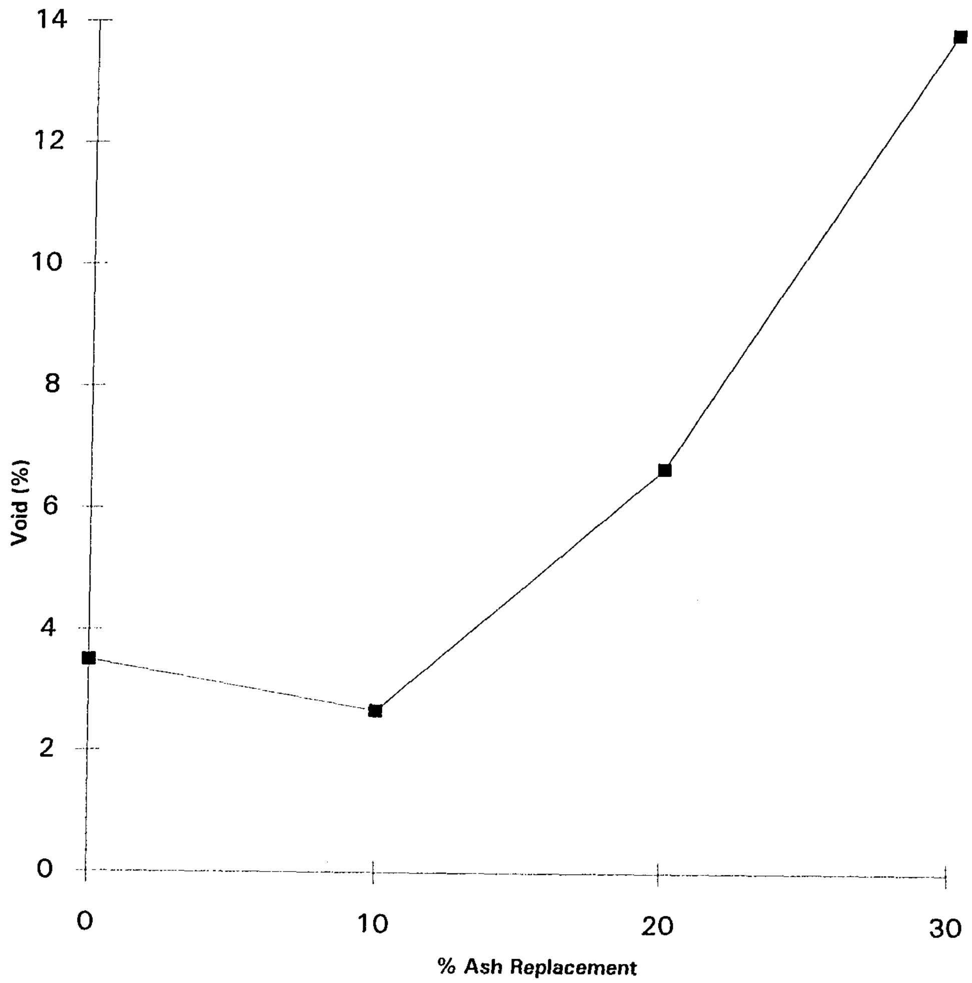


Figure 3-23 : Variation of Void with Ash Content (Asphalt Cylinders)



3.11 ASPHALT SLAB MIX PREPARATION

Based on the results obtained from the above cylinder tests 5 separate asphalt cement slabs, each about 3'X4'X4" were prepared. One slab, the control, contained no ash while in the other four batches, 11, 13, 15 and 17 percent by weight of the fine aggregate (sand) was replaced with ash. The quantities of the other mix components remained unchanged. The mix, prepared by Pave Company of Suffolk County, was transported to the SCDPW's Laboratory by truck, dumped on the previously prepared outdoor ground area, spread and compacted with a 3 ton roller. One additional slab, containing 15% vitrified ash, was also laid down using the same procedure. After 48 hours the following tests were conducted on the slabs:

1. Skid resistance (ASTM E303)
2. Durability tests (Wendlandt, 86)

3.12 ASPHALT SLAB TESTS

The desired asphalt mix design was given to an asphalt plant located near the offices of Suffolk County Department of Public Works. 6 different batches, as shown in Table 3-10, were prepared. Adequate quantities of the composite ash were transported to the asphalt plant in appropriately labeled separate containers. Prior to paving, an open area at the backyard of SCDPW's Laboratory was leveled and prepared for placing the asphalt slabs. All of the asphalt batches were delivered by a truck to the test area, dumped, spread, manually leveled, and finally rolled using a 3 ton vibration roller.

TABLE 3-10: BATCH MIX FOR ASPHALT SLABS

Mix No.	% Ash*	Aggregate % by wt.				Fill % by weight	A/C % by weight
		Ash	Sand	1/4"	3/8"		
1	11	4.04	32.71	23.50	29.99	3.76	6.0
2	13	4.78	31.37	23.50	29.99	3.76	6.0
3	15	5.51	31.24	23.50	29.99	3.76	6.0
4	17	6.25	30.50	23.50	29.99	3.76	6.0
5	0	0	36.75	23.5	29.99	3.76	6.0
6	15**	5.51	31.24	23.5	29.99	3.76	6.0

* % of fine aggregate.
** Vitrified ash was used.

3.12.1 SKID RESISTANCE OF ASPHALT SLABS

This test used the same procedure as described in article 3.7.1. The results of the skid resistance tests on different slabs are shown in Table 3-11 as well as Figure 3.24. It can be seen that, as in the case with concrete slabs, the skiding quality of asphalt slabs with different ash contents changes either very little or not at all.

TABLE 3-11: RESULTS OF SKID RESISTANCE TEST ON ASPHALT SLABS

Mix No	% Ash*	Skid Resistance	
		Test Result	Min. Allowable
1	0	76	55
2	11	79	55
3	13	75	55
4	15	74	55
5	17	75	55
6	15**	75	55

* % of fine aggregate by weight
** Vitrified ash was used.
$-Tests done on standard core taken from asphalt slabs

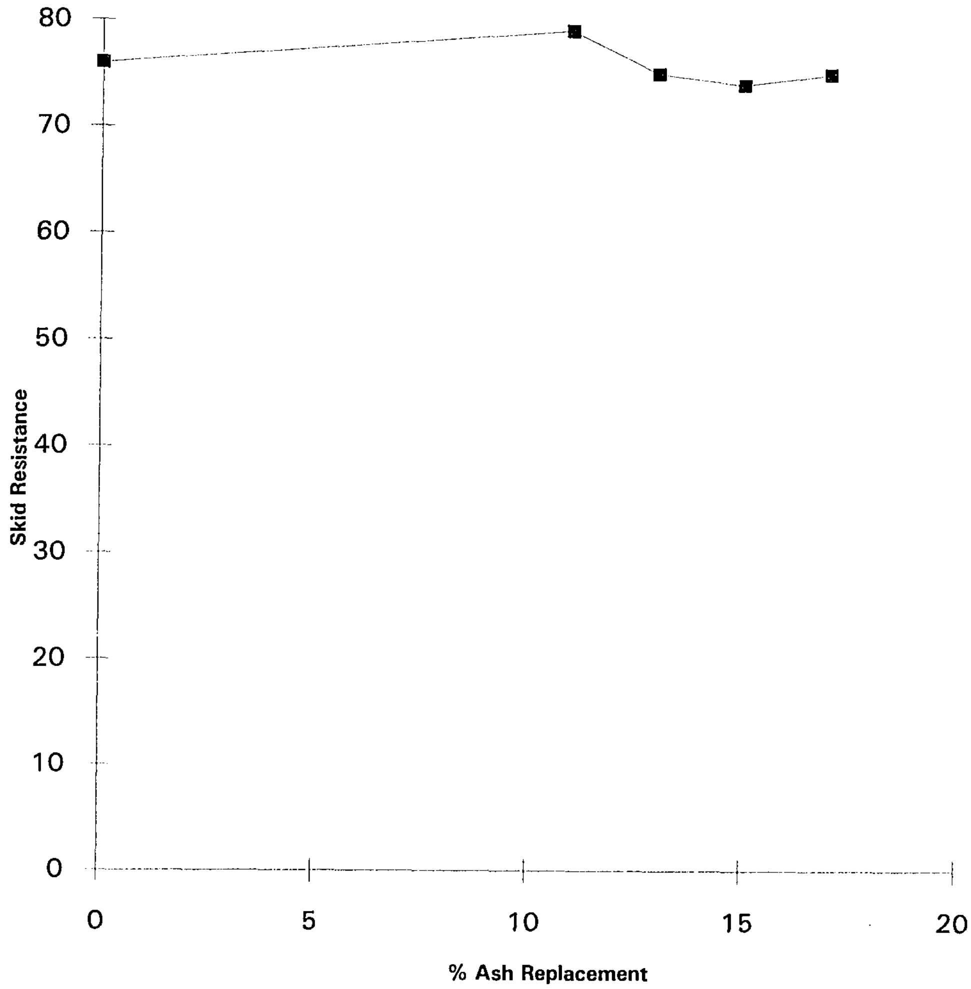
Note:

All the test results are the average of three test samples

3.12.2 DURABILITY TEST

Alterations of the physical parameters of construction materials such as volume, shape, length and other properties due to climatic and environmental changes is of particular concern to the design engineer. The most popular method for measuring these changes is known as the "Thermomechanical"

Figure 3-24 : Variation of Skid Resistance with Ash Content (Asphalt Slabs)



analysis. In thermomechanical analysis, a sample of the substance in question is prepared in a tiny mold containing almost 1 cu.cm. of the substance. This is placed in the apparatus where it undergoes a change in temperature from -100°C to +100°C at a specific rate. Changes in the dimensions of the sample can be detected by an optical or electrical transducer. The result is plotted by a computer which is connected to the apparatus.

The results of the thermomechanical analysis as a measure of durability of asphalt are shown in Figures 3-25 through 3-3-30. The strain per 1°C is measured by the slope of the indicated segment on the curves as shown in these figures. The softening point of the material tested (in terms of °C) is also indicated in this figures. The strain per 1°C for the samples containing 13% and 17% sludge ash replacement for sand in the mix are 50% and 30%, respectively, higher than the control sample (0% ash). For the samples with 11% and 15% sludge ash replacement the strain is found to be similar to that of the control sample. Since the result for the 13% ash replacement sample seem rather inconsistent with the rest of the samples it is possible that some inherent error occurred in preparing the batch. If so, replacing the sand in the asphalt mix by up to 15% sludge ash has little effect on the durability of the mix when compared to the control mix (0% ash).

Figure 3-25 : Durability Test For No-Ash Asphalt

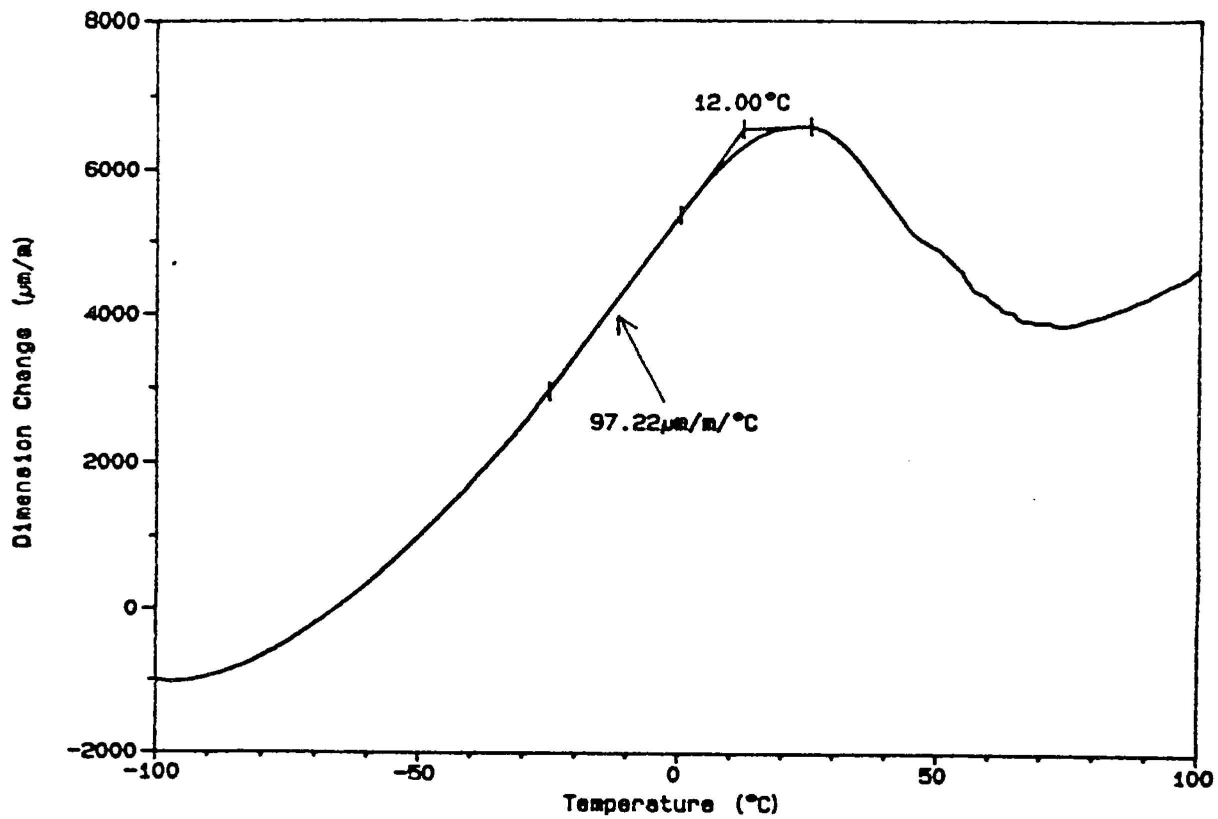


Figure 3-26 : Durability Test For 11% Ash Replacement Asphalt

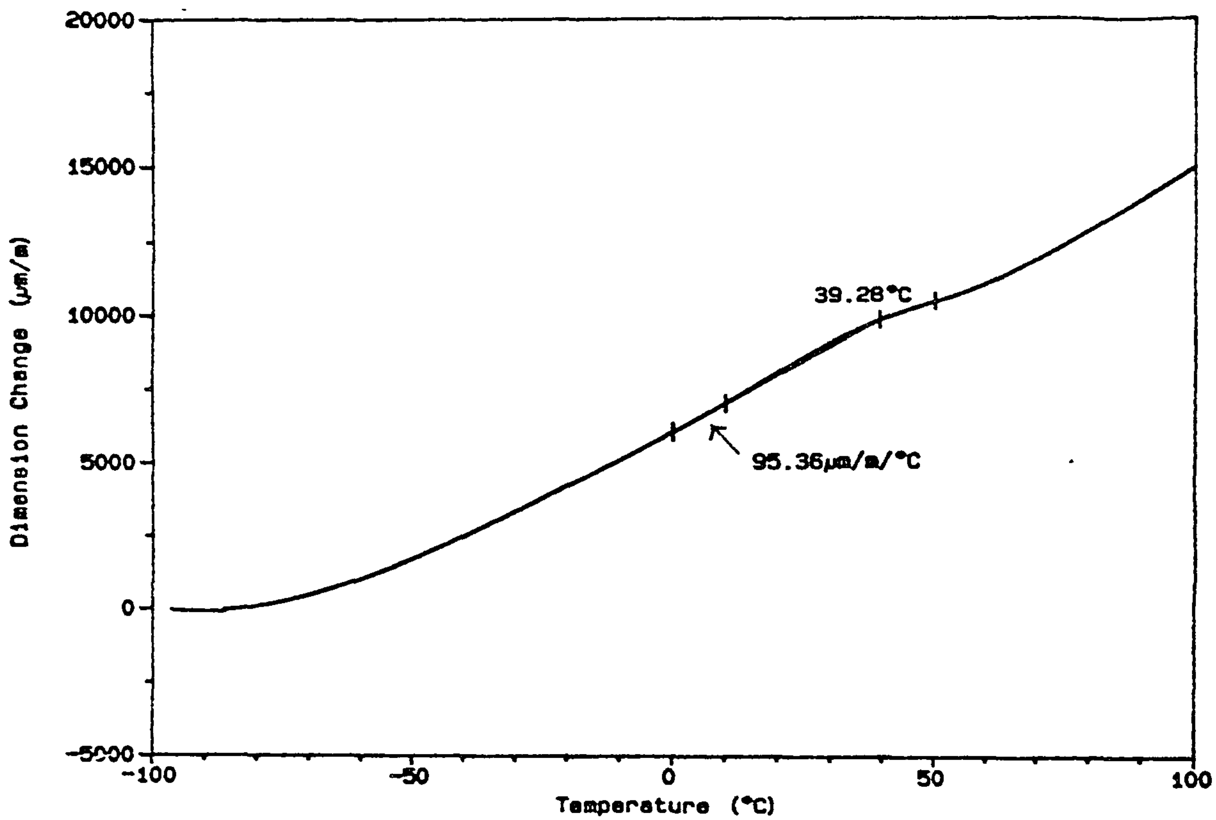


Figure 3-27 : Durability Test For 13% Ash Replacement Asphalt

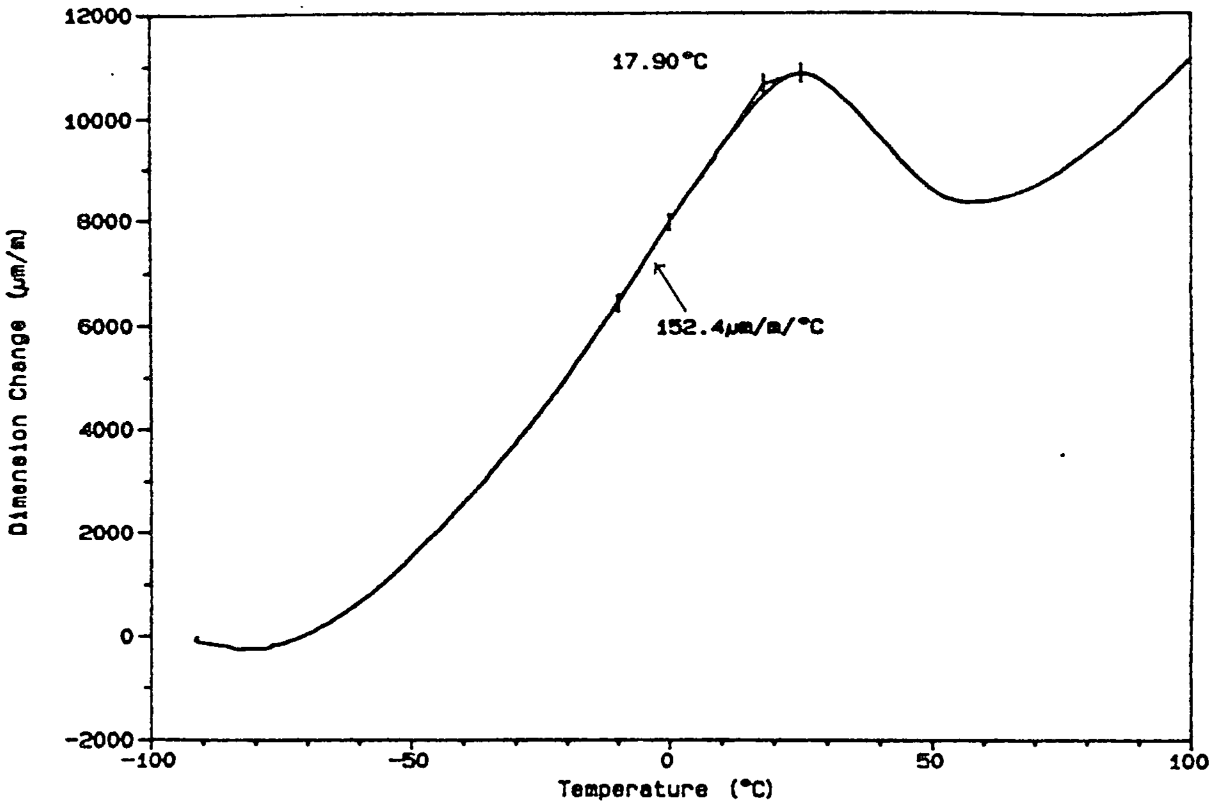


Figure 3-28 : Durability Test For 15% Ash Replacement Asphalt

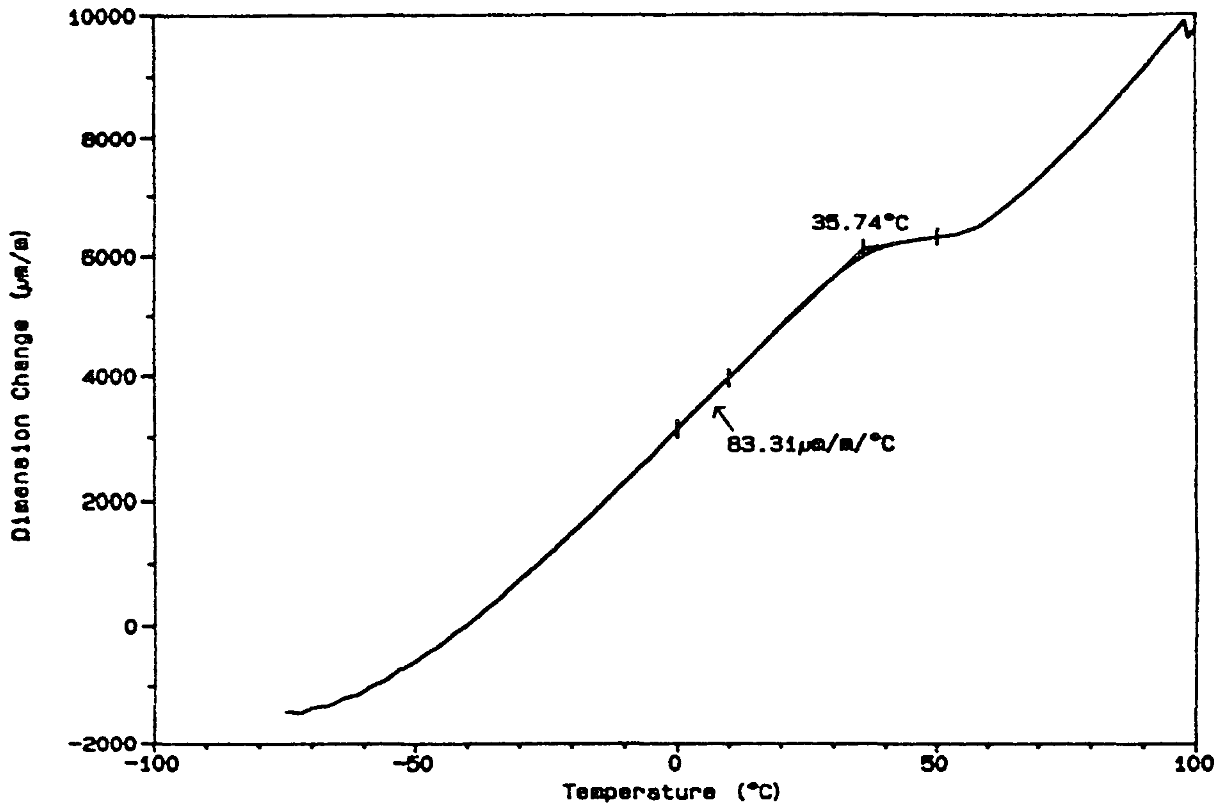


Figure 3-29 : Durability Test For 17% Ash Replacement Asphalt

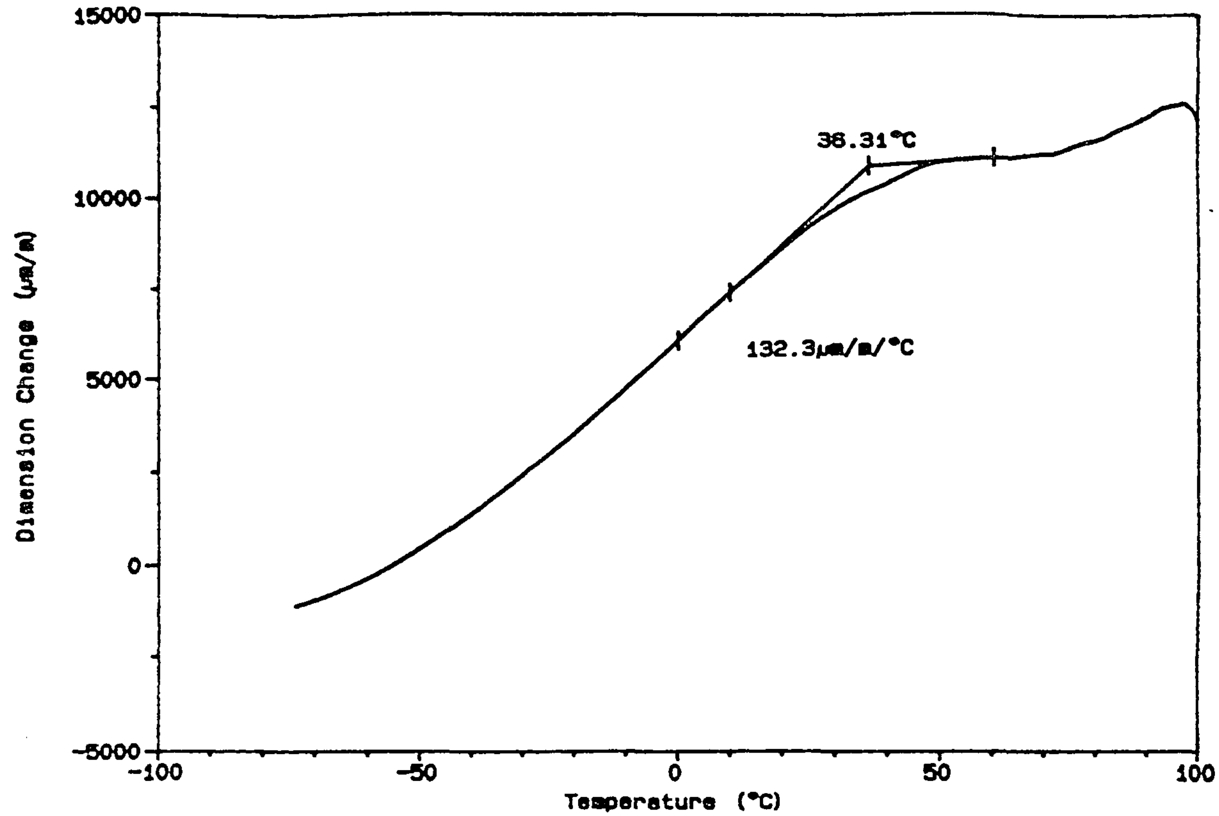
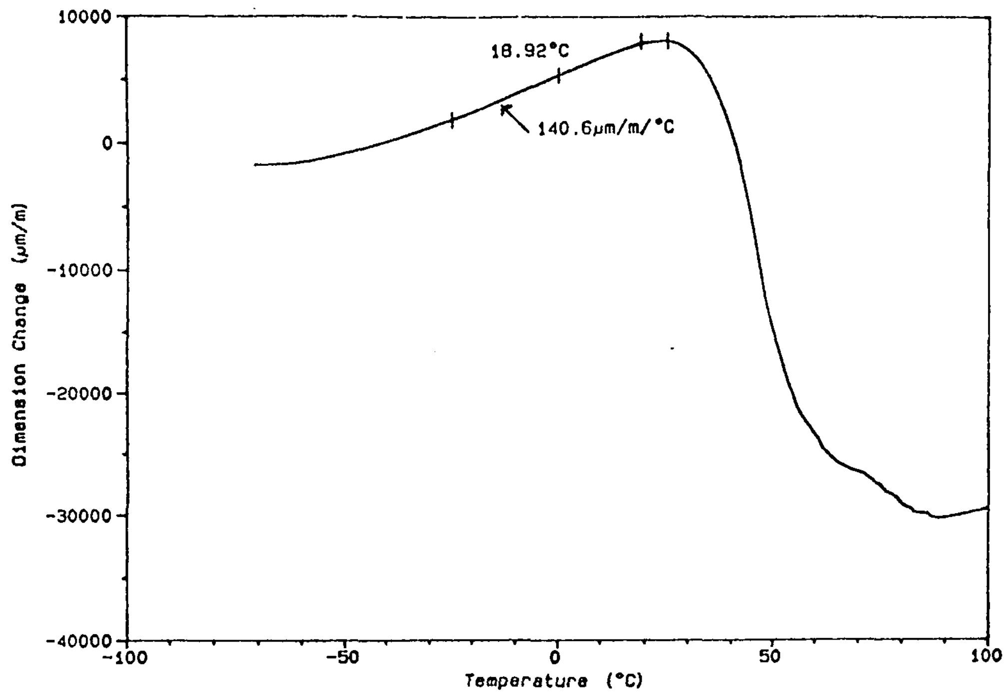


Figure 3-30 : Durability Test for 15% Vitrified-Ash Replacement Asphalt



3.13 EFFECTS OF THE pH OF ASH ON DURABILITY OF ASH-CONCRETE

Corrosion of steel embedded in concrete may occur when PH of concrete is reduced to about 11 or below. The PH of standard concrete is about 12 but the result of chemical analysis on the ash samples indicates that the PH of ash is 9.2. Although ash comprises only 10 percent of the ash-concrete mix but even this small percentage of ash, according to a mass balance accomplished for the concentration of the Hydrogen ion in the mix, is enough to drop the overall pH down to about 10. At this pH level the passive iron oxide layer on the surface of the iron will be destroyed, leading to the corrosion of steel bars. For reinforcing steel, chloride ions are the most potential source of corrosion. Deicing salts are generally mixtures of NaCl and CaCl2, and much of the salt will penetrate into the pores of the concrete and slowly diffuse down to the reinforcement.

Concentration of the chloride ion in pure ash did not exceed 200 part per million (ppm) and that of the concrete sample was considerably less, i.e. 20 ppm. According to the concrete literature the threshold concentration for which the chloride attack can be important is 500 ppm. Therefore, the existing chloride constituent of ash-concrete is unlikely to create a corrosion problem. The addition of deicing material, predominantly NaCl, may threaten the durability of the concrete through the defused chloride ion. This possibility , however, is common for the conventional concrete too.

Protection against chloride attack may be achieved by coating the reinforcing steel by some metal coatings such as zinc, cadmium, nickel, or copper galvanizing.

3.14 CONCLUSIONS

Based on the data obtained from this study the following conclusions can be made:

(1) According to the EP-Toxicity and TCLP tests on samples of Portland cement concrete with 30% ash and asphalt concrete with 15% ash replacing a portion of the fine aggregate of the mix, shows that the resulting values of toxic constituents for these construction materials fall well below the standard limits for hazardous materials.

(2) The ash alone is not a desirable material as a construction aggregate, but blending with a coarse material can yield a suitable aggregate.

(3) For portland cement concrete up to 30 percent by weight of the fine aggregate could be replaced by sludge ash.

(4) For asphalt concrete up to 15 percent by weight of the fine aggregate could be replaced by sludge ash.

(5) For protection of the ash-concrete against chloride attack it is suggested that the steel reinforcement to be coated by metal galvanizing agents prior to its embedment into concrete.

CHAPTER 4: RAINFALL SIMULATION

4.1 INTRODUCTION

Stability for driving is reflected in part by the speed at which surface water can be discharged from the pavement. This can be done by utilizing accepted procedures for analyzing rainfall runoff from paved surfaces, such as highways, streets, and runways. Pavement texture is an important factor in tire/pavement interaction. The surface roughness relative to runoff friction is an important element in hydroplaning. The utilization of ash as a pavement aggregate can become questionable if it creates an unsafe driving condition. This would be most critical during storm events. Consequently, it is important to study the relationships between ash-mixed pavement and hydraulic resistance.

Runoff from the roadway and highway right-of-way are normally discharged to a local watershed. The runoff may be contaminated with suspended solids, heavy metals, nutrients, oil and grease, bacteria and other pollutants. Furthermore, the application of road deicing agents such as sodium chloride (NaCl) could contribute to roadway runoff pollution. It is important to identify and evaluate the potential pollutants from a roadway surface paved with an ash-mixed asphalt or concrete and attempt to identify those contaminants that may be contributed from the ash alone or as a result of the ash-asphalt/ash-concrete mixtures.

4.1.1 RUNOFF ANALYSIS

Numerous methods are available for estimating the peak-rates of runoff required for design applications in highways and small watersheds. Some incorporate a rational analysis of the *rainfall-runoff* process whereas others are completely empirical or correlative in that they predict peak runoff rates by correlating the flow rates with simple drainage basin characteristics such as area or slope.

The Rational Formula for estimating peak runoff rates was introduced in the United States by Emil Kuichling in 1889. Since then it has become the most widely used method for designing drainage facilities for small urban areas and highways. Peak flow is found from

$$Q = CIA$$

where

Q = the peak runoff rate (ft^3/sec)

C = the runoff coefficient (assumed to be dimensionless)

I = the average rainfall intensity (in/hr)

A = the size of the drainage area (acres)

The runoff coefficient can be assumed to be dimensionless because 1.008 acre-in./hr is equivalent to 1.0 ft^3/sec.

A low runoff coefficient is, obviously, synonymous with a high infiltration. High infiltration through pavement is undesirable because it reduces the strength of under layer structures, i.e. granular base, subbase, and subgrade.

The use of rainfall simulators have been successfully used by other researchers to study different aspects of pavement - runoff combinations. Reed et al (1985) developed a rainfall simulator system to study the grooved pavement runoff. Later Krallis (1991) and Stong (1992) used rainfall simulators to investigate the effect of wind on grooved concrete pavement and sheet flow on concrete surfaces, respectively.

In this study, a rainfall simulator system was used to simulate runoff on both concrete and asphalt pavements, each with and without ash present in their mix. Then runoff coefficient was found for each pavement and the results were compared.

4.1.2 HYDRAULIC FLOW RESISTANCE

Rainfall on pavements produces a thin flow of water, called rainfall-runoff or sheetflow. Movement of runoff is resisted by friction forces developed between the runoff water and the pavement surface. This is referred to as hydraulic resistance or roughness. Roughness of a surface is very much a function of the surface texture and the manner in which that particular surface has been finished.

Several hydraulic parameters have been studied by researchers. Amongst these parameters, the Darcy friction factor, f, and Manning roughness coefficient, n, have been given most attention. Experimental results carried out previously by other researchers (e.g. Woo 1962, Morgali 1970, and Swanson 1985), indicate no consistent relationship between the Darcy friction factor and Reynolds Number for a Reynolds Number below 150. This lower Reynolds Number range is the case for rainfall-runoff. For this reason the Darcy friction factor has not been used in this study and the Manning's roughness coefficient is instead used to represent the friction factor.

While the Rational Formula estimates the volume of runoff that can be produced on a surface, the Manning equation determines how fast the runoff can be discharged from the surface. The Manning equation for shallow water is given by

$$q = [1.49/n]\ Y^{5/3}\ S^{0.5} \qquad (4\text{-}1)$$

where

q = flow rate per unit width (ft^2/sec)

n = Manning roughness coefficient (dimensionless)

Y = flow depth (ft)

S = slope of the surface

Although the Manning roughness coefficient, n, has been well established for open channel flow, there is a paucity of knowledge in regards to the value of n for sheetflow. It is known that for sheetflow, n is a function of flow depth. This is not the case for open channel flow. A few researchers have attempted to define this relationship but the validity of their work has been limited to the very particular physical and flow condition of their experiment, e.g., Stong (1992). Others have attempted to accomplish too much by testing so many different types of pavement surfaces at so many different flow conditions that the results of their work is overall but insufficient to use for any one specific set of conditions, e.g. Gallaway et al (1979).

Gallaway and his colleagues at Texas A & M University developed an empirical regression equation in 1971. This equation was the result of extensive experimental work using nine pavement surfaces of varying materials, each tested for a wide range of surface texture (the asperity height varied from as low as 0.003 inch to as high as 0.164 inch), each subjected to a wide range of rainfall rates (0.5 inch/hour to 15 inch/hour), at each of six different runoff slopes (0.005 to 0.083). Their equation was the best overall regression equation for all drainage surfaces with a coefficient of determination of R^2=0.83.

Stong (1992) accomplished an experiment which was confined to a much narrower range. He only considered rainfall-runoff simulated on concrete pavement for the slope varying between 0.005 and 0.025 and rainfall rate ranging from 1 inch/hour to 3 inch/hour. His best regression equation was:

$$y = 0.151\ [Li]^{0.279}/S^{0.231} \quad \text{with } R^2=0.899.$$

He, like other researchers as Reed (1989) and Krallis (1991), found that runoff slope has little effect, if at all, on the outcome.

The above equations should produce similar results, but they don't. It is believed, therefore, that different equations must be applied to different surface-rainfall conditions, if more accurate results are needed.

In this study the Manning roughness coefficient, n, is expressed as a function of flow depth for rainfall-runoff. Runoff is produced using rainfall simulators on ash-concrete and ash-asphalt platforms, as well as on their corresponding control no ash mixes. Depth of runoff is measured by means of pressure transducers. Pressure transducers are used since they give a more accurate indication of flow depth as compared with the conventional point gages which were used in previous research work. A database is established in terms of runoff depths corresponding to different rainfall intensities at various points on the platforms. This database is later incorporated in a regression analysis using kinematic wave theory to define the Manning roughness coefficient, n, for various pavements.

4.1.3 SCOPE OF THE WORK

Based on the aforementioned discussion the performance of ash in concrete and asphalt pavements must be checked for a low infiltration and a satisfactory hydraulic resistance. To address the above issues, the following objectives were established:

(i) Develop a 16' x6' physical model as a roadway platform with a rainfall simulator, and define intensity and duration of rainfall.

(ii) Monitor runoff formation using pressure transducers.

(iii) Evaluate runoff coefficient used in the Rational Method.

(iv) Collect surface runoff samples for chemical analysis.

(v) Apply deicing materials and analyze the probable pollution impacts which may arise due to interaction between the ash and deicing material.

The remainder of this chapter describes the methodology for accomplishment of the above items.

4.2 COMPOSITE ASH

The four existing ash stockpiles at the Bergen Point Wastewater Treatment Plant were used to provide the ash required for ash-concrete and ash-asphalt mixes. 150 lbs samples of ash were taken from each stockpile and placed in separate plastic barrels, sealed and labeled appropriately, and transported to the City College of New York (CCNY). Additional ash samples from each of the four stockpiles were blended together to obtain a uniform ash mixture that was used for the ash/portland cement concrete mixes. Four additional 100 pound samples of ash were taken from each stockpile and were placed in eight separate plastic bags. Each bag, weighing 50 lbs, was sealed and appropriately labeled and then sent to the Pave Asphalt Company in Holtsville L.I. to be used in the ash/asphalt concrete mixes.

4.3 CONCRETE MIXES

Two separate concrete batches were prepared. One batch contained no ash while the other had 30 percent of it's fine aggregate by weight replaced by ash. Except for the ash content, the two batches were identical in terms of coarse aggregate, Portland cement, and water. The coarse aggregate was crushed stone with a grading as shown in Table 4.1.
Sand was obtained from a local source and its grading is shown in Table 4.2. The portland cement used was Type 2. The control mix, concrete mix with no ash, was designed to ACI (American Concrete Institute) specifications for 3000 psi compressive strength at 28 days with a slump of 2" to 3" which is the most usual for pavement, footings and slabs. These

TABLE 4-1: COURSE AGGREGATE GRADATION USED IN CONCRETE

SIEVE SIZE	PERCENT PASSING
1"	100
3/4"	95.5
1/2"	56.0
3/8"	40.0
1/4"	12.3
1/8"	4.4

TABLE 4-2: FINE AGGREGATE GRADATION USED IN CONCRETE

SIEVE SIZE	PERCENT PASSING
1/4"	100
No.4	99.4
1/8"	98.6
No.8	96.4
No.10	95.5
No.16	89.6
No.20	83.0
No.30	70.0
No.40	48.9
No.50	24.4
No.80	7.4
No.100	5.0
No.200	1.5

concrete batches were poured as two separate platforms and subjected to different rain events using a rainfall simulator. The experimental set up will be described later in this report. The following analyses were conducted:

- Rainfall runoff
- Runoff coefficient
- Surface friction
- Chemical testing on composite runoff samples taken in duplicate (except for the TCLP test) from the different rainfall events. The chemical tests included:
    - Heavy metals
    - Chlorides
    - Sulfates
    - Phosphorus
    - Suspended Solids
    - EP Toxicity

The above mentioned experiments were conducted with and without deicing material being used on the surface.

- TCLP Toxicity (on the samples with deicing material only)

4.4 ASPHALT MIXES

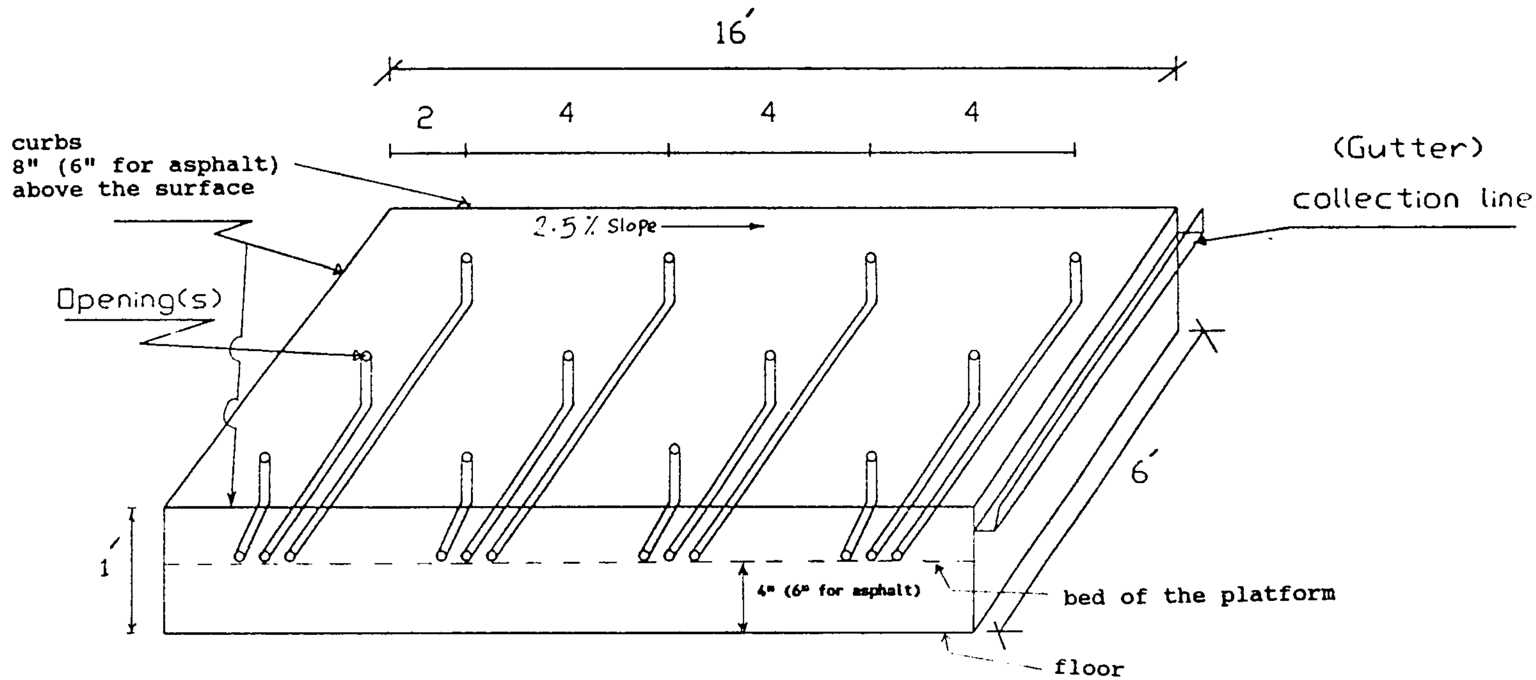
Two different batches were prepared in the Pave Company asphalt plant located in Holtsville. One batch contained no ash while in the other batch, 15 percent of the fine aggregate by weight was replaced with ash. The amount of other materials in the mixes, namely bitumens and coarse aggregate, remained the same for both batches. The control batch, the one with no ash, was prepared according to Suffolk County, Department of Public Works' specification 51F Type 1A Top. These asphalt mixes were placed as two separate platforms, described later in this report. The same chemical analyses were performed on asphalt mixes as on concrete mixes.

4.5 TEST PREPARATION

4.5.1 PLATFORM CONFIGURATION

Two platforms were built in the Fluids Laboratory of the City College, School of Engineering, the City University of New York. Each platform was first paved, using a concrete mix, and at a later stage, i.e after the completion of the experiments on the concrete mix, overlaid by an asphalt pavement. The platforms were each 16' x 6' with a thickness of two to three inches and a slope of about 2.5 percent. Curbs, six to eight inches high, were provided on three sides of the platforms to ensure surface runoff discharge through the downstream 6 ft. side of the platform. The surface runoff could easily be collected from this side of each platform through a gutter system (see FIG.4-1).

Figure 4-1 : Pavement Section Platforms



4.5.2 PRESSURE TRANSDUCERS

Validyne Engineering Corporation's pressure transducers, model DP 103 with a pressure range of 0.01" H_2O to 90" H_2O, were used to measure the pressure developed by the runoff flow. The expected range of pressure in the experiment would be 0.02 to 0.1 inch of H_2O. The pressure transducers are connected to a signal conditioner, model CD280 made by Validyne Engineering Corp., to provide excitation and to convert the ac half-bridge output into dc voltage or current which in turn can be measured with a voltmeter. The depth of the surface runoff at different points is obtained by transforming the number indicated by the voltmeter into its corresponding depth of water. The relation between hydrostatic pressure and depth of water is obtained through the calibration of the pressure transducers, as discussed in the next section. FIG.4.2 shows a pressure transducer.

4.5.3 CALIBRATION OF THE PRESSURE TRANSDUCERS

The apparatus used for the calibration of the pressure transducers, shown in Fig.4-3, consists of a vertical graduated cylinder connected to the pressure transducer through a 1/4 in. diameter tube. Prior to the calibration, air was removed from each transducer by introducing a few drops of xylene into them. The cylinder was then filled with water to

Figure 4-2 : Differential Pressure Transducer

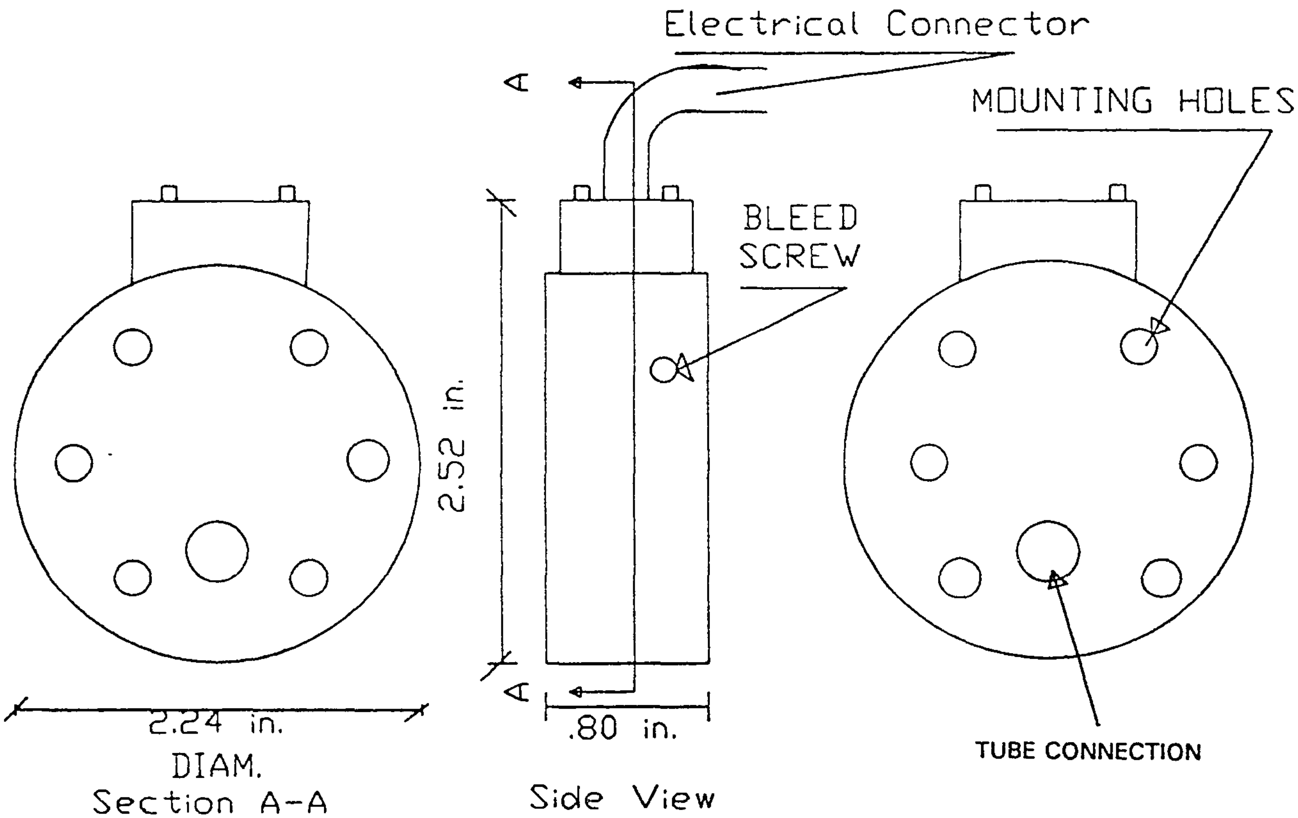
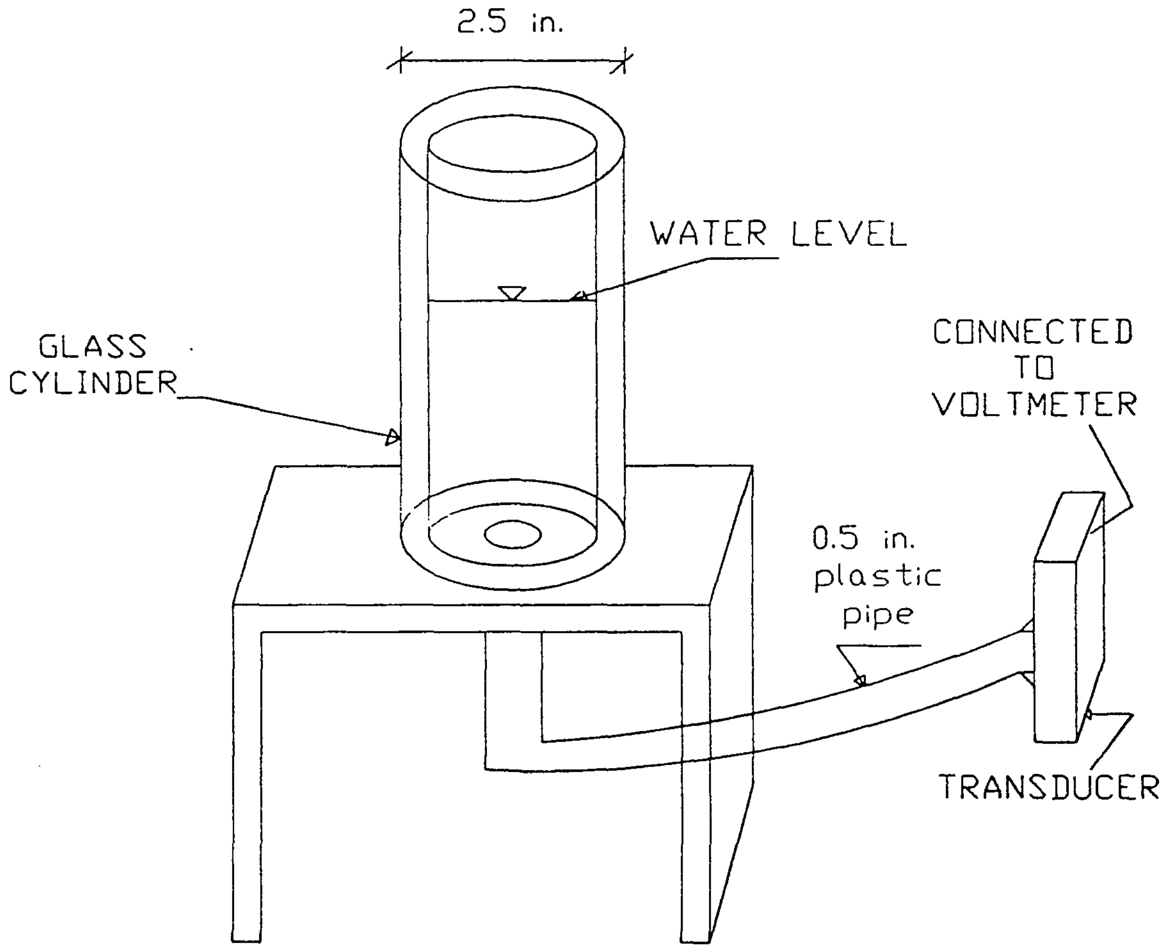
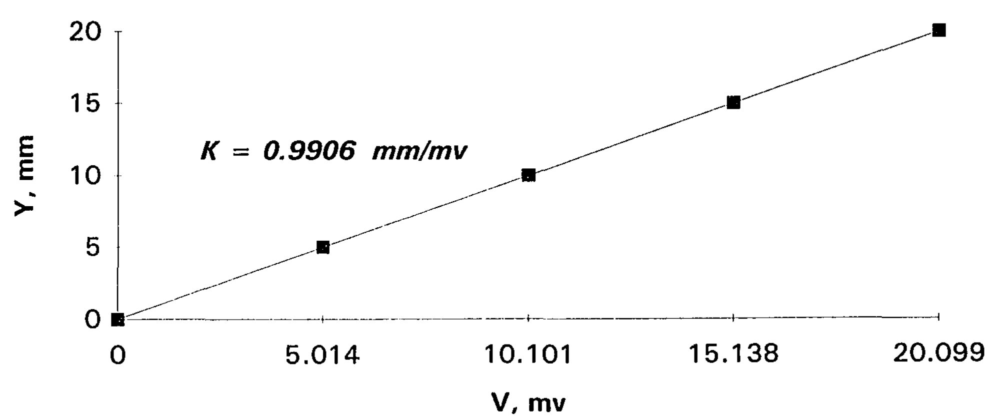


Figure 4-3 : Calibration Unit



measured levels and the corresponding transducer voltage was read with a voltmeter. The procedure was repeated using different water elevations. Corresponding voltage values were read and both water depth and voltage plotted on a graph. These points, plotted on a curve for each pressure transducer, was used to measure the depth of runoff by observing the indicated voltmeter readings. A separate curve was developed for each transducer used in the experiment. Figure 4.4 shows a typical calibration curve. A summary of the conversion factors for all transducers, as obtained from calibration charts, is also tabulated in Table 4.7, page 150.

Fig. 4. 4 - A Typical Calibration Chart



4.5.4 PLATFORMS INSTRUMENTATION

Four rows with three openings in each, for a total of twelve(12) holes, were provided in each platform. A 5/8 inch diameter PVC tube, was installed in each hole from the bottom of the platform and connected to a pressure transducer through a 3/4 inch diameter plastic tube. Once the tubes were filled with water, the height of water above the surface of the platform could be determined by monitoring the transducer's voltage and converting it to the corresponding runoff depth obtained from each transducer's calibration chart. Fig.4-5 shows the layout of the holes for each platform.

4.5.5 RAINFALL SIMULATORS

Rainfall simulation was achieved through the use of "spray-up" nozzles that were tested on the 16' x 6' pavement platforms. The whole platform was marked at intersections on a grid as shown in Fig.4.6. Twelve plexiglass cups (2.35 inch in diameter and 2 inch deep with vertical sides and flat bottoms) were placed at all openings throughout the grid to collect rain spray from the nozzles and to assist in calculating the rainfall intensity.

The 570 SHRUB HEAD BODY nozzles, manufactured by TORO Inc., were used for this experiment. Each nozzle was connected to the water supply system, and supported by a temporary wooden structure. The nozzles were tested for uniformity of rainfall over the whole platform.

4.5.6 SUPPORT FRAME DESIGN

Four wooden tripods (each 60 inches in height) were constructed to serve as the supports for the nozzles and their end tubes. Fig.4.7 shows a tripod used for the rainfall simulator system. Tripod No.1 has a 3/4 in. diameter plastic tube at the top which is connected, through a Jenkins Brothers FIG.370 valve, directly to the water supply system. Flow of water in this pipe is regulated by the extent to which this valve is opened, that is the number of turns of the valve handle controls the flow of water in the pipe. For this study it was found that 3 to 6 turns of the handle would produce the most uniform rainfall simulation throughout the platforms.

At the top of tripod No.1 the tube was divided by a PVC Tee into two sections. One section was directly connected through a 90 degree PVC elbow to a 1 in. diameter, 28 in. long PVC pipe which was horizontally resting on the top of the tripod, followed immediately by a 5/8 in. diameter, 24 in. long PVC pipe which was inclined 60 degrees below the horizontal and was connected to a single nozzle facing towards the platform. The other section was connected to a 3/4 in. diameter plastic tube which in turn would carry water to the next nozzle on the top of the next tripod. In this way a system of four nozzles in series, assembled on the top of four tripods, was established.

Several patterns for locating the tripods were attempted and the one which provided the best uniform rainfall distribution on the whole platform, as measured by the volume of the rainfall water accumulated in each plexiglass cup, was chosen. The water collected in the plexiglass cups was compared with each other. The nozzles were adjusted by revolving their opening and/or by changing the position of the wooden supports until an almost uniform rainfall distribution, as recorded in the plexiglass cups, was achieved.

Figure 4-5 : Platform Transducer Opening

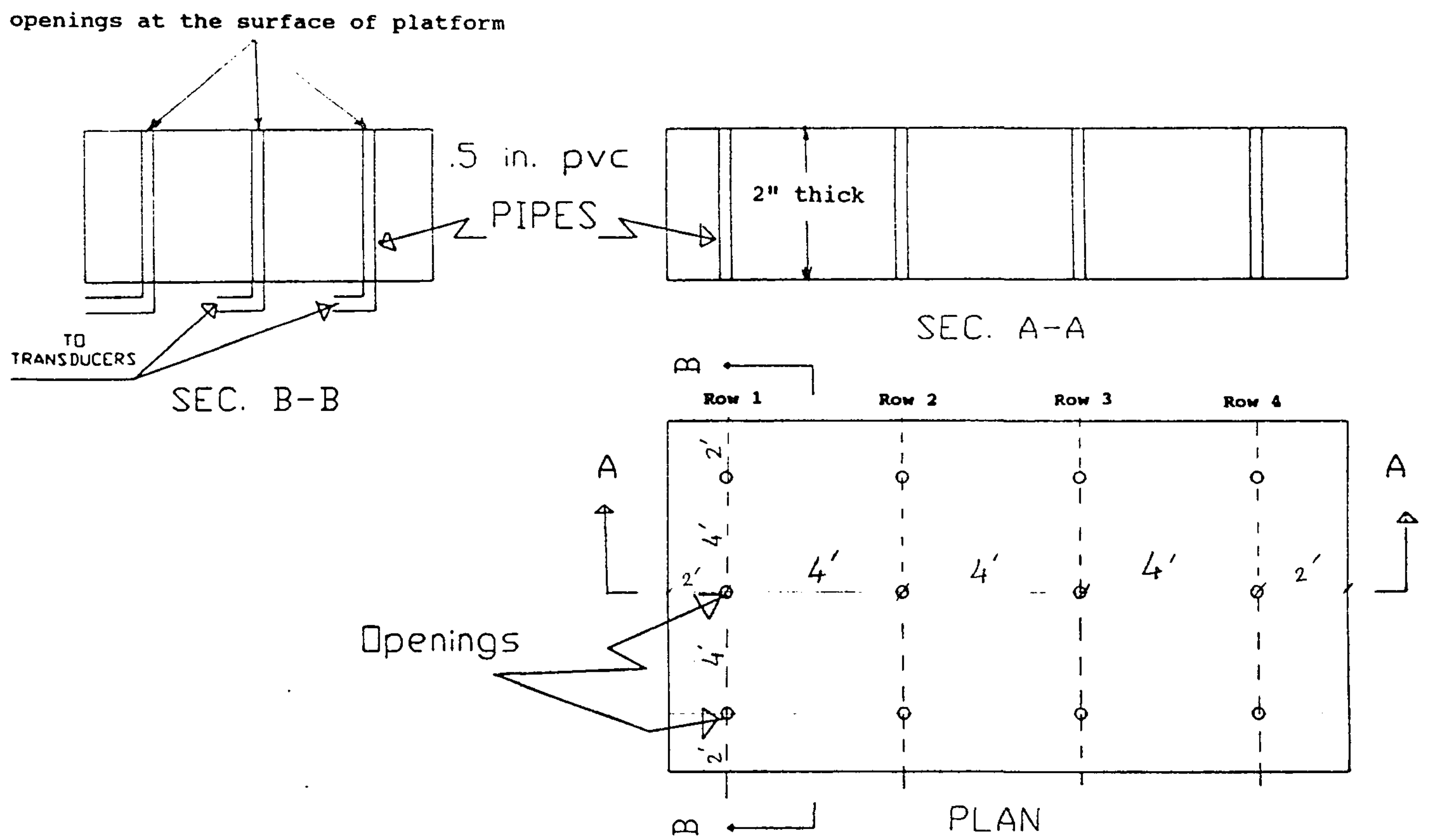


Figure 4-6 : Schematic Drawing of Rainfall Simulator System

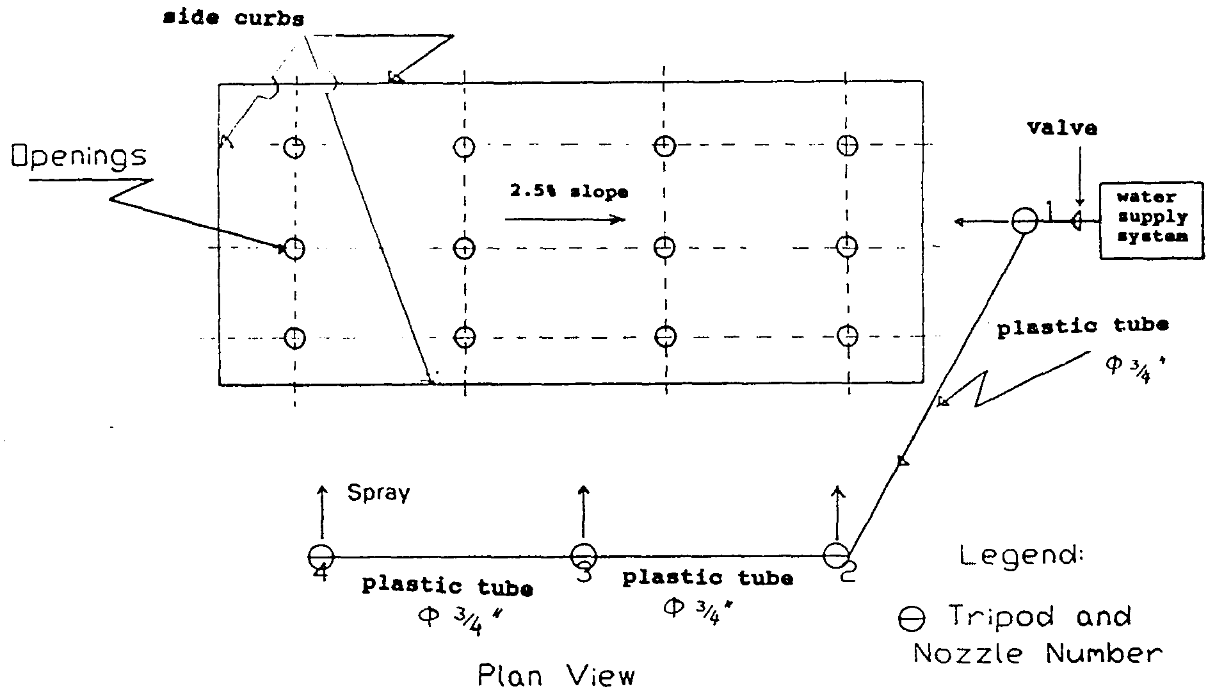
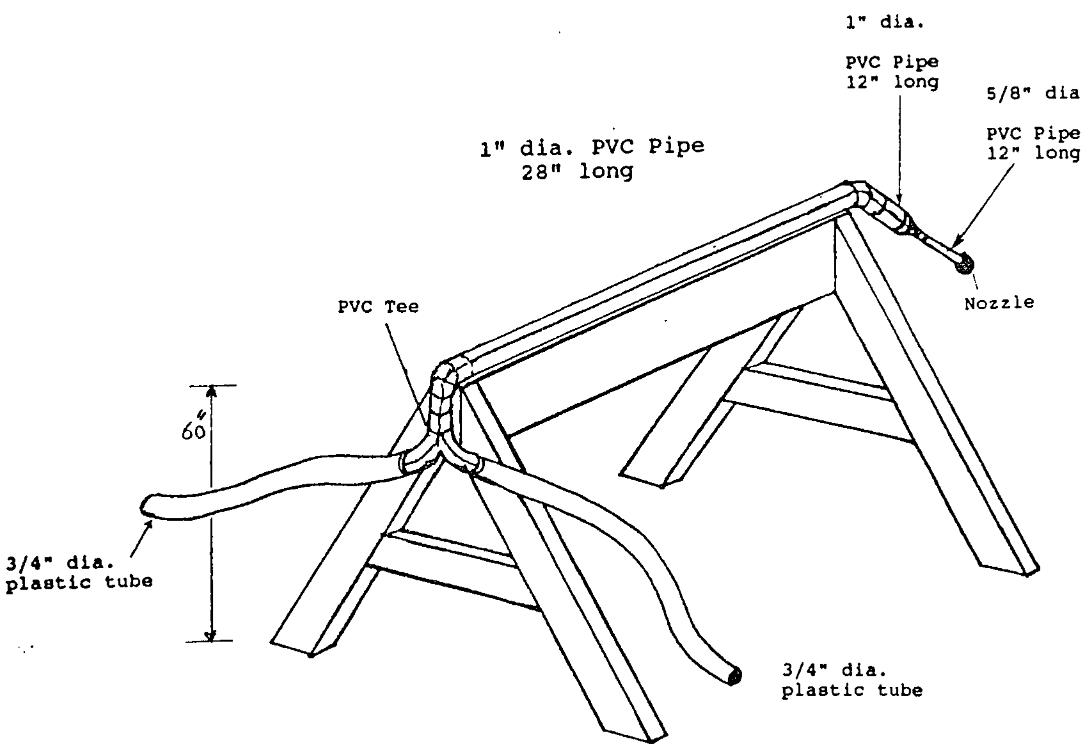


Figure 4-7 : A Rainfall Simulator Tripod



4.6 CONCRETE MIX PREPARATION

The concrete mixture of constituents tabulated in Table 4.3 was designed in accordance with current ACI standard for f'_c = 3000 psi and a 3 in. slump. For each mix the materials were appropriately weighed and placed into a mechanical concrete mixer. Allowing about 15 to 20 minutes for mixing to be completed, the fresh concrete was removed and placed on the platform described earlier in section 4.5.1. The control mix, with no ash, was placed on one platform while the mix containing the 30% by weight ash replacement of the fine aggregate was placed on the other one.

TABLE 4-3: ELEMENTS OF CONCRETE MIXES

Mix No.	Water #/cuyd	Cement #/cuyd	Sand #/cuyd	Ash #/cuyd	Stone #/cuyd
1	250	500	1380	0	1900
2	250	500	966	414	1900

The surface of the concrete was then levelled and finished, using trowels, to form a uniform surface with about a 2 percent slope. As much as possible, an attempt was made to finish the surface of each platform the same way. During the concrete placement care was taken not to clog or damage the subsurface piping system's openings by temporarily inserting a cork into them. After one week a plastic gutter was fixed at the downstream end in such a way that the surface runoff could easily enter the gutter. The platforms were bounded along their three other sides by wooden curbs, 15 in. high. The sides of the platform were sealed, using silicon sealant, to ensure that the simulated rainfall could not infiltrate from the interface between the edges of the concrete slab and side curbs and that water would only be able to flow on the concrete surface towards the end gutter.

4.7 ASPHALT MIX PREPARATION

Two separate asphalt batches were prepared at the Pave Company asphalt plant in Holtsville, LI, and were transported in a hot box by Culesa Brothers Co. to the Fluids Laboratory at the City College, School of Engineering, the City University of New York. The control batch contained no ash while the other batch had 15 percent of the fine aggregate (sand) replaced by ash. The quantity and quality of other components of the mix remained the same for both mixes. The asphalt batch formula (as shown in Table 4.4) is set by the New York State Department of Transportation, and is presently used by Suffolk County. Each asphalt mix was then placed over the previously tested concrete platforms.

TABLE 4-4: ELEMENTS OF ASPHALT MIXES

% Ash*	Aggregate % by wt.				Filler % by wt.	A/C % by wt.
	Ash	Sand	1/4"	3/8"		
0	0	36.750	23.50	29.99	3.76	6.0
15	5.51	31.24	23.50	29.99	3.76	6.0

The asphalt was leveled and compacted by means of a hand roller to get a uniform asphalt thickness of about two inches and a slope of about 2.5 percent. During placement of the asphalt care was taken not to clog or damage the subsurface piping system's openings. After 24 hours a gutter was fixed at the downstream end, in the same way as before. The sides of the platforms were sealed, in the same way as described earlier for the concrete mix, so that the simulated rainfall could not infiltrate through the edges of the platforms and could only flow on the asphalt surface.

4.8 DEICING MATERIAL

The deicing material used in the tests was sodium chloride. The application rate used was one pound per platform per test which is consistent with 600 pounds per lane mile presently used on New York State and Suffolk County highways. Prior to the start of each test, the deicing material was weighed and then spread by hand on the surface of the platforms.

4.9 TEST DESCRIPTION

All pressure transducers were fixed on a wooden board set at about the same elevation as the opening of the subsurface tube on the top surface of the platform to allow the readings to fall within the appropriate operating range of the multichannel carrier demodulator. Prior to starting each test, the pipes and their openings were filled with water and the multichannel carrier demodulator was set to zero. From then on every reading on the voltmeter would directly indicate the depth of runoff water. The tripods supporting the nozzles were set at their designated locations around the platform, as discussed in section 4.5.6, to get the best uniform coverage of the test site from the water discharging from the nozzles.

Two different procedures were used. The first procedure was used to study rainfall-runoff and the runoff-coefficient. In this procedure, each test was started by opening the main valve connecting the water supply system to the nozzles. The water then started to spray on the dry surface of the platform. The tripods were located in a pattern to eliminate or minimize water spray on the floor. After a few minutes lag time, the surface runoff started to form. For each test a volumetric measurement of the first ten minutes of runoff, as measured from the start on a dry surface, was obtained. This was done by collecting the water coming off the end gutter into a graduated 10 gal. plastic barrel. The time was measured using an Omega stop watch with an accuracy of one second. This ten minute volumetric measurement was then converted to a flow rate "cfs" basis to be used later in the calculations for runoff coefficient. This process was repeated for five different rainfall events and the corresponding data was collected and is shown in Appendix 4.A. In the above mentioned first process, runoff-coefficient was found to be about the same for all of the five events. Therefore, it was decided that no more than five events would be needed.

In conjunction with the above tests, and using another procedure for estimating the surface roughness in terms of the Manning's 'n', the depth of runoff was measured at each of the twelve openings. According to the theory, Manning's 'n' is a function of the depth of runoff, rainfall intensity, length of the flowline traveling along the platform and the slope of the platform. For the second procedure, all test runs began on a previously wetted surface. The simulated rainfall was allowed to wet the surface for about twenty minutes before the readings for each test run were taken. This was done to allow flow to reach an equilibrium condition. The pressure readings were taken at time intervals 15, 30, 45, 60, and 120 minutes after the start of the experiment. A mean flow depth, for each of the twelve openings was calculated using these readings. Finally an average runoff depth, Y, was calculated for each opening. The hourly rainfall intensity was calculated using the measurement of the depth of the water accumulated in the plexiglass cups. The empty cups (aligned in a row with, and about six inches away from the transducer openings) were placed as soon as the flow reached equilibrium, approximately twenty minutes exposure of the surface to the rainfall. The six inch distance was employed to avoid 'object effects' interfering with the flow in the vicinity of the transducer openings. This procedure was repeated for a minimum of eight different rainfall events and the corresponding data was collected. Due to the variability of the results obtained under the aforementioned second procedure, it was decided to run more than five events which was used for the first process. For each event the amount of rainfall was varied from the previous events by varying the opening of the main valve on the water supply system. There was a two to three hours interval between any two successive tests performed at the same day and no more than two tests were performed each day.

Finally a composite runoff sample, about 15 gal., was taken and kept in a container. The sample, in duplicate, was bottled, labeled and sealed and sent to the H2M laboratory for the following analysis.

- Heavy metals
- Chloride
- Sulfate
- Phosphorus

- Suspended solids
- EP toxicity

Another set of rainfall events was simulated on each platform in the same manner as described above except for deicing material which was hand placed over the surface of the platform prior to each test. Care was taken to obtain a uniform distribution of the deicing material on the surface. In addition to all the above mentioned chemical tests, a TCLP toxicity analysis was conducted on the runoff samples with deicing material.

4.10 DISCUSSION OF TEST RESULTS

4.10.1 RAINFALL RUNOFF

Five rainfall events, with and without deicing material on the surface of each platform, were employed to develop surface runoff values. A ten minute measurement of surface runoff volume was converted to a gallon per minute basis to establish the runoff values for each test. The rainfall intensities were measured, as discussed earlier, by use of plexiglass cups. The results of the rainfall - runoff experiment are shown in Table 4-5. The volumes indicated in the table are the average of five different events.

It was decided to keep the rainfall intensity about the same on all platforms so that the runoff produced from each platform could be compared easily. A rainfall intensity of

TABLE 4-5: VALUES OF RAINFALL-RUNOFF

DESCRIPTION	RAINFALL INTENSITY in/hr	RUNOFF gpm
No-ash concrete, without deicing material	3.09	3.00
No-ash concrete, with deicing material	3.67	3.50
30%ash concrete, without deicing material	3.13	3.00
30%ash concrete, with deicing material	3.55	3.30
No-ash asphalt, without deicing material	3.73	3.70
No-ash asphalt, with deicing material	3.8	3.80
15%ash asphalt, without deicing material	3.25	1.60
15%ash asphalt, with deicing material	3.13	1.55

Note : Numbers under the RAINFALL INTENSITY are the average of five rainfall events.

about 3 in/hr, which is not uncommon for a short period of time in the New York State area, was selected to simulate a major runoff producing rainfall event.

As can be seen from the results in Table 4-5, the runoff initiated by the simulated rainfall is similar for all platforms, except for the ash-asphalt one, where the value is halved. The low readings imply that there is significant infiltration through the ash-asphalt which is not seen in the asphalt. This excessive infiltration implies that either there is something fundamentally different about the ash-asphalt or that the experiment was invalid due to some non-constitutive factors. The former is dismissed because the measurement of infiltration was repeated during the field tests (discussed in the next chapter), and the results of the field experiment showed no significant difference between infiltration through the ash-asphalt and that of the control no-ash asphalt. The latter case may be explained by the fact that the ash-asphalt was delivered at a low temperature because of some problems with the hot box of the hauling truck. Due to the ash-asphalt mix being at a low temperature, the compaction process on the mix did not go well. Therefore, due to the lack of optimum compaction the ash-asphalt mix had excessive infiltration.

4.10.2 RUNOFF COEFFICIENT

The runoff coefficient " C " was calculated for each rainfall event by the "rational formula";

$$Q = CIA$$

where

Q = discharge, (cfs)

i = rainfall intensity, (in/hr)

A = drainage area contributing runoff, (acres)

C = runoff coefficient

Table 4-6 lists the calculated values of the average runoff coefficients for the five different rainfall events for each platform, with and without the use of the deicing material. The data indicate that the runoff coefficients from the ash-concrete and the no-ash concrete platforms are quite similar.

The use of the deicing material shows a slight decrease in the resulting runoff coefficients. The difference, however, being less than 2 percent which itself could have risen due to the errors in volumetric measurements. The runoff coefficients were the highest for the no-ash asphalt platform and it remained the same whether or not the deicing material was used. However the runoff coefficients for the ash-asphalt platform showed a dramatic decrease, dropping to about one-half the value of the other platforms. The major factor contributing to this difference could be inadequate compaction, all as described earlier.

TABLE 4-6: RESULTS OF RUNOFF COEFFICIENT

DESCRIPTION	AVERAGE RUNOFF COEFFICIENT
No-ash concrete, without deicing material	0.96
No-ash concrete, with deicing material	0.94
30%ash concrete, without deicing material	0.94
30%ash concrete, with deicing material	0.93
No-ash asphalt, without deicing material	0.99
No-ash asphalt, with deicing material	0.99
15%ash asphalt, without deicing material	0.49
15%ash asphalt, with deicing material	0.50

4.10.3 DEPTH OF RUNOFF

Rainfall simulations were conducted, as described in section 4.9, to measure runoff depth and to estimate Manning's roughness coefficient, n, for different platforms, with and without deicing material on the surface. After the completion of tests, using the alternate procedure mentioned in section 4.9, calculations were done as follows:

For each platform, the rainfall intensities (i) were obtained from the rainfall accumulated in the plexiglass cups. The average depth of runoff (Y) was calculated by taking the average of five pressure transducer readings (mV_{avg}) at 15, 30, 45, 60, and 120 minute intervals and calculating the corresponding flow depth as obtained from calibration charts (see Table 4.7 for summary of conversion factors). The result was a set of twelve i and Y values recorded for each rainfall event.

TABLE 4-7: SUMMARY OF CONVERSION FACTORS

	K=Y/V (inch)	K=Y/V (mm)
1L	0.039	0.9906
1C	0.05	1.27
1R	0.05	1.27
2L	0.043	1.0922
2C	0.039	0.9906
2R	0.048	1.2192
3L	0.044	1.1176
3C	0.045	1.143
3R	0.039	0.9902
4L	0.044	1.1179
4C	0.04	1.016
4R	0.046	1.1684

The i and Y, described above, were calculated for eight to twelve different rainfall events on each platform, and for each condition with and without use of deicing material to establish a database (see Appendix 4 - B). This database will be used later in chapter 6 in a regression analysis to develop an expression for hydraulic resistance for each platform.

4.10.4 CHEMICAL ANALYSIS OF RUNOFF

The results of the chemical analyses on the runoff samples taken from the concrete and asphalt platforms are shown in Appendix 4C (Tables 4.C-1 through 4.C-20). The values indicated are the average of the results of the duplicate tests. The results indicate that almost all parameters fall below NYSDEC standard limits for groundwater. A few pollutants (i.e. 1,4-Dichlorobenzene, Hexachlorobenzene, Vinyl Chloride, Chloroform, Carbon Tetrachloride, and Benzene) have a detectable limit which is greater than limiting standard and, therefore, for these few items comparison is not possible. There is only one occasion for which the pollutant concentration exceeds that of standard limit and that is for Selenium. However, the results of the ash mixed and conventional mixes are highly consistent. This consistency of the results is not only observed for Selenium but it is observed for all other parameters as well. It is concluded, therefore, that the presence of ash in the concrete/asphalt mix does not create an environmental impact in terms of developing excess pollutants.

The effect of the deicing material on the test results is demonstrated by the sharp increase in the "chloride" and "total suspended solids, TSS", values. The other parameters remained the same whether or not the deicing material was used. It is concluded that the sharp increase in the chloride and TSS values is due solely to the addition of the sodium chloride deicing material. Minor variations in test results between the samples taken from the runoff of the no-ash mixes and the ash-contained mixes are similar to the variations found between the duplicate samples taken from the same platform.

4.11 CONCLUSION

Among the four different types of pavements which were tested, the ash-asphalt pavement exhibited a runoff coefficient of about one-half that of the other pavements. This might imply that the runoff produced on this type of pavement will be only one-half that produced on the other types of pavements. However, it is more likely that due to the lack of optimum compaction, excessive infiltration occurred through the ash-asphalt pavement. This is verified from the field scale experiment as will be covered later in next chapter .

The results of the chemical analyses on the runoff samples taken from the concrete and asphalt platforms indicate that almost all parameters fall below the New York State Department of Environmental Conservation (NYSDEC) standard limits for groundwater. A few pollutants have a detectable limit which is greater than limiting standard and, therefore, for these few items comparison is not possible.

CHAPTER 5 : FIELD STUDY

5.1 INTRODUCTION

The friction between tire and pavement surface, known as skid resistance, is of vital importance to driver safety. The presence of ash in a pavement mix must not reduce further below minimum requirements for a good skid resistance. As mentioned in the previous chapter, the portable skid resistance tester, also known as the British Pendulum, has proved to give a reliable indication of skid resistance for different pavement surfaces. In this study the skid resistance of ash-concrete and ash-asphalt pavements is evaluated in a field scale experiment for a duration of five consecutive months. The results are compared with those for conventional pavements as well as with standard threshold limits.

Leaching characteristics of the ash mixed pavements have also been evaluated. Pavement surfaces are exposed to natural precipitation of which a portion infiltrates through the pavement. This infiltration of precipitation has the potential for carrying dissolved pollutants, which originated from contaminated pavement surfaces and/or pavement constituents. These pollutants in turn permeate to the underlying geological formation resulting in groundwater contamination. Ash mixed pavements must be tested for their potential leaching characteristics in order to avoid increased groundwater pollution. Introduction of deicing material on pavement surface should also be examined for its possible interaction with ash in the pavement mixture. In this study, the ash mixed pavement sections have been exposed to natural precipitation for six months and samples from leachate and runoff are chemically analyzed for their pollutant concentration. The results are compared with the results obtained from similar chemical tests on conventional no-ash pavements, as well as with the New York State Department of Conservation's (NYSDEC) Standard Limits for Groundwater Effluents.

The infiltration of rainfall water through ash-concrete and ash-asphalt pavements has also been investigated and the results were compared with those for no-ash control mixes to clarify the inconclusive results of the ash-asphalt platform in the previous chapter and to support the results found for other platforms.

To address the above issues, the following objectives have been established:

(i) create a set of four pavement sections outdoors and expose them to natural rainfall events.

(ii) evaluate the field skid resistance properties of ash-asphalt and ash-concrete, and compare these with conventional asphalt and concrete pavements.

(iii) collect and analyze data pertaining to rainfall and surface runoff and evaluate the infiltration process for ash-asphalt and ash-concrete sections as well as for the regular asphalt and concrete sections and compare results.

(iv) collect runoff for chemical analyses and evaluate potential effects on environmental water quality.

(v) apply deicing material and investigate the possibility of additional pollution impacts due to its interaction with the ash.

The remainder of this chapter describes the methodology for accomplishment of the above items.

5.2 COMPOSITE ASH

The total amount of ash used in the field experiments was 5500 pounds, of which 2000 pounds was required for the asphalt mix and 3500 pounds was required for the concrete mix. A composite sample from the four existing ash stockpiles described in chapter 2 was prepared. Plastic bags filled with 50 pounds of ash were taken from each stockpile, sealed, and appropriately labeled. Forty bags, ten from each stockpile, were sent to the Prima asphalt plant located at Holtsville, Long Island. Seventy two bags, eighteen from each of ash stockpile, were sent to the Star Ready Mix concrete batching plant located at Medford, Long Island. At each plant, equal weights of ash from each of the four stockpiles were introduced into the mechanical mixers until the weights of the ash material needed for each mix was reached.

5.3 CONCRETE MIXES

Two separate concrete batches were prepared at the Star Ready Mix central batching plant. One batch contained no ash, while the other had 30 percent by weight of it's fine aggregate replaced by ash. Except for the ash content, the two batches were identical, containing the same coarse aggregate, Portland cement Type 2, and water. The coarse aggregate was crushed stone, graded as shown in Table 5.1. Sand, obtained from a local source, is graded as shown in Table 5.2.

The control mix, concrete with no ash, was designed to meet American Concrete Institute (ACI) mix design specifications for 3000 psi compressive strength at 28 days with a slump of 2" to 3", which is usual for pavement, footings and slabs. These concrete mixes were placed as two separate pavement sections and exposed to the ambient weather conditions and natural rain events for a period of six months. The experimental set up will be described later in this report. Rainfall runoff and leachate for the test pavement section were collected in containers placed at the side of the roadway. The experiments were conducted both with and without deicing material being applied to the pavement surface.

TABLE 5-1: COARSE AGGREGATE GRADATION USED IN CONCRETE

SIEVE SIZE	PERCENT PASSING, BY WEIGHT
1"	100
3/4"	95.5
1/2"	56.0
3/8"	40.0
1/4"	12.3
1/8"	4.4

TABLE 5-2: FINE AGGREGATE GRADATION USED IN CONCRETE

SIEVE SIZE	PERCENT PASSING, BY WEIGHT
1/4"	100
No.4	99.4
1/8"	98.6
No.8	96.4
No.10	95.5
No.16	89.6
No.20	83.0
No.30	70.0
No.40	48.9
No.50	24.4
No.80	7.4
No.100	5.0
No.200	1.5

Subsequently the following analyses were conducted:

Skid resistance

- According to ASTM E303 (one test per section per month, minimum of 3 months, 5 readings per test).

Infiltration

- volumetric measurements of at least three rainfall events during six months.

Rainfall runoff

- volumetric measurements of at least three rainfall events during six months.

Chemical analyses

- Samples of both runoff and leachate with and without deicing materials, were collected from at least four rainfall events and composited. These samples were analyzed for:

  - Heavy metals
  - Chlorides
  - Sulfates
  - Phosphorus
  - Suspended solids
  - Toxicity (EP-Toxicity)
  - Toxicity (TCLP- only for sample with deicing materials)

5.4 ASPHALT MIXES

Two different asphalt concrete batches were prepared at the Prima Company asphalt plant. One batch contained no ash, while in the other 15 percent by weight of the fine aggregate was replaced by ash. The other components in the mixes, namely bitumens and coarse aggregate, remained the same for both batches. The control batch, the batch with no ash, was prepared according to Specification 51F Type 1A Top set by Suffolk County, Department of Public Works. These asphalt mixes were placed as two separate pavement sections and exposed to the ambient weather conditions and natural rain events for a period of six months. The experimental set up will be described later in this report. Rainfall runoff and leachate for the test pavement section were collected in containers placed at the side of the roadway. The experiments were conducted both with and without deicing material being applied to the pavement surface. Subsequently the following analyses were conducted:

Skid resistance

- According to ASTM E303 (one test per section per month, minimum of 3 months, 5 readings per test).

Infiltration

- volumetric measurements of at least three rainfall events during six months.

Rainfall runoff

- volumetric measurements of at least three rainfall events during six months.

Chemical analyses

- Samples of both runoff and leachate with and without deicing materials, were collected from at least four rainfall events and composited. These samples were analyzed for:

  - Heavy metals
  - Chlorides
  - Sulfates
  - Phosphorus
  - Suspended solids
  - Toxicity (EP-Toxicity)
  - Toxicity (TCLP- only for sample with deicing materials)

5.5 CONCRETE PAVEMENT SECTIONS

These experiments were conducted on an existing 21 foot wide roadway located in the vicinity of the Suffolk County offices at Yaphank, LI. Two consecutive sections, each 30 ft long and half the roadway width (10.5 ft) wide, were cut along the centerline from one side of the existing asphalt roadway to a depth of about 6 inches. Ash-concrete mix, described in section 5.3, was placed in the first 30 ft long section (labeled as Section 1 in Fig. 5.1). This was immediately followed by a 30 ft long no ash concrete mix control section, as described in section 5.3 (labeled as Section 2 in Fig. 5.1). The surface of the pavements were leveled to maintain a transverse slope of about 2%. The sections were separated from each other by an asphalt berm as shown in Fig. 5.1. Prior to placing the concrete, a leachate collection system consisting of nine one inch diameter perforated pipes was installed transversely in the bottom of the sections and connected to a one inch diameter solid header pipe. The transverse pipes were placed on a 3 ft spacing. Samples of infiltrating surface water would be collected through this perforated pipe system and would be conducted to the header pipe. The header pipe was installed about 1 ft outside the roadway. The end of the pipe terminated in a container fitted with a valve that was placed in a dug pit which serviced each pavement section. Each dug pit also accommodated a runoff collector, a 55 gallon container for the collection of surface runoff and enough space for the testing crew to take measurements of the volume of runoff water accumulated in this container. For each pavement section, the surface runoff was conveyed in a gutter along the roadway's side curb to a low point. The collected flow was carried, through a cut in the side-curb, to the above mentioned 55 gal container. The volume of water in the containers could be measured using a graduated dip stick to obtain the level of water. The separation berms were built high enough to insure the runoff from other section would not overflow. Figures. 5.1 and 5.2 present a schematic view of the pavement sections and the piping arrangements.

Figure 5-1 : Layout of the Pavement Sections

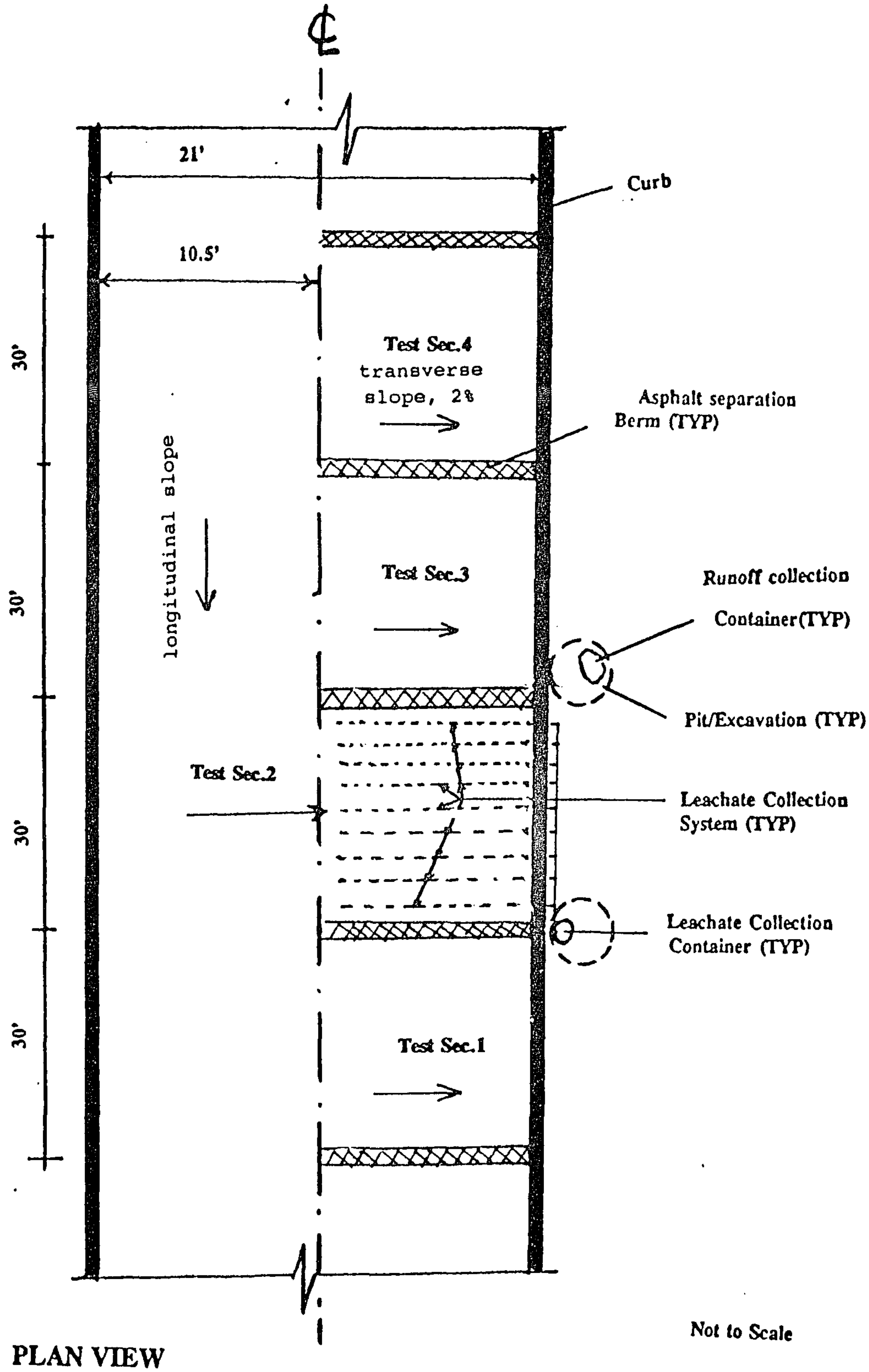
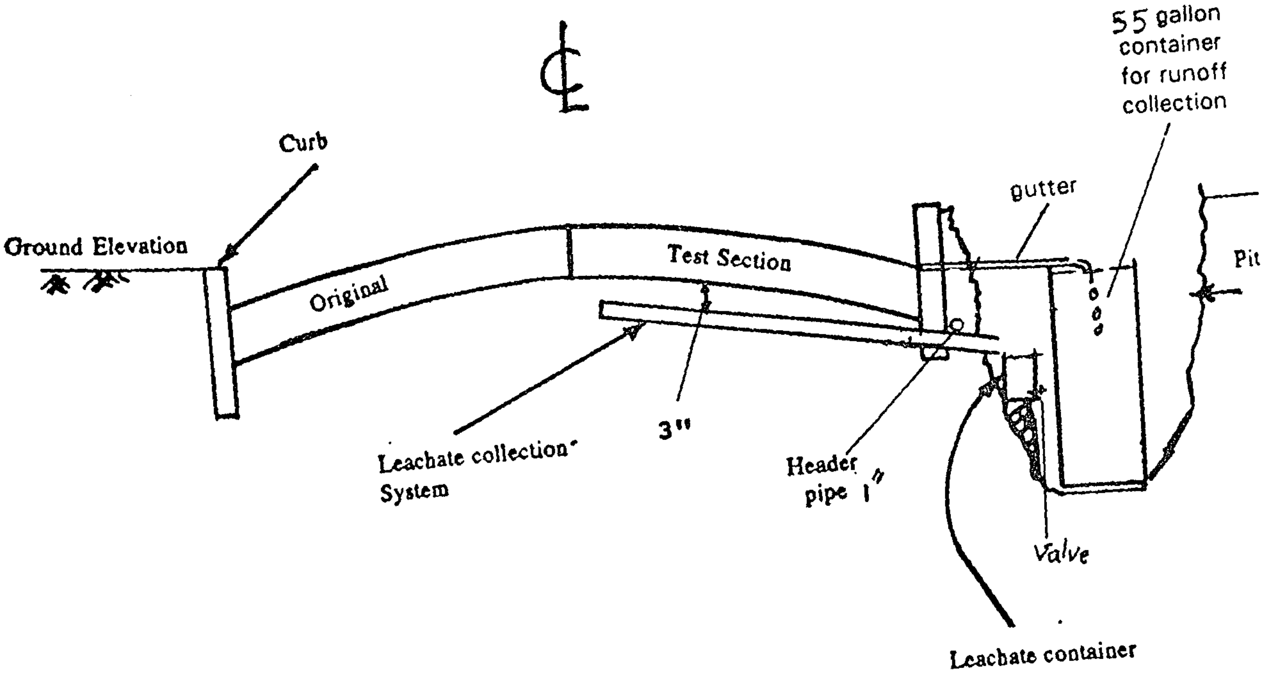


Figure 5-2 : Typical Piping and Leachate Collecting System for Each Road Section



Typical Road Section

Not To Scale

5.6 ASPHALT PAVEMENT SECTIONS

Two 30-ft asphalt pavement sections were constructed in the existing roadway immediately following the concrete pavement sections. An ash-asphalt mix, described in section 5.4, was placed in one section (labeled as Section 3 in Fig. 5.1) and was immediately followed by a no ash asphalt mix control section, as described in section 5.4, labeled as Section 4 in Fig. 5.1. The surface of the pavement sections was compacted and leveled to maintain a transverse slope of about 2%. The asphalt sections were separated from each other, and from the adjacent concrete pavement section, by means of an asphalt berm as shown in Fig.5.1. Both pavements were laid down at the same temperature (220°F which is common for asphalt). At this temperature the ash-asphalt was somewhat less workable, compared to the control no-ash mix. For this reason the surface of the ash-asphalt pavement contained more depressions and unevenness than the surface of the other pavement section. It is suggested that in order to maintain enough workability, the ash-asphalt mix has to be about 10 to 20° F hotter than the temperature commonly used for laying regular asphalt mixes. More research is needed to establish a specification for ash-asphalt laydown.

The size and configuration of the asphalt pavement sections and their piping and collection systems were identical to the concrete pavement sections described in section 5.5 and shown in Figs. 5.1 and 5.2.

5.7 TEST DESCRIPTIONS

The tests conducted on each concrete pavement section are described in the following sections. These tests are skid Resistance test, rainfall runoff measurement,infiltration measurement, and chemical analysis.

5.7.1 SURFACE FRICTION TEST

Driving safety is affected by the frictional properties of a surface. The British Pendulum Tester is the most usual device for the measurement of surface frictional properties. The details are covered in ASTM E303. The apparatus consists of a swinging arm pivoted at one end with a rubber slider provided at the other end of the arm. The rubber slider is set on the surface whose skid resistance is to be measured. The arm is raised to a horizontal position and then released. As it swings to the vertical position the rubber slider touches the surface and continues to rise up before swinging back in the reverse direction. The maximum rise of the arm is monitored by a pointer and a value, referred to as the skid resistance number, is recorded on the apparatus. A lower maximum rise implies a higher surface friction, giving a higher skid resistance number.

5.7.2 RAINFALL RUNOFF MEASUREMENT

Flow over a sloping section of pavement is relatively easy to visualize. As rainfall begins, some water runs down the surface of the pavement. The depth of flow generally increases with time and with distance from the upper boundary. A portion of the rainfall is retained in depressions while some tends to infiltrate into the pavement. The magnitude of the infiltrating water is a function of the velocity of the surface flow and the porosity of the pavement. A short while after the beginning of the rainfall, the depressions fill with rain water and an equilibrium condition will be reached for the infiltrating water. At this time a steady state runoff condition for all points on the surface is reached.

The amount of surface runoff from each pavement section was found by measuring the volume of rain water accumulated in the 55 gallon containers after a rainfall event. The depth of rainfall at the site was monitored by setting a field raingage and verifying the volume of rain water accumulated in the raingage during the same period of time.

Each pavement section was connected to a 55 gallon container by means of a sloping gutter as described in section 5.5. To insure that all surface runoff would enter the gutter and leakage would not take place, the space between the gutter and the cut curb edges were sealed. The gutter outfalls rested atop each 55 gallon container assuring that all the runoff collected by the gutter was discharged into the container.

The weather forecast was followed through the media and the system was set up prior to an expected rainfall event. During the period of rainfall the flow from the surface of each pavement section was conducted into the respective container through its connecting gutter. Following the start of the rain, the accumulated surface runoff water was monitored continually until it reached an amount sufficient to fill the container to at least 50-liter mark. In the course of this study there were rainfall events for which the system was set up but rain was insufficient to reach this mark or the rain was too intensive, leading to container overflow. The volume of the accumulated surface runoff water in each container was measured, using a graduated dip stick. The dip stick was previously calibrated for each container by recording the water depth in each container when a known volume of water was added to that container. For the same time period as it took for the containers to get filled, the total rainfall volume falling onto each pavement section was obtained by multiplying the surface area of each section by the rainfall depth, as monitored by the raingage. For example, if the surface area of each pavement section is 315 sq.ft. and the rainfall depth, accumulated in the raingage, is 0.1 in (0.00833 ft), then the total volume of rainfall contributed to each section is:

$315 \times 0.00833 = 2.425 \text{ ft}^3$ or 19.64 gal

5.7.3 INFILTRATION MEASUREMENT

The volume of that part of the rainfall which infiltrates into the pavement is obtained by subtracting the volume of surface runoff as measured within the 55 gallon container from the total volume of rainfall contributed to each pavement section as computed from the raingage data less the volume of the water retained in depressions.

5.7.4 ESTIMATE OF SURFACE DEPRESSION VOLUME

Although all pavement sections were designed to have a flat, uniform surface, some unevenness, or depressions, were formed on pavement surfaces. The unevenness was more pronounced on the asphalt pavements due to some shortcomings of the driver and the asphalt paving machine at the time paving took place. In order to establish reliable information regarding the infiltration process, one has to estimate the volume of depressions existing on each pavement section. This volume was estimated by allowing a known volume of water to flow over the surface of each pavement and measure the volume of the water accumulated in the 55 gallon containers, and then subtract the latter from the former. The addition of water onto the surface must be quick enough to prevent significant infiltration to occur.

5.7.5 CHEMICAL TEST DESCRIPTION

Samples of both runoff (taken from the containers) and leachate were collected and mixed together. This was because the collected leachate sample was half the amount needed for chemical analysis. Leachate samples were taken opening the valve of the header pipe connected to the underdrain piping system. Because the leachate produced by one single rainfall event, penetrating the underdrain piping system, was itself only a small portion of the infiltrating rainfall water, its amount was not enough to be collectable. Therefore a composite leachate from each pavement was collected after four rainfall events had occurred.

Runoff samples, about 1.5 gallon each, were taken from the 55 gallon containers right after each rainfall event. At the end of four rainfall events, all runoff samples collected, about 6 gallon in total volume, were placed in a 10 gallon container and 2 gallons of that was added to 2 gallons of the composite leachate sample, about all that was collected. The whole composite sample was mixed for about five minutes by hand stirring. About 3 gallons of the mixed composite sample from each pavement section was bottled, labeled, sealed and sent to the H2M Laboratory for the following chemical analyses: Heavy metals, Chlorides, Sulfates, Phosphorus, Suspended solids, and Toxicity (EP-Toxicity) test.

A second set of composite runoff and leachate samples, obtained as before, was collected after deicing material was distributed on the pavement surfaces prior to each test. The deicing material used was sodium chloride and was applied at a rate consistent with 600 pound per lane per mile presently used on New York State and Suffolk County highways. Prior to the start of each test, the required deicing material was weighed and then uniformly spread by hand on the surface of the pavement sections. All of the chemical tests listed above were performed on this second set of composite samples containing deicing material. In addition to the listed chemical tests, a TCLP-Toxicity analysis was also conducted.

5.8 DISCUSSION

5.8.1 RESULTS OF SURFACE FRICTION TEST

A surface skid resistance number was obtained during four rainfall events for each pavement section described above (see Table 5A.1 through 5A.4 in the Appendix 5A). The average of the five readings for each rainfall event is shown in Table 5.3. The mean value, for all pavement sections is also provided.

TABLE 5-3: AVERAGE SKID RESISTANCE NUMBER FOR CONCRETE AND ASPHALT PAVEMENT SECTIONS

date of test	12/30/92	1/22/93	3/3/93	4/21/93	mean
ash concrete	85	88	90	79	85.5
no ash concrete	92	90	88	80	87.5
ash asphalt	81	77	81	75	78.5
no ash asphalt	93	78	80	75	81.5

The skid resistance number is nearly the same for both concrete pavements. The no-ash concrete surface exhibits about a 2% higher friction when compared to the ash-concrete surface, but both skid numbers are well above the required minimum of 65 (ASTM E303). The skid number for the ash-asphalt surfaces is slightly less than the skid resistance of the control asphalt pavement. The no-ash asphalt surface exhibits about a 3.6% higher friction factor when compared to the ash-asphalt surface, but both skid numbers are well above the required minimum of 65.

5.8.2 RESULTS OF RAINFALL-RUNOFF MONITORING

Surface runoff from pavement sections for four rainfall events is shown in Tables 5.4 and 5.5.

TABLE 5-4: RUNOFF PRODUCED ON CONCRETE PAVEMENT SECTIONS

	date of test	rainfall (in.)	runoff (lit.)
ash concrete	3/24/93	0.16	105
	4/11/93	0.15	100
	4/22/9	0.17	114
	5/19/93	0.20	136
no-ash concrete	3/24/93	0.16	106
	4/11/93	0.15	100
	4/22/93	0.17	116
	5/19/93	0.20	138

The rainfall depths used are between 0.1 in. and 0.2 in. For rainfalls greater than 0.2 in. the runoff volume would overflow the containers making precise volumetric measurement impossible, on the other hand, for rainfalls less than 0.1 in. all rain water would retain in the surface depressions and no surface runoff would occur.

Comparing the runoff values for the two types of concrete pavements, as shown in Table 5.4, indicates little difference in runoff production. This result is in agreement with the results obtained in laboratory tests described in section 4.10.1.

Comparing the runoff values for the two types of asphalt pavements, as shown in Table 5.5, indicates some difference in runoff production. The difference, however, is not as big as the one obtained in the laboratory test. Since the volume of the surface depressions (Table 5-7) was almost 50% greater

TABLE 5-5 : RUNOFF PRODUCED ON ASPHALT PAVEMENT SECTIONS

	date of test	rainfall in.	runoff lit.
ash asphalt	3/24/93	0.16	73
	4/11/93	0.15	63
	4/22/9	0.17	78
	5/19/93	0.20	100
no-ash asphalt	3/24/93	0.16	87
	4/11/93	0.15	81
	4/22/93	0.17	94
	5/19/93	0.20	116

for the ash-asphalt, when compared to the control no-ash asphalt, it may follow that the difference between runoff for the two sections might have originated from the higher depressions on the ash asphalt pavement.

5.8.3 RESULTS OF INFILTRATION MEASUREMENT

The infiltration of rainfall into and through the concrete and asphalt pavements was computed for four specific rainfall events, according to section 5.7.3, and the values shown in Tables 5.6 and 5.7.

TABLE 5-6: INFILTRATION THROUGH CONCRETE PAVEMENT SECTIONS

	date of test	rainfall (in.)	runoff (lit.)	depression (lit.)	infiltration % total rain
ash concrete	3/24/93	0.16	105	10	5
	4/11/93	0.15	100	10	6
	4/22/93	0.17	114	10	4.6
	5/19/93	0.20	136	10	5.2
mean					5.2
no-ash concrete	3/24/93	0.16	106	10	4.1
	4/11/93	0.15	100	10	6
	4/22/93	0.17	116	10	7.3
	5/19/93	0.20	138	10	3.9
mean					5.3

TABLE 5-7 : INFILTRATION THROUGH ASPHALT PAVEMENT SECTIONS

	date of test	rainfall (in.)	runoff (lit.)	depression (lit.)	infiltration % total rain
ash asphalt	3/24/93	0.16	73	46	4
	4/11/93	0.15	63	46	6
	4/22/93	0.17	78	46	6
	5/19/93	0.20	100	46	5.8
mean					5.4
no-ash asphalt	3/24/93	0.16	84	30	5.8
	4/11/93	0.15	81	30	5.1
	4/22/93	0.17	94	30	4.6
	5/19/93	0.20	116	30	5.2
mean					5.2

The volume of rainfall infiltration, computed as a percentage of the total rainfall and shown in Table 5.6, is quite similar for both concrete pavements. Because of the number of the samples being small, i.e. four samples only, it is difficult to derive a strong conclusion, though the average infiltration for the two concrete pavements are found to be very close to each other.

The volume of rainfall infiltration, computed as a percentage of the total rainfall and shown in Table 5.7, is almost similar for both asphalt pavements. These results support the idea that the poor runoff coefficient, and consequently stronger infiltration, obtained in laboratory experiment was basically due to the lack of proper compaction of the ash-asphalt layer. It can be concluded, therefore, that the infiltration for both pavements are essentially the same.

5.8.4 CHEMICAL TEST RESULTS

The results of the chemical analysis on the runoff-leachate composite samples taken from the various pavement sections together with Maximum Groundwater Effluent Standard Levels are shown in Appendix 5B (Tables 5.B-1 through 5.B-20). The results are highly consistent with those previously obtained during laboratory experiments, indicating that almost all parameters fall below NYSDEC standard limits for groundwater. As before, the same few pollutants (i.e. 1,4-Dichlorobenzene, Hexachlorobenzene, Vinyl Chloride, Chloroform, Carbon Tetrachloride, and Benzene) have a detectable limit which is greater than the limiting standard and, therefore, for these few items comparison is not possible. Selenium which was found in the laboratory experiments to exceed the standard limit on a few occasions, is now found either to be below the standard limit or in some cases below the detectable limit. Once again the results of the ash mixed and conventional mixes are highly consistent. This consistency of the results is observed for all parameters, including those which have a detectable limit greater than the standard limit. It is concluded, therefore, that the presence of ash in the concrete/asphalt mix does not have a detrimental environmental impact due to the development of excess pollutants.

As the laboratory experiments described in the previous chapter, the effect of the deicing material on the test results is demonstrated by the sharp increase in the "chloride" and "total suspended solids, TSS", values. The other parameters remained the same whether or not the deicing material was used. It is concluded that the sharp increase in the chloride and TSS values is due solely to the addition of the sodium chloride deicing material.

5.9 CONCLUSIONS

The following conclusions can be derived from the results obtained under the above field studies:

(i) The presence of ash in a concrete mix has no significant effect on the surface friction of the concrete pavement.

(ii) The presence of ash in an asphalt mix has no significant effect on the surface friction of the asphalt pavement.

(iii) The surface friction of both concrete pavements are about 8% greater than that of their corresponding asphalt pavements.

(iv) The surface friction of all pavement sections (i.e. both concrete and asphalt, with and without ash) are found to be significantly greater than the minimum safety requirements set by the ASTM standard.

(v) The presence of ash in a concrete mix has no significant effect on the infiltration properties of a pavement made with that mix.

(vi) The presence of ash in an asphalt mix may have some effects on the infiltration properties of a pavement made with that mix. More research is needed to determine the extent of these effects.

(vii) Field experiments suggest that the significant infiltration which occurred in the ash-asphalt pavement during laboratory experiment was due primarily to the lack of optimum compaction of the ash-asphalt platform and was not caused by the presence of ash in the mix.

(viii) The amount of infiltration through the different pavements may be considered to be the same.

(ix) When compared to the available NYSDEC standards for ground water, the test results of all of the runoff-leachate samples from all pavements, with or without ash present, indicate them to be non-hazardous. The introduction of deicing material on the pavement surfaces had no detectable effect on chemical or toxicity results of runoff-leachate samples from the ash-asphalt and ash-concrete pavements.

CHAPTER 6 : HYDRAULIC FLOW RESISTANCE

6.1 INTRODUCTION

Rainfall on pavements produces a thin flow of water, called runoff or sheetflow. Movement of runoff is resisted by friction forces developed between the runoff water and the pavement surface, referred to as hydraulic resistance or roughness. Roughness of a surface is very much a function of the surface texture which for the case of highway pavement depends upon the way which that particular surface has been finished.

Several hydraulic parameters related to hydraulic resistance have been studied by researchers. Among these, the Darcy friction factor (f) and the Manning roughness coefficient (n) have reached most attention.

Experimental results, for example, those reported by Woo (1962), Morgali (1970), and Swanson (1985), indicate no consistent relationship between the Darcy friction factor and the Reynolds Number (N_R) , for the lower range of N_R (N_R<150). Since typical N_R values for runoff fall into this range, the Darcy friction factor has not been used in this study and Manning's roughness coefficient is utilized instead to parameterize the friction effect.

6.1.1 RAINFALL-RUNOFF FLOW RESISTANCE USING MANNING n

Manning's roughness coefficient is widely used to characterize the effect of channel surface properties on open channel flow. For open channel flow n values can be found by fitting experimental data to the Manning equation. Manning's n values for various surface types are tabulated in open channel reference books.

Runoff on a paved surface is similar to flow in a very wide and impervious open channel. The major drawback with using Manning equation for the case of interest here is that Manning's n has not been satisfactorily defined for sheet-flow runoff. For open channel flow, n can be represented as a single value constant coefficient but for sheetflow it cannot.

An empirical regression equation was developed by Gallaway et al. at Texas A & M University in 1971. This equation was the result of extensive rainfall-runoff simulation work accomplished on various types of surfaces, including concrete, under a wide range of rainfall intensities and surface slopes. The best overall regression with coefficient of determination (R^2), of 0.81 was given as

$$Y = [0.00254(Li)^{0.55} MTD^{0.11}] / S^{0.42} \qquad (6\text{-}1)$$

where Y = hydraulic flow depth (in),

MTD = mean texture depth (in),

L = drainage path length (ft),

i = rainfall intensity (in/hr),

S = drainage surface slope.

Gallaway et al. (1979) performed additional experiments, on concrete surfaces only. Combining past (1971) and present (1979) data, they arrived at the following equations for concrete pavements under a rainfall simulation:

$$Y = [0.003726 L^{0.519} i^{0.562} MTD^{0.125}] / S^{0.364} \quad (6\text{-}2)$$

$$Y = [0.2031 L^{0.443} i^{0.598} MTD^{1.325}] / S^{0.355} \quad (6\text{-}3)$$

The first equation was for all drainage surfaces with R^2=0.83 and the second one was for concrete surfaces only, with R^2≈0.68.

Sheetflow depth may also be predicted using kinematic wave approximation to the partial differential equations known as St. Venant equations. This was demonstrated by a number of researchers such as Lighthill and Whitham (1955), Woolhiser and Liggett (1967), Morris and Woolhiser (1980) and a number of other researchers. Reed and Kibler (1983) give the solution for steady state nonuniform flow as:

$$y = (nLi/1023S^{0.5}) \quad (6\text{-}4)$$

The difficulty with using equation (6-4) is that Manning's n has not been satisfactorily defined for sheetflow runoff. From his experiments on rainfall-runoff, Proctor (1986), concluded that no single value of Manning's n could be used in the equation (6-4) to get calculated y values to agree reasonably with the measured y values. He concluded that for the sheetflow case n is dependent on flow depth rather than a constant parameter.

Attempts were made by some researchers (Reed and Kibler, 1983) to relate Manning's n to pavement surface Mean Texture Depth (MTD). The results were highly scattered and could only reveal a general trend: n increases as MTD increases. These attempts have, so far, been of very limitted usefulness.

Reed et al. combined the regression equation (6-1) with the kinematic wave equation (6-4) by eliminating the Li term, and after substituting the fixed values of MTD and S, came up with the following equation

$$n = 0.0275\ Y^{-0.152} \qquad (6\text{-}5)$$

Krallis (1991), while working on wind effect on runoff on grooved concrete slabs, developed the following regression equation

$$y = (nLi/1023S^{0.5}) \qquad (6\text{-}6)$$

If n was a function only of y for the sheetflow case, then equations (6-5) and (6-6) should produce identical Y vs n plots, however, they do not.

It is evident, therefore, that no one functional relationship between y and n can be used for a wide range of flow surfaces. The equation for n has to be more specific in terms of pavement type, rainfall intensity range, and surface slope. Even for the same type of surface, different results are obtained if different finishing processes are used.

More recently, Reed (1991), followed subsequently by Stong (1992), combined an unbiased regression equation for hydraulic flow depth, Y, developed from experimental data, with the widely accepted kinematic wave expression for Manning's n. An unbiased regression equation is defined as one wherein no common experimental variables were used to formulate the values regressed on both sides of the regression. This procedure appears well suited for describing flow resistance.

6.1.2 SCOPE OF THE WORK

This chapter studies the effect of ash mixing on pavement surface as related to hydroplaning. To achieve this goal, the following objectives have been established

- use a regression equation to correlate depth of runoff to Manning's n for both plain and ash-mixed concrete pavements.

- use a regression equation to correlate depth of runoff to Manning's roughness coefficient, n, for both plain and ash-mixed asphalt pavements.

Using the database obtained in the laboratory experiments described in Chapter 4, regression equations have been developed for both concrete and asphalt surfaces to correlate runoff depth to Manning's n value. The remainder of this chapter first explains the kinematic wave theory and its justification for application to rainfall-runoff, then it covers the methodology for the regression analysis performed in this study.

6.2 HYDRAULICS OF OVERLAND FLOW

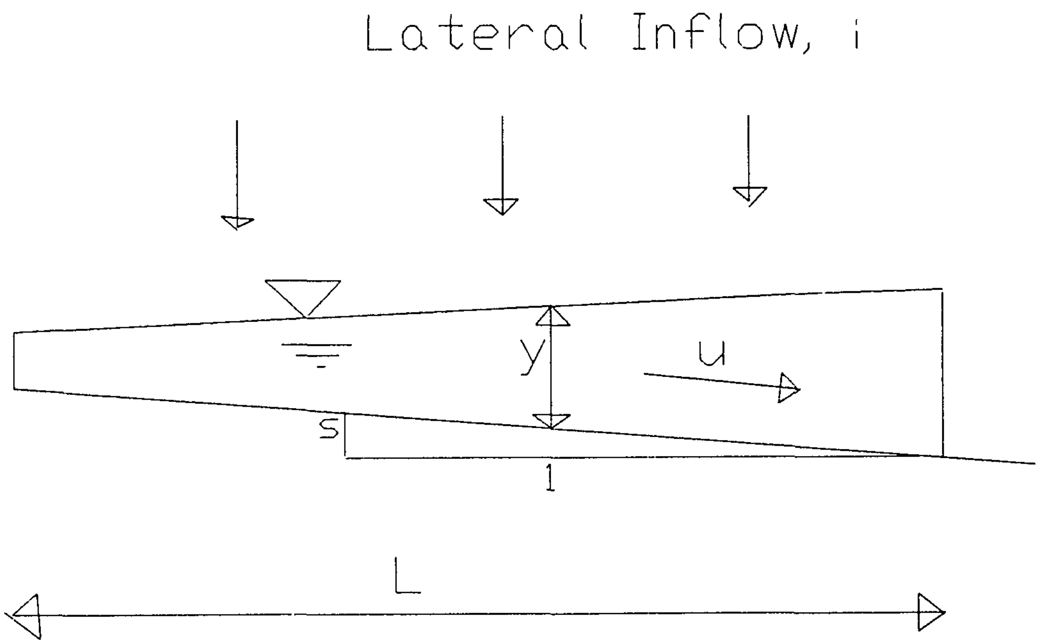
Complete shallow water equations can be derived by applying the principles of conservation of mass and momentum to a control volume of overland flow, as shown in Figure 6-1. the continuity equation is given by

$$\partial y/\partial t + \partial (uy)/\partial x = i \qquad (6\text{-}7)$$

and the momentum Equation by

$$\partial u/\partial t + u\partial u/\partial x + g\partial y/\partial x = g(S_0 - S_f) - (i/y)[u] \qquad (6\text{-}8)$$

Figure 6-1 : Surface Plane With Lateral Inflow



where

y = flow depth,

t = time coordinate,

x = horizontal coordinate (assumed to be equal to the drainage path for small slopes),

u = local velocity along the x direction,

g = acceleration of gravity,

S_o= slope of the bed of flow,

S_f= the friction slope defined by Manning equation for turbulent flow and

i = lateral inflow volumetric flux $[L^3/tL^2]$.

These nonlinear Partial Differential Equations are sometimes called the St. Venant equations.

The first serious attempts to apply these equations to hydrologic problems have been relatively recent, because of the fact that there is no general analytical solution to this system of equations. Analytic solutions have been restricted to limited regions of the solution domain or to special cases where simplifying assumptions could be made. Numerical and graphical solutions have been obtained for some special cases. Unfortunately, the graphical techniques are slow, and many of the numerical schemes have exhibited stability problems. The overland flow problem, from a numerical standpoint, is more difficult than river flood routing, because the overland flow problem is often poorly posed, i.e. a small variation in the coefficients or in the solving process have a large effect on the solution. Liggett [1959] utilized the method of characteristics in studying the problem. He obtained an analytical solution to the equations (omitting the momentum exchange term) in a portion of the solution domain and used a graphical technique to obtain solutions elsewhere. Morgali and Linsley [1965] utilized finite difference solutions to the shallow water equations in simulating runoff from natural watersheds. Although most of the previously mentioned analytical or numerical investigations have begun with the basic continuity and momentum equations (6-7) & (6-8), they have made simplifications or assumptions that have not been systematically examined.

6.3 KINEMATIC WAVE THEORY AND THE METHOD OF CHARACTERISTICS

In 1955, Lighthill and Whitham developed the kinematic wave equations for overland flow. Under the kinematic wave condition the gravity forces are assumed to be balanced by the frictional forces ($S_0=S_f$), resulting in a zero net force acting upon the body of water in motion. They suggested that when the lateral inflow is a function of time and distance, the solution could be found by numerical integration along the characteristics.

The analysis of kinematic flow below applies when flow is under a steady state (equilibrium) condition and also free of the gravity acceleration ($S_f = S_0$). Under these conditions the momentum equation reduces to an equation expressing the effects of surface friction ($\tau_0 = \gamma y S_0$). In fluid mechanics τ_0 itself is defined by $\tau_0 = c_f \rho U^2/2$. Combining these two equations yields

$$U = (2gS_0/c_f)^{1/2} y^{1/2} \tag{6-9}$$

or in general

$$q = Uy = \alpha y^m \tag{6-10}$$

where U = average velocity of flow, τ_0 = shear stress at the bottom, γ = unit weight of water, c_f = drag coefficient, and

ρ = density of water

Thus under the kinematic flow assumption, the continuity equation (6-7) remains unchanged while the momentum equation is replaced by equation (6-9) which is basically an equation of motion.

These equations, called kinematic wave equations, were treated by Lighthill and Whitham (1955). The boundary conditions for equation (6-7) are

$$y = 0 \quad \begin{cases} 0 < x < L & t = 0 \\ x = 0 & t > 0 \end{cases}$$

and q is spatially constant but can vary with time. Equations (6-7) and (6-10) are solved by the method of characteristics. The basic definitions

$$dq = \partial q/\partial x \; dx + \partial q/\partial t \; dt \qquad (6\text{-}11)$$

$$dy = \partial y/\partial x \; dx + \partial y/\partial t \; dt \qquad (6\text{-}12)$$

together with the derivative with respect to time of (6-10)

$$\partial q/\partial t = \alpha \; m \; y^{m-1} \; \partial y/\partial t \qquad (6\text{-}13)$$

and equation (6-7) lead to

$$(dx/dt)^2 = \alpha\ m\ y^{m-1}\ dx/dt = 0 \qquad (6\text{-}14)$$

This equation has the roots

$$dx/dt = c_1 = \alpha m y^{m-1} = mU \qquad (6\text{-}15)$$

and

$$dx/dt = c_2 = 0 \qquad (6\text{-}16)$$

where c_j ($j=1,2$) is the celerity of the wave. The zero wave speed (6-16) corresponds to zero slope, infinite roughness, or zero depth. Equations (6-15) and (6-16) define the characteristics for the kinematic wave equation, i.e. the path of an infinitesimal disturbance in the x-t plane (as seen by an observer moving with it), and the positive sign shows that the wave propagates downstream only at a celerity c_2. The celerity can also be expressed as

$$c_2 = d(Uy)/dy = \alpha m y^{m-1} = U + ydU/dy \qquad (6\text{-}17)$$

If U is defined by Manning equation (4-1), $c = 5/3\ U$ for a kinematic wave. For a dynamic wave $c = 5/3\ U + [gy]^{1/2}$. Further, the same four equations (6-7), (6-11), (6-12), and (6-13) yield the equations

$$dq/dx = i \tag{6-18}$$

$$dy/dt = i \tag{6-19}$$

$$dq/dt = i \ \alpha \ m \ y^{m-1} \tag{6-20}$$

$$dy/dx = i/[\alpha m y^{m-1}] \tag{6-21}$$

For overland flow along the characteristic defined by equations (6-15) and (6-16)

$$x - x_o = \alpha m \int_{to}^{t} y^{m-1} \, dt$$

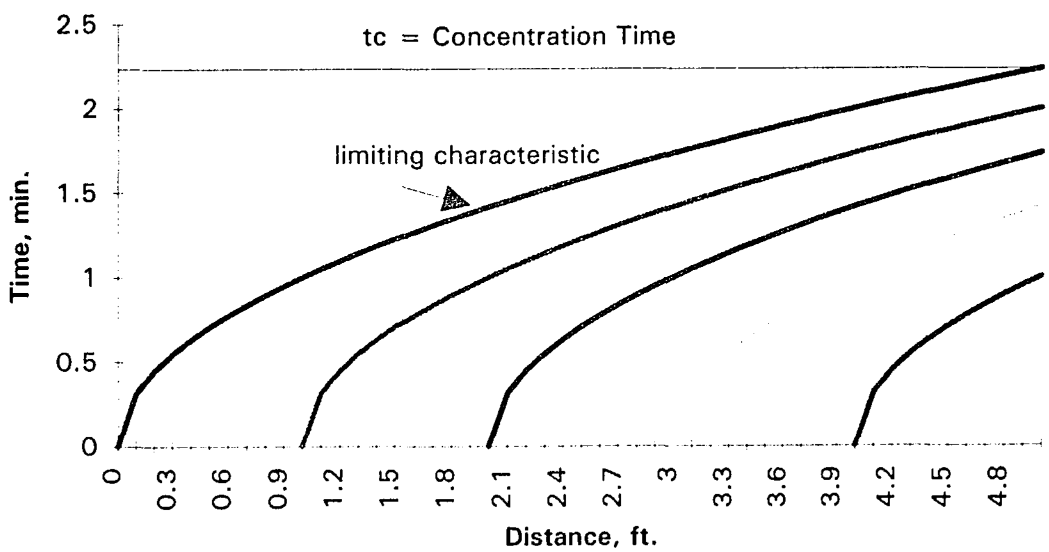
where x_o = coordinate of the upper boundary, t_o = initial time, and y is determined by $y = \int_{to}^{t} i \, dt$ where i=f(t).
When $i = i_e$ = *constant*, $y = i_e t$ *and*

$$x - x_o = \alpha i_e^{m-1} \, [t - to]^m \qquad \text{for} \quad t<T \tag{6-22}$$

where T is the duration of the rain. Equation (6-22) defines a characteristic curve on the x - t plane for each selected value of x_o (Figure 6-2). Characteristics above the limiting one imply inflow across the $x_o = 0$ *boundary condition*. At x = L the limiting characteristic defines the time of concentration t_c, which is the time required for the flow to reach equilibrium and is seen to be dependent on i_e. The depth will increase everywhere at $dy/dt = i_e$. For a given x, a different characteristic curve applies for each instant, and $q_{in} = q_{out}$ must be satisfied, except at x = 0 where $q_{in} = 0$. This disturbance at $x = 0$ travels downstream along the limiting characteristic and reaches a point x_e at t_e. At this point, and downstream of it, $y = i_e\, t_e$ = constant, because x_e is the most downstream point reached by disturbances created by a lack of inflow at $x = 0$.

In Figure (6-2) The intermidiate curves represent the characteristics for the cases which the upper boundary condition is $x = x_0 > 0$.

Figure 6-2 : Kinematic Wave Characteristics



If $t_o = 0$ and $x_o = 0$ then equation (6-22) becomes

$$x = \alpha i_e^{m-1} [t]^m \qquad \text{for} \quad t<T \tag{6-23}$$

from which for $t=t_e$ one obtains

$$t_e = [x_e \ i_e^{1-m}/\alpha]^{1/m} \tag{6-24}$$

t_e becomes equal to t_c when $x_e = L$. The water level, Figures 6-3a and 6-3b, at any point is given by

$$y_e = i_e \ t_e = [x_e \ i_e/\alpha]^{1/m} \qquad \text{when} \qquad 0< x <x_e \tag{6-25}$$

where $x_c = \int_o^{te} c \ dt = \alpha m \int_o^{te} y^{m-1} \ dt$, and $y = i_e \ t_e$ when $x > x_e$.

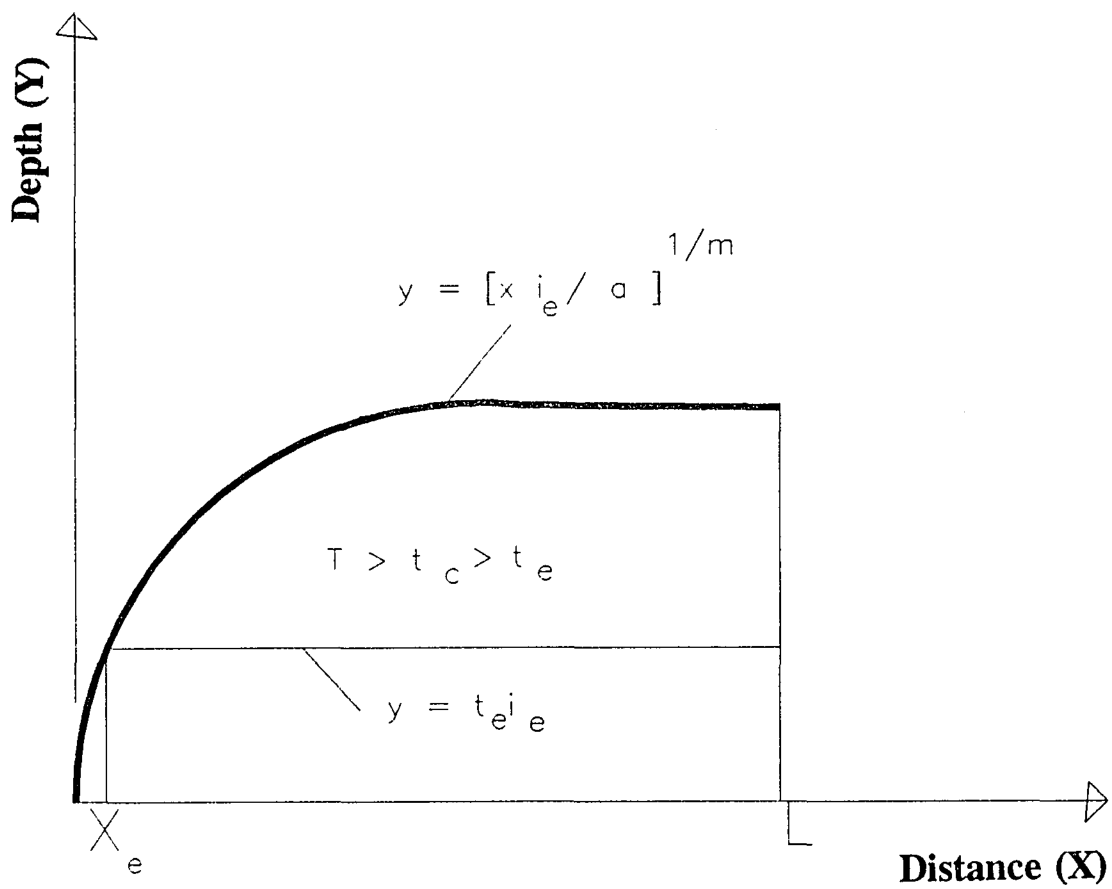
After the rain stops all four equations (6-15 to 6-18) are equal to zero. This means that along a characteristic line the depth, discharge and wave celerity remain constant.

From the integration of equation (6-15), for $t_o = x_o = 0$ and $t = T$, one obtains $x = \int^T_0 c_1 \ dt = \alpha m \int^T_0 y^{m-1} \ dt$. Recalling that $y = i_e \ T$ = constant, the integration leads to the equation $x = \alpha y^m/i_e$.

For t>T the equation for x becomes

$$x = \alpha y^m/i_e + \Delta x = \alpha \ y^{m-1} \ [y \ i_e^{-1} + m(t - T)] \tag{6-26}$$

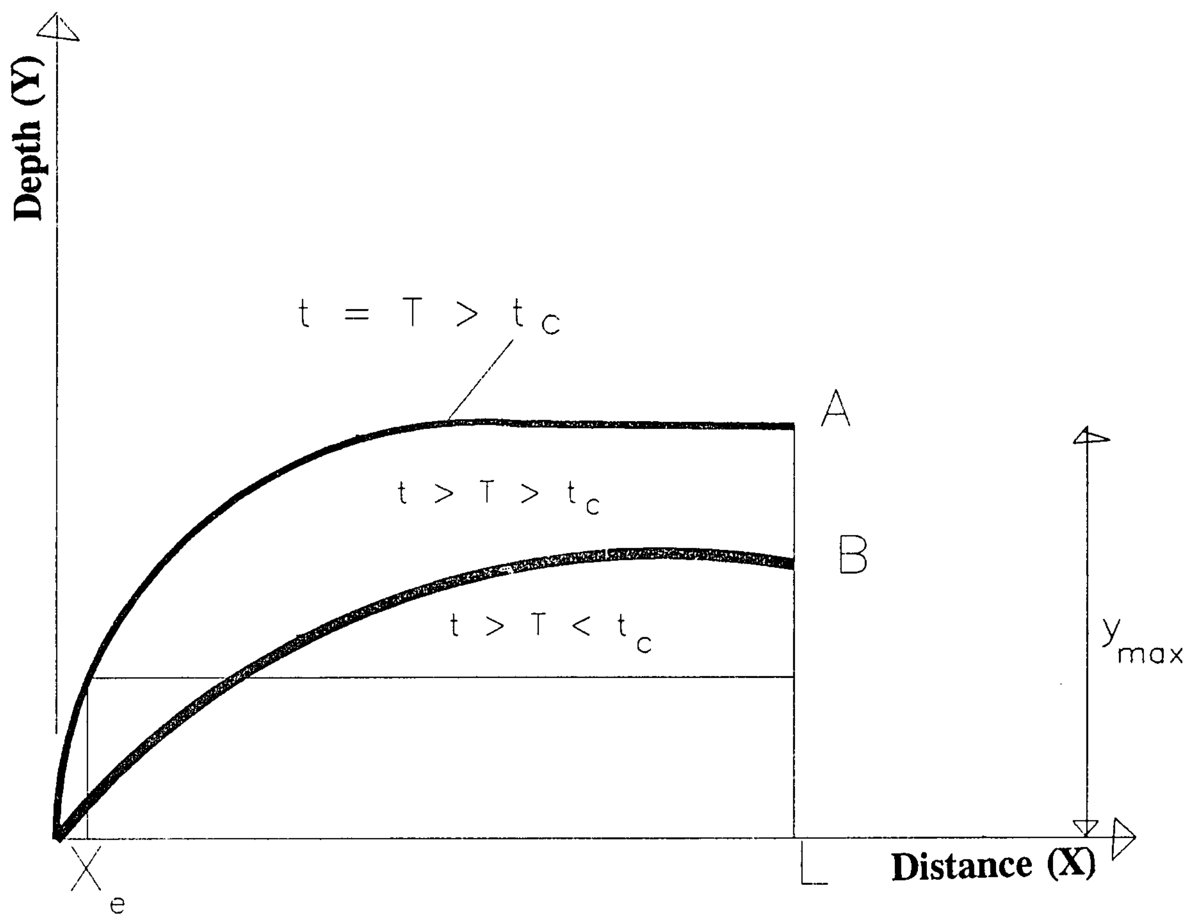
Figure 6-3a : Water Surface Profile (Increasing depth t<T)



Note:

- t_e is the time for an upstream disturbance to reach at point $X=X_e$
- tc is the time required for the flow to reach equilibrium
- T is the rainfall duration

Figure 6-3b : Water Surface Profile (Increasing depth t>T)



Note: Curve A represents the characteristic for the time t=T. As rain stops (for t>T), y decreases by time and the characteristic curve shifts to a lower position as indicated by curve B.

6.4 KINEMATIC WAVE APPROXIMATION

As previously indicated, integrating the characteristic equation of the partial differential form of the kinematic wave equation in the x-t plane under constant rainfall condition yields a simple relation for the equilibrium flow depth, y_e, at different points in the downstream direction (equation 6-25). The equilibrium flow time, t_c, on an impervious surface under constant rainfall rate, i_e, is given earlier by equation (6-24) and can be further written as

$$t_e = (1/i_e)\,[L i_e/\alpha]^{1/m} \qquad (6\text{-}27)$$

in which;

L = length along flow path, in feet

α and m = parameters of the hydraulic friction relationship as discussed above.

Under kinematic flow conditions, the friction or energy slope, S_f, is equal to the slope of the plane, S_o, and this permits the use of a simplified flow velocity relation of the form:

$$U = \alpha\, y^{m-1} \qquad (6\text{-}28)$$

For turbulent flow on an overland surface, α and m may be determined from the Manning equation (equation 4-1) as

$$\alpha = (1.49/n) S_o^{0.5} \quad ; \quad m=5/3 \qquad (6\text{-}29)$$

The overland flow exhibits a viscous laminar condition in the early rising limb of the runoff hydrograph, but then becomes more nearly turbulent around the peak. The Corps of Engineers, U.S. Army, 1954, has suggested in its analysis that, due to raindrop impact, all but the very low flows appear to be turbulent. Under the assumption of turbulent flow equations (6-28) and (6-29) can be applied to equation (6-27) for t_e to obtain

$$t_e = [56.25\ L^{0.6}\ n^{0.6}]\ /\ i_e^{0.4}\ S_o^{0.3} \qquad (6\text{-}30)$$

Equation (6-25) can now be written as

$$Y_e = \{nLi/1,023\ S_o^{0.5}\}^{0.6} \qquad (6\text{-}31)$$

or

$$n = 1023\ \{S_o^{0.5} Y_e^{1.67}\ /\ Li\} \qquad (6\text{-}32)$$

Woolhiser & Liggett (1967) have shown that the kinematic wave approximation to the complete shallow water equation is generally valid when the parameter, K (known as the kinematic wave number)

$$K = S_0 \;.\; L \;/\; y \;.\; N_F^2 \qquad (6\text{-}33)$$

exceeds 10. In the above equation N_F is the Froude Number and is defined as $N_F = V_0 / (gy)^{0.5}$ where V_0 = normal flow velocity, feet per second. V_0 is equal to $V_0 = iL/y$, where i = lateral inflow or or rainfall excess rate, feet per second.
Under flow conditions where K<10 and N_F is less than o.5, an additional criterion

$$N_F \;.\; K = S_0\, L \;/\; y > 5 \qquad (6\text{-}34)$$

must be met (Morris & Woolhiser, 1980).

Except on extremely flat slopes with intense rainfall, most cases of overland flow on paved surfaces will fall easily in the kinematic range based on the preceding criteria. This means that the more complex equations for spatially varied unsteady flow can be replaced by the simple equations involving mass continuity and uniform flow.

6.5 DATA ANALYSIS

Eight sets of data were recorded according to the procedure previously described in Chapter 4. Each set differed from the others for its type of pavement (i.e. concrete or asphalt), whether or not ash was present in the mix, and whether or not deicing material was introduced on the pavement surface.

A total of 76 rainfall events, with varying intensities, were simulated and a total of 917 local y-values were determined. Data and results for the test runs are shown in Appendix 6.A.

6.6 DATA EVALUATION

As indicated earlier, the kinematic wave approximation can be used to replace the full St. Venant equation if two criteria are met. First, the flow must be turbulent. Henderson (1966) showed that flow can be considered as turbulent if

$$n\ (R\ S_f)^{1/6} > 1.9 \times 10^{-13} \qquad (6\text{-}35)$$

where

n = Manning's roughness coefficient

R = hydraulic radius, equal to flow depth for rainfall-runoff

S_f= slope of the surface

is satisfied.

In equation (6-35), n can be tentatively approximated by equation (6-32). An evaluation of the 917 experimentally obtained data sets, which involved the determination of 5 x 17 = 4,585 flow depth readings, using equation (6-35) indicated that all flow data sets were fully turbulent.

The second criterion for use of the kinematic wave approximation requires that either K>10, for all cases, or N_F^2 K>5, for cases in which the Froude number is less than 0.5, (Woolhiser & Liggett (1969); Morris & Woolhiser (1980)). A review of Appendix 6-A reveals that the condition K>10 is satisfied for all data sets. Therefore, according to aforementioned criterion the use of kinematic wave approximation is justified.

6.7 FLOW-DEPTH REGRESSION EQUATION

A regression equation has been developed between flow per unit width of the pavement, q, and flow depth, y, for the laboratory results. At each point the value of q was obtained as

$$q = L\ i \tag{6-36}$$

where

L = length of flow-line from upstream boundary to the point in question,

i = rainfall intensity at the point in question, as measured by the volume of rainfall accumulated in the plexiglass cup located at the point in question.

At each point, for each rainfall event, a set of five transducer readings were recorded. Each data set was evaluated in terms of its data variation. Some of the data sets (sets of five readings at a point) included values which were very different from the other values in that set. The sources of error are possibly due to the occasional impact of the pelting rain drops on the very opening of the transducers and/or due to the formation of menisci within the piping system. In order to eliminate questionable data, a criterion was adopted which follows. For each set of five readings a mean (x) and standard deviation (s) was calculated. If the ratio s/x exceeded 5 percent then these statistics were recalculated using each subset of four data points. The subset of four which satisfied the $s/x < 0.05$ criterion was retained. If none of these subsets satisfied the criterion, then subsets of three were tried. This technique was found to be helpful in preventing the doubtful data from entering into the regression analysis. The number of the data sets which needed an adjustment did not exceed ten percent of the total. Those data sets which included more than two "bad" data points were discarded.

Table 6-1 shows the regression equations established for the various pavement mix-ash-deicing material combinations. Figures 6-4 through 6-11 plots the *log Y* vs *log q* data along with the corresponding regression (best-fit) line for various platforms.

TABLE 6-1 : REGRESSION EQUATIONS

DESCRIPTION	REGRESSION EQUATION
NO-ASH CONCRETE WITHOUT DEICING	$\log q = 3.091706 \log Y + 0.918118$
NO-ASH CONCRETE WITH DEICING	$\log q = 3.052594 \log Y + 0.884524$
ASH-CONCRETE WITHOUT DEICING	$\log q = 3.165299 \log Y + 1.021100$
ASH-CONCRETE WITH DEICING	$\log q = 3.269394 \log Y + 1.163037$
NO-ASH ASPHALT WITHOUT DEICING	$\log q = 2.690965 \log Y + 0.451265$
NO-ASH ASPHALT WITH DEICING	$\log q = 2.705851 \log Y + 0.455135$
ASH-ASPHALT WITHOUT DEICING	$\log q = 2.678002 \log Y + 0.499633$
ASH-ASPHALT WITH DEICING	$\log q = 2.722085 \log Y + 0.575720$

Fig. 6-4 : Variation of Runoff Depth (Y) with Flow Rate (q) for the concrete mix without ash , without deicing material

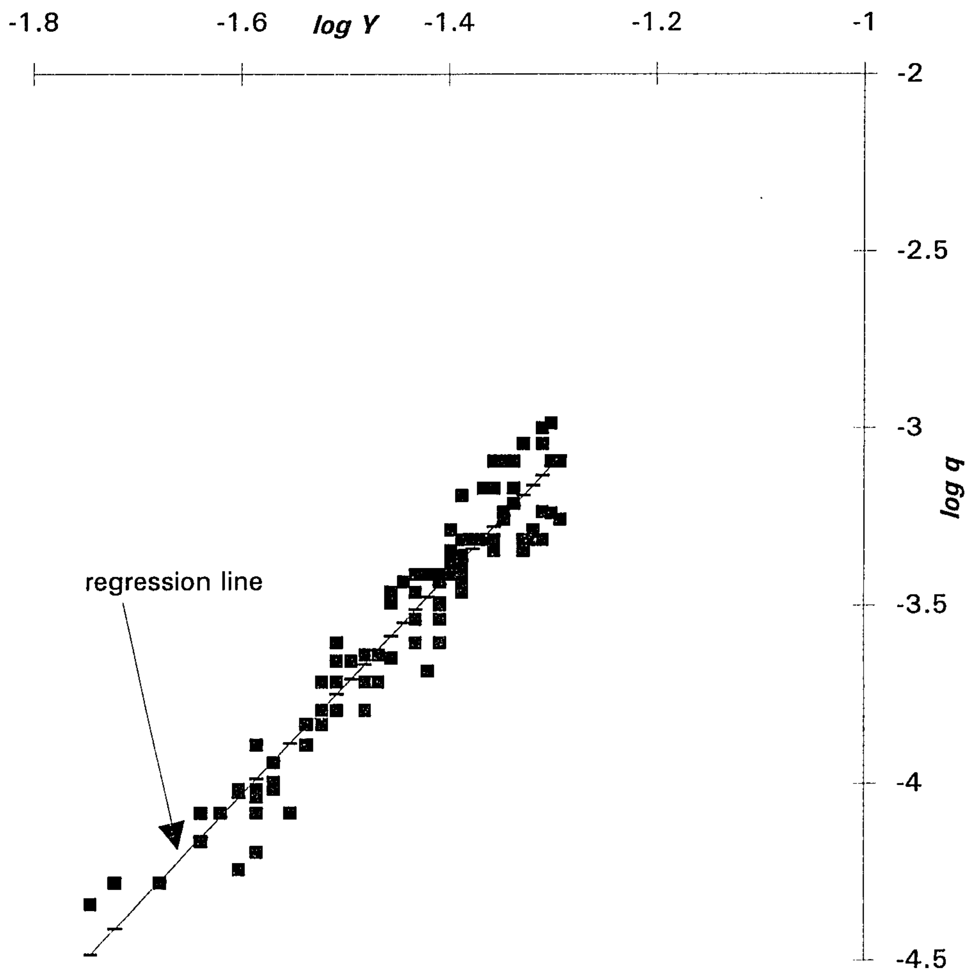


Fig. 6-5: Variation of Runoff Depth (Y) with Flow Rate (q) for the concrete mix without ash, with deicing material

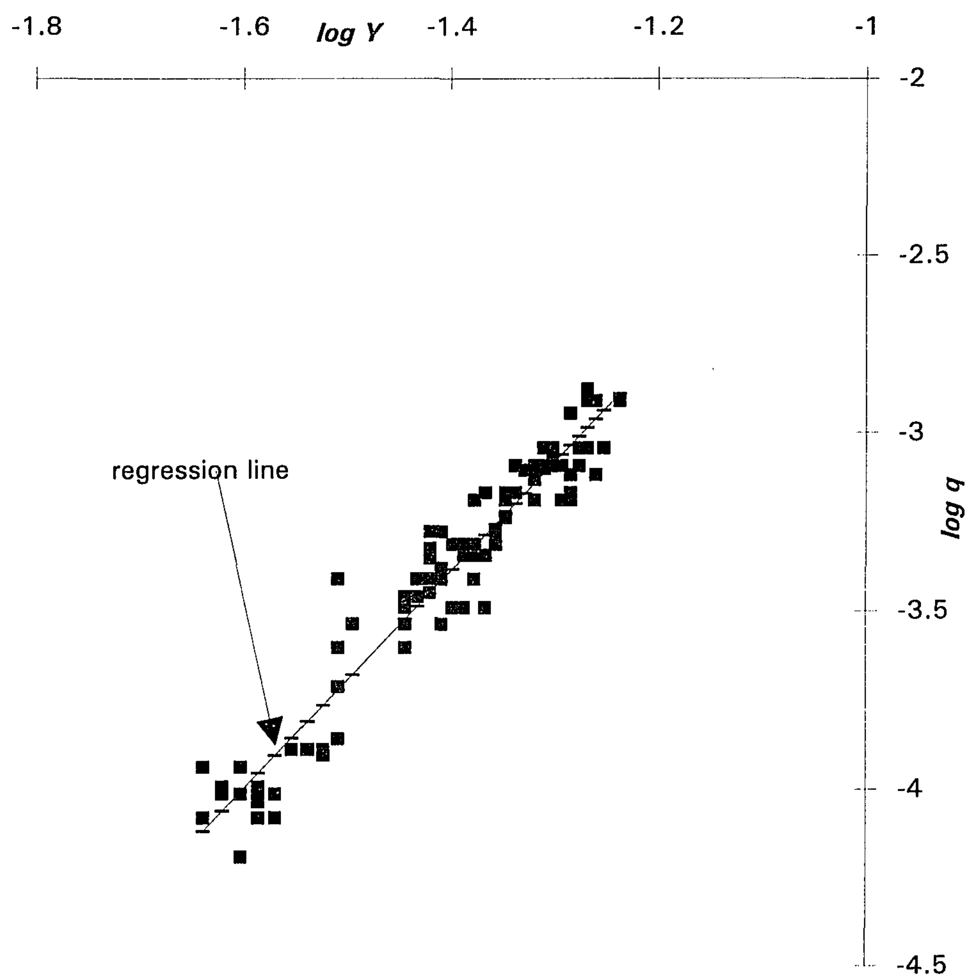


Fig. 6-6: Variation of Runoff Depth (Y) with Flow Rate (q) for the concrete mix with ash , without deicing material

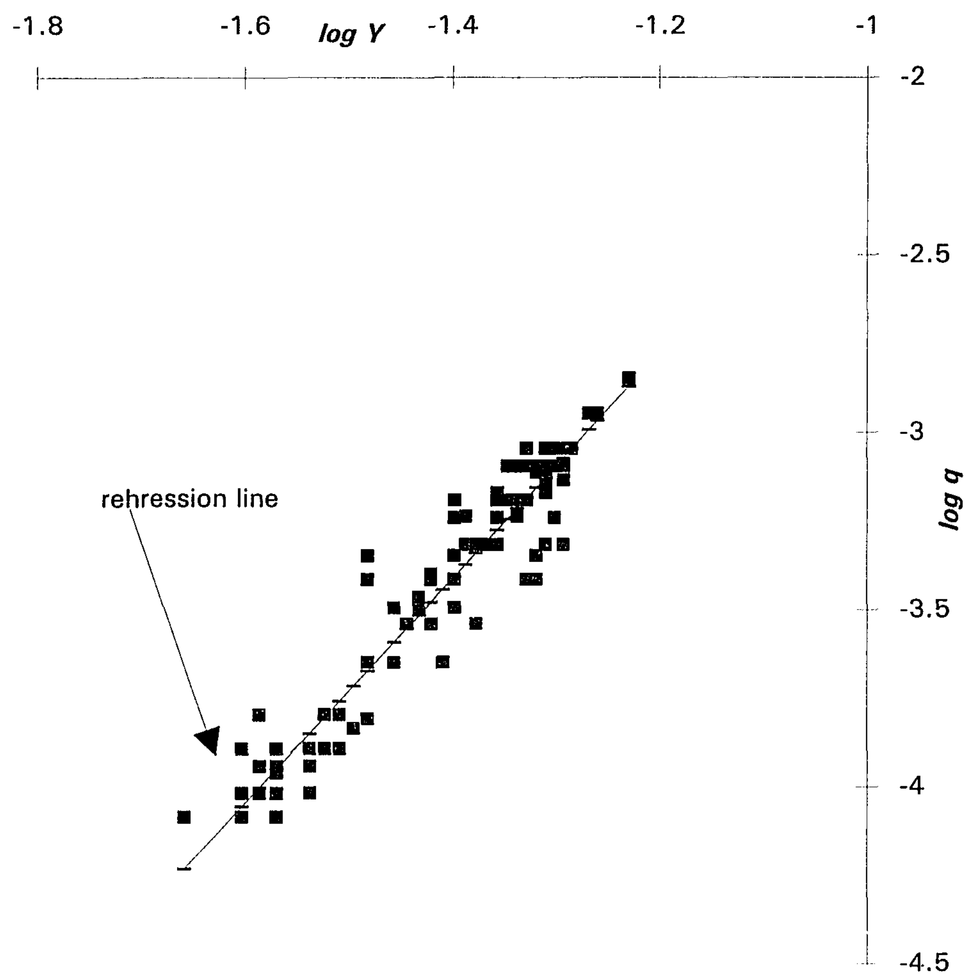


Fig. 6-7 : Variation of Runoff Depth (Y) with Flow Rate (q) for the concrete mix with ash, with deicing material

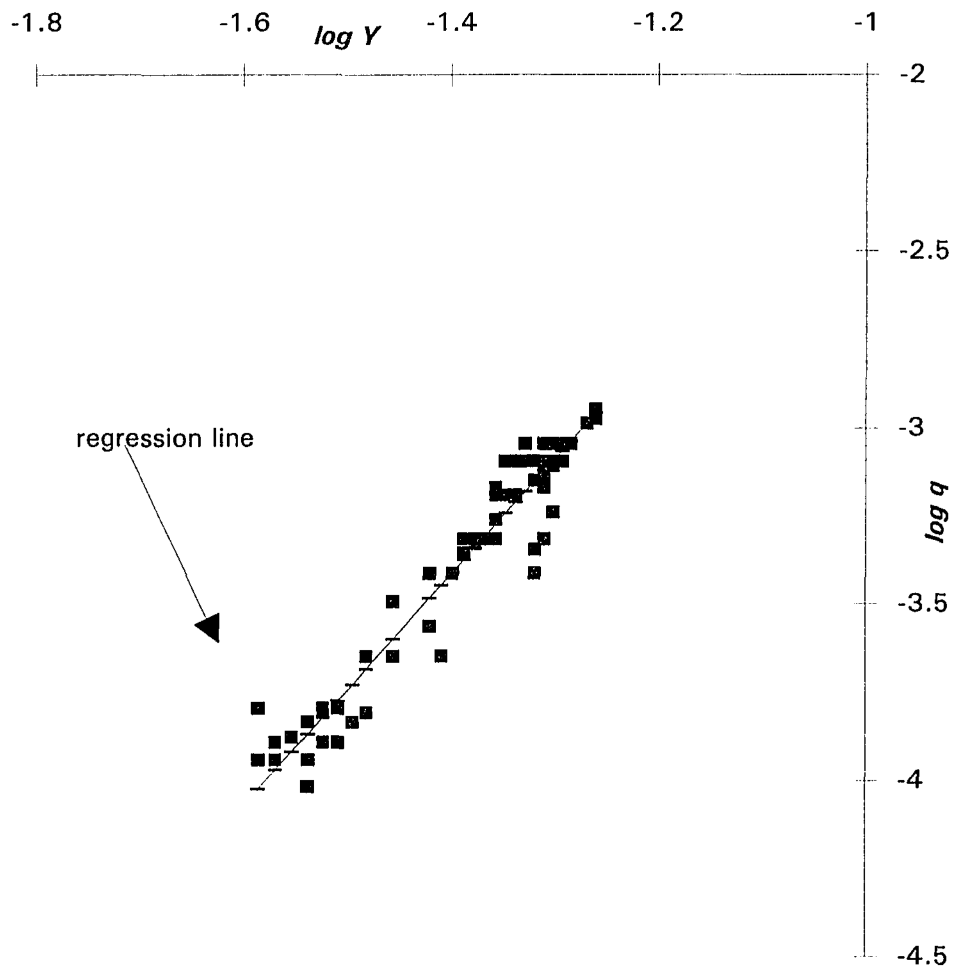


Fig. 6-8: Variation of Runoff Depth (Y) with Flow Rate (q) for the asphalt mix without ash, without deicing material

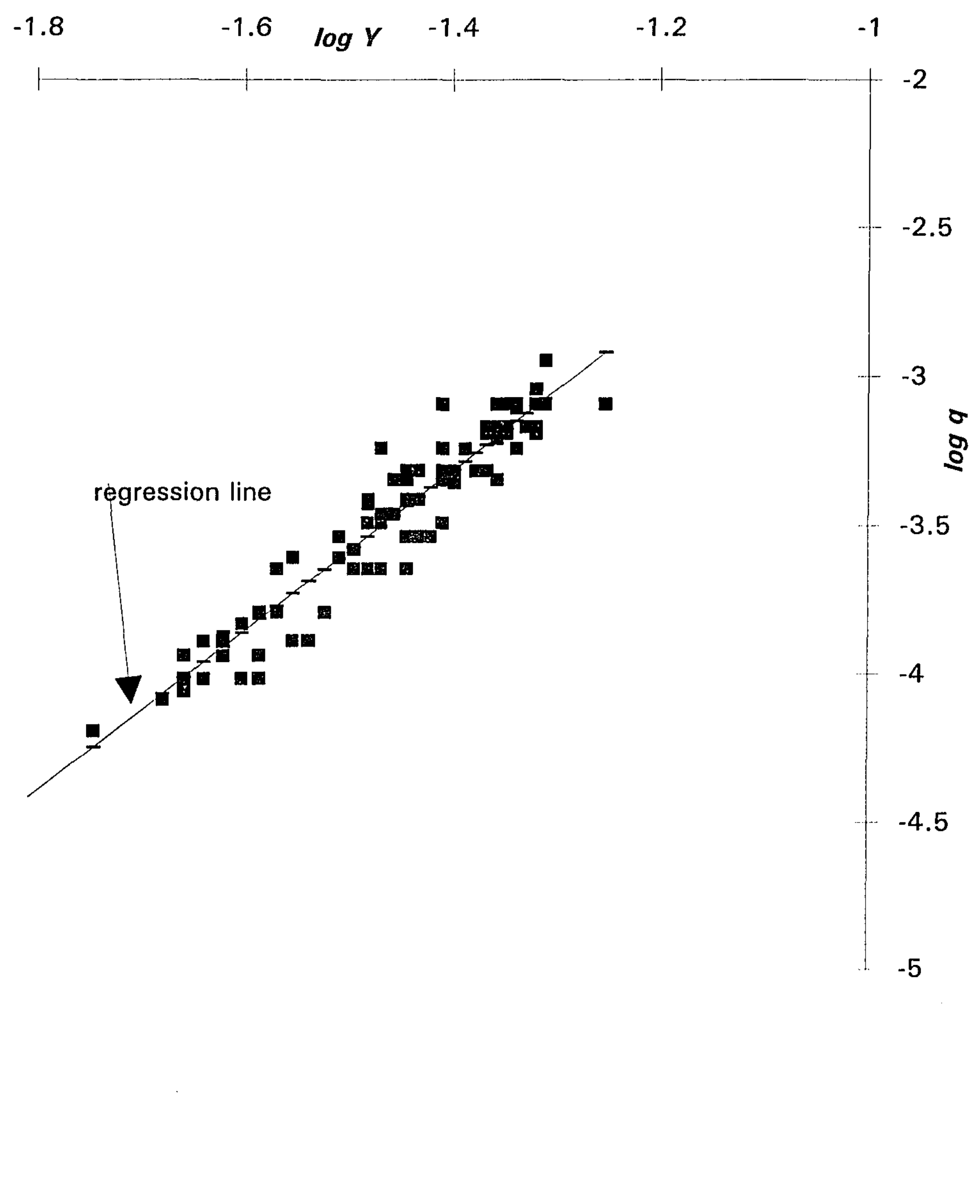


Fig. 6-9: Variation of Runoff Depth (Y) with Flow Rate (q) for the asphalt mix without ash, with deicing material

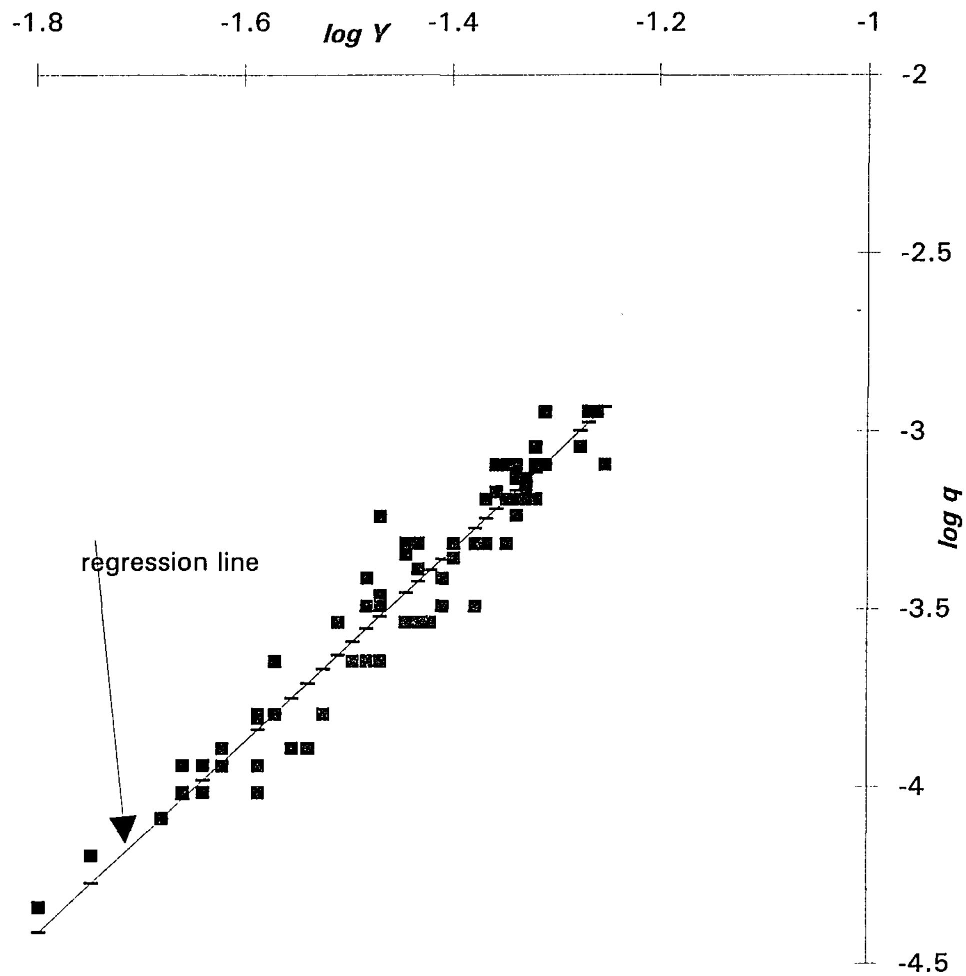


Fig. 6-10: Variation of Runoff Depth (Y) with Flow Rate (q) for the asphalt mix with ash, without deicing material

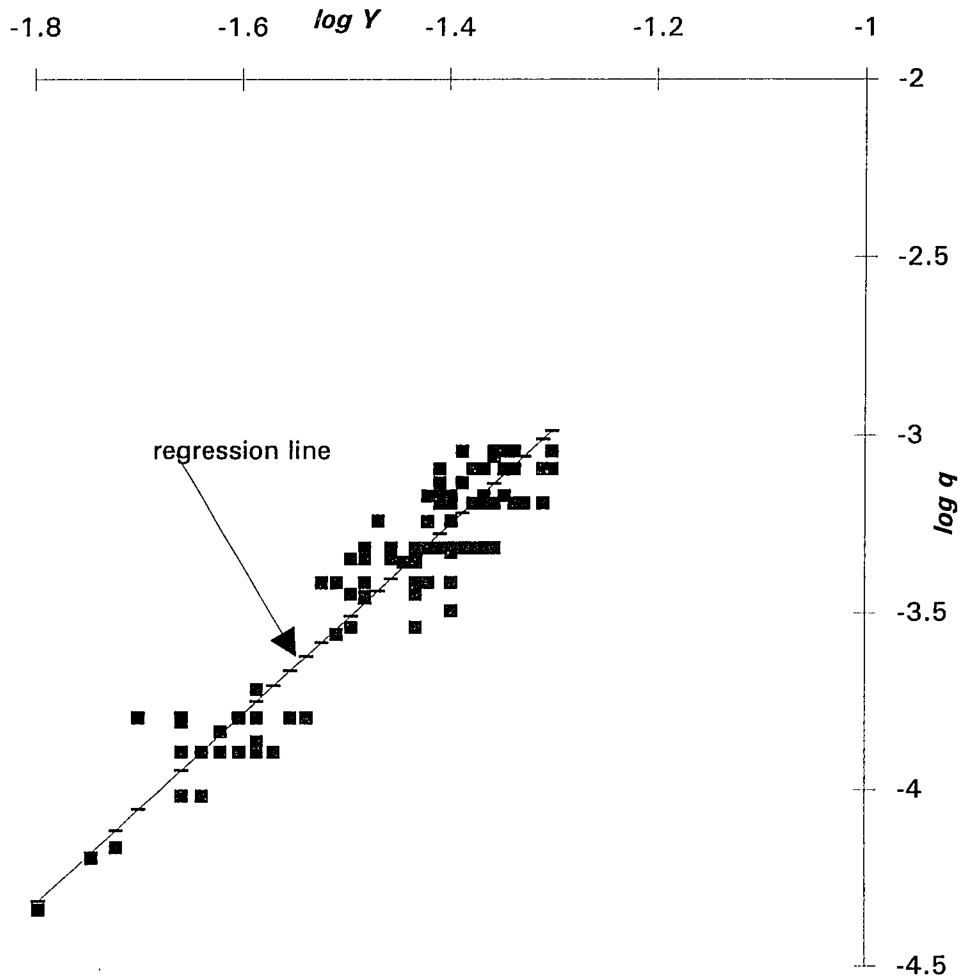
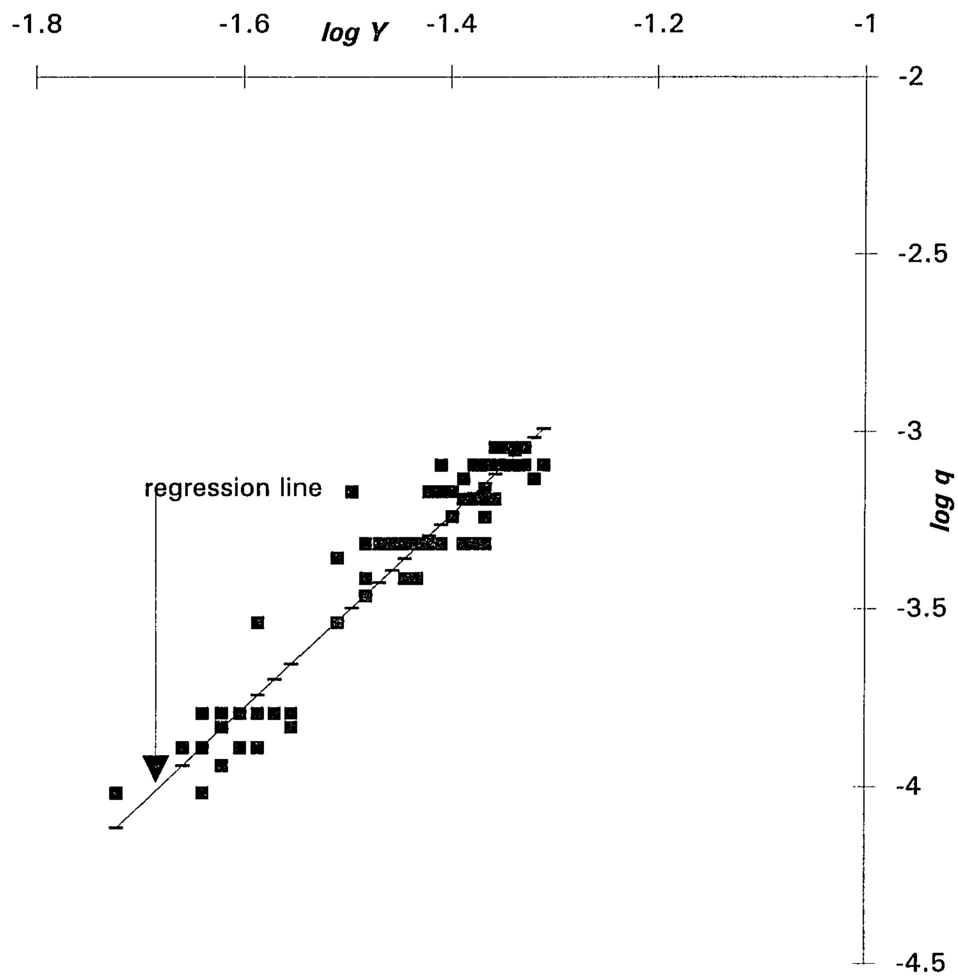


Fig. 6-11: Variation of Runoff Depth (Y) with Flow Rate (q) for the asphalt mix with ash, with deicing material



6.8 HYDRAULIC RESISTANCE OF DIFFERENT PAVEMENTS

The regression equations shown in Table 6-1 are unbiased regression equations. An unbiased regression equation is defined as one wherein no common experimental variables were used to formulate the values regressed on both sides of the regression. No bias is built into such an expression. These equations can be combined with equation (6-32) which can be rewritten as

$$n = 1023\ S_0\ Y^{1.67}/q \qquad (6\text{-}37)$$

All parameters are as defined previously.

Flow per unit width, q, enters into equation (6-37) to replace the Li term, previously presented, and its values are taken from the regression equations tabulated in Table 6-1.

By combining the unbiased regression equation given in Table 6-1 with kinematic wave theory, equation (6-37), an expression for the Manning's n has been developed as a function of flow depth, y.

Table 6-2 shows the resulting *n*-expressions for different categories of pavement mix-ash-deicing material combinations.

TABLE 6-2 : MANNING'S n EXPRESSIONS

Description	Expression
no-ash concrete without deicing material	$n = 0.00038\ Y^{-1.425}$
no-ash concrete with deicing material	$n = 0.00041\ Y^{-1.386}$
ash-concrete without deicing material	$n = 0.00029\ Y^{-1.499}$
ash-concrete with deicing material	$n = 0.00021\ Y^{-1.603}$
no-ash asphalt without deicing material	$n = 0.00106\ Y^{-1.024}$
no-ash asphalt with deicing material	$n = 0.00105\ Y^{-1.039}$
ash-asphalt without deicing material	$n = 0.00099\ Y^{-1.011}$
ash-asphalt with deicing material	$n = 0.00083\ Y^{-1.055}$

6.9 DISCUSSION

A review of the n-expressions shown in Table 6-2 indicates that different fitting parameters are obtained for different mixes. Differences are found in both the coefficient and the power of Y. Even for the same mix the results are somewhat different depending on whether deicing material was used. In an attempt to evaluate the roughness coefficients for various pavements, Table 6-3 has been established to compare the n-values resulting from the n-expressions as shown in Table 6-2. Table 6-3 demonstrates n-values for a range of rainfall-runoff depth which commonly develops on actual roadway surface.

It is interesting to observe that in spite of their different appearances, the n-expressions produce quite compatible results for the range of y-values which is more common. As can be seen from Table 6-3, n is somewhat greater for concrete surface when compared with that of asphalt. The difference for concrete and asphalt mixes is more pronounced for the very low Y's, however as the flow depth increases the difference in n tends to vanish.

Based on the results shown in Table 6-3, introduction of ash tends to decrease the roughness coefficient for both concrete and asphalt material combinations, leading to a faster discharge of surface water. The amount of reduction, however, does not exceed 12 percent.

TABLE 6-3 : VALUES OF "n" OBTAINED FOR TYPICAL RUNOFF DEPTH

Surface Description	Y, i ch					
	0.05	0.06	0.07	0.08	0.09	0.10
No-Ash Concrete Without Deicing Material	0.027	0.021	0.017	0.014	0.012	0.010
No-Ash Concrete With Deicing Material	0.026	0.020	0.016	0.014	0.012	0.010
Ash-Concrete Without Deicing Material	0.025	0.019	0.015	0.013	0.011	0.009
Ash-Concrete With Deicing Material	0.025	0.019	0.015	0.012	0.010	0.008
No-Ash Asphalt Without Deicing Material	0.023	0.019	0.016	0.014	0.012	0.011
No-Ash Asphalt With Deicing Material	0.024	0.020	0.017	0.015	0.013	0.011
Ash-Asphalt Without Deicing Material	0.021	0.017	0.015	0.013	0.011	0.010
Ash-Asphalt With Deicing Material	0.020	0.016	0.014	0.012	0.011	0.009

Presence of deicing material on the surface seems not to have a significant effect on roughness coefficient. For very low flow depths, less than 0.03 in., the values in Table 6-3 indicate that n increases up to 10 percent when deicing material is used. As flow depth increases n remains the same regardless of deicing material being present.

The applicability of the equations shown in Table 6-2 is limited. Based upon the experimental parameters used for their formation, validity is limited to a slope of about 2 percent, portland cement concrete surfaces finished with trowel and asphalt concrete surfaces in accordance to a mix design as described in Chapter 4, rainfall intensity values between 0.7 iph and 3.5 iph, and runoff flow path lengths from 2 to 14 ft. These equations are useful, however, for (a) evaluating changes in roughness due to the addition of ash,
(b) evaluating whether the assumed form of the governing equation is valid.

6.10 CONCLUSION

Based on the results of this study, the following conclusions can be reached concerning the hydraulic resistance of different cases of ash-mix-deicing material combinations under rainfall-runoff conditions.

1. There is a good correlation existing between rainfall-runoff per unit width , q, and depth of runoff, Y, for each of the surfaces studied. These surfaces include both concrete and asphalt pavements, with and without ash in their mix, and with and without deicing material distributed on their surfaces. A regression equation has been developed for each combination of mix-ash-deicing material and the results are shown in Table 6-1.

2. An expression for Manning's roughness coefficient n under sheetflow condition has been established by combining the regression equation developed from experimental data analysis and kinematic wave approximation equation. The results are shown in Table 6-2.

3. Even though the n-expressions include different regression parameters, comparable relationship between Manning's n and flow depth have been obtained by applying these expressions to a physically realistic range of flow depths.

4. Based on the results of these experiments, we conclude that the addition of ash into the mixture tends to decrease the roughness coefficient of a pavement surface. Decreases of up to 12 percent for both concrete and asphalt mixes were observed. These conclusions may be useful to hydraulic engineers concerned with rainfall-runoff events and highway engineers dealing with vehicular hydroplaning on roadway surface.

5. Presence of deicing material on pavement surface does not have a significant effect on the roughness coefficient except at very low flow depths for which a maximum of 10 percent increase in n has been observed.

CHAPTER 7 : ECONOMIC ANALYSIS

7.1 INTRODUCTION

The economic incentive for using ash in concrete and asphalt is based on the saving that can be achieved by avoiding the recycled ash disposal costs. The ash disposal cost (C_D), above which the use of ash would be economically justified, is referred to as the break-even disposal cost.

Given the current conditions on Long Island, stabilizing 60 percent of ash produced in concrete and asphalt mixes can result in significant ash management cost savings. Potential cost savings associated with the use of ash as a concrete and asphalt aggregate on Long Island is presented in the following section. The following presentation assumes that ash is used as an aggregate in concrete and asphalt instead of being disposed of in a Subtitle D landfill (i.e., a non-hazardous waste). The results suggest a potential cost savings of approximately $10 million per year. This estimate assumes ash to be disposed of in a local landfill. Should it be exported to off-state sites the savings will double, or more.

7.2 COST-BENEFIT ANALYSIS

A cost-benefit equation can be written as follows:

$$S = C_D - C_P + C_R \qquad (7\text{-}1)$$

where

S = cost savings expressed in terms of dollars per ton of combined ash,

C_D = cost of combined ash disposal expressed in terms of dollars per ton of combined ash,

C_P = cost of processing ash into a usable product expressed in terms of dollars per ton of combined ash, and

C_R = revenues received from the sale of the usable product expressed in terms of dollars per ton of combined ash.

Potential revenues that could be expected from the sale of ash as an aggregate replacement material depend on the local costs of the replaced aggregate. In our case, ash replaces the fine aggregate (e.g., sand) which has a value ranging from $5 to $15 per ton. For purposes of the economic analysis presented here, it is conservatively assumed that ash will be given away at no cost (e.g., $C_R = 0$). This assumption is made because the cost of local sand, as mentioned before, is relatively low.

The cost of combined ash disposal, expressed in terms of dollars per ton (C_D) is a function of site location and local conditions for each community. Congress and EPA have divided waste into two categories. Wastes are subject to management under Subtitle C of Resource Conservation and Recovery Act of 1976 (RCRA) in which they are regarded as hazardous waste, or they are subject to management under Subtitle D implying they are non-hazardous wastes. Household waste and the ash resulting from processing household waste are specifically excluded from Subtitle C. This means that household waste and incinerator ash are considered to be non-hazardous by legislation. In this analysis C_D represents the costs associated with disposal of ash in a local landfill and under Subtitle D criteria plus the costs required for exporting and disposing of the ash at a non-local disposal landfill. On Long Island, local landfill disposal cost, C_D, presently ranges from \$50 to as high as \$100 per ton depending on specific landfill construction, dimensions and local transportation requirements (Koppleman and Tannenbaum, 1993). If ash must be transported to other states for disposal, costs associated with such a long distance transport can be expected to be highly variable. During the past five years, off Long Island disposal costs have ranged from approximately \$65 to \$130 per ton (Koppleman and Tannenbaum, 1993). Among the factors affecting export costs are the status of the economy, the scheduled implementation of Subtitle D land disposal requirements, and the capacity of landfills available in other states.

The cost of processing ash into a usable product (C_P) is a function of the particular technology that uses ash (i.e., asphalt or concrete technologies), as well as regulatory criteria or requirements that could affect ash recycling costs. One example for regulatory criteria that can affect the ash processing costs is the cost of ash monitoring/quality control procedures that may be required of the ash generator or user. Another example of the ash processing costs is the ash storage requirements (e.g., enclosed facilities, drainage and ventilation requirements). In addition, processing costs expressed in terms of dollars per ton are also sensitive to the size of the operating facility (e.g, larger facilities tend to result in lower costs).

The value of C_P can be expressed by the sum of a number of individual cost components. These components are defined as follows:

C_1 = the cost of ash processing which includes the processing of the ash into sand/silt sized product.

C_2 = the cost of the storage required for stockpiling the ash.

C_t = the cost of combined ash and fly ash treatment.

C_t can be expanded to define the cost of special handling of the bottom ash and treatment and disposal of fly ash as follows:

$$C_t = (1-B)C_3 + (1-B)C_4 \qquad (7\text{-}2)$$

where

B = the fraction of the combined ash which is bottom ash (typically 0.85),

C_3 = the cost of fly ash treatment, if necessary, in terms of dollars per ton of fly ash treated (i.e., chemically stabilized),

C_4 = the cost of fly ash disposal in terms of dollars per ton of fly ash disposed of.

Substituting equation (7-2) into equation (7-1) and assuming a zero value for C_R, as discussed above, yields

$$S = C_D - [C_1 + C_2 + (1-B)C_3 + (1-B)C_4] \qquad (7-3)$$

Equation (7-3) is based on the assumption that all of the ash generated will be processed and used. Since some oversized reject materials (R) will result from screening operations, not all of the ash processed will be usable as an aggregate material.

To account for this unusable fraction, equation (7-3) can be rewritten as follows:

$$S = C_D - \{C_1 + U_1 \ [C_2 + (1-B)C_3 + (1-B)C_4] + RC_D\} \qquad (7-4)$$

where

R = the fraction of the combined ash that is oversized reject material,

U_1 = the fraction of the combined ash that is usable as an aggregate substitute material (= 1 - R).

Equation (7-4) is based on the additional assumption that all the ash will be processed and the entire fraction that is usable as an ash-aggregate material (U_1) will be reused in secondary products. This may not be the case. Given the uncertainty of market conditions, it is more likely that only a portion of the usable ash may be reused. Equation (7-4) can be rewritten to express the fact that only a portion of the usable ash may be reused and the remainder sent to a landfill for disposal as follows:

$$S = C_D - \{BC_1 + U_1 \{U_2 [B C_2 + (1-B) C_3 + (1-B) C_4] + (1-U_2) C_D\} + RC_D\} \quad (7\text{-}5)$$

where

B = the fraction of the combined ash which is bottom ash (typically 0.85),

1-B = the fraction of the combined ash which is fly ash (typically 0.15),

U_2 = fraction of usable ash (U_1) which is being recycled.

The unit costs C_1 through C_4 can be determined by estimating capital and operating costs associated with each application. Capital costs may be amortized over a 15 year period at an interest rate of 10 percent to obtain an annualized capital cost. This annualized capital cost may be added to the estimated annual operating cost to determine a total annual cost. Unit costs can be obtained by dividing the total annual cost by the quantity of ash output. The unit costs incorporated in this study are estimated as follows:

C_1 = cost of preprocessing of ash estimated to be 5.5 to 10.5 dollars per ton.

C_2 = cost of storage of ash estimated to be 5.0 to 6.5 dollars per ton.

C_3 = 0 if no fly ash treatment is needed, 36.0 to 50 dollars per ton, if treatment is required.

(In C_1, C_2 and C_3 the lower values correspond to large facilities and the higher values stand for smaller ones, all numbers are transmitted from Koppleman and Tanenbaum, 1993)

C_4 = cost of fly ash disposal which is dependent on the fly ash disposal assumptions and whether the case is under Subtitle D or C. If the case is under Subtitle D (i.e., non-hazardous waste) C_4 will be equal to C_D. For the cases under Subtitle C, the cost may well amount to 300 dollars per ton of fly ash.

B = fraction of bottom ash assumed to be 0.85

R = fraction of oversized ash which is rejected assumed to be 0.10

U_1 = the fraction of the combined ash that is usable as an aggregate substitute material (= 1 - R), assumed to be 0.90

Substituting above cost values in equation (7-5) gives rise to the following equation for large facilities.

$$S = 0.9\ C_D\ \ U_2 - 8.7\ U_2 - 4.7 \qquad (7\text{-}6)$$

In a similar way, equation (7-7) can be derived for smaller facilities.

$$S = 0.9\ C_D\ \ U_2 - 11.7\ U_2 - 8.9 \qquad (7\text{-}7)$$

Of special interest to the potential ash reuse is the break-even cost, or the disposal cost at or below which reuse of ash offers no net financial benefit (i.e., $S = 0$). The results suggest that if fly ash could be disposed of in Subtitle D landfill, the break-even disposal cost point (C_D) would be in the range of \$16 to \$23 per ton for large plants, depending on the utilization rate (U_2) which varies from 0.4 to 0.8, and \$25 to \$38 per ton for the smaller facilities.

The annual cost savings for Long Island can be roughly estimated on an average basis. For local landfill disposal on Long Island, values of C_D can be expected to range from \$50 to as high as \$100 per ton, depending on specific landfill construction, dimensions, and local transportation requirements (Koppleman and Tanenbaum, 1993). One may compare the average disposal cost with the average break-even cost, as discussed above, to conclude a net annual savings of about 50 dollars per ton. Total aggregate use for concrete and asphalt on Long Island is estimated to be 1,800,000 and 2,300,000 tons per year (Breslin, 1990 and Koppleman and Tanenbaum, 1993). Sand contribution in concrete and asphalt is about 40% and 45% of total aggregate, respectively. Assuming an application rate, i.e. market demand, to be 40% and 45% for concrete and asphalt, respectively, then for a 30% ash replacement for concrete and a 15% for asphalt it can be concluded that about 200,000 tons of ash could be recycled in market. This will lead to an annual cost savings of $10,000,000 for Long Island.

CHAPTER 8 : SUMMARY AND SUGGESTIONS

8-1 CONCLUSIONS AND CONTRIBUTIONS

From the physical test results presented in Chapter 2, we conclude that ash alone is not a desirable material for construction aggregates, but a suitable aggregate may be produced by blending it with a coarse material. The grain size distribution curve for the ash material falls outside the acceptable region specified by ASTM C-33 for aggregates. The portion finer than the #200 sieve is considerably, and unfavorably, high. The permeability is rather low and the shrinkage limit is high. However, the ash material has some positive characteristics: it is inorganic in composition and free of clay. These characteristics may counteract the potential for adverse effects such as volume change and loss of strength which might have arisen if ash contained organic or clay substances.

A critical issue, and a motivation for the research, is the question of whether ash can be used as an aggregate in concrete mixes and/or asphalt mixes. There have been examples of the use of ash as an aggregate in the work of previous researchers. However, these applications have been limited to the use of ash in non load bearing elements such as concrete blocks, lightweight concrete, and coastal reef structures. The contribution of this study is to extend the range of investigation to the use of ash as an aggregate for load bearing elements such as pavement slab or other reinforced concrete structures. As far as we are aware, this is the first time that the use of ash as an aggregate for asphalt has been investigated.

From the chemical test results presented in Chapters 2 and 3, ash can be classified as a non hazardous material. The composite and individual ash samples have a consistently satisfactory test results for EP-Toxicity and heavy metals. The results from the EP-Toxicity and TCLP tests on samples of concrete, with 30% ash, and asphalt with 15% ash replacement of the fine aggregate portion of their respective mixes show that the toxic constituent levels fall well below the standard limits for hazardous materials.

For concrete, it was found that up to 30 percent by weight of its fine aggregate could be replaced by ash. Design parameters for a 30% ash-concrete mix, such as tensile, bond, and flexural strength are all above the minimum design requirements. The results of the skid resistance tests for both the control and the ash-concrete are satisfactory. The introduction of ash into the concrete mix appears to have no significant effect on the skid resistance of the concrete surface. The durability of a surface using an ash-concrete can be improved if the moisture content of the ash is substantially reduced prior to it being introduced into the concrete mix. There is no significant difference in the creep pattern between the ash-concrete specimens and the no-ash concrete control specimen. The results of the "resistance to rapid freezing-and-thawing" test indicate that all specimens show a similar response to the test cycles. It is concluded, therefore, that replacement of a portion of the fine aggregate in concrete with ash would not adversely affect the freeze-thaw cycle behavior of the concrete.

For asphalt with the given batch mix, up to 15 percent by weight of its fine aggregate could be replaced by ash. As was the case with the ash-concrete slabs, there is little or no change in the skid resistance of the asphalt surface if ash is added into the asphalt mix. From the results of the thermomechanical analysis, which is a measure of durability for asphalt, replacing sand by up to 15% ash in the asphalt mix has little effect on the sample durability when compared to the control, or 0% ash, mix.

As described in Chapter 4, the ash-asphalt mix is more difficult to work with, when compared to the workability of the conventional asphalt mix. It is suggested that raising the temperature of the ash-asphalt mix during the lay-down process by about 10 to 20° F above what is commonly used for asphalt will make the ash-asphalt mix easier to handle.

The runoff developed from all of the pavements, be they no-ash concrete, ash-concrete, no-ash asphalt, or ash-asphalt, was shown to be essentially the same. Although the ash-asphalt platform tests produced considerably less runoff than the other platforms did, field test results suggested that this was an artifact of the lack of optimum compaction in the laboratory rather than an inherent property of the ash-asphalt mix. The placement of the deicing material on the pavement surfaces had no apparent effect on the surface runoff.

The runoff coefficient used in the Rational Method seems to be essentially the same for all of the concrete and asphalt test pavements. Once again in the laboratory runoff tests, for the ash-asphalt layer a low runoff coefficient, which was almost half the value of the control pavement, was obtained. Later field test results suggested that the low runoff coefficient value might have been mostly due to the lack of optimum compaction of this layer.

The values obtained from the chemical analyses performed on the runoff samples collected from the concrete and asphalt platforms with or without ash present, fall below the standard limits for groundwater effluent, as set forth by the NYSDEC. A few pollutants, however, had a detectible limit in the test which was greater than limiting standard. Deicing material placed on the pavement surface seems to have negligible on this pattern.

The results of the field tests, as presented in Chapter 5, indicated that the presence of ash in concrete and asphalt mixes has no significant effect on the surface friction of the pavements made from these mixes. The surface friction of the concrete pavements is about 8% greater than that of the asphalt pavements. As was found in the laboratory tests, the surface friction of all pavement sections, concrete and asphalt, with and without ash, is greater than the minimum safety requirements.

The use of ash in a concrete mix apparently has no significant effect on the infiltration properties of the pavement made with that mix. The use of ash in an asphalt mix may have some effects on the infiltration properties of a pavement made with that mix. More research is needed to determine the extent of these effects.

The results of the chemical analyses performed on the runoff-leachate samples from all studied pavements, with or without ash present, are considered to be non-hazardous when the values are compared to available NYSDEC groundwater standards. Deicing material placed on the surface of the pavement sections had no detectable effect on the results of the chemical analyses. It did not alter the non-toxicity of the ash-asphalt and ash-concrete pavement's runoff or leachate.

Based on the regression analysis presented in Chapter 6, there is a good correlation existing between rainfall-runoff per unit width , q, and depth of runoff, y, for each of the surfaces studied. These surfaces include both concrete and asphalt pavements, with and without ash in their mix, and with and without deicing material distributed on their surfaces. A regression equation has been developed for each combination of ash-mix-deicing material.

An expression for Manning's roughness coefficient n under sheetflow has been established by combining the previously mentioned regression equation developed from experimental data analysis and the kinematic wave approximation equation. Even though the n-expressions include different regression parameters, comparable relationships between Manning's n and flow depth have been obtained by applying these expressions to a physically realistic range of flow depths.

Based on the results of this experiment, we conclude that the addition of ash into the mixture tends to decrease the roughness coefficient of a pavement surface. Decrease of up to 12 percent for both the concrete and asphalt mixes were observed. Presence of deicing material on pavement surface does not seem to have a significant effect on the roughness coefficient except at very low flow depths for which a maximum of 10 percent increase in n has been observed. These conclusions may be useful to hydraulic engineers concerned with rainfall-runoff events and highway engineers dealing with vehicular hydroplaning on roadway surface.

The question is whether a single equation can be used to determine the Manning roughness coefficient for sheetflow on different types of pavement surfaces and for a wide range of rainfall intensities. Gallaway et al (1979) attempted to derive an overall equation for various types of surfaces like asphalt, turf, concrete etc..., for a wide range of rainfall intensities, i.e. from 1 inch/hour to 15 inch/hour. However, their equation was found to be not in full agreement with the results obtained by other researchers who worked on one single type of pavement surface and under a narrower range of rainfall intensity. Our study reveals that for the same type of pavement surfaces, even the spread of deicing material can somewhat alter the result. Also in this study, different equations are found for concrete and asphalt pavement surfaces. Moreover, a slight change in aggregate, like presence of ash, can also change the Manning roughness coefficient. Although this change is not significant, it supports the idea that the Manning roughness coefficient can not be expressed by only one single equation to apply to all kinds of surfaces and rainfall conditions. Therefore different equations must be developed to apply to each specific condition.

An economic analysis shows that utilizing ash in concrete and asphalt products can lead to an annual cost saving of $10,000,000 for Long Island. This saving would be a result of not having to dispose of the recycled ash.

8.2 FUTURE RESEARCH

At the present time, perhaps legal impediments and concerns over the liability issues pose a greater barrier in the use of ash residue as a construction material than any failure on the part of the engineering society to devise technologies needed to make the utilization of ash and its secondary products environmentally acceptable. This is a rapidly evolving technology which neither regulatory condition nor public perception have yet allied themselves. To a considerable degree, acceptance of this technology will depend on local and national attitudes toward interest and investment in testing and development of our knowledge of ash as well as on the presence of a clear federal guidance and comprehensive regulatory measures.

Based upon the limited scope of this study and the conditions presented, the following recommendations are made:

This study has been limited to the utilization of sludge ash produced at the Bergen Point Wastewater Treatment Plant. Due to the variability of the sludge ash chemistry, from one site to another, one has to be cautious in generalizing the results of this study for other sites. Unless sludge ash materials from other sites have proved to have characteristics similar to the above mentioned site, additional studies are needed to investigate the possibility of using ash materials from other wastewater treatment plants in asphalt mixtures.

For asphalt, as a viscoelastic material, the phenomenon known as fatigue is a critical issue. Fatigue can be defined as the failure of an asphalt pavement due to the alligator-type cracks developed on the pavement surface. This type of failure occurs as a result of excessive load cycles applied for a long period of time. Although the magnitude of each load is considerably less than the ultimate strength of asphalt, load cycling causes crocodile type cracks that appear on the pavement surface which lead to failure of pavement. It is suggested, therefore, that both laboratory and field scale "fatigue" test be performed on ash-asphalt pavements.

The ash-concrete in our study was designed for a 3000 psi 28-day compressive strength, it is suggested that more tests to be carried out to investigate the optimum ash content for other levels of concrete strength.

Another critical factor, which requires further investigation, is the resistance of ash-concrete against weathering erosion as well as vehicular tire abrasion. Only long term studies under actual field conditions can determine the merits, or otherwise, of the ash-concrete pavements with respect to erosion and abrasion.

Full scale road sections of ash-concrete and ash-asphalt mixtures have to be studied for the workability of these mixtures. It is expected that some practical difficulties will arise during the construction process. In our study, we found that from a workability point of view that the ash-asphalt mix needs to be processed with its temperature being 10 to 20°F higher as compared with the conventional mix. We also found that for ash-concrete, the mixing period has to be almost doubled for a workable product. It is only under a full scale practice that the problems associated with the lay down process of ash mixed products will appear. For ash to be recycled as an aggregate, appropriate specifications have to be established. These specifications can only be established through a full scale construction of ash-mixed projects.

It is evident that the Manning roughness coefficient, n, is highly dependent on the surface texture and the manner in which the surface has been finished. In our study a rather smooth concrete surface finished by trowelling was used. For other types of finishing more studies are needed to develop an appropriate expression for the Manning roughness coefficient.

This study has been conducted for rainfall intensities ranging between 1 inch/hour to 3 inch/hour, which is typical for New York area. Additional studies are needed to develop appropriate expression for the Manning roughness coefficient, for other rainfall intensities Typical for other regions.

APPENDIX 2A

INCINERATION SYSTEM DATA

INCINERATION SYSTEM DATA

Furnace:

Manufacturer: Zimpro/Passavant

Size: 18'9" O.D.

Number of Hearths: 7

Hearths numbered from top bottom of furnace

Number of Furnace: 2

Capacity per Furnace: 120 tons/day wet sludge at 24% solids

All odd hearths: Out hearths

All even hearths: In hearths

Hearth No.1: 30 dropholes, 4 rabble arms, 5 teeth per arm

Hearth No.2: Annular opening, 4 rabble arms, 4 teeth per arm

Hearth No.3: 30 dropholes, 4 rabble arms, 5 teeth per arm

Hearth No.4: Annular opening, 2 rabble arms, 8 teeth per arm

Hearth No.5: 30 dropholes, 2 rabble arms, 10 teeth per arm

Hearth No.6: Annular opening, 2 rabble arms, 10 teeth per arm

Hearth No.7: 1 drop hole, 2 rabble arms, 10 teeth per arm

Feed to Furnace No.1: Hearth No.1 or No.2

Feed to Furnace No.2: Hearth No.1 only

Exhaust breeching from Hearth No.1

Three oil fired burners on hearth No.3,4 and 6

Furnace off-gas temperature: 1200-1300 F

APPENDIX "2 - A" (Continued)

Excess air : 150% (current operation), 200% (design)

Supplemental fuel: No.2 fuel oil (138,000 Btu/gal)

Back rabbling: one arm in hearth No.1 and 2

Main combustion cooling air to hearths No.4 and 6 (proportionable)

Central shaft cooling air return to hearth No.4 and 6 (proportionable)

Central Shaft Drive:

Number of units: 2

Motor HP: 13.7

Drive Output Speed: 25.2 RPM

Drive Shaft Speed: 0.6-3.0 RPM (variable)

Central Shaft Cooling Air Fan:

Manufacturer: reliance

Number of units: 2

Type of Fan: Limited Load

Motor HP: 15

Operating Capacity: 5300 acfm

Operating Static Pressure: 8 in. W.C.

Operating Velocity: 3000 fpm

Burner Combustion Air Fan:

Manufacturer: Clarage

APPENDIX "2 - A" (Continued)

Number of units:4

Type of Fans: XL

Operating Capacity: 4816 acfm

Motor HP: 75

Sludge Combustion Air Fan:

Manufacturer: clarage

Number of Units: 2

Types of Fan: NH

Motor HP: 15

Operating Capacity: 13,406 acfm

Operating Pressure: 3 in. W.C.

Combustion Burners:

Manufacturer: North America

Number of Units: 18

Type of Burner: Oil-gas

Rating: 950 Btu/Burner

Afterburner:

Manufacturer: North America

Number: 2(one per furnace)

Six fuel oil burners per unit

Afterburner off-gas temp. 1400 F

APPENDIX "2 - A" (Continued)

Total capacity (design): 15.66 MBH

Breeching to boiler or scrubber

Scrubber:

Manufacturer: Peabody

Number: 2 systems (one per furnace)

Inlet Temp. to Precooler: 400-1100 F

Inlet Temp. to tray cooler: 60 F

Venturi pressure differential: 5-15 inches W.C.

Gas flow: 75,463 lbs/hr dry gas (design) @1400 F

Water use: 250,000 gal/day PW,1,500,000 gal/day FE

Waste Heat Boiler:

Manufacturer: Deltak (main boilers)

Steam production: 11,900 lbs/hr per boiler (design)

Steam Temperature: 454 F (design)

Heating Surface: 3200 sq.ft.

Steam pressure (design): 500psig.

Steam pressure (operating): 425 psig.

Feedwater temperature: 228 F

Waste gas per hour (design): 61,269 lbs/hr

Temperature Waste gas entering boiler (design): 1200 F

Temperature Waste gas leaving boiler (design): 530 F

APPENDIX "2 - A" (Continued)

Maximum boiler draft loss (design): 3" W.C.

Induced Draft Fan:

Manufacturer: Buffalo

Number of Units: 2

Type of Fans: 980 H-14

Motor HP: 250

Operating Capacity: 29,000 acfm at -36 inches W.C. static pressure

Operating Velocity: 3,100 fpm.

The chemicals added to the sludge prior to the incineration basically consist of potassium permanganate and a polymer from COARISCC (Known as C310). Being a cationic co polymer, it consists of Methacryloyloxyethyl, Trymethyle, Ammonium chloride and acrylamide in hydro carbon decomposition product.

APPENDIX 2B

Existing Data on

Orangetown Wastewater Treatment Plant Incinerator

Existing Data on

Orangetown Wastewater Treatment Plant Incinerator

The Orangetown Wastewater Treatment Plant is a secondary treatment facility which presently handles a wastewater flow of one MGD. It must be noted that 30% of the influent to the plant is industrial waste. At this plant 6350 lbs. of ash is produced daily from incinerating 70,000 lbs. of sludge in a multiple hearth incinerator consisting of six hearths.

The results of Heavy Metals and EP Toxicity tests on samples of incinerator ash from this plant is given in Table Appx
2-B-1. The results of sieve analysis on samples of incinerator ash collected from this plant are shown in Table Appx 2-B-2.

Table Appx 2-B-1

DATA SUMMARY OF ASH CHARACTERISTICS FOR ORANGETOWN WWTP

METALS		10/8/82	10/24/82	10/25/82	Average
Cadmium	mg/l	2.91	3.32	5.54	3.90
Chromium	mg/l	0.147	0.166	0.352	0.222
Copper	mg/l	1.160	1.960	1.520	1.500
Lead	mg/l	0.184	0.380	0.219	0.261
Mercury	mg/l	0.036	<0.05	<0.025	<0.037
Zinc	mg/l	1.350	1.240	1.380	1.320

EP TOXICITY

Arsenic	mg/l	<0.001	0.152	0.152	0.102
Barium	mg/l	<0.05	<0.05	<0.05	<0.05
Cadmium	mg/l	<0.003	<0.005	<0.003	<0.004
Chromium	mg/l	<0.01	0.02	<0.01	<0.013
Lead	mg/l	<0.025	0.11	<0.025	0.053
Mercury	mg/l	<0.005	<0.0007	<0.0005	<0.0006
Selenium	mg/l	0.002	0.037	0.031	0.023
Silver	mg/l	<0.006	<0.006	<0.006	<0.006

TABLE APPX 2 - B -2: SIEVE ANALYSIS FOR THE SAMPLE FROM WASTEWATER TREATMENT PLANT OF ORANGETOWNIN IN ROCKLAND-COUNTY, NEW YORK.

Date of Sample Collection: 02-22-91.

Sieve No.	% Finer		
	Test-1	Test-2	Mean
#4	100.0	100.0	100.0
#8	99.6	99.7	99.7
#16	94.4	94.6	94.5
#20	88.6	88.8	88.7
#30	82.6	83.0	82.8
#40	75.6	76.0	75.8
#50	63.4	64.6	64.0
#80	51.6	52.6	52.1
#100	45.8	46.9	46.3
#200	23.3	25.4	24.4
#270	10.1	11.4	10.7
#500	0.9	0.8	0.9

APPENDIX 4A

SURFACE RUNOFF MEASURMENTS

TABLE 4.A-1 : SURFACE RUNOFF MEASURMENTS ON

NO-ASH CONCRETE PLATFORM

WITHOUT DEICING MATERIAL

vol.of surface runoff gal/10min	10 min. Rainfall Readings												avg. rainfall intensity in/hr	Q gph
	1	2	3	4	5	6	7	8	9	10	11	12		
28	30	50	35	30	40	40	35	35	30	45	25	25	2.94	168
31.5	30	40	50	30	50	45	50	40	30	50	35	20	3.27	189
31	30	40	40	50	50	40	50	50	35	40	30	15	3.27	186
28	40	40	35	40	35	25	50	40	10	35	35	20	2.85	168
30	30	30	30	50	50	30	50	50	30	30	35	30	3.1	180

Average Surface Runoff = 3.00 gpm

Average Rainfall intensity = 3.09 in/hr

TABLE 4.A-2 : SURFACE RUNOFF MEASURMENTS ON

NO-ASH CONCRETE PLATFORM

WITH DEICING MATERIAL

vol.of surface runoff gal/10min	10 min. Rainfall Readings												avg. rainfall intensity in/hr	Q gph
	1	2	3	4	5	6	7	8	9	10	11	12		
37	40	45	35	50	65	40	65	65	30	50	40	25	3.85	222
35	25	45	30	65	65	30	65	65	25	50	50	30	3.78	210
30	30	40	40	45	50	30	50	50	25	40	40	20	3.20	180
36	40	50	40	65	60	25	50	50	40	40	40	40	3.78	216
35	40	40	50	45	40	50	65	65	25	45	45	25	3.74	210

Average Surface Runoff = 3.50 gpm

Average Rainfall intensity = 3.67 in/hr

TABLE 4.A-3 : SURFACE RUNOFF MEASURMENTS ON

30% ASH-CONCRETE PLATFORM

WITHOUT DEICING MATERIAL

vol.of surface runoff gal/10min	10 min. Rainfall Readings												avg. rainfall intensity in/hr	Q gph
	1	2	3	4	5	6	7	8	9	10	11	12		
33.5	50	40	40	50	50	50	50	50	40	25	40	30	3.61	201
34	40	40	35	50	50	50	50	50	35	30	40	30	3.53	204
26	30	25	25	40	45	30	45	40	35	20	30	30	2.77	156
28	30	30	25	50	40	30	50	50	35	15	50	25	3.00	168
26	25	30	30	40	40	35	50	40	30	15	35	20	2.73	156

Average Surface Runoff = 3.00 gpm

Average Rainfall intensity = 3.13 in/hr

TABLE 4.A-4 : SURFACE RUNOFF MEASURMENTS ON

30% ASH-CONCRETE PLATFORM

WITH DEICING MATERIAL

vol.of surface runoff gal/10min	10 min. Rainfall Readings												avg. rainfall intensity in/hr	Q gph
	1	2	3	4	5	6	7	8	9	10	11	12		
36	50	50	35	50	50	50	50	50	40	50	30	20	3.67	216
31.5	50	50	40	50	50	45	50	50	45	50	10	15	3.53	189
31.5	50	45	35	50	50	45	50	40	35	40	35	10	3.39	189
33	50	50	40	50	50	40	50	50	50	40	30	10	3.57	198
34.5	45	45	40	50	50	50	50	50	40	45	40	10	3.60	207

Average Surface Runoff = 3.30 gpm

Average Rainfall intensity = 3.55 in/hr

TABLE 4.A-5 : SURFACE RUNOFF MEASURMENTS ON

NO-ASH ASPHALT PLATFORM

WITHOUT DEICING MATERIAL

vol.of surface runoff gal/10min	10 min. Rainfall Readings												avg. rainfall intensity in/hr	Q gph
	1	2	3	4	5	6	7	8	9	10	11	12		
41	65	65	50	60	65	50	50	45	40	25	40	25	4.10	246
41	60	65	50	65	65	50	45	45	40	30	40	20	4.10	246
34	50	55	45	55	50	45	40	40	40	25	30	15	3.45	204
34	50	50	40	45	45	35	35	25	25	10	15	10	3.80	204
34	55	55	50	50	55	45	40	45	35	25	40	15	3.50	204

Average Surface Runoff = 3.70 gpm

Average Rainfall intensity = 3.73 in/hr

TABLE 4.A-6 : SURFACE RUNOFF MEASURMENTS ON

NO-ASH ASPHALT PLATFORM

WITH DEICING MATERIAL

vol.of surface runoff gal/10min	10 min. Rainfall Readings												avg. rainfall intensity in/hr	Q gph
	1	2	3	4	5	6	7	8	9	10	11	12		
33	55	55	35	50	50	45	45	40	40	25	30	15	3.36	196
35	55	55	40	55	50	50	45	45	40	25	35	15	3.57	210
40	65	65	55	65	65	50	50	40	40	25	35	20	4.00	240
41.5	65	65	50	60	65	50	45	45	45	35	45	25	4.16	249
39	60	60	50	65	65	50	45	45	40	25	35	20	3.92	234

Average Surface Runoff = 3.80 gpm

Average Rainfall intensity = 3.80 in/hr

TABLE 4.A-7 : SURFACE RUNOFF MEASURMENTS ON

15% ASH-ASPHALT PLATFORM

WITHOUT DEICING MATERIAL

vol.of surface runoff gal/10min	10 min. Rainfall Readings												avg. rainfall intensity in/hr	Q gph
	1	2	3	4	5	6	7	8	9	10	11	12		
15	47	47	33	50	60	40	50	37	33	27	33	17	3.32	90
16	47	53	33	63	63	37	50	47	37	30	33	23	3.61	67
18	53	53	40	63	63	30	53	43	37	30	33	17	3.57	108
19	53	53	40	63	63	40	50	40	33	30	30	17	3.54	114
11	43	43	40	50	63	40	50	33	33	27	27	17	2.33	66

Average Surface Runoff = 1.60 gpm

Average Rainfall intensity = 3.25 in/hr

TABLE 4.A-8 : SURFACE RUNOFF MEASURMENTS ON

15% ASH-ASPHALT PLATFORM

WITH DEICING MATERIAL

vol.of surface runoff gal/10min	10 min. Rainfall Readings												avg. rainfall intensity in/hr	Q gph
	1	2	3	4	5	6	7	8	9	10	11	12		
15	47	47	43	47	50	20	50	33	33	30	33	17	3.15	90
16	50	47	47	63	63	33	47	37	33	30	33	17	3.50	96
14	43	40	33	40	40	33	37	37	33	17	30	13	2.77	84
14	40	40	33	40	43	37	40	33	33	17	27	10	2.74	84
18	47	53	33	63	63	33	47	47	33	30	30	17	3.51	108

Average Surface Runoff = 1.55 gpm

Average Rainfall intensity = 3.13 in/hr

APPENDIX 4B

DATA USED FOR HYDROPLANING ANALYSIS

TABLE 4.B-1 : DATA FOR NO-ASH CONCRETE WITHOUT DEICING MATERIAL

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1L/9/23/92	0.66	0.665	0.667	0.669	0.672	2	0.6666	0.006045
1C	0.6	0.614	0.598	0.602	0.585	3.5	0.6	0.015456
1R	0.55	0.548	0.531	0.54	0.532	2.5	0.54	0.014103
2L	0.91	0.914	0.904	0.905	0.901	2.3	0.907	0.005265
2C	1.05	1.051	1.049	1.05	1.057	2.8	1.051	0.003009
2R	0.83	0.839	0.832	0.83	0.77	2.8	0.8204	0.030958
3L	1.14	1.134	1.135	1.135	1.137	2.5	1.136	0.001575
3C	1.89	1.052	0.991	0.982	0.981	2.5	1.1792	0.302215
3R	1.19	1.29	1.27	1.27	1.26	2.1	1.256	0.027396
4L	1.12	1.223	1.144	1.07	1.01	3.1	1.113	0.064219
4C	1.19	1.23	1.23	1.26	1.21	1.8	1.224	0.019055
4R	0.88	0.981	0.983	1.068	0.653	1.8	0.913	0.156621
1L/9/23/92	0.46	0.488	0.489	0.493	0.501	1.15	0.487	0.025416
1C	0.47	0.416	0.404	0.407	0.407	1.15	0.42	0.055594
1R	0.51	0.501	0.494	0.498	0.496	1.25	0.5	0.011933
2L	0.71	0.712	0.732	0.734	0.719	1.6	0.721	0.014467
2C	0.82	0.829	0.816	0.819	0.817	1.6	0.821	0.005917
2R	0.64	0.649	0.655	0.634	0.651	1.6	0.646	0.011667
3L	0.94	0.944	0.923	0.914	0.937	1.6	0.932	0.012457
3C	0.86	0.867	0.868	0.87	0.866	1.6	0.866	0.004321
3R	0.91	0.915	0.927	0.931	0.928	1.6	0.923	0.007661
4L	1.06	1.069	1.084	1.055	1.071	1.4	1.068	0.009212
4C	1.21	1.213	1.196	1.192	1.194	1.6	1.2	0.006562
4R	0.95	0.941	0.962	0.959	0.973	1.4	0.956	0.012199
1L/9/24/92	0.44	0.464	0.463	0.47	0.464	1	0.461	0.019207
1C	0.45	0.473	0.469	0.458	0.451	3.5	0.461	0.018559
1R	0.68	0.656	0.659	0.663	0.642	3.5	0.66	0.018557
2L	0.72	0.718	0.729	0.718	0.723	1.4	0.721	0.006264
2C	0.94	0.95	0.949	0.957	0.95	2.1	0.949	0.006072
2R	0.7	0.718	0.712	0.704	0.707	1.4	0.708	0.00924
3L	2.16	1.036	1.036	1.011	1.009	2.4	1.25	0.363319
3C	1.15	1.129	1.134	1.126	1.128	2.4	1.133	0.007017
3R	0.87	0.878	0.87	0.861	0.883	1	0.872	0.008853
4L	1.06	1.065	1.071	1.068	1.074	2.8	1.068	0.003973
4C	1	0.996	1.008	1.011	0.986	1.6	1	0.008922
4R	0.76	0.751	0.767	0.756	0.776	0.7	0.761	0.012072
1L/9/24/92	0.71	0.706	0.728	0.727	0.72	1.8	0.718	0.012612
1C	0.53	0.555	0.549	0.55	0.52	2.1	0.54	0.026215
1R	0.53	0.539	0.547	0.541	0.541	2.2	0.54	0.00892
2L	0.89	0.882	0.888	0.878	0.895	2.8	0.886	0.006503

TABLE 4.B-1 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
2C	1.05	1.049	1.058	1.054	1.047	2.5	1.051	0.004125
2R	0.62	0.61	0.633	0.63	0.637	1.4	0.625	0.016903
3L	0.97	0.987	0.975	0.977	0.816	2.1	0.9448	0.068438
3C	2.02	0.91	0.918	0.925	0.891	1.9	1.1328	0.391725
3R	0.86	0.84	0.836	0.848	0.843	1	0.846	0.011063
4L	1.05	1.041	1.044	1.044	0.705	1.9	0.977	0.139242
4C	0.99	0.983	1.015	1.012	1.001	1.4	1	0.01249
4R	0.75	0.755	0.781	0.759	0.763	0.7	0.761	0.014867
1L/9/28/92	0.67	0.669	0.643	0.649	0.698	1.4	0.666	0.029084
1C	0.53	0.531	0.53	0.501	0.505	1.8	0.52	0.026868
1R	0.49	0.499	0.478	0.451	0.294	1.8	0.4428	0.172071
2L	0.86	0.859	0.864	0.868	0.852	2.5	0.86	0.006453
2C	0.79	0.796	0.801	0.795	0.793	1.8	0.795	0.00457
2R	0.61	0.609	0.613	0.627	0.665	1.4	0.625	0.033562
3L	0.93	0.921	0.939	0.94	0.932	1.8	0.932	0.007587
3C	0.88	0.863	0.873	0.847	0.555	1.6	0.8038	0.155408
3R	0.76	0.768	0.752	0.785	0.779	0.7	0.769	0.015496
4L	1.02	1.028	1.024	0.983	0.611	1.8	0.9328	0.173336
4C	0.86	0.889	0.877	0.872	0.881	1	0.875	0.012582
4R	0.69	0.714	0.724	0.736	0.718	0.6	0.717	0.019685
1L/9/28/92	0.69	0.681	0.677	0.699	0.71	2.1	0.692	0.017341
1C	0.52	0.533	0.519	0.518	0.509	2.8	0.52	0.014796
1R	0.53	0.498	0.525	0.523	0.521	2.8	0.5202	0.022985
2L	1.11	1.094	1.099	1.098	1.065	3.5	1.093	0.013583
2C	1.09	1.086	1.118	1.114	1.1	3.5	1.102	0.011188
2R	0.79	0.788	0.764	0.769	0.766	2.8	0.7746	0.013256
3L	1.18	1.159	1.149	1.151	1.16	3.5	1.159	0.008222
3C	1.14	1.132	1.132	1.132	0.733	3.5	1.053	0.151954
3R	1.15	1.158	1.156	1.153	0.769	2.5	1.077	0.143018
4L	1.1	1.118	1.12	1.12	1.106	2.8	1.113	0.007143
4C	1.12	1.108	1.09	1.11	1.076	2.1	1.1	0.013459
4R	0.89	0.854	0.855	0.842	0.796	1	0.848	0.036727
1L/9/28/92	0.58	0.588	0.596	0.598	0.58	1.8	0.589	0.011957
1C	0.45	0.468	0.462	0.465	0.43	1.8	0.4546	0.030972
1R	0.45	0.459	0.469	0.464	0.457	1.5	0.46	0.01333
2L	0.93	0.901	0.915	0.895	0.898	1.8	0.907	0.012914
2C	0.98	0.986	0.971	0.969	0.962	1.5	0.974	0.009021
2R	1.3	1.288	1.296	1.273	1.325	1.8	1.297	0.013256
3L	0.8	0.796	0.786	0.785	0.809	1.5	0.795	0.011166
3C	0.87	0.877	0.896	0.89	0.904	1.8	0.888	0.013036

TABLE 4.B-1 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
3R	0.8	0.799	0.816	0.789	0.768	0.7	0.795	0.020173
4L	0.94	0.946	0.931	0.936	0.905	1.5	0.932	0.015489
4C	1.03	1.036	1.03	1.015	1.012	1.5	1.025	0.009398
4R	0.9	0.908	0.926	0.906	0.924	1.5	0.913	0.01104
1L/10/2/92	0.75	0.742	0.736	0.747	0.745	2.8	0.743	0.005178
1C	0.59	0.587	0.581	0.579	0.567	3.2	0.58	0.012337
1R	0.6	0.601	0.603	0.606	0.587	3.2	0.6	0.011155
2L	0.97	0.984	0.963	0.995	0.972	3.5	0.977	0.011489
2C	1.15	1.125	1.128	1.138	1.104	3.5	1.128	0.012373
2R	0.83	0.801	0.819	0.81	0.805	2.8	0.812	0.010904
3L	1.03	0.987	1.018	1.027	1.057	3.5	1.023	0.021867
3C	1.11	1.101	1.109	1.135	1.099	3.5	1.111	0.011555
3R	1.06	1.043	1.038	1.049	1.066	2.8	1.051	0.009759
4L	1.02	1.048	1.059	1.053	1.043	2.1	1.045	0.01212
4C	1.26	1.257	1.26	1.251	1.227	3.2	1.25	0.009493
4R	0.97	0.978	0.981	0.979	0.434	1.8	0.8692	0.250359
1L/10/2/92	0.7	0.699	0.688	0.69	0.687	2.1	0.692	0.006778
1C	0.5	0.493	0.506	0.502	0.502	2.1	0.5	0.009033
1R	0.52	0.528	0.519	0.52	0.511	2.1	0.52	0.010533
2L	0.98	1.001	0.977	0.964	0.962	3.5	0.977	0.014373
2C	1.23	1.202	1.229	1.263	1.235	3.5	1.231	0.015877
2R	0.81	0.808	0.817	0.831	0.796	2.1	0.812	0.014298
3L	1.07	1.041	1.047	1.032	1.031	3.5	1.045	0.014985
3C	1.01	1.021	1.02	1.036	1.027	3.5	1.022	0.009607
3R	1.08	1.073	1.078	1.082	1.072	2.1	1.077	0.00362
4L	1.02	0.992	1.04	1.02	0.931	2.1	1	0.03772
4C	1.12	1.123	1.101	1.089	1.066	2.5	1.1	0.019276
4R	0.93	0.928	0.942	0.939	0.941	2.1	0.935	0.007563

TABLE 4.B-2 : DATA FOR N0-ASH CONCRETE WITH DEICING MATERIAL

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1L/10/5/92	0.626	0.616	0.621	0.608	0.604	2.1	0.615	0.01317
1C	0.481	0.497	0.489	0.478	0.455	2.1	0.48	0.029463
1R	0.508	0.526	0.511	0.548	0.507	2	0.52	0.029965
2L	0.877	0.862	0.869	0.853	0.839	2.8	0.86	0.015285
2C	1.083	1.069	1.063	1.088	1.082	3.5	1.077	0.00873
2R	0.764	0.757	0.766	0.753	0.711	2.1	0.7502	0.026864
3L	1.188	1.196	1.206	1.199	1.221	3.5	1.202	0.009249
3C	1.161	1.158	1.173	1.189	1.209	3.5	1.178	0.016089
3R	1.017	1.007	0.994	0.99	0.992	1.8	1	0.010373
4L	1.127	1.11	1.143	1.142	1.158	2.8	1.136	0.014335
4C	1.144	1.133	1.112	1.119	1.117	2.1	1.125	0.010472
4R	0.919	0.934	0.914	0.901	0.897	1.4	0.913	0.014514
1L/10/5/92	0.638	0.654	0.626	0.629	0.658	1.4	0.641	0.020173
1C	0.507	0.499	0.515	0.494	0.486	2.5	0.5002	0.020127
1R	0.534	0.538	0.525	0.527	0.476	1.8	0.52	0.043259
2L	0.943	0.952	0.926	0.928	0.901	3.5	0.93	0.018711
2C	1.117	1.133	1.136	1.141	1.113	3.5	1.128	0.009744
2R	0.658	0.647	0.638	0.632	0.655	1.8	0.646	0.015262
3L	1.126	1.122	1.147	1.146	1.139	3.5	1.136	0.009029
3C	1.101	1.127	1.125	1.132	1.07	3.5	1.111	0.020815
3R	1.032	1.114	1.125	1.131	1.108	1.4	1.102	0.032592
4L	1.119	1.126	1.108	1.123	1.094	2.8	1.114	0.010515
4C	1.245	1.211	1.22	1.226	1.223	2.8	1.225	0.009134
4R	1.403	1.205	0.991	0.976	0.967	1.8	1.1084	0.15492
1L/10/7/92	0.776	0.787	0.771	0.748	0.763	2.8	0.769	0.016995
1C	0.619	0.622	0.564	0.603	0.587	2.8	0.599	0.035915
1R	0.595	0.61	0.607	0.599	0.589	2.7	0.6	0.012824
2L	0.736	0.748	0.755	0.741	0.74	2.1	0.744	0.009036
2C	1.05	1.054	1.047	1.053	0.818	3.4	1.0044	0.092824
2R	0.748	0.735	0.744	0.753	0.769	2.1	0.7498	0.015028
3L	1.198	1.196	1.173	1.169	1.174	3.3	1.182	0.010472
3C	1.22	1.242	1.209	1.221	1.218	3.3	1.222	0.008889
3R	1.73	1.266	0.913	0.934	0.922	1.4	1.153	0.275529
4L	1.235	1.241	1.231	1.217	1.212	2.8	1.2272	0.008932
4C	1.424	1.404	1.408	1.402	1.362	2.8	1.4	0.014652
4R	0.925	0.933	0.926	0.893	0.888	1.4	0.913	0.020421
1L/10/7/92	0.577	0.598	0.618	0.589	0.568	1.8	0.59	0.029376
1C	0.504	0.516	0.513	0.492	0.474	2.1	0.4998	0.030747
1R	0.522	0.501	0.503	0.486	0.488	2.1	0.5	0.02583
2L	1.671	0.979	0.858	0.867	0.855	2.5	1.046	0.302012

TABLE 4.B-2 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
2C	0.966	0.982	0.975	0.963	0.984	2.8	0.974	0.00859
2R	0.776	0.755	0.738	0.748	0.733	1.8	0.75	0.020115
3L	1.163	1.179	1.171	1.135	1.147	2.8	1.159	0.013805
3C	1.174	1.182	1.148	1.145	1.126	2.8	1.155	0.017659
3R	1.023	1.036	1.067	1.07	1.059	1.4	1.051	0.017493
4L	1.171	1.18	1.165	1.179	1.215	2.1	1.182	0.014712
4C	1.303	1.288	1.289	1.31	1.31	2.1	1.3	0.00749
4R	0.806	0.827	0.836	0.843	0.818	1.1	0.826	0.015822
1L/10/9/92	0.661	0.649	0.657	0.686	0.677	2.1	0.666	0.020323
1C	0.599	0.592	0.584	0.56	0.565	2.8	0.58	0.026102
1R	0.481	0.518	0.522	0.543	0.536	2.1	0.52	0.041371
2L	0.895	0.888	0.867	0.869	0.901	3.4	0.884	0.015511
2C	0.972	0.979	0.99	0.981	0.948	3.2	0.974	0.014592
2R	0.667	0.652	0.633	0.639	0.639	1.4	0.646	0.018883
3L	0.941	0.939	0.957	0.98	0.953	2.8	0.954	0.015406
3C	0.994	1.019	0.991	0.985	1.011	2.8	1	0.012837
3R	1.102	1.086	1.064	1.061	1.072	2.1	1.077	0.014118
4L	0.988	0.997	0.956	0.986	0.958	2.1	0.977	0.017152
4C	1.112	1.165	1.179	1.163	1.132	2.1	1.1502	0.021306
4R	1.038	1.01	0.982	0.979	0.991	2.1	1	0.021863
1L/10/9/92	0.701	0.705	0.748	0.722	0.714	2.8	0.718	0.023222
1C	0.495	0.553	0.528	0.525	0.499	2.2	0.52	0.04074
1R	0.488	0.502	0.491	0.474	0.445	2.2	0.48	0.040931
2L	1.026	1.033	1.048	1.007	1.001	3.8	1.023	0.016784
2C	0.986	0.994	0.972	0.961	0.957	3.8	0.974	0.014563
2R	0.835	0.814	0.802	0.803	0.806	3.8	0.812	0.015083
3L	1.099	1.083	1.316	1.095	1.087	3.2	1.136	0.079382
3C	1.101	1.092	1.113	1.125	1.124	3.8	1.111	0.011597
3R	1.213	1.255	1.238	1.207	1.242	2.8	1.231	0.014739
4L	1.255	1.225	1.238	1.276	1.256	3.8	1.25	0.013884
4C	1.489	1.463	1.431	1.427	1.44	3.8	1.45	0.015967
4R	1.267	1.257	1.259	1.261	1.261	3.8	1.261	0.002654
1L/10/14/92	0.632	0.656	0.665	0.644	0.608	2.5	0.641	0.031045
1C	0.487	0.472	0.499	0.531	0.511	2.5	0.5	0.040358
1R	0.478	0.464	0.433	0.447	0.478	2.5	0.46	0.038424
2L	0.719	0.736	0.712	0.706	0.732	2.8	0.721	0.015887
2C	1.863	1.441	1.087	1.075	1.069	3.5	1.307	0.238528
2R	0.652	0.671	0.649	0.634	0.624	2.8	0.646	0.024941
3L	1.09	1.11	1.101	1.062	1.085	3.5	1.0896	0.014964
3C	1.108	1.096	1.077	1.069	1.095	3.5	1.089	0.012921

TABLE 4.B-2 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
3R	1.18	1.131	1.153	1.124	1.182	2.5	1.154	0.020833
4L	1.165	1.188	1.144	1.151	1.147	2.5	1.159	0.013966
4C	1.313	1.302	1.326	1.339	1.345	2.8	1.325	0.012028
4R	1.935	1.081	1.06	1.062	1.057	2.5	1.239	0.280954
1L/10/14/92	0.675	0.689	0.671	0.646	0.649	1.8	0.666	0.024433
1C	0.538	0.547	0.551	0.533	0.531	1.8	0.54	0.01444
1R	0.542	0.529	0.518	0.506	0.505	1.8	0.52	0.02706
2L	0.851	0.844	0.865	0.869	0.871	2.8	0.86	0.01235
2C	1.032	1.067	1.049	1.041	1.065	3.5	1.0508	0.012886
2R	0.808	0.817	0.782	0.784	0.769	2.8	0.792	0.022402
3L	1.141	1.132	1.128	1.143	0.116	3.5	0.932	0.437809
3C	1.115	1.117	1.101	0.779	0.108	3.5	0.844	0.461915
3R	1.318	1.305	1.302	1.307	1.319	2.8	1.3102	0.005319
4L	1.212	1.201	1.236	1.224	1.262	3.8	1.227	0.017158
4C	1.366	1.353	1.345	1.35	1.336	3.8	1.35	0.007303
4R	1.164	1.181	1.199	1.16	1.166	4.1	1.174	0.012249
1L/10/15/92	0.707	0.715	0.689	0.674	0.675	2.1	0.692	0.023973
1C	0.556	0.569	0.543	0.537	0.495	2.1	0.54	0.046407
1R	0.607	0.618	0.605	0.636	0.634	3	0.62	0.02103
2L	0.849	0.831	0.848	0.832	0.826	2.5	0.8372	0.011291
2C	1.023	1.005	0.984	0.997	0.991	2.1	1	0.013416
2R	0.808	0.799	0.814	0.825	0.815	2.8	0.8122	0.010545
3L	1.094	1.087	1.063	1.052	1.044	3.4	1.068	0.018224
3C	1.071	1.066	1.053	1.089	1.056	3.4	1.067	0.011987
3R	1.016	1.024	1.029	1.028	1.028	1.4	1.025	0.004699
4L	1.119	1.117	1.106	0.811	0.277	2.5	0.886	0.368353
4C	1.212	1.217	1.206	1.164	1.201	2.5	1.2	0.015661
4R	1.808	0.882	0.887	0.896	0.899	1.4	1.0744	0.341447
2R/10/15/92	0.896	0.881	0.865	0.87	0.863	2.8	0.875	0.01396
3L	1.033	1.038	1.057	1.052	1.045	3.5	1.045	0.008408
3C	1.036	1.047	1.008	1.025	0.994	3.5	1.022	0.018617
3R	1.058	1.042	1.049	1.051	1.055	2.1	1.051	0.005211
4L	1.119	1.136	1.122	1.096	1.092	2.8	1.113	0.014905
4C	1.303	1.288	1.297	1.31	1.302	3.5	1.3	0.005611
4R	0.937	0.944	0.926	0.929	0.939	1.4	0.935	0.007062

TABLE 4.B-3 : DATA FOR NO-ASH ASPHALT WITHOUT DEICING MATERIAL

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1L/11/20/92	0.672	0.689	0.668	0.653	0.653	3.5	0.667	0.020137
1C	0.527	0.519	0.485	0.488	0.476	3.2	0.499	0.04038
1R	0.531	0.522	0.529	0.516	0.507	2.1	0.521	0.016864
2L	0.919	0.933	0.928	0.931	0.939	3.5	0.93	0.007067
2C	1.026	1.042	1.028	1.035	0.994	3.5	1.025	0.01609
2R	0.789	0.783	0.797	0.794	0.796	2.1	0.7918	0.006558
3L	1.025	1.032	1.018	1.018	1.022	3.5	1.023	0.005098
3C	0.986	0.994	1.013	1.017	0.985	3.5	0.999	0.013504
3R	1.134	1.15	1.149	1.162	1.175	3.5	1.154	0.011919
4L	1.056	1.069	1.061	1.071	1.083	2.1	1.068	0.008663
4C	1.19	1.185	1.176	1.172	1.152	2.1	1.175	0.011188
4R	0.744	0.742	0.736	0.735	0.738	0.7	0.739	0.004688
1L/11/20/92	0.626	0.618	0.611	0.608	0.612	2.9	0.615	0.010386
1C	0.478	0.485	0.474	0.479	0.484	2.5	0.48	0.008437
1R	0.437	0.443	0.432	0.428	0.459	1.9	0.4398	0.024632
2L	0.839	0.831	0.843	0.845	0.847	3.5	0.841	0.006726
2C	1.579	0.953	0.948	0.944	0.951	3.5	1.075	0.234436
2R	0.663	0.676	0.672	0.658	0.665	1.9	0.6668	0.009645
3L	0.99	0.997	1.011	1.009	1.003	2.7	1.002	0.007731
3C	1.248	1.256	1.261	1.244	1.211	3.5	1.244	0.014098
3R	1.086	1.095	1.089	1.11	1.166	2.8	1.1092	0.026668
4L	0.894	0.899	0.873	0.878	0.886	1.4	0.886	0.010896
4C	0.981	0.972	0.965	0.978	0.979	1.4	0.975	0.00598
4R	0.782	0.764	0.777	0.798	0.794	1.4	0.783	0.015579
1L/11/23/92	0.726	0.713	0.707	0.725	0.719	2.8	0.718	0.010043
1C	0.571	0.56	0.564	0.552	0.553	2.8	0.56	0.012627
1R	0.496	0.489	0.509	0.515	0.501	2.1	0.502	0.018344
2L	0.985	0.974	0.967	0.973	0.986	3.5	0.977	0.007521
2C	1.065	1.058	1.069	1.08	1.113	3.5	1.077	0.017976
2R	0.733	0.721	0.729	0.737	0.725	2.5	0.729	0.00776
3L	1.019	1.006	0.992	0.998	0.99	2.8	1.001	0.010572
3C	1.044	1.028	1.035	1.039	0.964	3.5	1.022	0.028834
3R	1.166	1.176	1.17	1.188	1.195	3.4	1.179	0.00926
4L	1.012	1.006	0.993	0.985	0.664	1.4	0.932	0.144137
4C	1.126	1.111	1.105	1.122	1.161	2	1.125	0.017337
4R	0.705	0.688	0.694	0.707	0.681	0.7	0.695	0.014244
1L/11/23/92	0.762	0.778	0.771	0.775	0.759	3.5	0.769	0.009556
1C	0.448	0.436	0.432	0.429	0.45	2.5	0.439	0.019329
1R	0.265	0.266	0.251	0.257	0.256	0.7	0.259	0.021977
2L	0.84	0.853	0.838	0.831	0.823	2.8	0.837	0.011924

TABLE 4.B-3 : *(Continued)*

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
2C	0.961	0.948	0.955	0.942	0.939	3.5	0.949	0.008561
2R	0.736	0.745	0.756	0.753	0.755	2.1	0.749	0.010098
3L	0.988	0.996	1.017	1.005	1.004	2.8	1.002	0.009676
3C	0.985	0.973	0.96	0.976	0.996	3.5	0.978	0.012321
3R	1.125	1.117	1.131	1.136	1.131	2.8	1.128	0.005773
4L	0.794	0.808	0.797	0.792	0.784	1.4	0.795	0.009808
4C	0.987	0.975	0.966	0.974	0.983	1.4	0.977	0.007521
4R	0.581	0.569	0.577	0.599	0.609	0.7	0.587	0.02513
1L/11/24/92	0.629	0.614	0.621	0.617	0.594	2.8	0.615	0.018935
1C	0.443	0.436	0.431	0.442	0.443	2.1	0.439	0.010877
1R	0.438	0.452	0.448	0.426	0.051	2.1	0.363	0.430465
2L	0.736	0.725	0.733	0.721	0.691	2.1	0.7212	0.022227
2C	1.067	1.062	1.073	1.079	1.104	3.5	1.077	0.013608
2R	0.878	0.864	0.875	0.88	0.877	3.5	0.8748	0.006442
3L	0.989	0.996	1.002	1.002	1.001	3.5	0.998	0.00503
3C	1.095	1.088	1.096	1.095	1.071	3.5	1.089	0.008673
3R	1.261	1.256	1.244	1.252	1.262	3.5	1.255	0.005237
4L	0.823	0.837	0.825	0.808	0.802	1.4	0.819	0.015309
4C	1.031	1.04	1.034	1.027	0.993	1.78	1.025	0.016149
4R	0.943	0.929	0.936	0.941	0.921	2.1	0.934	0.008672
1L/11/24/92	0.596	0.589	0.581	0.595	0.589	2.1	0.59	0.009096
1C	0.511	0.504	0.523	0.538	0.514	2.5	0.518	0.022612
1R	0.432	0.418	0.423	0.426	0.411	1.78	0.422	0.01689
2L	0.724	0.709	0.717	0.73	0.715	1.78	0.719	0.010144
2C	0.681	0.672	0.685	0.693	0.699	2.8	0.686	0.013675
2R	0.855	0.861	0.85	0.833	0.831	2.7	0.846	0.014145
3L	1.029	1.036	1.038	1.017	0.99	2.8	1.022	0.017228
3C	1.018	1.002	1.003	1.002	0.981	3.5	1.0012	0.011774
3R	1.006	0.993	0.985	0.991	1.015	2.1	0.998	0.01094
4L	0.879	0.897	0.885	0.88	0.889	1	0.886	0.007418
4C	1.158	1.142	1.137	1.146	1.162	1.78	1.149	0.008275
4R	0.747	0.749	0.736	0.727	0.731	1	0.738	0.01175
1L/11/25/92	0.467	0.462	0.47	0.455	0.451	1.4	0.461	0.015461
1C	0.36	0.369	0.357	0.362	0.042	1.4	0.298	0.429735
1R	0.368	0.346	0.351	0.362	0.363	1.4	0.358	0.02283
2L	0.641	0.64	0.652	0.667	0.655	1.78	0.651	0.015269
2C	0.882	0.875	0.86	0.873	0.865	2.5	0.871	0.008863
2R	0.762	0.756	0.774	0.763	0.779	2.1	0.7668	0.010986
3L	0.825	0.814	0.833	0.816	0.802	2.1	0.818	0.012822
3C	0.748	0.76	0.751	0.766	0.751	2.5	0.7552	0.008918

TABLE 4.B-3 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
3R	1.012	0.999	0.985	1.003	0.986	2.5	0.997	0.010327
4L	0.911	0.919	0.894	0.899	0.862	1.4	0.897	0.021835
4C	0.822	0.838	0.819	0.827	0.819	1	0.825	0.008639
4R	0.727	0.714	0.723	0.721	0.692	0.7	0.7154	0.017382
1L/11/25/92	0.754	0.738	0.736	0.742	0.745	2.8	0.743	0.008512
1C	0.522	0.516	0.508	0.518	0.531	3.5	0.519	0.014521
1R	0.6	0.592	0.607	0.613	0.603	3.5	0.603	0.011632
2L	0.872	0.88	0.865	0.846	0.837	3.5	0.86	0.018706
2C	1.019	1.004	1.013	1.031	1.058	3.5	1.025	0.018231
2R	0.837	0.846	0.832	0.811	0.839	3.2	0.833	0.014265
3L	1.051	1.058	1.044	1.027	1.39	3.5	1.114	0.124222
3C	1.116	1.105	1.128	1.133	1.128	3.5	1.122	0.009072
3R	1.239	1.224	1.217	1.231	1.244	2.8	1.231	0.007943
4L	1.015	1.001	0.996	0.991	0.992	2.5	0.999	0.008749
4C	1.228	1.241	1.233	1.216	1.207	3.5	1.225	0.009891
4R	1.032	1.045	1.037	1.019	1.082	2.8	1.043	0.020375
1L/11/26/92	0.773	0.784	0.775	0.761	0.752	3.5	0.769	0.014597
1C	0.455	0.464	0.467	0.452	0.467	2.8	0.461	0.01365
1R	0.449	0.453	0.467	0.462	0.459	2.8	0.458	0.013946
2L	0.936	0.948	0.931	0.915	0.915	3.5	0.929	0.013667
2C								
2R								
3L	1.063	1.056	1.028	1.032	1.046	3.5	1.045	0.012867
3C	1.029	1.043	1.016	1.002	1.005	3.5	1.019	0.015012
3R								
4L								
4C								
4R	0.967	0.949	0.975	0.993	1.006	2.1	0.978	0.020347
1L/11/26/92	0.705	0.69	0.698	0.684	0.683	3.5	0.692	0.012159
1C	0.569	0.543	0.554	0.546	0.573	2.8	0.557	0.021634
1R	0.437	0.45	0.444	0.435	0.439	2.1	0.441	0.012253
2L	1.026	1.008	1.01	0.983	0.973	3.5	1	0.019277
2C	0.954	0.936	0.945	0.958	0.952	2.8	0.949	0.008162
2R								
3L	1.078	1.094	1.088	1.081	1.104	3.5	1.089	0.008575
3C	1.061	1.052	1.047	1.066	1.099	3.5	1.065	0.01714
3R	1.023	0.988	1.007	0.994	0.603	3.5	0.923	0.173836
4L	1.078	1.063	1.085	1.099	1.11	2.1	1.087	0.015027
4C	1.126	1.138	1.112	1.103	1.106	2	1.117	0.011768
4R	0.955	0.967	0.969	0.951	0.948	2.1	0.958	0.008857

TABLE 4.B-4 : DATA FOR NO-ASH ASPHALT WITH DEICING MATERIAL

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1L/11/27/92	0.656	0.669	0.648	0.645	0.722	2.5	0.668	0.042289
1C	0.463	0.454	0.472	0.455	0.446	2.1	0.458	0.019283
1R	0.449	0.433	0.437	0.449	0.732	2.1	0.5	0.232351
2L	0.798	0.782	0.788	0.796	0.791	2.5	0.791	0.00724
2C	1.87	1.083	1.07	1.075	1.069	3.5	1.2334	0.258098
2R	0.681	0.694	0.678	0.686	0.696	2.8	0.687	0.010251
3L	1.099	1.083	1.075	1.088	1.12	2.8	1.093	0.014256
3C	1.034	1.012	1.022	0.983	0.954	3.5	1.001	0.028899
3R	1.163	1.146	1.149	1.155	1.157	2.8	1.154	0.005199
4L	0.736	0.744	0.757	0.753	0.755	1	0.749	0.010513
4C	0.855	0.869	0.861	0.848	0.822	1	0.851	0.018875
4R	0.712	0.723	0.729	0.714	0.707	0.7	0.717	0.011053
1L/11/27/92	0.456	0.451	0.466	0.47	0.462	1.4	0.461	0.014776
1C	0.819	0.415	0.429	0.41	0.422	1.78	0.499	0.320899
1R	0.316	0.332	0.328	0.322	0.312	1	0.322	0.022906
2L	0.865	0.879	0.861	0.848	0.852	2.1	0.861	0.012616
2C	0.81	0.796	0.791	0.803	0.775	2.1	0.795	0.014947
2R	0.748	0.743	0.766	0.757	0.746	2.1	0.752	0.011189
3L	0.849	0.836	0.84	0.832	0.848	1.78	0.841	0.007887
3C	0.813	0.818	0.804	0.789	0.786	2.1	0.802	0.015831
3R	0.942	0.933	0.957	0.946	0.967	1.78	0.949	0.012486
4L	0.877	0.881	0.905	0.901	0.866	1	0.886	0.01668
4C	0.888	0.896	0.91	0.904	0.892	1.4	0.898	0.008909
4R	1.496	0.536	0.515	0.501	0.537	0.4	0.717	0.543562
1L/11/30/92	1.64	0.626	0.62	0.613	0.601	2.8	0.82	0.500103
1C	0.538	0.534	0.493	0.523	0.517	3.5	0.521	0.030493
1R	0.569	0.597	0.572	0.566	0.591	2.8	0.579	0.021654
2L	0.856	0.871	0.879	0.852	0.842	3.5	0.86	0.015479
2C	1.084	1.074	1.067	1.078	1.082	3.5	1.077	0.005633
2R	0.826	0.815	0.831	0.84	0.853	3.5	0.833	0.01543
3L	1.037	1.023	1.048	1.051	1.066	3.5	1.045	0.013761
3C	0.983	0.995	0.972	0.968	0.972	3.5	0.978	0.010081
3R	1.224	1.217	1.199	1.203	1.182	3.2	1.205	0.012163
4L	1.018	1.005	1.019	0.989	0.974	2.5	1.001	0.017315
4C	1.213	1.206	1.204	1.227	1.275	3.5	1.225	0.021443
4R	0.734	0.741	0.748	0.744	0.728	1	0.739	0.009683
1L/11/30/92	0.722	0.734	0.725	0.707	0.702	2.8	0.718	0.016456
1C	0.598	0.588	0.605	0.612	0.607	3.5	0.602	0.013818
1R	0.613	0.624	0.592	0.56	0.601	3.5	0.598	0.036561
2L	0.985	0.997	0.991	1.009	1.018	3.5	1	0.012
2C	0.944	0.963	0.957	0.936	0.945	3.5	0.949	0.010216
2R	0.791	0.777	0.782	0.763	0.742	3.5	0.771	0.022179
3L	0.976	0.964	0.988	0.975	0.982	2.8	0.977	0.008188

TABLE 4.B-4 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
3C	1.054	1.039	1.065	1.077	1.1	3.5	1.067	0.019416
3R	1.162	1.186	1.174	1.161	1.212	3.2	1.179	0.015985
4L	1.083	1.088	1.062	1.075	1.147	2.8	1.091	0.026898
4C	1.361	1.345	1.367	1.342	1.335	3.5	1.35	0.008914
4R	0.917	0.902	0.904	0.91	0.932	1	0.913	0.011878
1L/12/1/92	0.672	0.678	0.663	0.655	0.022	3.5	0.538	0.479774
1C	0.57	0.554	0.562	0.565	0.554	2.8	0.561	0.01116
1R	0.433	0.426	0.435	0.44	0.456	2.5	0.438	0.022968
2L	0.878	0.854	0.861	0.851	0.856	3.5	0.86	0.011129
2C	1.136	1.119	1.104	1.085	1.066	3.5	1.102	0.022353
2R	0.865	0.873	0.858	0.879	0.901	3.5	0.8752	0.01683
3L	1.274	1.292	1.281	1.27	1.248	3.5	1.273	0.011438
3C	1.016	1.001	1.036	1.048	1.009	3.5	1.022	0.017049
3R	1.121	1.13	1.154	1.125	1.11	3.5	1.128	0.01292
4L	1.049	1.067	1.051	1.032	1.026	1.8	1.045	0.013973
4C	1.352	1.368	1.334	1.33	1.361	3.5	1.349	0.010995
4R	1.026	1.011	1.003	1.034	1.036	2.1	1.022	0.012667
1L/12/1/92	0.626	0.608	0.619	0.624	0.598	2.5	0.615	0.017147
1C	0.594	0.586	0.601	0.609	0.62	3.5	0.602	0.01957
1R	0.548	0.567	0.55	0.552	0.578	2.8	0.559	0.020801
2L	0.971	0.988	0.992	0.973	0.956	3.5	0.976	0.013233
2C	1.064	1.79	1.085	1.069	1.088	3.5	1.2192	0.234208
2R	0.836	0.823	0.837	0.836	0.508	3.5	0.768	0.169405
3L	1.025	1.032	1.041	1.017	1	3.5	1.023	0.013643
3C	0.981	0.99	0.997	1.015	1.007	3.5	0.998	0.012057
3R	1.166	1.173	1.192	1.178	1.186	2.8	1.179	0.007811
4L	1.23	1.216	1.188	1.201	1.185	2.8	1.204	0.014124
4C	1.369	1.377	1.384	1.37	0.375	3.5	1.175	0.340457
4R	0.582	0.579	0.591	0.585	0.598	0.7	0.587	0.011554
1L/12/2/92	0.624	0.617	0.609	0.621	0.604	2.5	0.615	0.012124
1C	0.483	0.486	0.482	0.466	0.478	2.5	0.479	0.014584
1R	0.531	0.522	0.507	0.509	0.521	2.1	0.518	0.01718
2L	0.385	0.945	0.936	0.92	0.919	3.2	0.821	0.265799
2C	1.011	1.025	0.994	0.99	0.975	2.8	0.999	0.017349
2R	0.787	0.799	0.772	0.776	0.826	2.1	0.792	0.024522
3L	1.018	1.013	1.036	1.027	1.021	3.5	1.023	0.007746
3C	1.041	1.049	1.065	1.063	1.002	2.8	1.044	0.021842
3R	0.884	0.862	0.866	0.877	0.871	2.5	0.872	0.008971
4L	2.013	0.746	0.785	0.783	0.778	1	1.021	0.485995
4C	1.093	1.098	1.088	1.114	1.102	2.1	1.099	0.008057
4R	0.705	0.71	0.691	0.686	0.688	0.7	0.696	0.013871
1L/12/2/92	0.653	0.68	0.679	0.664	0.649	3.4	0.665	0.019281
1C	0.526	0.544	0.537	0.541	0.547	3.5	0.539	0.013532

TABLE 4.B-4 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1R	0.441	0.462	0.476	0.455	0.456	2.5	0.458	0.024741
2L	1.048	1.04	1.067	1.059	1.016	3.5	1.046	0.016833
2C	1.166	1.181	1.143	1.149	1.131	3.5	1.154	0.015247
2R	0.935	0.942	0.932	0.928	0.948	3.5	0.937	0.007637
3L	1.101	1.126	1.122	1.109	1.112	3.5	1.114	0.008089
3C	1.097	1.116	1.078	1.08	1.074	3.5	1.089	0.014344
3R	1.172	1.195	1.184	1.161	1.183	3.4	1.179	0.009818
4L	1.013	1.026	1.022	1.027	0.612	2	0.94	0.174547
4C	1.36	1.365	1.389	1.396	1.364	3.5	1.3748	0.010704
4R	0.735	0.745	0.751	0.738	0.726	0.7	0.739	0.011577

TABLE 4.B-5 : DATA FOR ASH-CONCRETE WITHOUT DEICING

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1L/11/2/92	1.539	0.801	0.773	0.765	0.737	3.5	0.923	0.334425
1C	0.597	0.603	0.609	0.596	0.596	2.8	0.6002	0.008522
1R	0.592	0.595	0.594	0.611	0.607	2.8	0.5998	0.012802
2L	0.955	0.943	0.948	0.969	0.95	3.5	0.953	0.009315
2C	1.029	1.052	1.055	1.066	1.053	3.5	1.051	0.011497
2R	1.03	1.011	1.016	1.08	0.968	3.5	1.021	0.035303
3L	1.108	1.115	1.121	1.122	1.104	3.5	1.114	0.006347
3C	1.139	1.134	1.136	1.13	1.126	3.5	1.133	0.004025
3R	1.122	1.141	1.135	1.129	1.113	2.8	1.128	0.008686
4L	1.056	1.059	1.044	1.047	1.019	1.8	1.045	0.01352
4C	1.19	1.18	1.08	1.05	1	2.1	1.1	0.067297
1L/11/2/92	0.802	0.799	0.796	0.796	0.782	2.8	0.795	0.008642
1C	0.513	0.501	0.499	0.503	0.485	2.8	0.5002	0.017988
1R	0.513	0.532	0.529	0.528	0.503	2.5	0.521	0.021408
2L	0.988	0.98	0.964	0.966	0.962	3.5	0.972	0.010492
2C	1.104	1.108	1.107	1.104	1.087	3.5	1.102	0.006958
2R	0.902	0.898	0.904	0.905	0.871	3.5	0.896	0.014205
3L	1.122	1.117	1.116	1.11	1.105	3.5	1.114	0.005295
3C	1.076	1.083	1.088	1.091	1.107	3.5	1.089	0.00949
3R	1.129	1.132	1.137	1.125	1.117	2.5	1.128	0.005987
4L	1.144	1.138	1.137	1.133	1.128	2.5	1.136	0.004691
4C	1.268	1.278	1.271	1.271	1.287	2.8	1.275	0.005366
4R	1.098	1.084	1.085	1.078	1.09	2.8	1.087	0.006158
1L/11/3/92	0.723	0.737	0.729	0.755	0.771	2.1	0.743	0.023773
1C	0.466	0.457	0.436	0.444	0.407	1.8	0.442	0.045989
1R	0.44	0.438	0.453	0.449	0.445	1.8	0.445	0.012471
2L	0.886	0.892	0.897	0.875	0.87	2.8	0.884	0.011469
2C	0.972	0.968	0.961	0.965	1.004	2.9	0.974	0.015839
2R	0.888	0.873	0.878	0.881	0.855	2.1	0.875	0.012706
3L	1.16	1.166	1.169	1.17	1.13	3.2	1.159	0.012867
3C	3.022	1.03	1.013	1.018	1.027	2.8	1.422	0.562604
3R	1.273	1.284	1.281	1.273	1.299	2.5	1.282	0.007449
4L	0.782	0.766	0.771	0.726	0.705	1.4	0.75	0.039201
1L/11/3/92	0.649	0.687	0.658	0.676	0.66	2.1	0.666	0.020478
1C	0.485	0.498	0.517	0.513	0.492	2.1	0.501	0.024381
1R	0.513	0.509	0.521	0.507	0.465	1.8	0.503	0.038958
2L								
2C								
2R	1.116	1.114	1.105	1.094	1.081	3.5	1.102	0.011859
3L	1.168	1.154	1.165	1.16	1.148	3.5	1.159	0.00627

TABLE 4.B-5 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
3C	1.152	1.146	1.141	1.137	1.089	3.5	1.133	0.019917
3R	1.009	1.016	1.022	1.03	1.048	2.5	1.025	0.013089
4L	1.073	1.04	0.789	0.776	0.754	0.7	0.8864	0.157633
4C	1.384	1.375	1.366	1.013	0.862	3.5	1.2	0.183049
4R	0.908	0.917	0.885	0.892	0.853	1.8	0.891	0.024824
1L/11/4/92	0.678	0.698	0.707	0.703	0.674	1.8	0.692	0.019409
1L/11/2/92	1.539	0.801	0.773	0.765	0.737	3.5	0.923	0.334425
1C	0.495	0.491	0.518	0.497	0.499	1.8	0.5	0.018762
1R	0.555	0.547	0.551	0.541	0.506	2.4	0.54	0.032626
2L								
2C	1.252	1.249	1.194	1.222	1.238	2.8	1.231	0.017286
2R								
3L	1.141	1.132	1.138	1.133	0.468	3.5	1.0024	0.26658
3C	0.883	0.894	0.891	0.888	0.554	2.8	0.822	0.163077
3R	1.322	1.316	1.288	1.293	1.321	2.1	1.308	0.0111
4L	1.941	1.331	0.846	0.84	0.837	1	1.159	0.375005
4C	1.398	1.308	1.245	1.248	1.051	2.5	1.25	0.091142
4R	1.066	1.048	1.039	1.018	1.044	1.4	1.043	0.014828
1L/11/4/92	0.774	0.786	0.806	0.817	0.792	3.5	0.795	0.01896
1C	0.636	0.611	0.619	0.609	0.625	3.5	0.62	0.015869
1R	0.522	0.556	0.548	0.555	0.519	2.8	0.54	0.029975
2L								
2C	1.131	1.144	1.125	1.132	1.108	3.5	1.128	0.010414
2R								
3L	1.119	1.115	1.038	1.095	1.088	3.5	1.091	0.026546
3C	1.047	1.059	1.08	1.072	1.077	3.5	1.067	0.011539
3R	1.295	1.273	1.281	1.286	1.275	3.5	1.282	0.006201
4L	1.072	1.084	1.058	1.055	1.071	2.8	1.068	0.00982
4C	1.179	1.163	1.173	1.182	1.178	2.8	1.175	0.005671
4R	0.889	0.882	0.872	0.858	0.844	1	0.869	0.018726
1L/11/5/92	0.778	0.781	0.766	0.769	0.751	2.8	0.769	0.013737
1C	0.614	0.625	0.604	0.618	0.639	2.8	0.62	0.018837
1R	0.556	0.539	0.537	0.535	0.533	2.1	0.54	0.015271
2L	1.044	1.038	1.018	1.014	1.001	3.5	1.023	0.015493
2C	1.048	1.035	1.021	1.02	1.01	2.8	1.0268	0.012911
2R	0.743	0.749	0.742	0.738	0.778	2.1	0.75	0.019248
3L	1.047	1.077	1.069	1.062	1.085	3.5	1.068	0.012194
3C	1.139	1.124	1.116	1.128	1.158	3.5	1.133	0.012827
3R	1.142	1.148	1.112	1.12	1.118	2.8	1.128	0.012637
4L	0.89	0.898	0.915	0.923	0.919	1.4	0.909	0.014037

TABLE 4.B-5 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
4C	1.384	1.366	1.379	1.376	1.37	3.5	1.375	0.004645
4R	0.851	0.843	0.888	0.879	0.884	1	0.869	0.021131
1L/11/5/92	0.708	0.711	0.696	0.675	0.67	2.8	0.692	0.024233
1C	0.663	0.648	0.651	0.639	0.599	3.2	0.64	0.034204
1R	0.595	0.592	0.588	0.566	0.559	2.8	0.58	0.025222
2L	1.033	1.02	1.017	1.025	0.905	3.5	1	0.047808
2C	1.087	1.099	1.116	1.108	1.1	3.5	1.102	0.008798
2R	0.744	0.763	0.769	0.765	0.814	2.5	0.771	0.030039
3L	1.151	1.145	1.126	1.122	0.226	3.5	0.954	0.381725
3C	1.128	1.109	1.104	1.103	0.221	3.5	0.933	0.381687
3R	1.273	1.244	1.261	1.255	1.243	3.2	1.2552	0.008906
4L	1.189	1.186	1.175	1.178	0.497	2.8	1.045	0.262246
4C	1.212	1.202	1.193	1.188	1.205	2.5	1.2	0.00713
1L/11/2/92	1.539	0.801	0.773	0.765	0.737	3.5	0.923	0.334425
4R	0.751	0.775	0.769	0.746	0.764	0.7	0.761	0.014323
1L/11/6/92	0.788	0.779	0.813	0.802	0.793	2.8	0.795	0.014691
1C	0.641	0.629	0.606	0.603	0.623	2.8	0.6204	0.022968
1R	0.559	0.548	0.534	0.519	0.14	2.5	0.46	0.349049
2L	1.028	1.008	1.002	0.989	0.973	3.5	1	0.01845
2C	1.107	1.115	1.079	1.091	1.118	3.5	1.102	0.01346
2R	0.913	0.888	0.895	0.9	0.884	3.5	0.896	0.011316
3L	1.015	1.028	1.032	1.022	1.013	3.5	1.022	0.007137
3C	1.124	1.103	1.106	0.977	0.58	3.5	0.978	0.21041
3R	1.225	1.212	1.203	1.202	1.183	2.8	1.205	0.011415
4L	1.036	1.018	1.024	1.005	1.032	2.5	1.023	0.010708
4C	1.208	1.213	1.225	1.235	1.244	2.1	1.225	0.010916
4R	0.722	0.738	0.733	0.725	0.667	0.7	0.717	0.035754
1L/11/6/92	0.758	0.748	0.724	0.735	0.75	2.5	0.743	0.016196
1C	0.596	0.582	0.569	0.565	0.588	2.5	0.58	0.019958
1R	0.536	0.554	0.527	0.539	0.544	2.1	0.54	0.016522
2L	1.083	1.114	1.107	1.099	1.062	2.8	1.093	0.017038
2C	1.221	1.207	1.201	1.216	1.18	2.8	1.205	0.011865
2R	0.686	0.672	0.669	0.698	0.71	2.8	0.687	0.02255
3L	1.101	1.105	1.115	1.116	1.133	3.5	1.114	0.009964
3C	1.105	1.148	1.151	1.124	1.137	3.5	1.133	0.014926
3R	1.158	1.166	1.175	1.139	1.132	2.8	1.154	0.014026
4L	1.243	1.221	1.208	1.219	1.244	3.5	1.227	0.01156
4C	1.475	1.482	1.488	1.462	1.468	4.4	1.475	0.006331
4R	1.037	1.055	1.036	1.024	1.063	2.4	1.043	0.013491
1L/11/6/92	0.679	0.676	0.648	0.655	0.672	3.5	0.666	0.01839

TABLE 4.B-5 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1C	0.627	0.664	0.658	0.668	0.683	3.4	0.66	0.027954
1R	0.636	0.622	0.617	0.611	0.614	2.8	0.62	0.014172
2L	0.975	0.98	0.988	0.957	0.985	3.5	0.977	0.011194
2C	1.129	1.117	1.088	1.093	1.083	3.5	1.102	0.016192
2R	0.787	0.801	0.816	0.799	0.757	2.1	0.792	0.024973
3L	1.054	1.046	1.049	1.052	1.024	3.5	1.045	0.010377
3C	1.019	1.016	1.01	1.034	1.031	3.5	1.022	0.008904
3R	1.277	1.273	1.248	1.252	1.23	3.4	1.256	0.013726
4L	1.311	1.303	1.214	1.172	0.795	3.5	1.159	0.163493
4C	1.239	1.211	1.245	1.221	1.209	2.8	1.225	0.011908
4R	0.774	0.755	0.749	0.768	0.759	1	0.761	0.011783

TABLE 4.B-6 : DATA FOR ASH-CONCRETE WITH DEICING MATERIAL

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 min	i in/hr	mVavg	SD/mVavg
1L/11/9/92	0.806	0.817	0.773	0.769	0.81	3.5	0.795	0.025094
1C	0.666	0.651	0.672	0.679	0.63	3.4	0.66	0.025408
1R	0.584	0.599	0.592	0.559	0.57	2.5	0.58	0.026239
2L	1.038	1.03	1.012	1.017	1.02	3.5	1.023	0.009335
2C	1.137	1.103	1.11	1.125	1.17	3.5	1.128	0.019455
2R	0.899	0.903	0.888	0.891	0.9	3.5	0.8958	0.006131
3L	1.075	1.083	1.105	1.094	1.1	3.5	1.091	0.009821
3C	1.099	1.086	1.079	1.085	1.1	3.4	1.089	0.006798
3R	1.123	1.125	1.147	1.132	1.11	2.8	1.128	0.009998
4L	1.255	1.246	1.243	1.261	1.25	3.4	1.25	0.005496
4C	1.107	1.094	1.092	1.11	1.1	2.1	1.1	0.00653
4R	0.846	0.833	0.812	0.819	0.85	0.85	0.8314	0.016918
1L/11/9/92	0.781	0.748	0.765	0.773	0.78	3.5	0.769	0.015364
1C	0.626	0.613	0.634	0.64	0.59	3.5	0.62	0.030347
1R	0.552	0.559	0.543	0.532	0.51	2.8	0.54	0.029327
2L	0.965	0.972	0.984	0.968	1	3.5	0.977	0.01176
2C	1.118	1.107	1.101	1.098	1.09	3.5	1.102	0.009552
2R	0.866	0.878	0.883	0.873	0.26	3.4	0.751	0.330311
3L	1.122	1.11	1.107	1.101	1.13	3.5	1.113	0.008176
3C	1.14	1.145	1.132	1.116	1.13	3.5	1.133	0.008684
3R	1.239	1.247	1.268	1.266	1.26	3.4	1.256	0.008937
4L	1.253	1.271	1.238	1.242	1.25	3.5	1.25	0.009288
4C	1.216	1.213	1.224	1.217	1.26	2.1	1.225	0.012594
4R	0.771	0.765	0.768	0.77	0.73	1	0.761	0.019894
1L/11/10/92	0.751	0.767	0.755	0.774	0.8	3.5	0.769	0.021682
1C	0.646	0.632	0.645	0.661	0.62	3.2	0.64	0.023614
1R	0.541	0.538	0.528	0.503	0.49	2.5	0.5202	0.038049
2L	1.016	1.002	0.987	0.986	1	3.5	0.999	0.01129
2C	1.094	1.099	1.087	1.099	1.13	3.5	1.102	0.01375
2R	0.863	0.852	0.856	0.844	0.85	3.2	0.8538	0.007197
3L	1.147	1.161	1.169	1.153	1.17	3.5	1.159	0.006903
3C	1.027	1.006	1.008	1.024	1.05	2.8	1.022	0.013907
3R	1.283	1.299	1.285	1.263	1.28	2.5	1.282	0.008989
4L	1.136	1.155	1.147	1.142	1.16	2.8	1.1482	0.007778
4C	1.242	1.259	1.249	1.244	1.26	2.5	1.25	0.005282
4R	0.769	0.773	0.765	0.752	0.75	0.7	0.761	0.013529
1L/11/11/92	0.678	0.664	0.659	0.646	0.68	3.5	0.666	0.019987
1C	0.611	0.601	0.588	0.596	0.2	3.5	0.5184	0.311289
1R	0.617	0.622	0.605	0.589	0.57	2.8	0.601	0.030663
2L	0.951	0.963	0.969	0.942	0.94	3.5	0.953	0.011964

TABLE 4.B-6 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 min	i in/hr	mVavg	SD/mVavg
2C	1.236	1.252	1.257	1.278	1.26	3.5	1.256	0.010694
2R	0.784	0.771	0.765	0.768	0.77	2.8	0.772	0.008395
3L	1.134	1.119	1.105	1.101	1.11	3.5	1.113	0.010886
3C	1.153	1.168	1.147	1.162	1.17	3.5	1.159	0.00675
3R	1.265	1.251	1.249	1.243	1.27	3.5	1.256	0.008575
4L	1.148	1.144	1.13	1.126	1.13	2.8	1.136	0.007469
4C	1.204	1.209	1.211	1.172	0.33	2.2	1.025	0.339792
4R	0.843	0.836	0.857	0.855	0.85	0.7	0.848	0.009134
1L/11/11/92	0.739	0.752	0.733	0.757	0.73	3.2	0.743	0.013104
1C	0.575	0.588	0.581	0.574	0.58	3.2	0.58	0.008791
1R	0.622	0.604	0.581	0.593	0.6	2.8	0.599	0.022768
2L	0.942	0.969	0.958	0.95	0.95	3.5	0.953	0.010065
2C	1.107	1.098	1.085	1.095	1.13	3.5	1.102	0.012229
2R	0.904	0.891	0.895	0.896	0.89	3.5	0.896	0.004839
3L	2.046	1.141	1.139	1.138	1.13	3.5	1.318	0.276205
3C	1.119	1.124	1.128	1.109	1.08	3.5	1.111	0.017182
3R	1.135	1.124	1.122	1.124	1.14	2.8	1.128	0.005108
4L	1.223	1.231	1.239	1.224	1.22	3.2	1.227	0.005944
4C	1.214	1.226	1.235	1.225	1.22	2.8	1.2248	0.00545
4R	0.727	0.719	0.71	0.716	0.71	0.7	0.717	0.008132
1L/11/13/92	0.778	0.784	0.766	0.761	0.76	3.5	0.769	0.013614
1C	2.341	0.598	0.597	0.594	0.62	3.4	0.949	0.733444
1R	0.629	0.609	0.631	0.637	0.59	2.8	0.62	0.025887
2L	0.998	0.995	0.999	1.002	1.01	3.5	1	0.003742
2C	1.121	1.107	1.094	1.098	1.09	3.5	1.102	0.010023
2R	0.883	0.878	0.866	0.859	0.89	3.5	0.875	0.012582
3L	1.039	1.032	1.027	1.038	1.09	3.5	1.045	0.021458
3C	1.095	1.105	1.081	1.078	1.09	3.4	1.089	0.009053
3R	1.287	1.274	1.27	1.293	1.29	3.4	1.282	0.00671
4L	1.259	1.262	1.265	1.257	1.21	3.4	1.25	0.017336
4C	1.311	1.302	1.3	1.294	1.29	2.8	1.2992	0.005748
4R	2.122	0.718	0.715	0.712	0.72	0.7	0.998	0.563138
1L/11/13/92	0.707	0.701	0.684	0.687	0.68	2.5	0.692	0.01468
1C	0.57	0.558	0.561	0.555	0.55	2.9	0.559	0.011483
1R	0.562	0.573	0.595	0.586	0.59	2.1	0.581	0.02051
2L	1.02	1.007	1.001	0.991	0.98	3.5	0.999	0.014861
2C	1.115	1.102	1.086	1.098	1.11	3.5	1.102	0.008983
2R	0.866	0.871	0.849	0.844	0.84	3.2	0.854	0.014379
3L	1.118	1.127	1.125	1.13	1.18	3.5	1.1362	0.020019
3C	1.056	1.044	1.069	1.072	1.09	3.5	1.067	0.015727

TABLE 4.B-6 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 min	i in/hr	mVavg	SD/mVavg
3R	1.267	1.249	1.255	1.254	1.26	3.2	1.256	0.004724
4L	1.241	1.226	1.232	1.263	1.28	3.3	1.249	0.016924
4C	1.192	1.172	1.168	1.161	1.18	2.8	1.175	0.009261
4R	0.959	0.943	0.952	0.955	0.97	1.7	0.956	0.009587
1L/11/16/92	0.781	0.763	0.771	0.775	0.76	2.8	0.769	0.011861
1C	0.615	0.626	0.609	0.611	0.63	2.8	0.619	0.015394
1R	0.544	0.557	0.552	0.536	0.52	2.8	0.541	0.026607
2L	1.028	1.026	1.016	1.002	0.93	3.5	1.001	0.03519
2C	1.11	1.114	1.103	1.094	1.09	3.5	1.102	0.008532
2R	1.006	1.009	0.993	0.995	0.99	2.8	0.999	0.007078
3L	1.134	1.139	1.131	1.14	1.12	3.5	1.132	0.00764
3C	1.048	1.032	1.039	1.051	1.05	3.5	1.044	0.007039
3R	1.237	1.248	1.255	1.252	1.29	3.5	1.256	0.013633
4L	1.25	1.263	1.259	1.233	1.24	3.5	1.2488	0.00915
4C	1.171	1.178	1.183	1.185	1.16	2.8	1.175	0.008321
4R	1.055	1.037	1.039	1.034	1.05	1.4	1.0428	0.007585
1L/11/16/92	0.772	0.778	0.758	0.768	2.18	3.4	1.051	0.536668
1C	0.624	0.631	0.635	0.627	0.58	2.8	0.619	0.033655
1R	0.589	0.58	0.575	0.576	0.59	2.5	0.581	0.009172
2L	0.993	1.005	1.004	1.009	1	3.5	1.002	0.005503
2C	1.064	1.072	1.087	1.076	1.09	3.5	1.0771	0.008149
2R	0.829	0.814	0.835	0.833	0.85	2.8	0.833	0.015392
3L	1.027	1.034	1.022	1.018	1.01	3.5	1.023	0.006829
3C	1.125	1.116	1.097	1.105	1.11	3.4	1.11	0.008679
3R	1.144	1.153	1.151	1.162	1.16	2.8	1.154	0.005616
4L	1.265	1.238	1.247	1.255	1.24	3.4	1.248	0.008836
4C	1.121	1.113	1.108	1.127	1.13	2.2	1.119	0.006615
4R	0.709	0.721	0.725	0.703	0.73	0.7	0.717	0.013083

TABLE 4.B-7 : DATA FOR ASH-ASPHALT WITHOUT DEICING MATERIAL

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1L/12/4/92	0.672	0.655	0.653	0.661	0.684	3.5	0.665	0.017407
1C	0.523	0.533	0.519	0.508	0.512	3.5	0.519	0.016841
1R	0.454	0.466	0.47	0.462	0.458	2.1	0.462	0.012244
2L	0.902	0.919	0.924	0.92	0.871	3.5	0.9072	0.021616
2C	0.851	0.857	0.863	0.848	0.811	3.5	0.846	0.021564
2R	0.689	0.669	0.675	0.698	0.704	2.8	0.687	0.019333
3L	0.967	0.944	0.946	0.973	0.939	3.5	0.9538	0.014212
3C	1.088	1.093	1.097	1.086	1.081	2.8	1.089	0.005096
3R								
4L	0.99	0.975	0.971	0.983	0.966	2.1	0.977	0.008757
4C								
4R	0.922	0.936	0.94	0.912	0.965	2.1	0.935	0.019275
1L/12/7/92	0.661	0.673	0.675	0.659	0.662	3.5	0.666	0.00996
1C	0.512	0.536	0.529	0.51	0.518	3.5	0.521	0.019194
1R	0.531	0.517	0.524	0.513	0.505	2.8	0.518	0.017267
2L	0.889	0.872	0.866	0.881	0.917	3.5	0.885	0.020124
2C	1.498	0.975	0.997	1.001	1.039	3.5	1.102	0.180642
2R	0.796	0.808	0.779	0.781	0.786	2.8	0.79	0.01361
3L	0.897	0.883	0.869	0.878	0.893	3.5	0.884	0.011447
3C	0.881	0.875	0.848	0.852	0.884	3.2	0.868	0.017319
3R	1.027	1.043	1.036	1.023	0.981	2.8	1.022	0.021186
4L	0.899	0.885	0.914	0.946	0.446	2.1	0.818	0.22873
4C	1.138	1.112	1.127	1.159	1.199	2.8	1.147	0.026312
4R	0.819	0.808	0.823	0.834	0.841	1.78	0.825	0.013989
1L/12/7/92	0.66	0.639	0.648	0.637	0.626	3.5	0.642	0.01776
1C	0.492	0.485	0.506	0.501	0.5	3.5	0.4968	0.014923
1R	0.494	0.487	0.477	0.469	0.488	2.8	0.483	0.018379
2L	0.825	0.801	0.816	0.813	0.805	3.5	0.812	0.010392
2C	0.921	0.908	0.88	0.891	0.895	3.5	0.899	0.015778
2R	0.747	0.763	0.752	0.757	0.747	3.2	0.7532	0.008158
3L	0.969	0.984	0.988	0.978	0.961	3.5	0.976	0.010101
3C	0.953	0.976	0.964	0.942	0.925	3.5	0.952	0.018495
3R	1.01	0.993	0.988	1.002	0.987	2.8	0.996	0.008822
4L	0.926	0.907	0.96	0.923	0.489	2.8	0.841	0.210279
4C	1.232	1.249	1.236	1.215	1.208	2.5	1.228	0.012023
4R	0.828	0.814	0.817	0.843	0.813	2.1	0.823	0.013768
1L/12/8/92	1.345	0.707	0.698	0.699	0.656	2.8	0.821	0.319861
1C	0.516	0.507	0.482	0.491	0.519	2.8	0.503	0.028479
1R	0.322	0.329	0.314	0.314	0.306	1	0.317	0.024759
2L	0.875	0.85	0.862	0.858	0.861	3.5	0.8612	0.009388
2C	0.954	0.969	0.944	0.941	0.932	3.5	0.948	0.013326
2R	0.662	0.648	0.65	0.663	0.692	2.1	0.663	0.023714
3L	0.988	0.97	0.981	0.962	0.974	2.8	0.975	0.009174

TABLE 4.B-7 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
3C	0.963	0.925	0.942	0.971	0.954	3.5	0.951	0.01702
3R	1.037	1.011	1.022	1.029	1.041	2.5	1.028	0.010441
4L	1.021	1.043	1.024	1.017	1.02	2.5	1.025	0.009047
4C	0.936	1.006	0.936	0.945	0.922	2.1	0.949	0.031017
4R	0.725	0.738	0.713	0.721	0.698	1.4	0.719	0.01843
1L/12/8/92	0.627	0.632	0.608	0.599	0.603	3.2	0.6138	0.02155
1C	0.503	0.497	0.486	0.495	0.524	3.5	0.501	0.025405
1R	0.491	0.504	0.503	0.492	0.506	3.5	0.4992	0.012758
2L	0.99	0.988	0.976	0.964	0.962	3.5	0.976	0.011949
2C	1.055	1.087	1.078	1.069	1.081	3.5	1.074	0.010368
2R	0.771	0.774	0.789	0.765	0.766	2.8	0.773	0.011188
3L	1.049	1.038	1.056	1.04	1.052	2.8	1.047	0.006617
3C	0.929	0.91	0.907	0.916	0.898	3.2	0.912	0.011289
3R	1.096	1.082	1.065	1.075	1.047	2.8	1.073	0.015336
4L	1.017	1.032	1.003	1.019	1.034	2.1	1.021	0.011029
4C	1.142	1.138	1.157	1.141	1.162	2.8	1.148	0.008373
4R	0.731	0.724	0.716	0.706	0.713	1.4	0.718	0.01211
1L/12/9/92	1.075	0.56	0.561	0.568	0.571	2.1	0.667	0.30591
1C								
1R	0.934	0.434	0.437	0.448	0.437	2.1	0.538	0.368137
2L	0.501	0.496	0.514	0.505	0.534	2.8	0.51	0.026219
2C	0.83	0.814	0.822	0.811	0.808	2.6	0.817	0.009792
2R	0.535	0.546	0.526	0.539	0.559	1.4	0.541	0.020483
3L	0.943	0.904	0.897	0.912	0.889	2.1	0.909	0.020487
3C								
3R								
4L	0.733	0.728	0.73	0.723	0.716	1.4	0.726	0.008218
4C								
4R								
1L/12/9/92	0.556	0.541	0.569	0.569	0.575	3.4	0.562	0.021705
1C								
1R	0.439	0.432	0.444	0.437	0.448	3.5	0.44	0.012613
2L	0.807	0.825	0.804	0.809	0.815	3.4	0.812	0.00915
2C	0.801	0.788	0.799	0.782	0.795	2.8	0.793	0.008917
2R								
3L	0.904	0.905	0.923	0.919	0.904	2.8	0.911	0.009078
3C	0.977	0.991	0.986	0.962	0.954	2.1	0.974	0.014418
3R								
4L	1.019	1.002	1.027	1.04	1.028	2.1	1.0232	0.01226
4C								
4R	0.722	0.7	0.713	0.736	0.709	1.1	0.716	0.017105
1L/12/9/92	0.632	0.647	0.648	0.639	0.624	3.5	0.638	0.014262
1C	0.516	0.499	0.503	0.474	0.488	3.5	0.496	0.028598

TABLE 4.B-7 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1R	0.449	0.443	0.47	0.467	0.451	2.1	0.456	0.023208
2L	0.855	0.836	0.862	0.854	0.883	3.5	0.858	0.017676
2C	1.009	1.007	0.993	0.981	1.01	3.5	1	0.011314
2R	0.791	0.778	0.784	0.796	0.711	2.1	0.772	0.040293
3L	0.965	0.959	0.987	0.992	0.982	3.5	0.977	0.013092
3C	0.942	0.924	0.956	0.926	0.932	3.5	0.936	0.012605
3R	0.984	0.991	1.017	1.009	1.019	2.8	1.004	0.014001
4L	1.008	1.068	1.033	0.991	0.995	2.8	1.019	0.028026
4C	1.251	1.266	1.272	1.234	1.247	2.8	1.254	0.010852
4R	0.833	0.847	0.811	0.813	0.286	2.1	0.718	0.301405
1L/12/10/92	0.525	0.51	0.503	0.518	0.524	3.5	0.516	0.016307
1C	0.573	0.577	0.581	0.595	0.594	3.5	0.584	0.015316
1R	0.469	0.451	0.452	0.443	0.46	2.8	0.455	0.01941
2L	0.878	0.863	0.884	0.896	0.879	3.5	0.88	0.01209
2C	1.089	1.072	1.075	1.064	1.09	3.5	1.078	0.009332
2R	0.768	0.775	0.796	0.754	0.777	3.2	0.774	0.01762
3L	1.121	1.113	1.148	1.145	1.153	3.5	1.136	0.014018
3C	1.085	1.099	1.073	1.067	1.126	3.5	1.09	0.019331
3R	1.182	1.198	1.189	1.21	1.226	2.8	1.201	0.013006
4L	1.049	1.044	1.066	1.052	1.024	2.8	1.047	0.013012
4C	1.156	1.159	1.179	1.143	1.118	2.8	1.151	0.017489
4R	0.991	0.996	1.008	1.018	1.012	2.5	1.005	0.00999
1L/12/10/92	0.723	0.718	0.707	0.736	0.696	3.5	0.716	0.019089
1C	0.555	0.532	0.568	0.569	0.529	3.5	0.5506	0.031175
1R	0.501	0.513	0.482	0.496	0.483	2.8	0.495	0.023455
2L	0.957	0.944	0.968	0.961	0.935	3.5	0.953	0.012504
2C	1.025	1.039	1.064	1.058	1.066	3.5	1.0504	0.01512
2R	0.882	0.896	0.901	0.908	0.898	3.5	0.897	0.009512
3L	0.984	0.992	0.975	0.971	0.973	3.5	0.979	0.008043
3C	0.979	0.983	0.988	0.962	0.973	3.5	0.977	0.009178
3R	0.988	0.972	0.996	1.017	0.997	3.2	0.994	0.014662
4L	1.043	1.055	1.059	1.038	1.05	2.8	1.049	0.00731
4C	1.152	1.128	1.136	1.177	1.182	2.8	1.155	0.018618
4R	0.946	0.961	0.95	0.938	0.959	2.8	0.9508	0.008909
1L/12/14/92	0.577	0.58	0.554	0.562	0.557	2.8	0.566	0.018664
1C								
1R	0.379	0.375	0.371	0.379	0.073	1.5	0.3154	0.384389
2L	0.86	0.877	0.853	0.862	0.868	2.8	0.864	0.009346
2C	0.948	0.962	0.939	0.95	0.921	2.6	0.944	0.014447
2R	0.652	0.644	0.644	0.658	0.637	2	0.647	0.011231
3L	0.955	0.976	0.942	0.961	0.956	2.8	0.958	0.011454
3C	0.753	0.735	0.763	0.77	0.749	2.5	0.754	0.015959
3R								

TABLE 4.B-7 : (Continued)

Opening/ Date Tested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
4L	0.77	0.776	0.819	0.803	0.827	1.4	0.799	0.028375
4C	1.093	1.125	1.059	1.088	1.115	2.7	1.096	0.020981
4R	0.839	0.856	0.848	0.844	0.858	2.1	0.849	0.008428
1L/12/14/92	0.668	0.673	0.679	0.664	0.665	3		
1C								
1R	0.352	0.359	0.345	0.347	0.377	1.4	0.356	0.032468
2L	0.941	0.933	0.938	0.912	0.906	3.4	0.926	0.015379
2C	1.027	1.011	1.042	1.03	1.015	2.8	1.025	0.010811
2R								
3L	0.993	0.987	1.016	1.022	1.012	2.8	1.006	0.013498
3C	0.965	0.989	0.974	0.969	0.998	2.8	0.979	0.012774
3R	0.898	0.921	0.914	0.883	0.869	2.1	0.897	0.021421
4L	0.914	0.902	0.896	0.885	0.963	1	0.912	0.029787
4C								
4R	0.927	0.941	0.938	0.913	0.936	2.1	0.931	0.01089

TABLE 4.B-8 : DATA FOR ASH ASPHALT WITH DEICING MATERIAL

Opening/ DateTested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
1L/12/16/92	0.667	0.653	0.661	0.676	0.658	3.5	0.663	0.0119527
1C	0.514	0.517	0.501	0.499	0.494	3.5	0.505	0.0176671
1R	0.455	0.462	0.456	0.448	0.464	2.1	0.457	0.0123782
2L	1.352	0.772	0.769	0.751	0.776	3.5	0.884	0.2648828
2C	0.829	0.837	0.843	0.863	0.848	3.5	0.844	0.01353
2R	0.797	0.749	0.772	0.751	0.776	2.8	0.769	0.0230136
3L	0.903	0.89	0.901	0.874	0.878	3.5	0.8892	0.0131805
3C								
3R	1.074	1.083	1.066	1.085	1.052	2.8	1.072	0.0112715
4L	0.869	0.876	0.864	0.858	0.838	2.1	0.861	0.0150181
4C	0.955	0.96	0.981	0.977	0.992	2.1	0.973	0.0140467
4R								
1L/12/16/92	0.669	0.674	0.687	0.666	0.644	3.5	0.668	0.0209367
1C	0.525	0.524	0.533	0.507	0.491	3.5	0.516	0.0292629
1R	0.518	0.528	0.514	0.516	0.534	2.8	0.522	0.0147398
2L	0.897	0.91	0.906	0.899	0.138	3.5	0.75	0.4080479
2C								
2R	0.82	0.814	0.803	0.819	0.819	3.5	0.815	0.0077989
3L	0.969	0.958	0.951	0.944	0.948	3.5	0.954	0.00921
3C								
3R	1.052	1.061	1.055	1.036	1.036	2.8	1.048	0.0097496
4L	0.737	0.744	0.716	0.708	0.735	2.1	0.728	0.0187338
4C	1.138	1.121	1.13	1.163	1.178	2.8	1.146	0.0185435
4R								
1L/12/23/92	0.646	0.633	0.637	0.629	0.645	3.5	0.638	0.0103969
1C	0.551	0.538	0.54	0.531	0.545	3.5	0.541	0.0124272
1R	0.505	0.504	0.488	0.492	0.491	2.8	0.496	0.0142562
2L	0.827	0.823	0.806	0.814	0.78	3.5	0.81	0.0205844
2C	0.913	0.934	0.928	0.912	0.908	3.5	0.919	0.0110112
2R	0.649	0.637	0.656	0.641	0.647	3.2	0.646	0.0101744
3L	0.974	0.98	0.955	0.92	0.931	3.5	0.952	0.0245987
3C	0.958	0.943	0.967	0.952	0.955	3.5	0.955	0.0081917
3R	1.114	1.121	1.144	1.113	1.138	2.8	1.127	0.0104688
4L	1.055	1.058	1.032	1.027	1.053	2.8	1.045	0.0122995
4C	1.111	1.108	1.151	1.139	1.116	2.5	1.125	0.0150745
4R	0.824	0.832	0.823	0.809	0.842	2.1	0.826	0.0131956
1L/12/23/92	0.656	0.648	0.639	0.651	0.611	3.5	0.641	0.0249415
1C	0.492	0.499	0.507	0.506	1.371	3.5	0.675	0.5156177
1R	0.429	0.422	0.435	0.446	0.458	2.8	0.438	0.0290592
2L	0.866	0.883	0.87	0.851	0.839	3.5	0.8618	0.0177562

TABLE 4.B-8 : (Continued)

Opening/ DateTested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
2C	0.982	0.988	0.965	0.977	0.958	3.5	0.974	0.011303
2R	0.675	0.68	0.694	0.699	0.697	2.5	0.689	0.0140116
3L	0.993	0.986	0.963	0.961	0.967	3.5	0.974	0.0133391
3C								
3R	0.75	0.742	0.755	0.778	0.77	2.1	0.759	0.0173593
4L	0.973	0.951	0.957	0.994	1.01	2.1	0.977	0.0227493
4C	1.119	1.106	1.088	1.085	1.117	2.8	1.103	0.0128855
4R	0.828	0.814	0.821	0.813	0.849	2.1	0.825	0.0159522
1L/12/24/92	0.644	0.649	0.627	0.635	0.64	3.5	0.639	0.0118358
1C	0.52	0.526	0.531	0.507	0.506	3.5	0.518	0.0193436
1R	0.481	0.478	0.475	0.482	0.474	2.5	0.478	0.0066156
2L	0.798	0.813	0.819	0.793	0.832	3.5	0.811	0.0174553
2C	1.062	1.065	1.038	1.047	1.033	3.5	1.049	0.0121034
2R	0.691	0.686	0.675	0.677	0.696	2.5	0.685	0.0117153
3L	0.956	0.964	0.98	0.963	1.022	3.5	0.977	0.0243938
3C								
3R								
4L	1.11	1.137	1.125	1.109	1.084	2.5	1.113	0.0160019
4C	1.171	1.166	1.151	1.142	1.146	2.8	1.1552	0.0098151
4R	0.822	0.83	0.843	0.818	0.832	2.1	0.829	0.0104605
1L/1/4/93	0.594	0.601	0.583	0.587	0.58	3.5	0.589	0.01293
1C	0.507	0.488	0.496	0.502	0.502	3.5	0.499	0.0130492
1R	0.388	0.375	0.371	0.393	0.398	2.1	0.385	0.026943
2L	0.936	0.949	0.937	0.954	0.984	3.5	0.952	0.0183026
2C	1.049	1	1.059	1.06	1.082	3.5	1.05	0.0259286
2R	0.535	0.555	0.551	0.536	0.543	2.1	0.544	0.0146137
3L	0.943	0.917	0.939	0.925	0.946	3.2	0.934	0.0119224
3C	0.962	0.97	0.934	0.934	0.955	3.5	0.951	0.0154255
3R	1.118	1.103	1.136	1.155	0.853	2.8	1.073	0.1037945
4L	1.057	1.032	1.029	1.043	1.044	2.8	1.041	0.0095483
4C	1.154	1.153	1.138	1.147	0.513	2.5	1.021	0.2488382
4R	1.475	0.934	0.922	0.946	0.938	1.78	1.043	0.207228
1L/1/4/93	0.726	0.734	0.727	0.712	0.691	3.5	0.718	0.0212686
1C	0.513	0.508	0.525	0.53	0.504	2.8		
1R	0.515	0.533	0.529	0.507	0.516	3.5	0.52	0.0184455
2L	0.994	0.989	0.963	0.975	0.974	3.5	0.979	0.0113927
2C	1.081	1.082	1.072	1.09	1.065	3.5	1.078	0.0080229
2R	0.749	0.736	0.755	0.758	0.762	2.8		
3L	0.979	0.963	0.986	0.991	0.981	3.5	0.98	0.0096589

TABLE 4.B-8 : (Continued)

Opening/ DateTested	15 - min	30 - min	45 - min	60 - min	120 - min	i in/hr	mVavg	SD/mVavg
3C	0.965	0.938	0.942	0.944	0.956	3.5	0.949	0.0105374
3R								
4L	1.028	1.049	1.02	1.023	0.991	2.8	1.0222	0.0182013
4C	1.142	1.176	1.165	1.138	1.134	2.8		
4R	0.966	0.952	0.943	0.969	0.94	2.5	0.954	0.0123138
1L/1/5/93	0.624	0.621	0.607	0.608	0.101	3.5	0.5122	0.401624
1C	0.487	0.473	0.468	0.511	0.475	3.5	0.4828	0.0319376
1R	0.482	0.477	0.492	0.486	0.488	3.2	0.485	0.010594
2L	1.02	1.003	0.991	0.995	1.021	3.5	1.006	0.0123836
2C	1.105	1.11	1.088	1.084	1.108	3.5	1.099	0.0098339
2R	0.853	0.875	0.881	0.869	0.892	3.5	0.874	0.0148301
3L	0.975	0.989	0.99	0.972	0.964	3.5	0.978	0.0102861
3C	0.898	0.886	0.893	0.874	0.889	2.5	0.888	0.0090931
3R								
4L	1.023	1.012	1.047	1.035	1.018	2.8	1.027	0.0122083
4C	1.18	1.169	1.171	1.136	1.109	2.8	1.153	0.0230579
4R	0.869	0.844	0.857	0.865	0.895	2.1	0.866	0.0194325
1L/1/5/93	1.209	0.733	0.716	0.707	0.72	3.5	0.817	0.2401206
1C	1.064	0.54	0.566	0.562	0.548	3.2	0.656	0.3113042
1R	1.056	0.554	0.565	0.569	0.556	3.5	0.66	0.3001178
2L	0.857	0.873	0.861	0.855	0.864	3.5	0.862	0.0073371
2C	0.962	0.936	0.948	0.937	0.942	3.5	0.945	0.0100613
2R	0.688	0.693	0.671	0.675	0.683	2.8	0.682	0.0118759
3L	0.981	0.964	0.979	0.968	0.983	3.5	0.975	0.007757
3C	1.063	1.05	1.044	1.027	1.036	3.5	1.044	0.0117313
3R	0.956	0.945	0.969	0.979	0.941	2.8	0.958	0.0149382
4L	1.067	1.098	1.056	1.054	1.065	2.8	1.068	0.0148047
4C	1.013	1.007	1.037	1.042	1.001	2.8	1.02	0.0161214
4R	0.995	1.006	0.98	0.979	0.959	2.5	0.9838	0.0162049
1L/1/6/93	0.745	0.601	0.609	0.628	0.622	3.5	0.641	0.0824622
1C	0.49	0.477	0.482	0.486	0.471	3.2	0.4812	0.0138723
1R	0.473	0.494	0.485	0.503	0.515	3.5	0.494	0.0292508
2L	0.886	0.865	0.852	0.857	0.839	3.5	0.8598	0.0181288
2C	0.791	0.809	0.803	0.786	0.786	2.1	0.795	0.0117729
2R	0.769	0.754	0.765	0.788	0.784	3.5	0.772	0.0161995
3L	1.063	1.078	1.083	1.152	0.719	3.2	1.019	0.1502479
3C	0.977	0.965	0.989	0.96	0.974	2.8	0.973	0.010339
4L	1.056	1.079	1.045	1.061	1.099	2.8	1.068	0.0177853
4C	1.181	1.194	1.199	1.152	1.154	2.8	1.176	0.0167411
4R	0.984	0.975	0.983	0.981	0.972	2.5	0.979	0.004791

APPENDIX 4C

RESULTS OF CHEMICAL ANALYSIS ON RUNOFF SAMPLES

(RAINFALL SIMULATION)

TABLE 4.C-1: RESULTS OF TCLP TOXICITY TEST ON SAMPLES FROM THE NO-ASH CONCRETE PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual		Max. Groundwater Standard (NYSDEC)	
SILVER	<0.01	mg/l	0.1	mg/l
ARSENIC	0.05	mg/l	0.05	mg/l
BARIUM	<0.20	mg/l	2.00	mg/l
CADMIUM	<0.005	mg/l	0.02	mg/l
CHROMIUM	<0.01	mg/l	0.10	mg/l
COPPER	0.04	mg/l	1.00	mg/l
MERCURY	<0.20	ug/l	4.00	ug/l
LEAD	<0.03	mg/l	0.05	mg/l
SELENIUM	<0.07	mg/l	0.04	mg/l
TOTAL SOLIDS	215	mg/l	-	
TCLP SEMI-VOLATILES				
1,4-DICHLOROBENZENE	<17	ug/l	4.70	ug/l
HEXACHLOROETHANE	<17	ug/l	-	
NITROBENZENE	<17	ug/l	-	
HEXACHLOROBUTADIENE	<17	ug/l	-	
2,4-DINITROTOLUENE	<18	ug/l	-	
HEXACHLOROBENZENE	<19	ug/l	0.35	
2,4,6-TRICHLOROPHENOL	<20	ug/l	-	
PENTACHLOROPHENOL	<44	ug/l	-	
2-METHYLPHENOL	<18	ug/l	-	
2,4,5-TRICHLOROPHENOL	<45	ug/l	-	
4-METHYLPHENOL	<10	ug/l	-	
3-METHYLPHENOL	<10	ug/l	-	
PYRIDINE	<15	ug/l	-	
TCLP VOLATILES				
VINYL CHLORIDE	<10	ug/l	5.0	ug/l
1,1-DICHLOROETHENE	<10	ug/l	-	
CHLOROFORM	<11	ug/l	7.0	ug/l
1,2-DICHLOROETHANE	<10	ug/l	-	
CARBON TETRACHLORIDE	<10	ug/l	5.0	ug/l
TRICHLOROETHENE	<10	ug/l	-	
BENZENE	<10	ug/l	0.7	ug/l
TETRACHLOROETHENE	<10	ug/l	-	
CHLOROBENZENE	<10	ug/l	-	
2-BUTANONE (MEK)	<10	ug/l	-	

TABLE 4.C-2: RESULTS OF TCLP TOXICITY TEST ON SAMPLES FROM THE 30% ASH-CONCRETE PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<0.005mg/l	0.02 mg/l
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	0.06 mg/l	0.04 mg/l
TOTAL SOLIDS	392 mg/l	-
TCLP SEMI-VOLATILES		
1,4-DICHLOROBENZENE	<17 ug/l	4.70 ug/l
HEXACHLOROETHANE	<17 ug/l	-
NITROBENZENE	<17 ug/l	-
HEXACHLOROBUTADIENE	<17 ug/l	-
2,4-DINITROTOLUENE	<18 ug/l	-
HEXACHLOROBENZENE	<19 ug/l	0.35
2,4,6-TRICHLOROPHENOL	<20 ug/l	-
PENTACHLOROPHENOL	<44 ug/l	-
2-METHYLPHENOL	<18 ug/l	-
2,4,5-TRICHLOROPHENOL	<45 ug/l	-
4-METHYLPHENOL	<10 ug/l	-
3-METHYLPHENOL	<10 ug/l	-
PYRIDINE	<15 ug/l	-
TCLP VOLATILES		
VINYL CHLORIDE	<10 ug/l	5.0 ug/l
1,1-DICHLOROETHENE	<10 ug/l	-
CHLOROFORM	<11 ug/l	7.0 ug/l
1,2-DICHLOROETHANE	<10 ug/l	-
CARBON TETRACHLORIDE	<10 ug/l	5.0 ug/l
TRICHLOROETHENE	<10 ug/l	-
BENZENE	<10 ug/l	0.7 ug/l
TETRACHLOROETHENE	<10 ug/l	-
CHLOROBENZENE	<10 ug/l	-
2-BUTANONE (MEK)	<10 ug/l	-

TABLE 4.C-3 : RESULTS OF CHEMICAL TEST ON SAMPLES FROM THE NO - ASH CONCRETE PLATFORM WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	14.0 mg/l	-
CHROMIUM	0.04 mg/l	0.10 mg/l
COPPER	<0.165mg/l	1.00 mg/l
MERCURY	<0.56 ug/l	4.00 ug/l
LEAD	<21.1 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.39 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	12.8 mg/l	-
TOTAL SOLIDS	89.0 mg/l	-
ZINC	<0.065mg/l	5.0 mg/l

TABLE 4.C-4 : RESULTS OF CHEMICAL TEST ON SAMPLES FROM THE NO - ASH CONCRETE PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	1500.0 mg/l	-
CHROMIUM	0.01 mg/l	0.10 mg/l
COPPER	<0.155mg/l	1.00 mg/l
MERCURY	<0.315ug/l	4.00 ug/l
LEAD	10.2 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.15 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	57.0 mg/l	-
TOTAL SOLIDS	2550.0 mg/l	-
ZINC	<0.08 mg/l	5.0 mg/l

TABLE 4.C-5 : RESULTS OF CHEMICAL TEST ON SAMPLES FROM THE 30% ASH - CONCRETE PLATFORM WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	7.0 mg/l	-
CHROMIUM	0.015mg/l	0.10 mg/l
COPPER	<0.24 mg/l	1.00 mg/l
MERCURY	<0.35 ug/l	4.00 ug/l
LEAD	39.8 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.49 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	26.35 mg/l	-
TOTAL SOLIDS	79.0 mg/l	-
ZINC	<0.11 mg/l	5.0 mg/l

TABLE 4.C-6 : RESULTS OF CHEMICAL TEST ON SAMPLES FROM THE 30% ASH - CONCRETE PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	5491.0 mg/l	-
CHROMIUM	0.01 mg/l	0.10 mg/l
COPPER	<0.14 mg/l	1.00 mg/l
MERCURY	<0.235ug/l	4.00 ug/l
LEAD	<7.5 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.55 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	30.55 mg/l	-
TOTAL SOLIDS	8691.0 mg/l	-
ZINC	0.08 mg/l	5.0 mg/l

TABLE 4.C-7 : RESULTS OF EP TOXICITY TEST ON SAMPLES FROM THE NO - ASH CONCRETE PLATFORM WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.175 mg/l	1.00 mg/l
MERCURY	<0.47 ug/l	4.0 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.06 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 4.C-8 : RESULTS OF EP TOXICITY TEST ON SAMPLES FROM THE NO - ASH CONCRETE PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.05 mg/l	0.05 mg/l
BARIUM	<0.02 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.175 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.06 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 4.C-9 : RESULTS OF EP TOXICITY TEST ON SAMPLES FROM THE 30% ASH-CONCRETE PLATFORM WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	0.01 mg/l	0.10 mg/l
COPPER	0.24 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.06 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 4.C-10 : RESULTS OF EP TOXICITY TEST ON SAMPLES FROM THE 30% ASH-CONCRETE PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.06 mg/l	0.05 mg/l
BARIUM	<0.125 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.09 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.04 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 4.C-11 : RESULTS OF TCLP TOXICITY TEST ON SAMPLES FROM THE NO-ASH ASPHALT PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual		Max. Groundwater Standard (NYSDEC)	
SILVER	<0.01	mg/l	0.1	mg/l
ARSENIC	0.05	mg/l	0.05	mg/l
BARIUM	<0.20	mg/l	2.00	mg/l
CADMIUM	<0.005	mg/l	0.02	mg/l
CHROMIUM	<0.01	mg/l	0.10	mg/l
COPPER	0.02	mg/l	1.00	mg/l
MERCURY	<0.20	ug/l	4.00	ug/l
LEAD	<0.05	mg/l	0.05	mg/l
SELENIUM	0.05	mg/l	0.04	mg/l
TCLP SEMI-VOLATILES				
1,4-DICHLOROBENZENE	<17	ug/l	4.70	ug/l
HEXACHLOROETHANE	<17	ug/l	-	
NITROBENZENE	<17	ug/l	-	
HEXACHLOROBUTADIENE	<17	ug/l	-	
2,4-DINITROTOLUENE	<18	ug/l	-	
HEXACHLOROBENZENE	<19	ug/l	0.35	
2,4,6-TRICHLOROPHENOL	<20	ug/l	-	
PENTACHLOROPHENOL	<44	ug/l	-	
2-METHYLPHENOL	<18	ug/l	-	
2,4,5-TRICHLOROPHENOL	<45	ug/l	-	
4-METHYLPHENOL	<10	ug/l	-	
3-METHYLPHENOL	<10	ug/l	-	
PYRIDINE	<15	ug/l	-	
TCLP VOLATILES				
VINYL CHLORIDE	<10	ug/l	5.0	ug/l
1,1-DICHLOROETHENE	<10	ug/l	-	
CHLOROFORM	<11	ug/l	7.0	ug/l
1,2-DICHLOROETHANE	<10	ug/l	-	
CARBON TETRACHLORIDE	<10	ug/l	5.0	ug/l
TRICHLOROETHENE	<10	ug/l	-	
BENZENE	<10	ug/l	0.7	ug/l
TETRACHLOROETHENE	<10	ug/l	-	
CHLOROBENZENE	<10	ug/l	-	
2-BUTANONE (MEK)	<10	ug/l	-	

TABLE 4.C-12 : RESULTS OF TCLP TOXICITY TEST ON SAMPLES FROM THE 15% ASH-ASPHALT PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<0.005mg/l	0.02 mg/l
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<0.05 mg/l	0.05 mg/l
SELENIUM	0.05 mg/l	0.04 mg/l
TCLP SEMI-VOLATILES		
1,4-DICHLOROBENZENE	<17 ug/l	4.70 ug/l
HEXACHLOROETHANE	<17 ug/l	-
NITROBENZENE	<17 ug/l	-
HEXACHLOROBUTADIENE	<17 ug/l	-
2,4-DINITROTOLUENE	<18 ug/l	-
HEXACHLOROBENZENE	<19 ug/l	0.35
2,4,6-TRICHLOROPHENOL	<20 ug/l	-
PENTACHLOROPHENOL	<44 ug/l	-
2-METHYLPHENOL	<18 ug/l	-
2,4,5-TRICHLOROPHENOL	<45 ug/l	-
4-METHYLPHENOL	<10 ug/l	-
3-METHYLPHENOL	<10 ug/l	-
PYRIDINE	<15 ug/l	-
TCLP VOLATILES		
VINYL CHLORIDE	<10 ug/l	5.0 ug/l
1,1-DICHLOROETHENE	<10 ug/l	-
CHLOROFORM	<11 ug/l	7.0 ug/l
1,2-DICHLOROETHANE	<10 ug/l	-
CARBON TETRACHLORIDE	<10 ug/l	5.0 ug/l
TRICHLOROETHENE	<10 ug/l	-
BENZENE	<10 ug/l	0.7 ug/l
TETRACHLOROETHENE	<10 ug/l	-
CHLOROBENZENE	<10 ug/l	-
2-BUTANONE (MEK)	<10 ug/l	-

TABLE 4.C-13 : RESULTS OF CHEMICAL TEST ON SAMPLES FROM THE NO-ASH ASPHALT PLATFORM WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	8 mg/l	-
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.21 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	<0.10 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	10.7 mg/l	-
TOTAL SOLIDS	<5.0 mg/l	-
ZINC	0.31 mg/l	5.0 mg/l

TABLE 4.C-14 : RESULTS OF CHEMICAL TEST ON SAMPLES FROM THE NO-ASH ASPHALT PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	147 mg/l	-
CHROMIUM	0.01 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	11.3 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	<0.10 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	10.5 mg/l	-
TOTAL SOLIDS	<5.0 mg/l	-
ZINC	1.42 mg/l	5.0 mg/l

TABLE 4.C-15 : RESULTS OF CHEMICAL TEST ON SAMPLES FROM THE 15%-ASH ASPHALT PLATFORM WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	9 mg/l	-
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.04 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS. (AS P)	<0.10 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	10.7 mg/l	-
TOTAL SOLIDS	<5.0 mg/l	-
ZINC	0.06 mg/l	5.0 mg/l

TABLE 4.C-16 : RESULTS OF CHEMICAL TEST ON SAMPLES FROM THE 15%-ASH ASPHALT PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	2650 mg/l	-
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.11 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS. (AS P)	<0.10 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	24.7 mg/l	-
TOTAL SOLIDS	15.0 mg/l	-
ZINC	0.07 mg/l	5.0 mg/l

TABLE 4.C-17 : RESULTS OF EP TOXICITY TEST ON SAMPLES FROM THE NO-ASH ASPHALT PLATFORM WITHOUT DEICING MATERIAL

PARAMETER	Actual		Max. Groundwater Standard (NYSDEC)	
SILVER	<0.01	mg/l	0.10	mg/l
ARSENIC	<0.05	mg/l	0.05	mg/l
BARIUM	<0.20	mg/l	2.0	mg/l
CADMIUM	<0.005	mg/l	0.02	mg/l
CHROMIUM	<0.02	mg/l	0.10	mg/l
COPPER	0.03	mg/l	1.00	mg/l
MERCURY	<0.20	ug/l	4.0	ug/l
LEAD	<0.05	mg/l	0.05	mg/l
SELENIUM	<0.05	mg/l	0.04	mg/l
E.P. TOXICITY HERBICIDES				
2,4,-D	<2.0	ug/l	4.4	ug/l
2,4,5-TP(silvex)	<0.5	ug/l	35.0	ug/l
E.P. TOXICITY PESTICIDES				
LINDANE	<0.5	ug/l	-	
ENDRIN	<1.0	ug/l	-	
METHOXYCHLOR	<5.0	ug/l	35.0	ug/l
TOXAPHENE	<10.0	ug/l	-	ug/l

TABLE 4.C-18 : RESULTS OF EP TOXICITY TEST ON SAMPLES FROM THE NO-ASH ASPHALT PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.02 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.05 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 4.C-19 : RESULTS OF EP TOXICITY TEST ON SAMPLES FROM THE 15% ASH-ASPHALT PLATFORM WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.03 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.05 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 4.C-20 : RESULTS OF EP TOXICITY TEST ON SAMPLES FROM THE 15% ASH-ASPHALT PLATFORM WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	0.07 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.05 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

APPENDIX 5A

RESULTS OF SKID RESISTANCE TEST
(FIELD-TESTS)

TABLE 5A.1 - Results of tests made with a portable skid-resistance tester on ASH-CONCRETE pavement section

date	readings #					mean
	1	2	3	4	5	
4/21/93	79	79	79	79	79	79
3/03/93	90	90	91	90	90	90
1/22/93	88	88	89	88	88	88
12/30/92	87	85	85	85	85	85

TABLE 5A.2 - Results of tests made with a portable skid-resistance tester on NO-ASH CONCRETE pavement section

date	reading #					mean
	1	2	3	4	5	
4/21/93	79	79	80	80	80	80
3/03/93	85	85	90	90	90	88
1/22/93	85	90	90	90	90	90
12/30/92	93	93	92	91	91	92

TABLE 5A.3 - Results of tests made with a portable skid-resistance tester on ASH-ASPHALT pavement section

date	reading #					mean
	1	2	3	4	5	
4/21/93	74	74	76	75	75	75
3/03/93	83	83	80	80	80	81
1/22/93	78	76	79	78	78	77
12/30/92	82	81	80	80	80	81

TABLE 5A.4 - Results of tests made with a portable skid-resistance tester on NO-ASH ASPHALT pavement section

date	reading #					mean
	1	2	3	4	5	
4/21/93	74	75	75	75	75	75
3/03/93	80	82	80	80	80	80
1/22/93	80	78	78	78	78	78
12/30/92	93	95	92	92	92	93

APPENDIX 5B

RESULTS OF CHEMICAL ANALYSIS ON RUNOFF SAMPLES

(FIELD TESTS)

TABLE 5.B-1 : RESULTS OF CHEMICAL TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO-ASH CONCRETE PAVEMENT SECTION WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	8.0 mg/l	-
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.20 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	29.0 mg/l	-
TOTAL SOLIDS	6.0 mg/l	-
ZINC	0.06 mg/l	5.0 mg/l

TABLE 5.B-2 : RESULTS OF CHEMICAL TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO-ASH CONCRETE PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	1700.0 mg/l	-
CHROMIUM	0.01 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.20 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	21.1 mg/l	-
TOTAL SOLIDS	44.0 mg/l	-
ZINC	<0.03 mg/l	5.0 mg/l

TABLE 5.B-3 : RESULTS OF CHEMICAL TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 30% ASH-CONCRETE PAVEMENT SECTION WITHOUT DEICING MATERIAL

PARAMETER	Actual Max. Groundwater	Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	35.0 mg/l	-
CHROMIUM	0.02 mg/l	0.10 mg/l
COPPER	<0.03 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.80 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	18.1 mg/l	-
TOTAL SOLIDS	11.0 mg/l	-
ZINC	<0.04 mg/l	5.0 mg/l

TABLE 5.B-4 : RESULTS OF CHEMICAL TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 30% ASH-CONCRETE PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	2100.0 mg/l	-
CHROMIUM	<0.02 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.31 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	25.5 mg/l	-
TOTAL SOLIDS	46.0 mg/l	-
ZINC	<0.02 mg/l	5.0 mg/l

TABLE 5.B-5 : RESULTS OF EP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO-ASH CONCRETE PAVEMENT SECTION WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	0.06 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.02 mg/l	0.05 mg/l
SELENIUM	<0.04 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 5.B-6 : RESULTS OF EP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO-ASH CONCRETE PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.04 mg/l	0.05 mg/l
BARIUM	<0.2 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.05 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 5.B-7: RESULTS OF EP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 30% ASH-CONCRETE PAVEMENT SECTION WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.04 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	0.07 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.02 mg/l	0.05 mg/l
SELENIUM	<0.04 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 5.B-8 : RESULTS OF EP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 30% ASH-CONCRETE PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.04 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.05 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 5.B-9 : RESULTS OF TCLP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO-ASH CONCRETE PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<0.04 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<0.005mg/l	0.02 mg/l
CHROMIUM	<0.05 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
TCLP SEMI-VOLATILES		
1,4-DICHLOROBENZENE	<17 ug/l	4.70 ug/l
HEXACHLOROETHANE	<17 ug/l	-
NITROBENZENE	<17 ug/l	-
HEXACHLOROBUTADIENE	<17 ug/l	-
2,4-DINITROTOLUENE	<18 ug/l	-
HEXACHLOROBENZENE	<19 ug/l	0.35
2,4,6-TRICHLOROPHENOL	<20 ug/l	-
PENTACHLOROPHENOL	<44 ug/l	-
2-METHYLPHENOL	<18 ug/l	-
2,4,5-TRICHLOROPHENOL	<45 ug/l	-
4-METHYLPHENOL	<10 ug/l	-
3-METHYLPHENOL	<10 ug/l	-
PYRIDINE	<15 ug/l	-
TCLP VOLATILES		
VINYL CHLORIDE	<10 ug/l	5.0 ug/l
1,1-DICHLOROETHENE	<10 ug/l	-
CHLOROFORM	<11 ug/l	7.0 ug/l
1,2-DICHLOROETHANE	<10 ug/l	-
CARBON TETRACHLORIDE	<10 ug/l	5.0 ug/l
TRICHLOROETHENE	<10 ug/l	-
BENZENE	<10 ug/l	0.7 ug/l
TETRACHLOROETHENE	<10 ug/l	-
CHLOROBENZENE	<10 ug/l	-
2-BUTANONE (MEK)	<10 ug/l	-

TABLE 5.B-10 : RESULTS OF TCLP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 30% ASH-CONCRETE PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<0.04 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<0.005mg/l	0.02 mg/l
CHROMIUM	<0.05 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
TCLP SEMI-VOLATILES		
1,4-DICHLOROBENZENE	<17 ug/l	4.70 ug/l
HEXACHLOROETHANE	<17 ug/l	-
NITROBENZENE	<17 ug/l	-
HEXACHLOROBUTADIENE	<17 ug/l	-
2,4-DINITROTOLUENE	<18 ug/l	-
HEXACHLOROBENZENE	<19 ug/l	0.35
2,4,6-TRICHLOROPHENOL	<20 ug/l	-
PENTACHLOROPHENOL	<44 ug/l	-
2-METHYLPHENOL	<18 ug/l	-
2,4,5-TRICHLOROPHENOL	<45 ug/l	-
4-METHYLPHENOL	<10 ug/l	-
3-METHYLPHENOL	<10 ug/l	-
PYRIDINE	<15 ug/l	-
TCLP VOLATILES		
VINYL CHLORIDE	<10 ug/l	5.0 ug/l
1,1-DICHLOROETHENE	<10 ug/l	-
CHLOROFORM	<11 ug/l	7.0 ug/l
1,2-DICHLOROETHANE	<10 ug/l	-
CARBON TETRACHLORIDE	<10 ug/l	5.0 ug/l
TRICHLOROETHENE	<10 ug/l	-
BENZENE	<10 ug/l	0.7 ug/l
TETRACHLOROETHENE	<10 ug/l	-
CHLOROBENZENE	<10 ug/l	-
2-BUTANONE (MEK)	<10 ug/l	-

TABLE 5.B-11 : RESULTS OF CHEMICAL TESTS ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO - ASH ASPHALT PAVEMENT SECTION WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	8.0 mg/l	-
CHROMIUM	0.01 mg/l	0.10 mg/l
COPPER	<0.21 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	<0.10 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	10.7 mg/l	-
TOTAL SOLIDS	<5.0 mg/l	-
ZINC	<0.31 mg/l	5.0 mg/l

TABLE 5.B-12 : RESULTS OF CHEMICAL TESTS ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO - ASH ASPHALT PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	1000.0 mg/l	-
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.10 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	22.0 mg/l	-
TOTAL SOLIDS	6.0 mg/l	-
ZINC	0.04 mg/l	5.0 mg/l

TABLE 5.B-13 : RESULTS OF CHEMICAL TESTS ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 15% ASH-ASPHALT PAVEMENT SECTION WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	8.0 mg/l	-
CHROMIUM	0.01 mg/l	0.10 mg/l
COPPER	0.21 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	<0.10 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	10.7 mg/l	-
TOTAL SOLIDS	<5.0 mg/l	-
ZINC	0.31 mg/l	5.0 mg/l

TABLE 5.B-14 : RESULTS OF CHEMICAL TESTS ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 15% ASH-ASPHALT PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	<10.0 ug/l	50.0 ug/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<5.0 ug/l	0.02 mg/l
CHLORIDE	640.0 mg/l	-
CHROMIUM	<0.01 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<5.0 ug/l	50.0 ug/l
TOTAL PHOS.(AS P)	0.44 mg/l	-
SELENIUM	<5.0 ug/l	40.0 ug/l
SULFATE	15.4 mg/l	-
TOTAL SOLIDS	56.0 mg/l	-
ZINC	0.05 mg/l	5.0 mg/l

TABLE 5.B-15 : RESULTS OF EP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO-ASH ASPHALT PAVEMENT SECTION WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.04 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	0.06 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.02 mg/l	0.05 mg/l
SELENIUM	<0.04 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 5.B-16 : RESULTS OF EP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO-ASH ASPHALT PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.04 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	0.05 mg/l	0.10 mg/l
COPPER	0.03 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 5.B-17 : RESULTS OF EP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 15% ASH-ASPHALT PAVEMENT SECTION WITHOUT DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.05 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	<0.02 mg/l	0.10 mg/l
COPPER	0.03 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	<0.05 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 5.B-18 : RESULTS OF EP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE 15% ASH-ASPHALT PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.10 mg/l
ARSENIC	<0.04 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.0 mg/l
CADMIUM	<0.005 mg/l	0.02 mg/l
CHROMIUM	0.01 mg/l	0.10 mg/l
COPPER	0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.0 ug/l
LEAD	0.58 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
E.P. TOXICITY HERBICIDES		
2,4,-D	<2.0 ug/l	4.4 ug/l
2,4,5-TP(silvex)	<0.5 ug/l	35.0 ug/l
E.P. TOXICITY PESTICIDES		
LINDANE	<0.5 ug/l	-
ENDRIN	<1.0 ug/l	-
METHOXYCHLOR	<5.0 ug/l	35.0 ug/l
TOXAPHENE	<10.0 ug/l	- ug/l

TABLE 5.B-19 : RESULTS OF TCLP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE NO-ASH ASPHALT PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual		Max. Groundwater Standard (NYSDEC)	
SILVER	<0.01	mg/l	0.1	mg/l
ARSENIC	0.04	mg/l	0.05	mg/l
BARIUM	<0.20	mg/l	2.00	mg/l
CADMIUM	<0.005	mg/l	0.02	mg/l
CHROMIUM	<0.05	mg/l	0.10	mg/l
COPPER	<0.02	mg/l	1.00	mg/l
MERCURY	<0.20	ug/l	4.00	ug/l
LEAD	<0.03	mg/l	0.05	mg/l
SELENIUM	<0.05	mg/l	0.04	mg/l
TCLP SEMI-VOLATILES				
1,4-DICHLOROBENZENE	<17	ug/l	4.70	ug/l
HEXACHLOROETHANE	<17	ug/l	-	
NITROBENZENE	<17	ug/l	-	
HEXACHLOROBUTADIENE	<17	ug/l	-	
2,4-DINITROTOLUENE	<18	ug/l	-	
HEXACHLOROBENZENE	<19	ug/l	0.35	
2,4,6-TRICHLOROPHENOL	<20	ug/l	-	
PENTACHLOROPHENOL	<44	ug/l	-	
2-METHYLPHENOL	<18	ug/l	-	
2,4,5-TRICHLOROPHENOL	<45	ug/l	-	
4-METHYLPHENOL	<10	ug/l	-	
3-METHYLPHENOL	<10	ug/l	-	
PYRIDINE	<15	ug/l	-	
TCLP VOLATILES				
VINYL CHLORIDE	<10	ug/l	5.0	ug/l
1,1-DICHLOROETHENE	<10	ug/l	-	
CHLOROFORM	<11	ug/l	7.0	ug/l
1,2-DICHLOROETHANE	<10	ug/l	-	
CARBON TETRACHLORIDE	<10	ug/l	5.0	ug/l
TRICHLOROETHENE	<10	ug/l	-	
BENZENE	<10	ug/l	0.7	ug/l
TETRACHLOROETHENE	<10	ug/l	-	
CHLOROBENZENE	<10	ug/l	-	
2-BUTANONE (MEK)	<10	ug/l	-	

TABLE 5.B-20 : RESULTS OF TCLP TOXICITY TEST ON COMPOSITE RUNOFF-LEACHATE SAMPLES FROM THE ASH-ASPHALT PAVEMENT SECTION WITH DEICING MATERIAL

PARAMETER	Actual	Max. Groundwater Standard (NYSDEC)
SILVER	<0.01 mg/l	0.1 mg/l
ARSENIC	0.04 mg/l	0.05 mg/l
BARIUM	<0.20 mg/l	2.00 mg/l
CADMIUM	<0.005mg/l	0.02 mg/l
CHROMIUM	<0.05 mg/l	0.10 mg/l
COPPER	<0.02 mg/l	1.00 mg/l
MERCURY	<0.20 ug/l	4.00 ug/l
LEAD	<0.03 mg/l	0.05 mg/l
SELENIUM	<0.05 mg/l	0.04 mg/l
TCLP SEMI-VOLATILES		
1,4-DICHLOROBENZENE	<17 ug/l	4.70 ug/l
HEXACHLOROETHANE	<17 ug/l	-
NITROBENZENE	<17 ug/l	-
HEXACHLOROBUTADIENE	<17 ug/l	-
2,4-DINITROTOLUENE	<18 ug/l	-
HEXACHLOROBENZENE	<19 ug/l	0.35
2,4,6-TRICHLOROPHENOL	<20 ug/l	-
PENTACHLOROPHENOL	<44 ug/l	-
2-METHYLPHENOL	<18 ug/l	-
2,4,5-TRICHLOROPHENOL	<45 ug/l	-
4-METHYLPHENOL	<10 ug/l	-
3-METHYLPHENOL	<10 ug/l	-
PYRIDINE	<15 ug/l	-
TCLP VOLATILES		
VINYL CHLORIDE	<10 ug/l	5.0 ug/l
1,1-DICHLOROETHENE	<10 ug/l	-
CHLOROFORM	<11 ug/l	7.0 ug/l
1,2-DICHLOROETHANE	<10 ug/l	-
CARBON TETRACHLORIDE	<10 ug/l	5.0 ug/l
TRICHLOROETHENE	<10 ug/l	-
BENZENE	<10 ug/l	0.7 ug/l
TETRACHLOROETHENE	<10 ug/l	-
CHLOROBENZENE	<10 ug/l	-
2-BUTANONE (MEK)	<10 ug/l	-

Appendix 6A

INPUT DATA FOR REGRESSION ANALYSIS

TABLE 6.A-1 : NO-ASH CONCRETE WITHOUT DEICING MATERIAL (So=0.0175)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
9/23/92	2	2	0.026	-1.585	-4.0334	9.24	0.162292	613.3141
	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	266.6261
	2	2.5	0.027	-1.5686	-3.9365	11.55	0.191699	423.2956
	6	2.3	0.039	-1.4089	-3.4956	31.878	0.304775	347.8152
	6	2.8	0.041	-1.3872	-3.4102	38.808	0.344215	259.3741
	6	2.8	0.04	-1.3979	-3.4102	38.808	0.357204	246.876
	10	2.5	0.05	-1.301	-3.2375	57.75	0.380348	290.3262
	10	2.5	0.045	-1.3468	-3.2375	57.75	0.445469	235.1642
	10	2.1	0.049	-1.3098	-3.3133	48.51	0.329323	395.1662
	14	3.1	0.049	-1.3098	-2.998	100.254	0.6806	129.529
	14	1.8	0.049	-1.3098	-3.2341	58.212	0.395187	384.1894
	14	1.8	0.045	-1.3468	-3.2341	58.212	0.449033	324.0248
9/23/92	2	1.15	0.019	-1.7212	-4.2738	5.313	0.149381	990.6215
	2	1.15	0.021	-1.6778	-4.2738	5.313	0.128557	1210.15
	2	1.25	0.025	-1.6021	-4.2375	5.775	0.107579	1451.631
	6	1.6	0.031	-1.5086	-3.6532	22.176	0.299175	454.1072
	6	1.6	0.032	-1.4949	-3.6532	22.176	0.285261	483.877
	6	1.6	0.031	-1.5086	-3.6532	22.176	0.299175	454.1072
	10	1.6	0.041	-1.3872	-3.4314	36.96	0.327824	476.5999
	10	1.6	0.039	-1.4089	-3.4314	36.96	0.353362	431.2365
	10	1.6	0.036	-1.4437	-3.4314	36.96	0.39844	367.4441
	14	1.4	0.047	-1.3279	-3.3432	45.276	0.327194	584.3026
	14	1.6	0.048	-1.3188	-3.2852	51.744	0.362312	466.5957
	14	1.4	0.044	-1.3565	-3.3432	45.276	0.361222	512.0914
9/24/92	2	1	0.018	-1.7447	-4.3345	4.62	0.14087	1175.821
	2	3.5	0.033	-1.4815	-3.7904	16.17	0.19862	322.6176
	2	3.5	0.033	-1.4815	-3.7904	16.17	0.19862	322.6176
	6	1.4	0.031	-1.5086	-3.7112	19.404	0.261778	593.1196
	6	2.1	0.037	-1.4318	-3.5351	29.106	0.301137	375.5258
	6	1.4	0.034	-1.4685	-3.7112	19.404	0.227907	713.4717
	10	2.4	0.045	-1.3468	-3.2553	55.44	0.427651	255.1695
	10	2.4	0.051	-1.2924	-3.2553	55.44	0.354448	327.751
	10	1	0.034	-1.4685	-3.6355	23.1	0.271318	839.0427
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	146.0757
	14	1.6	0.04	-1.3979	-3.2852	51.744	0.476271	324.0248
	14	0.7	0.035	-1.4559	-3.6443	22.638	0.254578	1296.099
9/24/92	2	1.8	0.028	-1.5528	-4.0792	8.316	0.130696	878.1471
	2	2.1	0.027	-1.5686	-4.0122	9.702	0.161028	599.9087
	2	2.2	0.027	-1.5686	-3.992	10.164	0.168696	546.611
	6	2.8	0.038	-1.4202	-3.4102	38.808	0.385772	222.8056

TABLE 6.A-1 : (COntinued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	6	2.5	0.041	-1.3872	-3.4594	34.65	0.307335	325.3589
	6	1.4	0.03	-1.5229	-3.7112	19.404	0.274975	555.471
	10	2.1	0.043	-1.3665	-3.3133	48.51	0.400602	304.3158
	10	1.9	0.041	-1.3872	-3.3567	43.89	0.389291	337.9767
	10	1	0.033	-1.4815	-3.6355	23.1	0.283743	790.413
	14	1.9	0.046	-1.3372	-3.2106	61.446	0.458608	303.8832
	14	1.4	0.04	-1.3979	-3.3432	45.276	0.416738	423.216
	14	0.7	0.035	-1.4559	-3.6443	22.638	0.254578	1296.099
9/28/92	2	1.4	0.026	-1.585	-4.1883	6.468	0.113604	1251.661
	2	1.8	0.026	-1.585	-4.0792	8.316	0.146063	757.1779
	2	1.8	0.024	-1.6198	-4.0792	8.316	0.164696	645.1693
	6	2.5	0.037	-1.4318	-3.4594	34.65	0.358497	264.971
	6	1.8	0.031	-1.5086	-3.6021	24.948	0.336572	358.8008
	6	1.4	0.03	-1.5229	-3.7112	19.404	0.274975	555.471
	10	1.8	0.041	-1.3872	-3.3802	41.58	0.368802	376.5728
	10	1.6	0.039	-1.4089	-3.4314	36.96	0.353362	431.2365
	10	0.7	0.03	-1.5229	-3.7904	16.17	0.229146	1333.13
	14	1.8	0.045	-1.3468	-3.2341	58.212	0.449033	324.0248
	14	1	0.035	-1.4559	-3.4894	32.34	0.363683	635.0885
	14	0.6	0.033	-1.4815	-3.7112	19.404	0.238344	1568.28
9/28/92	2	2.1	0.027	-1.5686	-4.0122	9.702	0.161028	599.9087
	2	2.8	0.026	-1.585	-3.8873	12.936	0.227208	312.9153
	2	2.8	0.026	-1.585	-3.8873	12.936	0.227208	312.9153
	6	3.5	0.047	-1.3279	-3.3133	48.51	0.350565	218.1396
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	182.5895
	6	2.8	0.037	-1.4318	-3.4102	38.808	0.401516	211.2333
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	154.1099
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	154.1099
	10	2.5	0.045	-1.3468	-3.2375	57.75	0.445469	235.1642
	14	2.8	0.049	-1.3098	-3.0422	90.552	0.614736	158.7721
	14	2.1	0.044	-1.3565	-3.1671	67.914	0.541832	227.5962
	14	1	0.039	-1.4089	-3.4894	32.34	0.309192	788.5467
9/28/92	2	1.8	0.023	-1.6383	-4.0792	8.316	0.175553	592.5253
	2	1.8	0.023	-1.6383	-4.0792	8.316	0.175553	592.5253
	2	1.5	0.023	-1.6383	-4.1584	6.93	0.146294	853.2364
	6	1.8	0.039	-1.4089	-3.6021	24.948	0.238519	567.8834
	6	1.5	0.038	-1.4202	-3.6812	20.79	0.206663	776.3537
	6	1.8	0.037	-1.4318	-3.6021	24.948	0.258118	511.1324
	10	1.5	0.035	-1.4559	-3.4594	34.65	0.38966	395.1662
	10	1.8	0.04	-1.3979	-3.3802	41.58	0.382718	358.4274

TABLE 6.A-1 : (COntinued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	10	0.7	0.031	-1.5086	-3.7904	16.17	0.218148	1423.487
	14	1.5	0.041	-1.3872	-3.3133	48.51	0.430269	387.332
	14	1.5	0.041	-1.3872	-3.3133	48.51	0.430269	387.332
	14	1.5	0.042	-1.3768	-3.3133	48.51	0.414994	406.4567
10/2/92	2	2.8	0.029	-1.5376	-3.8873	12.936	0.19288	389.2926
	2	3.2	0.029	-1.5376	-3.8293	14.784	0.220434	298.0521
	2	3.2	0.03	-1.5229	-3.8293	14.784	0.209505	318.9619
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	3.5	0.044	-1.3565	-3.3133	48.51	0.387023	191.1808
	6	2.8	0.039	-1.4089	-3.4102	38.808	0.37103	234.6865
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	119.9817
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	148.1256
	10	2.8	0.041	-1.3872	-3.1883	64.68	0.573692	155.6245
	14	2.1	0.046	-1.3372	-3.1671	67.914	0.506882	248.757
	14	3.2	0.05	-1.301	-2.9842	103.488	0.681584	126.5722
	14	1.8	0.045	-1.3468	-3.2341	58.212	0.449033	324.0248
10/2/92	2	2.1	0.027	-1.5686	-4.0122	9.702	0.161028	599.9087
	2	2.1	0.025	-1.6021	-4.0122	9.702	0.180732	514.325
	2	2.1	0.026	-1.585	-4.0122	9.702	0.170406	556.2939
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	3.5	0.048	-1.3188	-3.3133	48.51	0.339667	227.5209
	6	2.1	0.039	-1.4089	-3.5351	29.106	0.278272	417.2205
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	125.3735
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	125.3735
	10	2.1	0.042	-1.3768	-3.3133	48.51	0.414994	290.3262
	14	2.1	0.044	-1.3565	-3.1671	67.914	0.541832	227.5962
	14	2.5	0.044	-1.3565	-3.0914	80.85	0.645038	160.5919
	14	2.1	0.043	-1.3665	-3.1671	67.914	0.560843	217.3684
	r^2	0.925			max =	103.488		119.9817
					min =	4.62		119.9817

TABLE 6.A-2 : NO-ASH CONCRETE WITH DEICING MATERIAL

Date Tested	L ft	i in/hr	Y in.	X1 = log (Y)	Z = log (q)	Re	Fr	K
10/5/92	2	2.1	0.024	-1.6198	-4.0122	9.702	0.192145	474.0019
	2	2.1	0.024	-1.6198	-4.0122	9.702	0.192145	474.0019
	2	2	0.026	-1.585	-4.0334	9.24	0.162292	613.3141
	6	2.8	0.037	-1.4318	-3.4102	38.808	0.401516	211.2333
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	2.1	0.036	-1.4437	-3.5351	29.106	0.313771	355.5015
	10	3.5	0.053	-1.2757	-3.0914	80.85	0.487922	166.4339
	10	3.5	0.053	-1.2757	-3.0914	80.85	0.487922	166.4339
	10	1.8	0.039	-1.4089	-3.3802	41.58	0.397532	340.73
	14	2.8	0.05	-1.301	-3.0422	90.552	0.596386	165.3188
	14	2.1	0.045	-1.3468	-3.1671	67.914	0.523872	238.059
	14	1.4	0.042	-1.3768	-3.3432	45.276	0.387328	466.5957
10/5/92	2	1.4	0.025	-1.6021	-4.1883	6.468	0.120488	1157.231
	2	2.5	0.025	-1.6021	-3.9365	11.55	0.215158	362.9077
	2	1.8	0.026	-1.585	-4.0792	8.316	0.146063	757.1779
	6	3.5	0.04	-1.3979	-3.3133	48.51	0.446505	158.0006
	6	3.5	0.044	-1.3565	-3.3133	48.51	0.387023	191.1808
	6	1.8	0.031	-1.5086	-3.6021	24.948	0.336572	358.8008
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	148.1256
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	148.1256
	10	1.4	0.043	-1.3665	-3.4894	32.34	0.267068	684.7106
	14	2.8	0.049	-1.3098	-3.0422	90.552	0.614736	158.7721
	14	2.8	0.049	-1.3098	-3.0422	90.552	0.614736	158.7721
	14	1.8	0.045	-1.3468	-3.2341	58.212	0.449033	324.0248
10/7/92	2	2.8	0.03	-1.5229	-3.8873	12.936	0.183317	416.6033
	2	2.8	0.03	-1.5229	-3.8873	12.936	0.183317	416.6033
	2	2.7	0.03	-1.5229	-3.9031	12.474	0.17677	448.0342
	6	2.1	0.032	-1.4949	-3.5351	29.106	0.374405	280.89
	6	3.4	0.041	-1.3872	-3.3259	47.124	0.417976	175.9077
	6	2.1	0.036	-1.4437	-3.5351	29.106	0.313771	355.5015
	10	3.3	0.052	-1.284	-3.117	76.23	0.473375	180.2208
	10	3.3	0.055	-1.2596	-3.117	76.23	0.435178	201.6154
	10	1.4	0.036	-1.4437	-3.4894	32.34	0.348635	479.927
	14	2.8	0.054	-1.2676	-3.0422	90.552	0.531364	192.8278
	14	2.8	0.056	-1.2518	-3.0422	90.552	0.503154	207.3758
	14	1.4	0.042	-1.3768	-3.3432	45.276	0.387328	466.5957
10/7/92	2	1.8	0.023	-1.6383	-4.0792	8.316	0.175553	592.5253
	2	2.1	0.025	-1.6021	-4.0122	9.702	0.180732	514.325
	2	2.1	0.025	-1.6021	-4.0122	9.702	0.180732	514.325
	6	2.5	0.037	-1.4318	-3.4594	34.65	0.358497	264.971

TABLE 6.A-2 : (Continued)

Date Tested	L ft	i in/hr	Y in.	X1 = log (Y)	Z = log (q)	Re	Fr	K
	6	2.8	0.038	-1.4202	-3.4102	38.808	0.385772	222.8056
	6	1.8	0.036	-1.4437	-3.6021	24.948	0.268947	483.877
	10	2.8	0.051	-1.2924	-3.1883	64.68	0.413523	240.7967
	10	2.8	0.052	-1.284	-3.1883	64.68	0.401652	250.3323
	10	1.4	0.041	-1.3872	-3.4894	32.34	0.286846	622.4979
	14	2.1	0.052	-1.284	-3.1671	67.914	0.421734	317.8822
	14	2.1	0.052	-1.284	-3.1671	67.914	0.421734	317.8822
	14	1.1	0.038	-1.4202	-3.448	35.574	0.353624	618.6998
10/9/92	2	2.1	0.026	-1.585	-4.0122	9.702	0.170406	556.2939
	2	2.8	0.029	-1.5376	-3.8873	12.936	0.19288	389.2926
	2	2.1	0.026	-1.585	-4.0122	9.702	0.170406	556.2939
	6	3.4	0.038	-1.4202	-3.3259	47.124	0.468437	151.1069
	6	3.2	0.038	-1.4202	-3.3522	44.352	0.440882	170.5855
	6	1.4	0.031	-1.5086	-3.7112	19.404	0.261778	593.1196
	10	2.8	0.042	-1.3768	-3.1883	64.68	0.553325	163.3085
	10	2.8	0.045	-1.3468	-3.1883	64.68	0.498926	187.4715
	10	2.1	0.042	-1.3768	-3.3133	48.51	0.414994	290.3262
	14	2.1	0.043	-1.3665	-3.1671	67.914	0.560843	217.3684
	14	2.1	0.046	-1.3372	-3.1671	67.914	0.506882	248.757
	14	2.1	0.046	-1.3372	-3.1671	67.914	0.506882	248.757
10/9/92	2	2.8	0.028	-1.5528	-3.8873	12.936	0.203305	362.9077
	2	2.2	0.026	-1.585	-3.992	10.164	0.178521	506.8711
	2	2.2	0.024	-1.6198	-3.992	10.164	0.201295	431.8902
	6	3.8	0.044	-1.3565	-3.2775	52.668	0.420196	162.1859
	6	3.8	0.038	-1.4202	-3.2775	52.668	0.523547	120.9692
	6	3.8	0.039	-1.4089	-3.2775	52.668	0.503541	127.4198
	10	3.2	0.048	-1.3188	-3.1303	73.92	0.517589	163.3085
	10	3.8	0.05	-1.301	-3.0557	87.78	0.578129	125.6606
	10	2.8	0.048	-1.3188	-3.1883	64.68	0.45289	213.3009
	14	3.8	0.055	-1.2596	-2.9096	122.892	0.701559	108.6066
	14	3.8	0.058	-1.2366	-2.9096	122.892	0.647838	120.7778
	14	3.8	0.058	-1.2366	-2.9096	122.892	0.647838	120.7778
10/14/92	2	2.5	0.025	-1.6021	-3.9365	11.55	0.215158	362.9077
	2	2.5	0.025	-1.6021	-3.9365	11.55	0.215158	362.9077
	2	2.5	0.023	-1.6383	-3.9365	11.55	0.243823	307.1651
	6	2.8	0.031	-1.5086	-3.4102	38.808	0.523556	148.2799
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	2.8	0.031	-1.5086	-3.4102	38.808	0.523556	148.2799
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	136.5126
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	142.2598

TABLE 6.A-2 : (Continued)

Date Tested	L ft	i in/hr	Y in.	X1 = log (Y)	Z = log (q)	Re	Fr	K
	10	2.5	0.045	-1.3468	-3.2375	57.75	0.445469	235.1642
	14	2.5	0.051	-1.2924	-3.0914	80.85	0.516903	215.7538
	14	2.8	0.053	-1.2757	-3.0422	90.552	0.546473	185.7522
	14	2.5	0.049	-1.3098	-3.0914	80.85	0.548871	199.1638
10/14/92	2	1.8	0.026	-1.585	-4.0792	8.316	0.146063	757.1779
	2	1.8	0.027	-1.5686	-4.0792	8.316	0.138024	816.5424
	2	1.8	0.026	-1.585	-4.0792	8.316	0.146063	757.1779
	6	2.8	0.037	-1.4318	-3.4102	38.808	0.401516	211.2333
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	165.9994
	6	2.8	0.038	-1.4202	-3.4102	38.808	0.385772	222.8056
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	148.1256
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	148.1256
	10	2.8	0.051	-1.2924	-3.1883	64.68	0.413523	240.7967
	14	3.8	0.054	-1.2676	-2.9096	122.892	0.721137	104.6932
	14	3.8	0.054	-1.2676	-2.9096	122.892	0.721137	104.6932
	14	4.1	0.054	-1.2676	-2.8766	132.594	0.778068	89.93277
10/15/92	2	2.1	0.027	-1.5686	-4.0122	9.702	0.161028	599.9087
	2	2.1	0.027	-1.5686	-4.0122	9.702	0.161028	599.9087
	2	3	0.031	-1.5086	-3.8573	13.86	0.186984	387.5048
	6	2.5	0.036	-1.4437	-3.4594	34.65	0.373537	250.8418
	6	2.1	0.039	-1.4089	-3.5351	29.106	0.278272	417.2205
	6	2.8	0.039	-1.4089	-3.4102	38.808	0.37103	234.6865
	10	3.4	0.047	-1.3279	-3.104	78.54	0.567582	138.6961
	10	3.4	0.048	-1.3188	-3.104	78.54	0.549938	144.6608
	10	1.4	0.04	-1.3979	-3.4894	32.34	0.29767	592.5024
	14	2.5	0.049	-1.3098	-3.0914	80.85	0.548871	199.1638
	14	2.5	0.048	-1.3188	-3.0914	80.85	0.566112	191.1176
	14	1.4	0.041	-1.3872	-3.3432	45.276	0.401584	444.6413
10/15/92	6	2.8	0.042	-1.3768	-3.4102	38.808	0.331995	272.1808
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	125.3735
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	125.3735
	10	2.1	0.041	-1.3872	-3.3133	48.51	0.430269	276.6657
	14	2.8	0.049	-1.3098	-3.0422	90.552	0.614736	158.7721
	14	3.5	0.052	-1.284	-2.9453	113.19	0.70289	114.4376
	14	1.4	0.043	-1.3665	-3.3432	45.276	0.373895	489.079
	r^2	0.933			max=	132.594		1157.231
					min	6.468		89.93277

TABLE 6.A-3 : NO-ASH ASPHALT WITHOUT DEICING MATERIAL (So=0.016)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
11/20/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	183.1002
	2	3.2	0.025	-1.6021	-3.8293	14.784	0.275402	202.5155
	2	2.1	0.026	-1.585	-4.0122	9.702	0.170406	508.6116
	6	3.5	0.04	-1.3979	-3.3133	48.51	0.446505	144.4577
	6	3.5	0.04	-1.3979	-3.3133	48.51	0.446505	144.4577
	6	2.1	0.038	-1.4202	-3.5351	29.106	0.289329	362.1475
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	14	2.1	0.047	-1.3279	-3.1671	67.914	0.490792	237.4309
	14	2.1	0.047	-1.3279	-3.1671	67.914	0.490792	237.4309
	14	0.7	0.034	-1.4685	-3.6443	22.638	0.265891	1118.258
11/20/92	2	2.9	0.024	-1.6198	-3.8721	13.398	0.265343	227.2504
	2	2.5	0.024	-1.6198	-3.9365	11.55	0.228744	305.7881
	2	1.9	0.022	-1.6576	-4.0557	8.778	0.198083	444.8528
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	123.6016
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	123.6016
	6	1.9	0.032	-1.4949	-3.5786	26.334	0.338748	313.7254
	10	2.7	0.044	-1.3565	-3.2041	62.37	0.497601	176.2325
	10	3.5	0.056	-1.2518	-3.0914	80.85	0.449244	169.8823
	10	2.8	0.043	-1.3665	-3.1883	64.68	0.534136	156.5053
	14	1.4	0.039	-1.4089	-3.3432	45.276	0.432868	367.8352
	14	1.4	0.039	-1.4089	-3.3432	45.276	0.432868	367.8352
	14	0.7	0.036	-1.4437	-3.6443	22.638	0.244044	1253.687
11/23/92	2	2.8	0.028	-1.5528	-3.8873	12.936	0.203305	331.8014
	2	2.8	0.028	-1.5528	-3.8873	12.936	0.203305	331.8014
	2	2.1	0.025	-1.6021	-4.0122	9.702	0.180732	470.24
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	2.5	0.035	-1.4559	-3.4594	34.65	0.38966	216.7769
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	163.8692
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	10	3.4	0.046	-1.3372	-3.104	78.54	0.58619	121.4691
	14	1.4	0.044	-1.3565	-3.3432	45.276	0.361222	468.1978
	14	2	0.045	-1.3468	-3.1883	64.68	0.498926	239.9635
	14	0.7	0.032	-1.4949	-3.6443	22.638	0.291204	990.5673
11/23/92	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	2.5	0.022	-1.6576	-3.9365	11.55	0.260635	256.947
	2	0.7	0.013	-1.8861	-4.4894	3.234	0.160661	1144.376
	6	2.8	0.036	-1.4437	-3.4102	38.808	0.418362	182.8293

TABLE 6.A-3 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	123.6016
	6	2.1	0.036	-1.4437	-3.5351	29.106	0.313771	325.0299
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	163.8692
	10	3.5	0.044	-1.3565	-3.0914	80.85	0.645038	104.8763
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	163.8692
	14	1.4	0.035	-1.4559	-3.3432	45.276	0.509156	296.2512
11/20/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	183.1002
	14	1.4	0.039	-1.4089	-3.3432	45.276	0.432868	367.8352
	14	0.7	0.027	-1.5686	-3.6443	22.638	0.375731	705.1988
11/24/92	2	2.8	0.024	-1.6198	-3.8873	12.936	0.256193	243.7724
	2	2.1	0.022	-1.6576	-4.0122	9.702	0.218933	364.1539
	2	2.1	0.022	-1.6576	-4.0122	9.702	0.218933	364.1539
	6	2.1	0.031	-1.5086	-3.5351	29.106	0.392667	241.0137
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	10	3.5	0.044	-1.3565	-3.0914	80.85	0.645038	104.8763
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	14	1.4	0.036	-1.4437	-3.3432	45.276	0.488089	313.4217
	14	1.78	0.041	-1.3872	-3.2389	57.5652	0.510586	251.4825
	14	2.1	0.043	-1.3665	-3.1671	67.914	0.560843	198.7369
11/24/92	2	2.1	0.023	-1.6383	-4.0122	9.702	0.204811	398.0111
	2	2.5	0.026	-1.585	-3.9365	11.55	0.202865	358.8763
	2	1.78	0.021	-1.6778	-4.084	8.2236	0.198984	461.8243
	6	1.78	0.031	-1.5086	-3.6069	24.6708	0.332832	335.4596
	6	2.8	0.033	-1.4815	-3.4102	38.808	0.476689	153.6274
	6	2.7	0.033	-1.4815	-3.426	37.422	0.459664	165.218
	10	2.8	0.045	-1.3468	-3.1883	64.68	0.498926	171.4025
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	2.1	0.039	-1.4089	-3.3133	48.51	0.463787	228.8752
	14	1	0.039	-1.4089	-3.4894	32.34	0.309192	720.9569
	14	1.78	0.046	-1.3372	-3.2389	57.5652	0.429643	316.5598
	14	1	0.034	-1.4685	-3.4894	32.34	0.379845	547.9462
11/25/92	2	1.4	0.018	-1.7447	-4.1883	6.468	0.197218	548.488
	2	1.4	0.018	-1.7447	-4.1883	6.468	0.197218	548.488
	2	1.4	0.018	-1.7447	-4.1883	6.468	0.197218	548.488
	6	1.78	0.028	-1.5528	-3.6069	24.6708	0.387731	273.6736
	6	2.5	0.034	-1.4685	-3.4594	34.65	0.406977	204.5666
	6	2.1	0.037	-1.4318	-3.5351	29.106	0.301137	343.3379
	10	2.1	0.036	-1.4437	-3.3133	48.51	0.522952	195.0179

TABLE 6.A-3 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	10	2.5	0.034	-1.4685	-3.2375	57.75	0.678294	122.74
	10	2.5	0.039	-1.4089	-3.2375	57.75	0.552128	161.4944
	14	1.4	0.036	-1.4437	-3.3432	45.276	0.488089	313.4217
	14	1	0.033	-1.4815	-3.4894	32.34	0.397241	516.1881
	14	0.7	0.033	-1.4815	-3.6443	22.638	0.278068	1053.445
11/25/92	2	2.8	0.029	-1.5376	-3.8873	12.936	0.19288	355.9247
	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	183.1002
	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	123.6016
	6	3.5	0.04	-1.3979	-3.3133	48.51	0.446505	144.4577
	6	3.2	0.04	-1.3979	-3.3522	44.352	0.408233	172.8132
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	124.8115
11/20/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	183.1002
	10	2.8	0.048	-1.3188	-3.1883	64.68	0.45289	195.0179
	14	2.5	0.044	-1.3565	-3.0914	80.85	0.645038	146.8268
	14	3.5	0.049	-1.3098	-2.9453	113.19	0.76842	92.90438
	14	2.8	0.048	-1.3188	-3.0422	90.552	0.634046	139.2985
11/26/92	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	2.8	0.023	-1.6383	-3.8873	12.936	0.273082	223.8813
	2	2.8	0.023	-1.6383	-3.8873	12.936	0.273082	223.8813
	6	3.5	0.04	-1.3979	-3.3133	48.51	0.446505	144.4577
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	14	2.1	0.045	-1.3468	-3.1671	67.914	0.523872	217.6539
11/26/92	2	3.5	0.027	-1.5686	-3.7904	16.17	0.268379	197.4557
	2	2.8	0.028	-1.5528	-3.8873	12.936	0.203305	331.8014
	2	2.1	0.022	-1.6576	-4.0122	9.702	0.218933	364.1539
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	2.8	0.037	-1.4318	-3.4102	38.808	0.401516	193.1276
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	124.8115
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	124.8115
	10	3.5	0.039	-1.4089	-3.0914	80.85	0.772979	82.39508
	14	2.1	0.048	-1.3188	-3.1671	67.914	0.475534	247.6418
	14	2	0.048	-1.3188	-3.1883	64.68	0.45289	273.0251
	14	2.1	0.044	-1.3565	-3.1671	67.914	0.541832	208.0879
	r^2	0.927			max =	113.19		1253.687
					min =	3.234		82.39508

TABLE 6.A-4 : NO-ASH ASPHALT WITH DEICING MATERIAL (So=0.016)

Date Tested	L ft	i in/hr	Y in	X1= log (Y)	Z= log (q)	Re	Fe	K
11/27/92	2	2.5	0.026	-1.585	-3.9365	11.55	0.202865	358.8763
	2	2.1	0.023	-1.6383	-4.0122	9.702	0.204811	398.0111
	2	2.1	0.022	-1.6576	-4.0122	9.702	0.218933	364.1539
	6	2.5	0.034	-1.4685	-3.4594	34.65	0.406977	204.5666
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	2.8	0.033	-1.4815	-3.4102	38.808	0.476689	153.6274
	10	2.8	0.048	-1.3188	-3.1883	64.68	0.45289	195.0179
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	2.8	0.045	-1.3468	-3.1883	64.68	0.498926	171.4025
	14	1	0.033	-1.4815	-3.4894	32.34	0.397241	516.1881
	14	1	0.034	-1.4685	-3.4894	32.34	0.379845	547.9462
	14	0.7	0.033	-1.4815	-3.6443	22.638	0.278068	1053.445
11/27/92	2	1.4	0.018	-1.7447	-4.1883	6.468	0.197218	548.488
	2	1.78	0.021	-1.6778	-4.084	8.2236	0.198984	461.8243
	2	1	0.016	-1.7959	-4.3345	4.62	0.168092	849.4115
	6	2.1	0.037	-1.4318	-3.5351	29.106	0.301137	343.3379
	6	2.1	0.031	-1.5086	-3.5351	29.106	0.392667	241.0137
	6	2.1	0.036	-1.4437	-3.5351	29.106	0.313771	325.0299
	10	1.78	0.037	-1.4318	-3.3851	41.118	0.425416	286.729
	10	2.1	0.036	-1.4437	-3.3133	48.51	0.522952	195.0179
	10	1.78	0.037	-1.4318	-3.3851	41.118	0.425416	286.729
	14	1	0.039	-1.4089	-3.4894	32.34	0.309192	720.9569
	14	1.4	0.036	-1.4437	-3.3432	45.276	0.488089	313.4217
	14	0.4	0.024	-1.6198	-3.8873	12.936	0.256193	1706.407
11/30/92	2	2.8	0.024	-1.6198	-3.8873	12.936	0.256193	243.7724
	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	183.1002
	2	2.8	0.029	-1.5376	-3.8873	12.936	0.19288	355.9247
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	123.6016
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	3.5	0.04	-1.3979	-3.3133	48.51	0.446505	144.4577
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	10	3.5	0.044	-1.3565	-3.0914	80.85	0.645038	104.8763
	10	3.2	0.047	-1.3279	-3.1303	73.92	0.534195	143.1541
	14	2.5	0.044	-1.3565	-3.0914	80.85	0.645038	146.8268
	14	3.5	0.049	-1.3098	-2.9453	113.19	0.76842	92.90438
	14	1	0.034	-1.4685	-3.4894	32.34	0.379845	547.9462
11/30/92	2	2.8	0.028	-1.5528	-3.8873	12.936	0.203305	331.8014
	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939

TABLE 6.A-4 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fe	K
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	123.6016
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	123.6016
	10	2.8	0.043	-1.3665	-3.1883	64.68	0.534136	156.5053
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	124.8115
	10	3.2	0.046	-1.3372	-3.1303	73.92	0.551709	137.1273
	14	2.8	0.048	-1.3188	-3.0422	90.552	0.634046	139.2985
	14	3.5	0.054	-1.2676	-2.9453	113.19	0.664205	112.8318
	14	1	0.042	-1.3768	-3.4894	32.34	0.276663	836.1394
12/1/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	183.1002
	2	2.8	0.028	-1.5528	-3.8873	12.936	0.203305	331.8014
	2	2.5	0.022	-1.6576	-3.9365	11.55	0.260635	256.947
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	123.6016
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	10	3.5	0.056	-1.2518	-3.0914	80.85	0.449244	169.8823
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	10	3.5	0.044	-1.3565	-3.0914	80.85	0.645038	104.8763
	14	1.8	0.046	-1.3372	-3.2341	58.212	0.434471	309.5642
	14	3.5	0.054	-1.2676	-2.9453	113.19	0.664205	112.8318
	14	2.1	0.047	-1.3279	-3.1671	67.914	0.490792	237.4309
12/1/92	2	2.5	0.024	-1.6198	-3.9365	11.55	0.228744	305.7881
	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	2.8	0.028	-1.5528	-3.8873	12.936	0.203305	331.8014
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	3.5	0.04	-1.3979	-3.3133	48.51	0.446505	144.4577
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	2.8	0.046	-1.3372	-3.1883	64.68	0.482745	179.105
	14	2.8	0.053	-1.2757	-3.0422	90.552	0.546473	169.8305
	14	3.5	0.055	-1.2596	-2.9453	113.19	0.646173	117.0495
	14	0.7	0.027	-1.5686	-3.6443	22.638	0.375731	705.1988
12/2/92	2	2.5	0.024	-1.6198	-3.9365	11.55	0.228744	305.7881
	2	2.5	0.024	-1.6198	-3.9365	11.55	0.228744	305.7881
	2	2.1	0.026	-1.585	-4.0122	9.702	0.170406	508.6116
	6	3.2	0.04	-1.3979	-3.3522	44.352	0.408233	172.8132
	6	2.8	0.039	-1.4089	-3.4102	38.808	0.37103	214.5705
	6	2.1	0.038	-1.4202	-3.5351	29.106	0.289329	362.1475
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	2.8	0.047	-1.3279	-3.1883	64.68	0.467421	186.9768

TABLE 6.A-4 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fe	K
	10	2.5	0.034	-1.4685	-3.2375	57.75	0.678294	122.74
	14	1	0.034	-1.4685	-3.4894	32.34	0.379845	547.9462
	14	2.1	0.044	-1.3565	-3.1671	67.914	0.541832	208.0879
	14	0.7	0.032	-1.4949	-3.6443	22.638	0.291204	990.5673
12/2/92	2	3.4	0.026	-1.585	-3.803	15.708	0.275896	194.0292
	2	3.5	0.027	-1.5686	-3.7904	16.17	0.268379	197.4557
	2	2.5	0.023	-1.6383	-3.9365	11.55	0.243823	280.8367
	6	3.5	0.045	-1.3468	-3.3133	48.51	0.374194	182.8293
	6	3.5	0.045	-1.3468	-3.3133	48.51	0.374194	182.8293
	6	3.5	0.045	-1.3468	-3.3133	48.51	0.374194	182.8293
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	3.4	0.046	-1.3372	-3.104	78.54	0.58619	121.4691
	14	2	0.045	-1.3468	-3.1883	64.68	0.498926	239.9635
	14	3.5	0.055	-1.2596	-2.9453	113.19	0.646173	117.0495
	14	0.7	0.034	-1.4685	-3.6443	22.638	0.265891	1118.258

	r^2	0.925			Max =	113.19		1706.407
					Min =	4.62		92.90438

TABLE 6.A-5 : ASH-CONCRETE WITHOUT DEICING MATERIAL (SO=0.016)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
11/2/92	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	2.8	0.03	-1.5229	-3.8873	12.936	0.183317	380.8944
	2	2.8	0.03	-1.5229	-3.8873	12.936	0.183317	380.8944
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	151.7709
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	151.7709
	6	3.5	0.049	-1.3098	-3.3133	48.51	0.329323	216.7769
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	140.9005
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	163.8692
	14	1.8	0.046	-1.3372	-3.2341	58.212	0.434471	309.5642
	14	2.1	0.044	-1.3565	-3.1671	67.914	0.541832	208.0879
11/2/92	2	2.8	0.031	-1.5086	-3.8873	12.936	0.174519	406.7106
	2	2.8	0.025	-1.6021	-3.8873	12.936	0.240976	264.51
	2	2.5	0.026	-1.585	-3.9365	11.55	0.202865	358.8763
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	2.5	0.044	-1.3565	-3.2375	57.75	0.460742	205.5576
	14	2.5	0.05	-1.301	-3.0914	80.85	0.532488	189.6008
	14	2.8	0.051	-1.2924	-3.0422	90.552	0.578932	157.255
	14	2.8	0.05	-1.301	-3.0422	90.552	0.596386	151.1486
11/3/92	2	2.1	0.029	-1.5376	-4.0122	9.702	0.14466	632.755
	2	1.8	0.022	-1.6576	-4.0792	8.316	0.187657	495.6539
	2	1.8	0.022	-1.6576	-4.0792	8.316	0.187657	495.6539
	6	2.8	0.038	-1.4202	-3.4102	38.808	0.385772	203.708
	6	2.9	0.038	-1.4202	-3.3949	40.194	0.399549	189.9014
	6	2.1	0.042	-1.3768	-3.5351	29.106	0.248996	442.4018
	10	3.2	0.051	-1.2924	-3.1303	73.92	0.472597	168.5577
	10	2.8	0.046	-1.3372	-3.1883	64.68	0.482745	179.105
	10	2.5	0.05	-1.301	-3.2375	57.75	0.380348	265.4411
	14	1.4	0.033	-1.4815	-3.3432	45.276	0.556137	263.3613
11/3/92	2	2.1	0.026	-1.585	-4.0122	9.702	0.170406	508.6116
	2	2.1	0.025	-1.6021	-4.0122	9.702	0.180732	470.24
	2	1.8	0.025	-1.6021	-4.0792	8.316	0.154913	640.0489
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	140.9005
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	140.9005
	10	2.5	0.04	-1.3979	-3.2375	57.75	0.531553	169.8823

TABLE 6.A-5 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	14	0.7	0.039	-1.4089	-3.6443	22.638	0.216434	1471.341
	14	3.5	0.055	-1.2596	-2.9453	113.19	0.646173	117.0495
	14	1.8	0.041	-1.3872	-3.2341	58.212	0.516323	245.9251
11/4/92	2	1.8	0.027	-1.5686	-4.0792	8.316	0.138024	746.553
	2	1.8	0.025	-1.6021	-4.0792	8.316	0.154913	640.0489
	2	2.4	0.027	-1.5686	-3.9542	11.088	0.184031	419.9361
	6	2.8	0.048	-1.3188	-3.4102	38.808	0.271734	325.0299
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	10	2.8	0.04	-1.3979	-3.1883	64.68	0.595339	135.4291
	10	2.1	0.051	-1.2924	-3.3133	48.51	0.310142	391.3902
	14	1	0.037	-1.4318	-3.4894	32.34	0.334597	648.9086
	14	2.5	0.05	-1.301	-3.0914	80.85	0.532488	189.6008
	14	1.4	0.048	-1.3188	-3.3432	45.276	0.317023	557.1941
11/4/92	2	3.5	0.031	-1.5086	-3.7904	16.17	0.218148	260.2948
	2	3.5	0.031	-1.5086	-3.7904	16.17	0.218148	260.2948
	2	2.8	0.027	-1.5686	-3.8873	12.936	0.214703	308.5245
	6	3.5	0.044	-1.3565	-3.3133	48.51	0.387023	174.7939
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	124.8115
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	124.8115
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	133.5549
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	133.5549
	14	1	0.04	-1.3979	-3.4894	32.34	0.29767	758.4031
11/5/92	2	2.8	0.03	-1.5229	-3.8873	12.936	0.183317	380.8944
	2	2.8	0.031	-1.5086	-3.8873	12.936	0.174519	406.7106
	2	2.1	0.027	-1.5686	-4.0122	9.702	0.161028	548.488
	6	3.5	0.044	-1.3565	-3.3133	48.51	0.387023	174.7939
	6	2.8	0.04	-1.3979	-3.4102	38.808	0.357204	225.7152
	6	2.1	0.036	-1.4437	-3.5351	29.106	0.313771	325.0299
	10	3.5	0.047	-1.3279	-3.0914	80.85	0.584276	119.6652
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	140.9005
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	163.8692
	14	1.4	0.04	-1.3979	-3.3432	45.276	0.416738	386.9404
	14	3.5	0.055	-1.2596	-2.9453	113.19	0.646173	117.0495
	14	1	0.04	-1.3979	-3.4894	32.34	0.29767	758.4031
11/5/92	2	2.8	0.027	-1.5686	-3.8873	12.936	0.214703	308.5245
	2	3.2	0.032	-1.4949	-3.8293	14.784	0.190174	331.8014
	2	2.8	0.029	-1.5376	-3.8873	12.936	0.19288	355.9247
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939

TABLE 6.A-5 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	6	2.5	0.037	-1.4318	-3.4594	34.65	0.358497	242.2592
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	10	3.2	0.049	-1.3098	-3.1303	73.92	0.501825	155.5967
	14	2.8	0.052	-1.284	-3.0422	90.552	0.562312	163.4823
	14	2.5	0.048	-1.3188	-3.0914	80.85	0.566112	174.7361
	14	0.7	0.035	-1.4559	-3.6443	22.638	0.254578	1185.005
11/6/92	2	2.8	0.031	-1.5086	-3.8873	12.936	0.174519	406.7106
	2	2.8	0.031	-1.5086	-3.8873	12.936	0.174519	406.7106
	2	2.5	0.027	-1.5686	-3.9365	11.55	0.191699	387.0131
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	10	2.8	0.047	-1.3279	-3.1883	64.68	0.467421	186.9768
	14	2.5	0.045	-1.3468	-3.0914	80.85	0.623657	153.5766
	14	2.1	0.049	-1.3098	-3.1671	67.914	0.461052	258.0677
	14	0.7	0.033	-1.4815	-3.6443	22.638	0.278068	1053.445
11/6/92	2	2.5	0.029	-1.5376	-3.9365	11.55	0.172214	446.4719
	2	2.5	0.029	-1.5376	-3.9365	11.55	0.172214	446.4719
	2	2.1	0.027	-1.5686	-4.0122	9.702	0.161028	548.488
	6	2.8	0.047	-1.3279	-3.4102	38.808	0.280452	311.6281
	6	2.8	0.047	-1.3279	-3.4102	38.808	0.280452	311.6281
	6	2.8	0.033	-1.4815	-3.4102	38.808	0.476689	153.6274
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	140.9005
	10	2.8	0.045	-1.3468	-3.1883	64.68	0.498926	171.4025
	14	3.5	0.054	-1.2676	-2.9453	113.19	0.664205	112.8318
	14	4.4	0.059	-1.2291	-2.8459	142.296	0.731138	85.22731
	14	2.4	0.048	-1.3188	-3.1091	77.616	0.543468	189.6008
11/6/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	183.1002
	2	3.4	0.033	-1.4815	-3.803	15.708	0.192945	312.5707
	2	2.8	0.031	-1.5086	-3.8873	12.936	0.174519	406.7106
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	2.1	0.038	-1.4202	-3.5351	29.106	0.289329	362.1475
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	10	3.4	0.049	-1.3098	-3.104	78.54	0.533189	137.8296

TABLE 6.A-5 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	14	3.5	0.055	-1.2596	-2.9453	113.19	0.646173	117.0495
	14	2.8	0.049	-1.3098	-3.0422	90.552	0.614736	145.1631
	14	1	0.035	-1.4559	-3.4894	32.34	0.363683	580.6524
	r^2	0.915			max =	142.296		1471.341
					min =	8.316		85.22731

TABLE 6.A-6 : ASH-CONCRETE WITH DEICING MATERIAL (So=0.016)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
11/9/92	2	3.5	0.031	-1.5086	-3.7904	16.17	0.218148	260.2948
	2	3.4	0.033	-1.4815	-3.803	15.708	0.192945	312.5707
	2	2.5	0.029	-1.5376	-3.9365	11.55	0.172214	446.4719
	6	3.5	0.044	-1.3565	-3.3133	48.51	0.387023	174.7939
	6	3.5	0.044	-1.3565	-3.3133	48.51	0.387023	174.7939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	124.8115
	10	3.4	0.049	-1.3098	-3.104	78.54	0.533189	137.8296
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	163.8692
	14	3.4	0.055	-1.2596	-2.9579	109.956	0.627711	124.036
	14	2.1	0.044	-1.3565	-3.1671	67.914	0.541832	208.0879
	14	0.85	0.038	-1.4202	-3.5599	27.489	0.273255	947.3478
11/9/92	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	3.5	0.031	-1.5086	-3.7904	16.17	0.218148	260.2948
	2	2.8	0.027	-1.5686	-3.8873	12.936	0.214703	308.5245
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.4	0.042	-1.3768	-3.3259	47.124	0.403137	168.7709
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	140.9005
	10	3.4	0.049	-1.3098	-3.104	78.54	0.533189	137.8296
	14	3.5	0.055	-1.2596	-2.9453	113.19	0.646173	117.0495
	14	2.1	0.049	-1.3098	-3.1671	67.914	0.461052	258.0677
	14	1	0.035	-1.4559	-3.4894	32.34	0.363683	580.6524
11/10/92	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	3.2	0.032	-1.4949	-3.8293	14.784	0.190174	331.8014
	2	2.5	0.026	-1.585	-3.9365	11.55	0.202865	358.8763
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.2	0.041	-1.3872	-3.3522	44.352	0.393389	181.5619
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	140.9005
	10	2.8	0.046	-1.3372	-3.1883	64.68	0.482745	179.105
	10	2.5	0.05	-1.301	-3.2375	57.75	0.380348	265.4411
	14	2.8	0.051	-1.2924	-3.0422	90.552	0.578932	157.255
	14	2.5	0.05	-1.301	-3.0914	80.85	0.532488	189.6008
	14	0.7	0.035	-1.4559	-3.6443	22.638	0.254578	1185.005
11/11/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	183.1002
	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	2.8	0.03	-1.5229	-3.8873	12.936	0.183317	380.8944
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	151.7709

TABLE 6.A-6 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	6	3.5	0.049	-1.3098	-3.3133	48.51	0.329323	216.7769
	6	2.8	0.038	-1.4202	-3.4102	38.808	0.385772	203.708
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	10	3.5	0.051	-1.2924	-3.0914	80.85	0.516903	140.9005
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	130.0661
	14	2.8	0.05	-1.301	-3.0422	90.552	0.596386	151.1486
	14	2.2	0.048	-1.3188	-3.1469	71.148	0.498179	225.6406
	14	0.7	0.039	-1.4089	-3.6443	22.638	0.216434	1471.341
11/11/92	2	3.2	0.029	-1.5376	-3.8293	14.784	0.220434	272.5048
	2	3.2	0.029	-1.5376	-3.8293	14.784	0.220434	272.5048
	2	2.8	0.03	-1.5229	-3.8873	12.936	0.183317	380.8944
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	151.7709
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	163.8692
	14	3.2	0.054	-1.2676	-2.9842	103.488	0.607273	134.9795
	14	2.8	0.049	-1.3098	-3.0422	90.552	0.614736	145.1631
	14	0.7	0.033	-1.4815	-3.6443	22.638	0.278068	1053.445
11/13/92	2	3.5	0.03	-1.5229	-3.7904	16.17	0.229146	243.7724
	2	3.4	0.03	-1.5229	-3.803	15.708	0.222599	258.3229
	2	2.8	0.031	-1.5086	-3.8873	12.936	0.174519	406.7106
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	10	3.5	0.046	-1.3372	-3.0914	80.85	0.603431	114.6272
	10	3.4	0.049	-1.3098	-3.104	78.54	0.533189	137.8296
	10	3.4	0.05	-1.301	-3.104	78.54	0.517274	143.5127
	14	3.4	0.055	-1.2596	-2.9579	109.956	0.627711	124.036
	14	2.8	0.052	-1.284	-3.0422	90.552	0.562312	163.4823
	14	0.7	0.033	-1.4815	-3.6443	22.638	0.278068	1053.445
11/13/92	2	2.5	0.027	-1.5686	-3.9365	11.55	0.191699	387.0131
	2	2.9	0.028	-1.5528	-3.8721	13.398	0.210566	309.313
	2	2.1	0.029	-1.5376	-4.0122	9.702	0.14466	632.755
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.2	0.041	-1.3872	-3.3522	44.352	0.393389	181.5619
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	10	3.5	0.048	-1.3188	-3.0914	80.85	0.566112	124.8115

TABLE 6.A-6 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	10	3.2	0.049	-1.3098	-3.1303	73.92	0.501825	155.5967
	14	3.3	0.055	-1.2596	-2.9708	106.722	0.609249	131.6672
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	133.5549
	14	1.7	0.044	-1.3565	-3.2589	54.978	0.438626	317.5321
11/16/92	2	2.8	0.03	-1.5229	-3.8873	12.936	0.183317	380.8944
	2	2.8	0.031	-1.5086	-3.8873	12.936	0.174519	406.7106
	2	2.8	0.027	-1.5686	-3.8873	12.936	0.214703	308.5245
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	2.8	0.048	-1.3188	-3.4102	38.808	0.271734	325.0299
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	135.4291
	10	3.5	0.047	-1.3279	-3.0914	80.85	0.584276	119.6652
	10	3.3	0.049	-1.3098	-3.117	76.23	0.517507	146.3095
	14	3.5	0.055	-1.2596	-2.9453	113.19	0.646173	117.0495
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	133.5549
	14	1.4	0.048	-1.3188	-3.3432	45.276	0.317023	557.1941
11/16/92	2	3.4	0.03	-1.5229	-3.803	15.708	0.222599	258.3229
	2	2.8	0.031	-1.5086	-3.8873	12.936	0.174519	406.7106
	2	2.5	0.029	-1.5376	-3.9365	11.55	0.172214	446.4719
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	166.939
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	159.2646
	6	2.8	0.04	-1.3979	-3.4102	38.808	0.357204	225.7152
	10	3.5	0.045	-1.3468	-3.0914	80.85	0.623657	109.6976
	10	3.4	0.05	-1.301	-3.104	78.54	0.517274	143.5127
	10	2.8	0.045	-1.3468	-3.1883	64.68	0.498926	171.4025
	14	3.4	0.055	-1.2596	-2.9579	109.956	0.627711	124.036
	14	2.2	0.048	-1.3188	-3.1469	71.148	0.498179	225.6406
	14	0.7	0.033	-1.4815	-3.6443	22.638	0.278068	1053.445
	r^2	0.947			max =	113.19		109.6976
					min =	9.702		109.6976

TABLE 6.A-7 : ASH-ASPHALT WITHOUT DEICING MATERIAL (So=0.0175)

Date Tested	L ft	i in/hr	Y in	X1= log (Y)	Z= log (q)	Re	Fr	K
12/4/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	2	2.1	0.023	-1.6383	-4.0122	9.702	0.204811	435.3247
	6	3.5	0.039	-1.4089	-3.3133	48.51	0.463787	150.1994
	6	3.5	0.033	-1.4815	-3.3133	48.51	0.595861	107.5392
	6	2.8	0.033	-1.4815	-3.4102	38.808	0.476689	168.03
	10	3.5	0.042	-1.3768	-3.0914	80.85	0.691657	104.5174
	10	2.8	0.049	-1.3098	-3.1883	64.68	0.439097	222.281
	14	2.1	0.043	-1.3665	-3.1671	67.914	0.560843	217.3684
	14	2.1	0.043	-1.3665	-3.1671	67.914	0.560843	217.3684
12/7/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	2	2.8	0.026	-1.585	-3.8873	12.936	0.227208	312.9153
	6	3.5	0.038	-1.4202	-3.3133	48.51	0.482215	142.5956
	6	3.5	0.039	-1.4089	-3.3133	48.51	0.463787	150.1994
	6	2.8	0.038	-1.4202	-3.4102	38.808	0.385772	222.8056
	10	3.5	0.039	-1.4089	-3.0914	80.85	0.772979	90.11962
	10	3.2	0.039	-1.4089	-3.1303	73.92	0.706724	107.8091
	10	2.8	0.04	-1.3979	-3.1883	64.68	0.595339	148.1256
	14	2.1	0.04	-1.3979	-3.1671	67.914	0.625106	188.096
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	1.78	0.038	-1.4202	-3.2389	57.5652	0.572228	236.2791
12/7/92	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	2.8	0.024	-1.6198	-3.8873	12.936	0.256193	266.6261
	6	3.5	0.035	-1.4559	-3.3133	48.51	0.545524	120.9692
	6	3.5	0.035	-1.4559	-3.3133	48.51	0.545524	120.9692
	6	3.2	0.036	-1.4437	-3.3522	44.352	0.478128	153.1017
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	2.8	0.039	-1.4089	-3.1883	64.68	0.618383	140.8119
	14	2.8	0.041	-1.3872	-3.0422	90.552	0.803169	111.1603
	14	2.5	0.049	-1.3098	-3.0914	80.85	0.548871	199.1638
	14	2.1	0.038	-1.4202	-3.1671	67.914	0.675101	169.7566
12/8/92	2	2.8	0.027	-1.5686	-3.8873	12.936	0.214703	337.4486
	2	2.8	0.025	-1.6021	-3.8873	12.936	0.240976	289.3078
	2	1	0.016	-1.7959	-4.3345	4.62	0.168092	929.0438
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	135.1893
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	135.1893
	6	2.1	0.032	-1.4949	-3.5351	29.106	0.374405	280.89

TABLE 6.A-7 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	10	2.8	0.043	-1.3665	-3.1883	64.68	0.534136	171.1777
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	2.5	0.04	-1.3979	-3.2375	57.75	0.531553	185.8088
	14	2.5	0.045	-1.3468	-3.0914	80.85	0.623657	167.9744
	14	2.1	0.038	-1.4202	-3.1671	67.914	0.675101	169.7566
	14	1.4	0.033	-1.4815	-3.3432	45.276	0.556137	288.0514
12/8/92	2	3.2	0.024	-1.6198	-3.8293	14.784	0.292792	204.1356
	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	2.8	0.037	-1.4318	-3.4102	38.808	0.401516	211.2333
	10	2.8	0.046	-1.3372	-3.1883	64.68	0.482745	195.8961
	10	3.2	0.041	-1.3872	-3.1303	73.92	0.655648	119.15
	10	2.8	0.042	-1.3768	-3.1883	64.68	0.553325	163.3085
	14	2.1	0.045	-1.3468	-3.1671	67.914	0.523872	238.059
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	1.4	0.033	-1.4815	-3.3432	45.276	0.556137	288.0514
12/9/92	2	2.1	0.022	-1.6576	-4.0122	9.702	0.218933	398.2933
	2	2.1	0.022	-1.6576	-4.0122	9.702	0.218933	398.2933
	6	2.8	0.03	-1.5229	-3.4102	38.808	0.549951	138.8678
	6	2.6	0.032	-1.4949	-3.4424	36.036	0.46355	183.2434
	6	1.4	0.026	-1.585	-3.7112	19.404	0.340813	417.2205
	10	2.1	0.04	-1.3979	-3.3133	48.51	0.446505	263.3344
	14	1.4	0.032	-1.4949	-3.3432	45.276	0.582408	270.8582
12/9/92	2	3.4	0.022	-1.6576	-3.803	15.708	0.354463	151.9441
	2	3.5	0.022	-1.6576	-3.7904	16.17	0.364889	143.3856
	6	3.4	0.035	-1.4559	-3.3259	47.124	0.529937	128.1897
	6	2.8	0.031	-1.5086	-3.4102	38.808	0.523556	148.2799
	10	2.8	0.04	-1.3979	-3.1883	64.68	0.595339	148.1256
	10	2.1	0.044	-1.3565	-3.3133	48.51	0.387023	318.6346
	14	2.1	0.045	-1.3468	-3.1671	67.914	0.523872	238.059
	14	1.1	0.033	-1.4815	-3.448	35.574	0.436965	466.5957
12/9/92	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	2.1	0.023	-1.6383	-4.0122	9.702	0.204811	435.3247
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	135.1893
	6	3.5	0.039	-1.4089	-3.3133	48.51	0.463787	150.1994
	6	2.1	0.037	-1.4318	-3.5351	29.106	0.301137	375.5258
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537

TABLE 6.A-7 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	10	3.5	0.042	-1.3768	-3.0914	80.85	0.691657	104.5174
	10	2.8	0.039	-1.4089	-3.1883	64.68	0.618383	140.8119
	14	2.8	0.045	-1.3468	-3.0422	90.552	0.698496	133.9082
	14	2.8	0.05	-1.301	-3.0422	90.552	0.596386	165.3188
	14	2.1	0.038	-1.4202	-3.1671	67.914	0.675101	169.7566
12/10/92	2	3.5	0.02	-1.699	-3.7904	16.17	0.420968	118.5005
	2	3.5	0.029	-1.5376	-3.7904	16.17	0.2411	249.1473
	2	2.8	0.023	-1.6383	-3.8873	12.936	0.273082	244.8701
	6	3.5	0.038	-1.4202	-3.3133	48.51	0.482215	142.5956
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	3.2	0.037	-1.4318	-3.3522	44.352	0.458876	161.7255
	10	3.5	0.05	-1.301	-3.0914	80.85	0.532488	148.1256
	10	3.5	0.049	-1.3098	-3.0914	80.85	0.548871	142.2598
	10	2.8	0.047	-1.3279	-3.1883	64.68	0.467421	204.5059
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.5	0.046	-1.3372	-3.0914	80.85	0.603431	175.5229
12/10/92	2	3.5	0.028	-1.5528	-3.7904	16.17	0.254131	232.2609
	2	3.5	0.028	-1.5528	-3.7904	16.17	0.254131	232.2609
	2	2.8	0.025	-1.6021	-3.8873	12.936	0.240976	289.3078
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	165.9994
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	165.9994
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	182.5895
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	3.2	0.039	-1.4089	-3.1303	73.92	0.706724	107.8091
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.8	0.044	-1.3565	-3.0422	90.552	0.722443	128.0228
12/14/92	2	2.8	0.022	-1.6576	-3.8873	12.936	0.291911	224.04
	2	1.5	0.019	-1.7212	-4.1584	6.93	0.194844	582.2653
	6	2.8	0.037	-1.4318	-3.4102	38.808	0.401516	211.2333
	6	2.6	0.037	-1.4318	-3.4424	36.036	0.372837	244.9806
	6	2	0.031	-1.5086	-3.5563	27.72	0.373969	290.6286
	10	2.8	0.042	-1.3768	-3.1883	64.68	0.553325	163.3085
	10	2.5	0.034	-1.4685	-3.2375	57.75	0.678294	134.2468
	14	1.4	0.035	-1.4559	-3.3432	45.276	0.509156	324.0248
	14	2.7	0.044	-1.3565	-3.058	87.318	0.696641	137.6816
	14	2.1	0.039	-1.4089	-3.1671	67.914	0.649302	178.8088
12/14/92	2	3	0.026	-1.585	-3.8573	13.86	0.243438	272.584

TABLE 6.A-7 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	2	1.4	0.018	-1.7447	-4.1883	6.468	0.197218	599.9087
	6	3.4	0.04	-1.3979	-3.3259	47.124	0.433747	167.4315
	6	2.8	0.04	-1.3979	-3.4102	38.808	0.357204	246.876
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	179.232
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	179.232
	10	2.1	0.035	-1.4559	-3.3133	48.51	0.545524	201.6154
	14	1	0.04	-1.3979	-3.4894	32.34	0.29767	829.5034
	14	2.1	0.043	-1.3665	-3.1671	67.914	0.560843	217.3684
	r^2	0.903			max =	90.552		929.0438
					min =	4.62		90.11962

TABLE 6.A-8 : ASH-ASPHALT WITH DEICING MATERIAL (So=0.0175)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
12/16/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	2.1	0.023	-1.6383	-4.0122	9.702	0.204811	435.3247
	6	3.5	0.033	-1.4815	-3.3133	48.51	0.595861	107.5392
	6	3.5	0.033	-1.4815	-3.3133	48.51	0.595861	107.5392
	6	2.8	0.037	-1.4318	-3.4102	38.808	0.401516	211.2333
	10	3.5	0.039	-1.4089	-3.0914	80.85	0.772979	90.11962
	10	2.8	0.042	-1.3768	-3.1883	64.68	0.553325	163.3085
	14	2.1	0.038	-1.4202	-3.1671	67.914	0.675101	169.7566
	14	2.1	0.039	-1.4089	-3.1671	67.914	0.649302	178.8088
12/16/92	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	2	2.8	0.023	-1.6383	-3.8873	12.936	0.273082	244.8701
	6	3.5	0.039	-1.4089	-3.3133	48.51	0.463787	150.1994
	6	3.5	0.039	-1.4089	-3.3133	48.51	0.463787	150.1994
	10	3.5	0.042	-1.3768	-3.0914	80.85	0.691657	104.5174
	10	2.8	0.041	-1.3872	-3.1883	64.68	0.573692	155.6245
	14	2.1	0.032	-1.4949	-3.1671	67.914	0.873613	120.3814
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
12/23/92	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	3.5	0.027	-1.5686	-3.7904	16.17	0.268379	215.9671
	2	2.8	0.025	-1.6021	-3.8873	12.936	0.240976	289.3078
	6	3.5	0.035	-1.4559	-3.3133	48.51	0.545524	120.9692
	6	3.5	0.036	-1.4437	-3.3133	48.51	0.522952	127.9805
	6	3.2	0.031	-1.5086	-3.3522	44.352	0.59835	113.5268
	10	3.5	0.042	-1.3768	-3.0914	80.85	0.691657	104.5174
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	179.232
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.5	0.045	-1.3468	-3.0914	80.85	0.623657	167.9744
	14	2.1	0.038	-1.4202	-3.1671	67.914	0.675101	169.7566
12/23/92	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	2.8	0.022	-1.6576	-3.8873	12.936	0.291911	224.04
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	135.1893
	6	3.5	0.038	-1.4202	-3.3133	48.51	0.482215	142.5956
	6	2.5	0.033	-1.4815	-3.4594	34.65	0.425615	210.7768
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	2.1	0.034	-1.4685	-3.3133	48.51	0.569767	190.2591
	14	2.1	0.043	-1.3665	-3.1671	67.914	0.560843	217.3684

TABLE 6.A-8 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	14	2.8	0.044	-1.3565	-3.0422	90.552	0.722443	128.0228
	14	2.1	0.038	-1.4202	-3.1671	67.914	0.675101	169.7566
12/24/92	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	2	2.5	0.024	-1.6198	-3.9365	11.55	0.228744	334.4558
	6	3.5	0.035	-1.4559	-3.3133	48.51	0.545524	120.9692
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	165.9994
	6	2.5	0.033	-1.4815	-3.4594	34.65	0.425615	210.7768
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	14	2.5	0.049	-1.3098	-3.0914	80.85	0.548871	199.1638
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.1	0.038	-1.4202	-3.1671	67.914	0.675101	169.7566
1/4/93	2	3.5	0.023	-1.6383	-3.7904	16.17	0.341352	156.7169
	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	2	2.1	0.019	-1.7212	-4.0122	9.702	0.272782	297.0741
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	165.9994
	6	3.5	0.041	-1.3872	-3.3133	48.51	0.430269	165.9994
	6	2.1	0.026	-1.585	-3.5351	29.106	0.511219	185.4313
	10	3.2	0.041	-1.3872	-3.1303	73.92	0.655648	119.15
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	179.232
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.5	0.046	-1.3372	-3.0914	80.85	0.603431	175.5229
	14	1.78	0.043	-1.3665	-3.2389	57.5652	0.475381	302.5486
1/4/93	2	3.5	0.028	-1.5528	-3.7904	16.17	0.254131	232.2609
	2	2.8	0.026	-1.585	-3.8873	12.936	0.227208	312.9153
	2	3.5	0.026	-1.585	-3.7904	16.17	0.284011	200.2658
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	6	2.8	0.036	-1.4437	-3.4102	38.808	0.418362	199.9696
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	14	2.8	0.045	-1.3468	-3.0422	90.552	0.698496	133.9082
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.5	0.044	-1.3565	-3.0914	80.85	0.645038	160.5919
1/5/93	2	3.5	0.024	-1.6198	-3.7904	16.17	0.320242	170.6407
	2	3.5	0.024	-1.6198	-3.7904	16.17	0.320242	170.6407
	2	3.2	0.024	-1.6198	-3.8293	14.784	0.292792	204.1356
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	182.5895
	6	3.5	0.043	-1.3665	-3.3133	48.51	0.400602	182.5895

TABLE 6.A-8 : (Continued)

Date Tested	L ft	i in/hr	Y in	X1 = log (Y)	Z = log (q)	Re	Fr	K
	6	3.5	0.042	-1.3768	-3.3133	48.51	0.414994	174.1957
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	2.5	0.04	-1.3979	-3.2375	57.75	0.531553	185.8088
	14	2.8	0.045	-1.3468	-3.0422	90.552	0.698496	133.9082
	14	2.8	0.046	-1.3372	-3.0422	90.552	0.675843	139.9258
	14	2.1	0.04	-1.3979	-3.1671	67.914	0.625106	188.096
1/5/93	2	3.5	0.028	-1.5528	-3.7904	16.17	0.254131	232.2609
	2	3.2	0.028	-1.5528	-3.8293	14.784	0.232348	277.8512
	2	3.5	0.028	-1.5528	-3.7904	16.17	0.254131	232.2609
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	135.1893
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	135.1893
	6	2.8	0.033	-1.4815	-3.4102	38.808	0.476689	168.03
	10	3.5	0.043	-1.3665	-3.0914	80.85	0.66767	109.5537
	10	3.5	0.047	-1.3279	-3.0914	80.85	0.584276	130.8838
	10	2.8	0.043	-1.3665	-3.1883	64.68	0.534136	171.1777
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	146.0757
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	146.0757
	14	2.5	0.045	-1.3468	-3.0914	80.85	0.623657	167.9744
1/6/93	2	3.5	0.024	-1.6198	-3.7904	16.17	0.320242	170.6407
	2	3.2	0.024	-1.6198	-3.8293	14.784	0.292792	204.1356
	2	3.5	0.025	-1.6021	-3.7904	16.17	0.301221	185.157
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	135.1893
	6	2.1	0.031	-1.5086	-3.5351	29.106	0.392667	263.6087
	6	3.5	0.037	-1.4318	-3.3133	48.51	0.501895	135.1893
	10	3.2	0.048	-1.3188	-3.1303	73.92	0.517589	163.3085
	10	2.8	0.044	-1.3565	-3.1883	64.68	0.516031	179.232
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	146.0757
	14	2.8	0.047	-1.3279	-3.0422	90.552	0.654389	146.0757
	14	2.5	0.045	-1.3468	-3.0914	80.85	0.623657	167.9744
	r^2	0.917			max =	90.552		435.3247
					min =	9.702		90.11962

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