THE EFFECT OF FREEZE-THAW AND FROST HEAVE ON FLOWABLE FILL

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16. Abstract

Flowable Fill mixes were evaluated in the laboratory and field. Consideration was given to strength, flowability and time of set. Emphasis was placed on evaluating the freeze-thaw durability of typical Flowable Fill mixes. Flowable Fill mix criteria were established. Flowable Fill mix design and evaluation consisted of testing various combinations of concrete sand, wash wastes, crusher waste fines, an ASTM C 618 fly ash, a high carbon fly ash, air entraining admixtures, and Type II portland cement. Freeze thaw testing was done on selected mixes.

Laboratory testing showed that high quality Flowable Fills could be made from almost any material. However, it was found that Flowable fill made with 100% high carbon fly ash as the aggregate should be limited to an ash with an LOI less than 25% due to increased cement demand. Freeze thaw durability of Flowable Fill could not be effectively evaluated in the laboratory due to the high rate of freezing criteria of ASTM C 666. Recommended trial Flowable Fill mix designs are included in the report.

Field testing of Flowable Fill consisted of evaluating the settlement, freeze thaw durability and frost heaving properties of selected mixes. Flowable Fill was found to have better settlement performance than granular fill when used to backfill a simulated bridge abutment on a very heavy loaded haul road in an aggregate plant. With the exception of the top two inches the freeze thaw durability was found to be very good even when the material was allowed to freeze prior to setting.

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TABLE OF CONTENTS

TABLE OF CONTENTS continued

Section. Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Flowable Fill is a name given to backfill materials which when mixed and deposited are fluid like and when in place gain sufficient strength at an early age to essentially eliminate later settlement. Flowable Fill is an unique fluid-like material designed to be self flowing and, when set and hardened, has strength and physical properties similar to a soil. Flowable Fill may be made with a variety of materials including fly ash materials and waste wash materials.

A literature review revealed a wide variety of mixes as well as many names for the product commonly called Flowable Fill.[1...55] A sampling of the names found include controlled-density fill, flowable mortar, Flowable Fill, lean-mix backfill, unshrinkable fill, flowable fly ash, etc.. The American Concrete Institute (ACI) formed Committee 229 to investigate the properties of what it has designated as controlled low-strength materials (CLSM). The wide variety of names is an indication of the number of potential uses for the material and the many unique properties it can possess. The name Flowable Fill easily describes the most important attributes of the product without misleading the public as to the properties of the product. Flowable Fill should not be considered to be concrete.[4,20,23] It does not have the strength of concrete, and it is not intended to. Its most important properties are that it is flowable and will fill a cavity completely without extensive labor.

Flowable Fill has been used for many purposes.[1,2,7,9,10,13,14,18,32,33,37,40,46] It has been used as a backfill for utility trenches, sewer trenches, building excavations, bridge abutments and conduit trenches, as a structural fill to serve as a foundation sub-base or a sub-footing. It has been used to fill abandoned underground storage tanks and other underground voids which might have come to exist under pavements or foundations or in any other normally inaccessible area. Each project has certain needs which require special design parameters to be implemented into the site's specific requirements.

A Flowable Fill can be comprised of up to five components, 1.) portland cement, 2.) aggregate (usually fine), 3.) water, 4.) fly ash, and sometimes 5.) admixtures. The proportions of these ingredients affect the characteristics of the Flowable Fill. Portland cement affects setting and strength development, aggregate provides bulk volume and its gradation affects flowability of the mix, fly ash provides flowability and increases long term strength, and water is necessary for hydration and flowability of the mixture. Air entraining admixtures help make mixes flowable by adding entrained air to the mix.[44] Such also lowers the unit weight and may affect time of set by reducing bleeding.

BACKGROUND

History

Fly ash is a waste by-product from the combustion of coal in coal-fired electricity power plants. The viable use of fly ash in Flowable Fill means that a material which would otherwise require the expense of disposal in a landfill can be put to productive use and actually be a resource. In the late 1960's, Detroit Edison Co. started using a fly ash cement grout as a backfill material placed at a fluid consistency. Initial field placement tests were conducted at the Greenwood Energy Center in Avoca, Michigan. This material became marketed as K-Krete Controlled Density Fill. Numerous mix variations were later developed independently, including M-Crete, S-Crete Flowable Fill, Flowable Grout, Flowable Mortar, and One Sack Mix.[8,35]

Flowable Fly Ash was developed in 1978 to fill a need for a low cost backfill material to construct a railroad embankment in water up to 9.1 meters (30 feet) deep. Fly ash was available for use which proved to be an economical solution because backfill had to be hauled 42 km (26 miles). A trial program in 1979 proved that flowable fly ash could be placed in water at a slope of one to two in a current estimated at 61 cm/sec (2 feet per second). The erosion characteristics of flowable fly ash were compared to other available conventional materials. Flowable fly ash was shown to be superior to other materials in both the amount of material lost and suspended in the flowing water. Clean rock was the only other material estimated to be comparable. Flowable fly ash backfill placed in water eliminates the need for silt curtains, containment weirs, and other required environmental constrictions.[28]

Municipalities, state departments of transportation and utility companies began using Flowable Fill for various applications around 1978. In 1985, seeing the need for more technical information, the American Concrete Institute (ACI) set up Committee 229 to study the subject and to provide technical information for the uses, mix designs and general information needed to better utilize CLSM.[8]

In 1988, the Public Works Department for the City of Peoria, Illinois studied the use of Flowable Fill in their projects.[13] The City of Peoria was particularly interested in developing specifications for the use of CLSM in backfilling operations for city streets. The mix included a small amount of cement, fine aggregate, fly ash and mixing water. The City monitored the shrinkage of the placed Flowable Fill mixtures, and performed in-situ dry density and moisture content tests using a nuclear moisture density gauge. They documented the ambient air temperature and the temperature of the fill. Unconfined compressive strength tests were performed on air cured specimens at 24 hours, 14 days and later at 56 days. Highway traffic was simulated by driving an empty concrete truck over the test pits after a four and a half day period.

The test results showed that the unconfined compressive strength, recorded when the cylinders were tested during the 1 to 14 day period was greatly affected by the amount of water and cementitious material utilized in the mix as would be expected. The Peoria study concluded that the Flowable Fill mixes demonstrated excellent in-place density with minimal shrinkage. The mixes were found to be susceptible to surface deterioration when subjected to highway traffic.[24] The results of the field tests led the City of Peoria to specify the use of CLSM in its backfilling projects.

The Metropolitan Toronto Roads and Traffic Division requires the use of unshrinkable fill for utility cuts. They have approximately 4000 utility cuts each year and have found that inadequate backfill compaction, improper backfill materials and voids under adjacent pavement results in shortened pavement life, additional maintenance costs, long-term settlement, cracking, pavement roughness and nuisance effects such as ponding water.[14] The use of Flowable Fill helps to alleviate or at least minimize these problems.

The City of Edmonton, Alberta also uses unshrinkable fill until winter freeze-up. Flowable Fill was found to be particularly helpful in areas where the speed of construction is important, for small jobs, and in tight areas where conventional compaction equipment will not fit. To protect utility lines that need to be excavated at a later date, they sometimes compact around the pipe with a layer of sand for protection if excavation is needed in the future, and to provide a warning that the pipe line is near.[27]

In Iowa, they have taken the use of Flowable Fill so far as to use it to first backfill culverts and then later to backfill bridges. The culvert procedure includes filling the first half of the culvert with granular backfill to keep the culvert from floating during the backfilling procedure and to also provide drainage through the outside of the lower half of the culvert. They have also replaced badly deteriorated culverts by putting a new culvert inside the old and filling the gap between them with Flowable Fill. Iowa has extended this application to bridges. Culvert pipe or reinforced box culvert is placed under the bridge and the perimeter of the ends is sealed with soil. The culvert is then backfilled using the soil at each end to act as a form. The bridge is formed by pouring the Flowable Fill in lifts so that it has an opportunity to set and so the lateral pressures created by the Flowable Fill will not be too great for the retaining soil.[9] This has enabled them to create relatively low cost bridges.

Materials

Fly ash is defined by ASTM C 618, "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete", as "finely divided residue that results from the combustion of ground or powdered coal". Fly ashes are pozzolans which are siliceous and aluminous materials which in themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. There are 3 classes of fly ashes defined by ASTM C 618: Class N, Class F and Class C, however only the Class F fly ash is available for use in New Hampshire. Class F is defined as fly ash normally produced from burning anthracite or bituminous coal. It has pozzolanic properties. The fly ashes used in this study were from PSNH power plants located at Bow New Hampshire (Merrimack Fly Ash) and Portsmouth, New Hampshire (Schiller Fly Ash).

Fly ash is a by-product of the combustion of pulverized coal in an electric power generating plant and has been a major component of Flowable Fill projects to date. The combustion process in the plant burns most of the volatile matter and the carbon in the coal, and the other mineral components such as clay, feldspar, quartz and shale are fused together and carried in the exhaust gas where they cool and solidify and form spherical particles of fly ash. Bag filters, or electrostatic precipitators remove the fly ash from the exhaust gas. Typical fly ash particles are solid spheres, although some are hollow (cenospheres) , and some are spheres within spheres (plerospheres). The size of fly ash spheres can vary from 1 micron to 100 microns. Typical high quality fly ash particles are under 20 microns.[45] Fly ash is primarily a glass containing silica, alumina, iron and calcium. It also contains lesser amounts of magnesium, sulfur, sodium, potassium as well as trace amounts of heavy metals. Fly ash has a specific gravity in the range of 2.2 to 2.8 and is tan or gray in color.[45]

Aggregate, when used in Flowable Fill, functions as a filler and in some cases as a flowability agent . Most specifications require the aggregate meet ASTM C 33 "Standard Specification for Concrete Aggregates". The type and size distribution of the aggregate affects the flowability of Flowable Fill. Fine aggregate sand is the most common aggregate used. Pea gravel with sand, 2 cm (3/4 inch) minus aggregate with sand, native soils with more then 10% passing the #200 sieve and quarry waste products (generally 1 cm (3/8 inch) minus aggregate), have been used successfully.[39]

Thomas A Fox, writing in the Transportation Research Record, relates that while CLSMs have evolved using sand as fillers, in the Pacific Northwest gravels up to one inch in size have been used successfully.[21] The use of gravel may even result in less subsidence.

Strength

The strength of a Flowable Fill depends on the amount of portland cement and water and the quality and quantity of fly ash if used. Early strength is a function of the portland cement and the hydration process. The cement particles in the mixture begin the process of hydration the instant they come into contact with water. Calcium silicate hydrate, CSH, is formed on the surface of each cement particle and it continues to form as long as there is space, water and favorable temperature conditions. In concrete, the majority of the strength development occurs during the first twenty-eight days, although the hydration process can continue for years yielding an ever increasing strength.

Fly ash, a pozzolanic material, reacts with calcium hydroxide released from hydration of the cement or added as lime and creates a calcium silicate hydrate material. This leads to a long term gain in strength. This is of particular concern when fly ash is used in Flowable Fill when low strength is a requirement.

Richard C. Meininger, the Vice President of Research for the NAA-NRMCA (National Aggregate Association and National Readymix Concrete Association), conducted research on a series of Flowable Fill mixtures using Type I cement, Class F fly ash, concrete sand, water and air-entraining admixture. The results showed the addition of fly ash significantly increases the compressive strength of Flowable Fill. The correct proportioning of the cement and fly ash is critical to the long term ability to excavate the Flowable Fill. The results showed that as with conventional concrete, Flowable Fill in an enclosed cylinder lost strength when there was excess water. Most applications of Flowable Fill are in an environment where the excess water either escapes through a permeable soil or is free to rise to the top of a full trench and run off. The use of extra water is often needed to promote flowability and while it will impact the compressive strength of Flowable Fill, the results will not be as dramatic as in laboratory testing. This is especially true when the extra water leaves the mix through the surrounding soil. Work at UNH has shown samples placed in plastic molds and cured in 100% R.H. (relative humidity) develop much less strength than the same mix placed in a permeable soil and not cured.[55] The normal rule of increased strength with curing time is overwhelmed by the strength gain due to drying.

The American Stone-Mix, Inc. specify compressive strength testing of sample test cylinders using ASTM C 39 "Test Method for Compressive Strength of Cylindrical Concrete Specimens". These procedures use modified molds to allow the escape of excess water to better simulate field conditions. A series of 1/16th inch holes are drilled in the base of each mold. The holes are approximately one inch apart and one third of the radius from the mold wall. Two or more holes are drilled near the center of the mold, and filter paper is placed in the bottom of the mold.[1] Meininger used plastic 15 x 30 cm (6 x 12 inch) cylinder molds and because of the low early strengths the molds were cut so sulfur capping procedures were not required.[31] Meininger used two capping procedures for the 90 day strength tests, pad caps and high strength gypsum capping material. He noted in his report that the gypsum caps gave a 20% higher result in all but one of the tests. ASTM D 4832-88 "Standard Test Method for Preparation and Testing of Soil-Cement Slurry Test Cylinders" is commonly utilized to test the strength of Flowable Fill. The ASTM C 403 "Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance" is also used to assess the early strength development of CLSM as well as setting time.[39] The strength of 2 inch cubes is measured by methods outlined in ASTM C 109 "Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50 mm Cube Specimens) . Specimens are cured for 3 days before removal. They are then cured in 95% relative humidity or higher but not submerged in water. For self-leveling mixes, the provisions of ASTM C 39-86 "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" are followed.

Flowability

There are many different ways to measure the flowability . In Iowa, the flowability of a fill material is measured by passing the mortar through a 6 mm (1/4 inch) screen before placing it in a Corps of Engineers flow cone according to CRD-C611-80. The time of efflux ranges from 10 to 16 seconds where fluidity is considered to be critical. The time of efflux ranges from 10 to 26 seconds where fluidity is not critical.[26]

An easy field test for Flowable Fill is a modified slump test. A 7.6 cm x 15 mm (3"x 6") cylinder with the bottom removed is filled with Flowable Fill and lifted vertically . The cylinder is lifted with a three second count to allow for static friction on the inside of the cylinder. The Flowable Fill 'pancakes', and the diameter of the spread is measured. An 18 to 20 cm (7 to 8 inch) diameter is required for a mix to be considered Flowable. Work at UNH has shown this simple test to be very field reliable and relates to the standard rule of thumb of a diameter increase of 2.5 cm (1 inch) per an increase of mix water of 2.2 l/m3 (1 gallon per cubic yard) of mix.[55]

The fly ash content of a Flowable Fill directly affects its flowability. Special admixtures capable of producing large quantities of entrained air up to 30 percent are sometimes used to control density and increase flowability of Flowable Fill. These agents also act as a strength reducer by adding high percentage of air voids to the structural matrix of the fill.[44] Conventional air entraining admixtures are used to help maintain flowability[30,39] Flowable Fill requires a well designed mix with either air entrainment or fly ash to obtain adequate flowability.

Durability

Durability is the ability to resist deterioration from the environment or service in which it is placed. Backfill durability under high sulfate or freeze-thaw conditions varies with the mix and should be tested with the local conditions prior to use. Fly ash slurries are brittle once set and require support on all sides.[5]

Technical information published by K. Krete states that when their product is used in areas subject to freezing it should be designed on the basis of the friction angle only. Cohesion is apparently significantly reduced by freezing and thawing damage. Freeze thaw damage does not significantly affect density and friction angles providing the material is confined.

William C. Krell noted in Concrete International, that flowable fly ash has been used successfully in waterfront applications.[28] When it was placed in a zone of total water saturation and subject to severe freezing at temperatures below 0 F, it broke into slabs about the size of a persons hand. Sacrificial material was included in the design to provide for freeze thaw loss, and according to Krell the projects were successful. The work of Krell and the K-Krete technical data sheet was the only published information found relative to freeze thaw durability of Flowable Fill. Flowable Fill with a 5% cement content appears to perform well in the field if it is not allowed to become saturated with water. Laboratory results show that a 10% cement content is effective when freeze thaw tests are conducted. Such cement contents, however, would not be expected to be easily excavated. Vacuum saturation tests conducted by the Michigan Department of Transportation have confirmed that 5% cement is satisfactory in a freeze thaw environment. Nothing was found in the literature relative to the effect of air entrainment on durability. Krell feels a 5% mixture may be adequate for a road base under severe winter conditions.[28] Tommy Mantung, a recent Ph.D. graduate from Purdue University, conducted research on Flowable Fill. His unpublished research suggests that the standard ASTM C666 freeze thaw test is too severe to evaluate Flowable Fill. He developed a modified test which better simulates actual Indiana winters. His research suggests that Flowable Fill is resistant to freeze thaw cycling if the rate of freezing is lowered to what is expected under actual field conditions. His work also suggested that non air entrained mixes were as durable as air entrained mixes and that durability could be achieved when the compressive strength was at least 1030 kPa (150 psi).

Permeability

The permeability of most Flowable Fill materials ranges between 1.9×10^{-6} and 3.3×10^{-7} cm/sec.[28] This is in the range of silt and clay. The exact permeability is affected by the quality and quantity of the mix components of the Flowable Fill.

OBJECTIVES

The objectives of this study were to evaluate the effect of freeze-thaw cycles and frost heaving on Flowable Fill materials when used in transportation facilities. A concurrent investigation of evaluating the freeze thaw and frost heaving of 100% fly ash flowable Fill mixes was funded by the PSNH.

TESTING PROCEDURES

The laboratory testing consisted of a fly ash sampling program and Flowable Fill mix design and evaluation. The fly ash sampling program consisted of ASTM 618 testing of fly ash samples of Schiller fly ash, taken over a period of 31 days in order to quantify the range of properties to be expected under production. Flowable Fill mix design and evaluation consisted of testing various combinations of concrete sand, wash wastes, fly ashes, air entraining admixtures, and Type II portland cement. Freeze thaw testing was done on selected mixes.

Development of the Flowable Fill mixes gave consideration to strength, flowability and time of set. Design criteria were established based on information obtained from past users of Flowable Fill.

Strength must be limited for the effective use of Flowable Fill. It must have a minimum value to assure adequate bearing capacity for its intended use. Normally a high strength is not required for typical backfill because conventional soils are not high strength materials. For example, a typical soil foundation might require a soil bearing capacity of 193 kPa (2 tons / ft^2 which is 28 psi). Flowable Fill must also have a maximum value to assure the in situ fill remains excavatable over the period of its life, preferably by hand tools. Ultimate strengths exceeding 1030 kPa (150 psi) are difficult to excavate with hand tools, and in general should be avoided. A 28 day compressive strength of 210 kPa (30 psi) was targeted as the minimum strength. This was selected based on

Section M4.08.00 of the report entitled "Controlled Density Fills" published by the Massachusetts Concrete and Aggregate Producers Association (MCAPA). The MCAPA report likewise recommends 690 kPa (100 psi) as a maximum strength. Consideration must be given to pozzolanic properties when selecting strength criteria if a fly ash is specified. Both the high and low design 28 day strength limits were selected on the low side due to enhanced curing achieved in subsurface placements. Hydration of cement is more complete in subsurface placements because the Flowable Fill never dries. The mix design strength criteria selected for this study was therefore set at 28 day strengths falling between a minimum of 210 kPa (30 psi) and a maximum of 690 kPa (100 psi).

High flowability was needed to ensure self leveling and adequate lateral movement. The mixes were designed to assure these properties were achieved. A spread of 20 cm (8 inches) using a 100 cm x 200 cm (4 x 8") open cylinder test was laboratory evaluated as being an excellent indicator of a self leveling and good flowing mix. A spread of 20 cm was taken as the minimum spread in developing the mixes.

Time of set was an important mix design consideration. Safety and construction economics require that exposed trenches be backfilled as quickly as possible to minimize the inconvenience to traffic. A laboratory time of set under 12 hours as determined by the ASTM standard Vicat test apparatus was judged adequate for the time of set mix design criteria.

The chemical analysis and physical tests performed on the fly ashes were conducted in accordance with ASTM C 311 "Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolan for Use as a Mineral Admixture in Portland-Cement Concrete" with the exception that the pH test, was performed in accordance with California Test 643 (CALTRAN). The chemical analysis included loss on ignition, and pH. Standard testing procedures were performed on the laboratory test mixes to develop a data base on the Schiller and Merrimack fly ashes.

The physical tests performed on the fly ashes included moisture content, specific gravity, fineness, strength activity index, water requirement, and SEM analysis. The plastic properties of the mixes were evaluated by density, yield, flowability and time of set testing. The hardened properties of the Flowable Fill mixes were evaluated by unconfined compressive strength, permeability and freeze thaw testing. Physical testing of the plastic and hardened properties of the Flowable Fill mixes was done in accordance with ASTM Standard Tests except as where noted.

Fly Ash Sampling Program

moisture content

The moisture content of the fly ash was determined by drying as received samples to constant weight at 105°C to 110 C. Moisture content was calculated as follows:

Moisture content, % = (A/B) x 100

where:

A = weight loss during drying, and B = weight as received

loss on ignition

Dried ash from the moisture content testing was ignited to a constant weight in a porcelain dish at 750 C ± 50 C. Loss on ignition was calculated as follows:

LOI, % = (A/B) x 100

where:

A = weight loss between 105 C and 750 ± 50 C and B = dry weight of sample

pH

The pH of the fly ash samples was determined in accordance with California Test 643, part 3. After calibration of the pH meter approximately 5 ml (2 teaspoons) of ash were thoroughly mixed with approximately 30 ml (2 tablespoons) of distilled water. The pH probe was placed in the slurry, allowed to stabilize and then recorded.

specific gravity

A Le Chatelier flask was filled with kerosene, allowed to stabilize at 20 C and the initial level was recorded. A measured mass of approximately 50g of ash was then introduced into the flask and thoroughly mixed. The flask was then placed in the water bath and allowed to stabilized at 20 C. The difference between the original and final level of the kerosene was the volume of liquid displaced by the fly ash. The specific gravity of the sample was calculated as follows:

$$\text{Specific gravity} = \text{mass of fly ash} \; / \; \text{displaced volume}$$

fineness

The fineness of fly ash was determined by the wet sieve method. A one gram oven-dried sample was placed on a 45 μm (No. 325) sieve, washed for 1 minute with water under a pressure of 69 kPa (10 psi), oven dried and then weighed to determine the change in weight of the sample. The fineness was then calculated as the % retained on the 45 μm (No.325) sieve.

strength activity index

The strength activity index (SAI) was determined by making 5x5x5 cm (2"x 2"x 2") control mix test cubes with only portland cement. The test mix cubes were made by replacing 20% of the mass of cement with an equal mass of fly ash. The cubes were tested for compressive strength after curing for 7 days in lime water at room temperature. The ratio of the compressive strengths of the test mixture to that of the control mix expressed as a percentage was the SAI.

water requirement

Determination of the water requirement was done in conjunction with the SAI test. The amount of water required for the test mix to have a flow within ± 5% of the flow of the control was determined following ASTM C 109 "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars". This amount of water divided by the amount of water required for the control expressed as a percentage was the water requirement.

sem

Scanning electron microscopy (SEM) was used to visually evaluate the fly ash surface textures and fineness. An AMR model 100 scanning electron microscope, equipped with energy dispersive x-ray capabilities, was used to examine powder mounted samples of the ashes.

The samples were mounted on carbon stubs with double sided sticky conductive tape and coated with carbon in a sputter coater. The samples were analyzed with an accelerating voltage of 20KV, a specimen tilt angle of 30° and a 12 mm working distance on a general area of the sample at varying magnifications. The samples were visually scrutinized and a photograph was taken at a magnification of 1000x. This magnification was selected so that the ash photographs could be compared to evaluate surface texture and fineness. A magnification of 1000x creates a scale on a photograph such that 10 mm is approximately 10μm. A typical portland cement has a fineness such that the average particle size is approximately 45μm. A good ASTM C 618 fly ash has particles much smaller than portland cement with an average size around the 10μm size, which is why the SEM photographic scale was selected

Mix Design And Evaluation

density and yield

The density of the mix was determined in accordance with ASTM D 4380 "Test Method for Density of Bentonitic Slurries". The mix was placed in a container of known volume and weighed. Density was taken as the weight divided by the volume of the container.

Since the specific gravities and weights of each of the mix constituents were known, the volume of each constituent was easily calculated. The sum of the weights divided by the sum of the calculated volumes gave the theoretical maximum density (TMD) with no air. The yield was calculated as:

Yield (cu ft) = sum of volumes x (actual density) / TDM

compressive strength

Compressive strength of the mixes was evaluated using 5 cm (2 inch) cube specimens. Samples of the mix were cast into plastic molds which were lightly coated with a non stick spray to facilitate sample removal. Samples were fog cured in the molds for 28 days. The cubes were removed from the mold by gently blowing through a hole in the bottom of the mold with compressed air. The cubes were placed in a uniaxial compression testing machine and loaded to failure.

time of set

Time of set was determined according to ASTM C 191 "Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle", with minor modifications. Time of sets were determined for drained and undrained situations. An ASTM standard time of set mold was placed on a bed of dry sand for the drained test. The mix was poured into the mold and water was free to leave the mix by draining into the sand. This was done to simulate free draining field conditions. During the undrained test the mix was poured into a 23 x 23 cm

(9"x 9") baking pan to a depth of 2.5 cm (1 inch). This case approximated field conditions with very poor drainage as in a tight clay.

The time of set test was performed with an ASTM standard Vicat test apparatus. The plunger end of the Vicat needle was placed in contact with the surface of the sample and released. After 30 seconds, the depth of penetration of the plunger was measured. This was performed every 15 minutes after the mold was cast. Time of set was taken as the time elapsed between casting and zero penetration of the plunger.

flowability

The flowability of each mix was evaluated by one of two methods. Mixes that exhibited very liquid behavior were evaluated using the ASTM C 939 "Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)". The mix was timed as it drained through a12.5 mm (1/2") orifice in the bottom of an ASTM specified conical container, called a flow cone. Any mixes that would not drain through completely in 90 seconds were evaluated with a modified version of the slump test with an open end 100 cm x 200 cm (4" x 8") plastic cylinder as previously discussed. The cylinder was held firmly against a perfectly horizontal, flat and smooth metal surface as the mix was poured. The cylinder was lifted vertically off the plate in no more than three seconds, and the diameter of the spread was measured. A spread diameter equal to or greater than 200 cm (8 inches) was considered flowable.

permeability

The permeabilities of each mix were evaluated using a constant head permeability test. The apparatus consisted of a constant head tank and test cells, as shown in Figure 1. The tank was made from a 15 x 30 cm (6" x 12") plastic concrete test mold. An overflow hole was drilled to let excess water run out, thus keeping the water head constant. Water was introduced to the reservoir via a flexible tube running from a water faucet. A hole was made in the bottom of the tank for another tube to carry the water to the manifold and test cells. The manifold was constructed from an 200 cm (8") long section of 64 mm (2 1/2") schedule 40 PVC pipe and end caps. Holes were drilled to attach 10 mm (3/8") flexible tubing to direct the water to the individual test cells. A valve was provided on the top of the manifold to bleed excess air out of the system.

Individual test cells were also constructed from 64 mm (2 1/2") schedule 40 PVC pipe. Each cell consisted of two parts. The top part, where the tubing was attached, consisted of a 5 cm (2") length of PVC, a threaded female PVC coupling, and an end cap with an air bleed valve. The bottom section was made from a 7.5 cm (3") section of 64 mm (2 1/2") PVC pipe and a threaded male coupling. This section was filled with the test mix and screwed into the top section for testing after curing. The inside of each bottom cell was scored and roughened to provide a bonding surface for the plastic mix to help prevent piping of the sample.

Samples from each test mix were placed into six cells. Three of these cells were placed in a bed of sand with an open bottom to allow the sample to freely drain to simulated placement in a well drained soil. The three other cells had their bottoms sealed with duct tape to prevent water from draining to simulated placement in an impermeable soil. The samples were cured in a fog room at approximately 70 ° F for seven days and then tested.

The mix samples were screwed into the top test cell sections on the permeability test apparatus. The cells were covered with a plastic skirt to hinder evaporation and prevent incursion of extraneous water. The water was turned on until a constant trickle escaped from the overflow hole, and then left on at a rate so that slight overflow ensured a constant head of 110 cm for all tests. Ambient temperature was used to calculate the temperature coefficient in Darcy's Law for permeability due to the low volume of water drawn from the tank during the test. After ensuring that water had started to seep completely through each cell (about an hour), each cell was then placed in a weighed beaker half filled with dry sand. The samples were left in the beaker for approximately one hour. At the termination of each test, the elapsed time was noted, and each beaker was weighed to determine the mass of water that had seeped through each cell. The depth of each sample was measured and noted. Permeability was calculated from Darcy's law:

$$k = qLf_t / DhA$$

Where:

k = Permeability (in cm/s)

L = Depth of sample (in cm)

f_t = Temperature correction factor

Dh = Head (110 cm)

A = Cross sectional area of sample (13.2 cm^2)

freeze thaw

The laboratory freeze thaw testing procedure consisted of evaluating the Flowable Fill mixes under standard conditions utilizing ASTM 666 B freezing and thawing in water and a special test developed to simulate field freezing rates. The special freeze thaw test consisted of evaluating the effect of freezing standard freeze thaw beams in a highly insulated box designed to allow freezing and thawing from the top only. The intent of the test was to simulate the rate of freezing that would be expected in Flowable Fill that was placed under the surface of a pavement. Under such conditions the rate of freezing is much lower than the standard rate of freezing expected in an above ground structure as the ASTM 666 test specifies. The open top box was constructed of Dow Styrofoam® with 7.5 cm walls and a 12.5 cm bottom. The insulating properties of the box were such that freezing and thawing occurred from the open top. The freeze thaw beams were uniformly placed in the box and were surrounded by small foam "squiggle" pieces commonly used as a light weight packing material. The samples were submerged in water for 20 minutes prior to being placed in the box. The box was supported by several small pieces of wood so an air flow would act as a thermal conductivity break between the floor of the chest type freezer and the bottom of the box. A cycle of freezing consisted of closing the freezer lid and turning on the freezer and allowing the samples to slowly freeze for a period of at least 48 hours. The thaw cycle was started by turning the freezer off, opening the lid, and turning a fan on to pass air at room temperature over the top of the box. After 24 hours the samples were tested for resonant frequency with a Techtronics wave form analyzer. The samples were tested without removing them from the box by attaching a transducer to the top side of the beams with a rubber band and striking a copper penny mounted with epoxy on the top of the beams with the test hammer. Each beam was struck with the test hammer three times, and the average wave form was stored on a disk for future analysis. After the wave form testing was completed the freezer was turned on and the beginning of another cycle was started. Two cycles of freezing and thawing were obtained per week. Although the freezing cycle exceeded 48 hours on the weekends the thaw cycle was held constant at 24 hours. The freeze thaw testing was conducted at the Turner Fairbank research facility of the Federal Highway Administration located at McLean Virginia.

materials

The aggregate materials used in this study consisted of a conventional concrete sand from Brox's Rochester Plant, a gravel waste wash from Coastal materials Farmington Plant, a crushed stone waste wash from Coastal Materials Raymond plant, and fly ashes from the Public Service of New Hampshire power plants, Schiller Station, located at Portsmouth and, Merrimack, located at Bow New Hampshire. Figure 2 shows the particle size distribution of the two waste materials. Two Schiller Station fly ashes with LOI's of 17.3 % and 18.0% and pH's of 9.3 and 4.3 respectively were evaluated in Flowable Fill mixes. The ashes were collected in 210 liter (55 gallon) drums prior to the fly ash sampling testing program and were not from the same source of coal as was used during the fly ash sampling program. The fly ash obtained from Merrimack Station, an ASTM C 618 fly ash typical of the plant's production, was used in the laboratory study. The ash had an LOI of 4.3%, a pH of 4.2 and was obtained by combining three 19 liter (five gallon) samples obtained during the fly ash sampling testing program.

Type II portland cement was used in all of the mixes.

The MCAPA report was used to obtain a starting point for the Flowable Fill Mixes. Since a type F fly ash such as the PSNH fly ash can greatly increase long term strength a cement content of 35.6 kg/m^3 (60 lb/yd) was recommended. A mix was made using this cement factor, and additional mixes evolved by changing the amount of ash, cement, sand and water contents. Aggregate was not utilized in all of the mixes so that maximum advantage in using large volumes of fly ash in the mixes could be achieved.

FIELD TESTING

The field investigation was designed to evaluate the use of Flowable Fill for backfilling bridge abutments and trenches. The test site was located at Coastal Materials Corporation's Farmington, New Hampshire plant. A bridge abutment was simulated by constructing a concrete wall traversing Coastal material's entrance road. All traffic entering or leaving the plant had to drive over the wall, thus assuring the test section would be subjected to very heavily loaded truck traffic. A lined test pit was also constructed such that subsurface water could be controlled to force frost heaving to occur. Four trenches were excavated and backfilled with Flowable Fill mixes each with five different depth configurations as shown in figure 4. The trenches were monitored for frost heaving and freezing and thawing damage.

Bridge Abutment

Construction of test sites began in early November, 1993 with the installation of the simulated bridge abutment. An excavation was made across the main access road to the Coastal Materials Farmington plant. A 30 cm (12") thick by 7.3 m (24') long and 1.6 m (63") high concrete wall was placed on a footing 23 cm (9") thick by 7.9 m (26') and .9 m (3') wide as shown on Figure 3. Four benchmarks were established for elevation control and were sleeved with 2 cm (3/4") PVC pipe and capped to ensure stability.

The down hill east side of the wall was backfilled with a granular base material and compacted to 98% of modified proctor as per NHDOT specifications for backfilling of bridge abutments. Uniform compaction procedures were performed over the total surface for all lifts to assure consistent results. The west side of the wall was backfilled with a sand Flowable Fill. The Flowable Fill and base material was covered with 5 cm of an asphaltic concrete surface mix so that a smooth transition over the top of the concrete was achieved. The performance of the test section relative to settlement, frost heaving and heavy truck dynamic loading was monitored through two winter-spring seasons. The field testing was extended to two years because the first winter was relatively mild and the depth of frost was not typical of a New Hampshire winter.

Trenches

A second test site was constructed at Coastal Materials Farmington facility. A pit approximately 14 m by 16 m by 1.5 m deep was excavated and the bottom and sides were lined with a one piece 5 mm (20 mil) fiber reinforced geomembrane. A 30 cm deep layer of 19 mm gravel was placed at the bottom of the excavation to act as a reservoir to supply a uniform subsurface water source. A 25 cm (10 ") diameter by 2.1 m (7') long plastic pipe was set vertically on top of the gravel layer. The pipe was used to add water to the test pit and to monitor the water level throughout the test period. A spun geotextile filter fabric was placed over the gravel layer in order to prevent infiltration of fines. A 1.2 m (4 ') deep layer of frost susceptible material consisting of wash waste from Coastal Materials as shown by Figure 2 was compacted in layers over the geotextile fabric filter.

The surface was paved with a 50 to 75 mm (2 to 3") thick hot bituminous layer of surface mix in order to help control intrusion of water from the surface, to protect the Flowable Fill from abrasion during snow removal operations and to simulate an actual pavement. Four trench lines 15.2 m (50') long and 76 cm (30") wide were cut into the asphalt using a chisel head on a pneumatic jack hammer. Four 61 cm wide trenches approximately 1 m apart were excavated with five different depths. Figure 4 shows the cross section of the five cases which were backfilled with different Flowable Fill mixes in each trench. Each case was approximately 2.7 m (9') long as shown in Figure 5. The cases were separated by a plywood divider sandwiched between two pieces of rigid insulation to assure independent joints between each case. The dividers were removed after placement of the flowable fill leaving a 11 cm (4") joint between each case which was filled with a non-frost susceptible sand. This was done to isolate each case and allow independent movement relative to each other.

Four different flowable fill mixes were evaluated at the frost heave facility (two sand mixes (NHDOT 1 and NHDOT 2), and two 100% fly ash mixes (PSNH 1 and PSNH 2). NHDOT mix one and two were similar to mixes which have been utilized on several projects throughout New Hampshire. The NHDOT 1 mix, placed in trench one, was designed with a standard air entrainment admixture, and the NHDOT 2 mix, placed in trench two, with a new air entraining admixture designed to entrain high air contents. The PSNH 1 mix, placed in trench three, was designed to incorporate 100 % Merrimack fly ash without any aggregate. The PSNH 2 mix two, placed in trench four, was designed for 100 % fly ash obtained from Schiller Station.

instrumentation

Instrumentation of the trenches was installed prior to placement of the Flowable Fill mixes. A thermocouple probe as shown on Figure 6 was placed near the center of case two in each of the four trenches. A thermocouple-resistance ring combination probe was placed in the wash waste soil between trenches one and two and trenches three and four.

The thermocouple and resistance ring probes installed in the frost susceptible material were useful in determining the relative level of moisture saturation and the depth of frost where the moisture changed phase. The resistance between the copper rings gave a good indication of the state of the moisture in the soil. As the moisture content of the soil at a given depth increased the resistance between the rings at that location dropped and approached zero at saturation. The actual depth of frost was easily monitored with resistance due to the large increase in resistance when water changed phase from water to ice. Temperature alone was not adequate for determining depth of frost due to super cooling of water in and around the soil particles. A Campbell Scientific Data Collector, model 21x, was used to record the sensor data. A total of forty-three thermocouples (two sets of 16 and one set of 11) and sixteen resistance rings were monitored. Temperature and resistance measurements were made at 7.6 to 14.2 cm (3" to 6") intervals starting at the surface to a depth of 1.4 m below the pavement.

Frost heave probe assemblies were used to measure the frost heave movement of the backfilled trenches. A frost heave probe assembly was installed in each of the five cases in trenches one and three. Each assembly consisted of an outer case of 10 cm (4") PVC schedule 40 pipe bonded to the Flowable Fill as shown by Figure 7. An inverted 19 mm (3/4") schedule PVC T pipe was mounted in the underlying 19 mm (3/4") aggregate below the trench backfill to secure a point below the expected depth of frost. Differential movement was measured between the outer casing and the mounted PVC pipe. A Magna Rule deformation measuring device was mounted on a platform secured to the casing. The metal rod of the Magna Rule extended down inside the 19 mm (3/4") mounted pipe which supported a ring magnet. A linear voltage output was produced when the ring magnet moved up and down the metal rod of the Magna Rule. The change of voltage was converted to deformation through a linear calibration of the Magna Rule.

Measurement of frost heaving of the asphaltic concrete surface was accomplished by surveying of points established on the surface with pk nails.

procedure

Water was fed into the 19 mm (3/4") stone reservoir through the fill pipe, by a water truck from Tilcon Corporation of Farmington NH. A total of 25000 liters (6600 gallons) of water was added over a two day period starting on March 4, 1993. The temperature of the water added was purposely kept low at about 1°C (34 °F) in order to not thermally affect the soil temperature. An attempt was made to maintain a two foot head above the stone in the fill pipe so the frost susceptible soil would have access to water by capillary rise. After allowing the water to absorb into the soil the water table stabilized at 10 cm above the stone. Water was similarly added during the fall and winter of 1993/94.

RESULTS AND DISCUSSION

Fly Ash Sampling Program

The sampling program was designed to evaluate the variation of the fly ashes over a period of approximately one month. The Schiller and Merrimack ASTM 618 data are presented in Table 1. Emphasis in the sampling program was given to the Schiller fly ash in an effort to create a viable data base of its physical and chemical properties. The Merrimack fly ash is routinely used and therefore required less testing to establish a data base.

moisture content

The moisture content varied with sampling day. The average moisture content of the Schiller fly ash ranged from 0.11% to 1.11%, with an overall average of 0.29 % and a standard deviation of 0.22%. These moisture content data clearly show the ashes are extremely dry. The average moisture content for the Merrimack fly ash was 0.33% with a standard deviation of 0.02%.

loss on ignition

Loss on ignition, (LOI), varied significantly with sampling day. The average daily LOI ranged from 20.0% to 61.3%, with an overall average of 39.1 % and a standard deviation of 13.7%. The Merrimack fly ash had an average LOI of 2.89% with a standard deviation of 0.87%.

The Schiller fly ashes used in the test mixes had an LOI of 17.3 and 18.0%. These LOI's were less than the lowest LOI found during the fly ash sampling program. The selection of these ashes for the laboratory study was based on what was thought to be attainable from the Schiller power station when the ash is marketed for use in Flowable Fill.

pH

The pH of the Schiller fly ashes ranged from 3.72 to 12.32. The pH data varied little with sampling day except for the ash samples collected from 3/6/93 to 3/17/93. These data were significantly different, indicating a different coal was being fired during that period. Variable pH is to be expected if coal sources change. The pH of the Merrimack fly ash ranged from 3.33 to 3.70.

specific gravity

The specific gravity data also varied with sampling day as was expected due to the variability of the LOI test results. The Schiller specific gravity data ranged from 1.91 to 2.25, with an overall average of 2.09 and a standard deviation of 0.11. The variation of the specific gravities among the daily samples exceeded 5% on ten of the sampling days. Such variation gives an indication of the variability of the product. The Merrimack fly ash had an average specific gravity of 2.70 with a standard deviation of 0.02.

fineness

The Schiller fly ash average percentage retained on the No.325 sieve varied with sampling day significantly. The average fineness data ranged from 16.0% to 68%, with an average of 37.1% and a standard deviation of 16.1%. The Merrimack fly ash had an average fineness of 0% with a standard deviation of 0%. The 0% fineness shows how superior the Merrimack fly ash was relative to the coarser Schiller fly ash. The partial size distribution of the Merrimack fly ash was found to be 100% smaller than approximately 45μm. The effect of fineness will be addressed in the SEM results section.

strength activity index

The Schiller fly ash strength activity index ranged from 45% to 103%, with an average of 76.2% and a standard deviation of 19.3%. ASTM C 618 requires a minimum value of 75%. The average SAI value is slightly in excess of this requirement showing that the ash is capable of good pozzolanic activity. The Merrimack average SAI was 116.2% with a standard deviation of 9.8%.

water requirement

The Schiller fly ash water requirement varied with sampling day significantly. The water requirement data ranged from 111.6% to 146.7%, with an average of 125.5% and a standard deviation of 9.9%. The average water requirement value is high due to the increased carbon content as indicated by LOI. The Merrimack fly ash had an average water requirement of 96.3% with a standard deviation of 0.9%. ASTM C 618 allows a maximum value of 105%.

Interaction of Properties

A visual evaluation of the plotted data suggested the physical properties of the ash were interrelated. Linear regression was performed on the data in an effort to obtain a better understanding of how the different properties related to each other. An understanding of these relationships would be a useful tool for mix design consideration.

Figure 8 presents the SAI as a function of LOI. A good linear relationship was found between the two variables (correlation coefficient $r^2 = 0.866$), indicating SAI decreased linearly with increased LOI. Such a relationship was expected with increased carbon content as is estimated with the LOI test.

Water requirement as a function of LOI is presented in Figure 9. A good linear relationship was also found between these two variables (correlation coefficient $r^2 = 0.960$). As was expected the water requirement increased linearly with increased LOI.

Specific gravity as a function of LOI is presented in Figure 10. The correlation coefficient of 0.879 indicated there was a good linear relation between the two variables. Specific gravity decreased with increasing LOI due to the increase in the lighter weight carbon with increased LOI.

Fineness as a function of LOI is shown in Figure 11. A good linear relation between the two variables was shown by the 0.887 correlation coefficient. The amount of material retained on the 45μm sieve increases with increased carbon content as indicated by LOI.

sem

Thirty-two (32) samples of ash were analyzed for elemental analysis and particle size at the micro level with an electron microscope. Table 2 presents the average elemental analysis data. As pointed out earlier these are elemental data and not oxide data. Use of these data must be with the understanding that their accuracy is about +/- 20%. These data show as with standard ASTM C 618 fly ashes that the composition of any ash consists of silicon, aluminum and iron. Comparing these data to the averages of the Merrimack ash shows differences in elemental composition. Most of the elements in the two ashes were very similar. The exceptions were that the Schiller ash has higher carbon contents and lower iron contents than the Merrimack ash. There was a large difference between the carbon content as determined by elemental analyses and implied by LOI. The data were however, trend wise, consistent with each other. The results of the Merrimack ash are typical of the fly ashes tested from the plant for ASTM C 618 compliance. A significant amount of the Merrimack fly ash is utilized in the production of portland cement concrete and Flowable Fill, mostly in the Commonwealth of Massachusetts.

The SEM photographs taken of the Schiller and Merrimack fly ashes were mostly taken at 1000x and have approximate scales of 10 mm = 10 μm. Some samples were also taken at a magnification of 200x and have approximate scales of 10 mm = 50 μm. The first two photographs shown on Figure 12 are the Merrimack samples MAC 1 and 2. The large spherical particle in the upper left corner of MAC-1 has a diameter of about 40 μm which is smaller than an average portland cement particle. The fineness analyses showed 100% of the particles were smaller than 45 μm. The average particle size is very small and as easily seen many are less than 0.5 μm. These fly ashes are to be considered good, relative to particle shape, surface texture and size. Such properties have a very significant effect on the performance of portland cement mixtures (workability, strength and segregation). These ashes are typical of a good

ASTM C 618 fly ash and were used as a standard for comparing the Schiller ashes.

Figure 13 shows photographs of samples S9 and S10 all from Schiller. These show completely different ash properties when compared to the Merrimack ashes shown on Figure 12. Ash samples S9 and S10 had LOI's of 48.0% and 39.7% respectively. The ashes tend to be large conglomerates of the smaller ash particles described in the Merrimack ashes. The small particles are held together by a matrix of carbon. Photographs S30 and S31 shown on Figure 14 had LOI's of 34.0% and 61.3% respectively, and also show large conglomerations of ash particles in excess of 100 μm. Such conglomerates are extremely large relative to conventional fly ash and do not contribute to portland cement mixes in the same positive manner as do standard ASTM C 618 ashes. When the LOI 's decreased to their lowest values the resulting ashes had increased surface areas due to reduced conglomerations. Photographs of ashes S22 and S23 shown on Figure 15 had the lowest LOI's of the test period (24.7% and 20.0% respectively). These ashes show increased surface area with many small particles similar to the high quality Merrimack ashes. In general the photographs show that when the LOI of the Schiller fly ash is below approximately 25% a usable ash in terms of fineness is produced.

Evaluation of Mixes

Mixes were evaluated for density, yield, flowability, time of set, permeability, and 28 day compressive strength. The laboratory mix data are presented in Table 3, Table 4 and Table 5.

cement content

In general, increasing the cement content, above a minimum level, increases the compressive strength of a Flowable Fill. This relationship becomes more complex when a fly ash is utilized in a Flowable Fill. Figure 16 shows the effect of increasing the cement content with the two waste materials identified as Farmington and Raymond and the concrete sand from Brox. The symbols following the mixes , DV and DF represent a conventional and a high volume air entraining admixture respectively. Strength increased with increased cement content as was expected. The effect of the high volume (DF), air admixture is to entrain more air than the conventional (DV), air entraining admixture. The result, in general, was for the higher air entrained mixes to show lower 28 day strengths.

fly ash content

Figure 17 shows the effect of increasing the ash content at constant cement content for Merrimack ash. All fly ashes respond similar to the Merrimack ash shown depending on the pH of the ash. In this case the pH is low at 4.3 and the maximum strength peak occurs at approximately 25% ash. Portland cement will not react unless it is at a pH of about 12. Upon hydration about 25 % $Ca(Oh)_2$ is released from the original portland cement which in the presence of a pozzolanic material reacts and forms a new cementious material similar to the reaction product of portland cement. This effect was noted in Figure 17, holding cement content constant while increasing the ash content results in increased strength up to a certain point due to the pozzlanic reaction of the ash. Adding ash beyond where the peak occurs lowers the strength due to inhibited hydration caused by overall decreased pH of the mix. Eventually, at 100 % ash, for the case of the cement content shown (36 kg/m^3) the reaction is totally stopped due to the low mixture pH. Both strength and the fly ash content required to achieve maximum strength, increased with increasing pH. Increasing the cement content at constant ash content as in the Schiller mixes showed similar results with increased strength. Increased cement content also decreased time of set and permeability in addition to increased compressive strength.

compressive strength

Compressive strength was found to be directly proportional to cement content and as discussed above was affected by pH. Mix AA utilizing 59.4 kg/m^3 (100 lbs/yd) cement with a low 4.3 pH achieved strengths only about 40% of the high 9.3 pH ash mix T. This was due to the detrimental effect of the low pH on the hydration mechanism of the portland cement as discussed above. The inclusion of lime to bring the pH up so the portland cement could effectively hydrate was not considered due to the increased cost and inconvenience of handling another material at the batch plant.

It was found that the effect of low pH on the hydration of portland cement had a major impact for low cement contents. A mix containing 100 % Merrimack ash with a pH of 4.3 and 35.6 kg/m^3 (60 lbs) of cement per yard was found to be severely retarded and after 28 days it still had not set. It was found that for 100 % Merrimack ash mixes a minimum cement content of 59.4 kg/m^3 (125 lbs/yd) was required to create a Flowable Fill mix which would set in a reasonable time and obtain adequate strength.

time of set

Time of set, as defined by Vicat needle penetration, for a given mix was found to be a function of the amount of cement, air content, the pH of the ash (if used), and the ability of the water to migrate out of the mix. These phenomena were observed in all of the laboratory mixes.

Figures 18 and 19 show the effect of cement content on time of set for several mixes. When the material (soil) surrounding the Flowable Fill had low permeability as identified on the figure as "undrained", time of set was highly dependent on the ability of the cement to develop a structure, as it does in conventional concrete. When the surrounding soil material has high permeability as identified on the figures as "drained", time of set was more dependent on the rate of water removal from the mix than the development of the cement structure. Any variable which slows down the rate of water removal from the mix increased time of set. This was shown to be the case for air entrainment. All mixes showed increased time of set with increased air content. The high range air entraining admixture always showed increased time of set over the conventional air entraining agent.

Set times were less in the drained mixes for all cases. The drained mixes were not significantly sensitive to increased cement content or pH. This was due to the overwhelming effect of the consolidation of the solid particles caused by loss of mix water as discussed above. The undrained mixes were however significantly affected by increased cement content and pH. Time of set decreased with increasing pH. The Schiller fly ash set time increased with increasing cement content due to some unknown confounding effect. Both waste materials decreased set time with increasing cement content as was expected.

Hydration of portland cement is pH dependent and will not occur if the mix has a low pH. The set time of Schiller ash mix AA (compared to mix T) under undrained conditions increased by about 2.5 hours when the fly ash pH changed from 9.3 to 4.3 for 59.4 kg/m^3 (100 lb/yd) of cement. The drained case of the two mixes had almost equal time of sets, again showing the overwhelming effect of consolidation by loss of water. The Merrimack mix J did not set under undrained conditions for pH of 4.2 and 35.6 kg/m^3 (60 lbs) of cement per yard.

flowability

Flowability increased, as was expected, with increased water. The more water that was present in a mix, the more flowable it became. There was however a point where the additional water causes severe segregation and the resulting mix loses flowability when the mix is removed from the mixer. Such mixes are of little practical use due to lack of flowability as well as drastically increased settlement when the water bleeds from the mix before it hardens.

Flowability was easily achieved without admixtures with the high volume fly ash mixes due to the fineness of the ash particles. The waste materials and sand mixes did not achieve good flowability without air entrainment. Based on the results of these mixes it appears almost any material may be used as an aggregate in making a good Flowable Fill. When the natural fines in the aggregate are low or lacking as in the Raymond wash waste flowability must be achieved with air entrainment or the addition of a fine grained material such as slag cement or fly ash.

permeability

Permeability for all Flowable Fill mixes was on the order of 10^{-5} cm/sec, about that of a compacted silt material as shown by Figure 20. Although the data are limited, the drained permeabilities are somewhat smaller than the undrained samples. The more opened microstructure of the undrained samples is expected to be responsible for this observation. The permeability of the drained samples decreased with increasing cement content as was expected.

freeze thaw

The initial laboratory freeze thaw testing of the Flowable Fill mixes presented in Table 5 was done in accordance with the standard ASTM 666 test. The results were extremely poor because all samples were totally destroyed in only one cycle. The samples developed ice lenses and had the appearance of a soil which had undergone excessive frost heaving. This result led to the development of the special freeze thaw test described earlier. Figure 21 shows the sample's top and middle surface temperatures for freeze thaw cycles 4 and 5 as a function of time. The results of 16 cycles of freezing over an 8 week period are shown on Figure 22. The relative E of the mixes gradually declined with increased cycles of freezing and thawing. All mixes reduced to less than 50 % of their initial relative E values by 16 freeze thaw cycles. Based on these test conditions none of the Flowable Fill mixes are durable. These results were not expected due to the purposely designed test using a slow rate of freezing.

Destruction due to excessive hydraulic pressures during freezing only occurs if the pore system is critically saturated and/or the rate of freezing is relatively fast. This is why ASTM 666 requires precise curing and moisture conditions as well as the rate of temperature change within the samples, in fact with these stringent conditions it is very difficult for a concrete to pass this test unless the sample has a good air bubble distribution. A concrete which is allowed to hydrate for at least 2 weeks and then air dried before being tested will in most cases pass the test because it does not become critically saturated during the test. The samples in the special freeze thaw test were allowed to soak up water for about 20 minuets prior to being tested. The rate of moisture intake was very fast and was easily observed by the equal volume of air bubbles that are released when the sample was submerged. The moisture state after 20 minutes was relatively high as compared to what a Flowable Fill might be expected to stabilize at when used as a backfill material under a pavement. This is especially true if the pavement has good subsurface drainage.

Field Testing

Field testing consisted of monitoring freeze thaw durability and elevations of the simulated bridge abutment and backfill trenches for settlement , and frost heaving. The field mix utilized in the bridge abutment and trench 1 was mix NHDOT 1. Trenches 2, 3 and 4 were placed with mixes NHDOT 2, PSNH 1 and PSNH 2 respectively. Detailed mix design data are presented in Table 10.

bridge abutment

The granular fill material compaction results are presented in Table 6. The results show the effort applied to compaction was more than adequate relative to the NHDOT specifications for granular backfill (not less than 98 % of standard Proctor test). Weekly visual inspections were performed on the paved surfaces with extra attention given to observations of the asphalt pavement and concrete wall interfaces in order to identify any large differential movements. After seven months of heavy truck traffic the original 99 points were located and elevations were taken. The results are reported in Table 7. These data show that settlement occurred in both the compacted fill and the Flowable Fill . Rows 1-4 represent the compacted fill, row 5 is the concrete wall, and rows 6-9 are the elevations of the Flowable Fill. A contour of the surveyed area is presented in Figure 23. The compacted granular fill side of the abutment shows more extensive settlement than the Flowable Fill section. Typical settlements occurred in the granular fill in the 1 cm to 1.5 cm range (.4" to .6") with a maximum of 2.5 cm (1"). The Flowable Fill side remained more level than the compacted granular fill with typical settlements in the 0.5 cm range (.2") range with a maximum of 1.5 cm (.6") occurring at the edge of the backfilled area where the Flowable Fill was feathered to meet the original road elevation. The settlement characteristics of the Flowable Fill appear to be superior to those of the compacted granular fill. Not only were the settlements less in the Flowable Fill but they also appeared to be more uniform across the surface of the pavement. Disregarding the settlements that occurred in the thin tapered edge the performance of the Flowable Fill was unquestionably superior to the granular fill. These are especially interesting results because of the very high stresses the Flowable Fill had to withstand being the base material immediately under the surface of the asphalt concrete pavement. If this material had been placed on an actual highway abutment it would have been covered with a high quality base material then the surface mix, thus drastically lowering the stress level in the Flowable Fill. Frost heaving did not occur in either the conventional granular base or the Flowable Fill.

trenches

Four mixes were placed in the field trench test facility. Two mixes were installed the first winter of the project These two mixes were selected based on their past performance under actual field conditions. These mixes were originally placed during the annual spring 1992 UNH T^2 demonstration project held at Waterville New Hampshire. These mixes have been adjusted and tuned since their original use and have been used on several projects throughout New Hampshire. These mixes consisted of a small amount of portland cement in conjunction with a slag cement used with a standard concrete sand. One mix used a standard air entraining admixture and the other a high range air entraining admixture. The other two mixes were designed to utilize high volumes of fly ash from two PSNH power facilities, one from the Merrimack facility and the other from the Schiller facility. Table 8 contains the data for the four mixes.

Laboratory testing was performed on the wash waste soil to determine the capillary rise of the material. The results of the testing showed a capillary rise of approximately two feet. The gradation of the material was typical of the Farmington waste wash material previously shown on Figure 2.

Subsurface water elevation was maintained so that the height of capillary rise intercepted the depth of freezing when the frost heaving was being monitored. Temperatures and resistance were monitored with the thermocouple-resistance ring probes installed in the frost susceptible material. The relative level of moisture saturation, and actual depth where the moisture changed phase was monitored by plotting temperature and resistance as a function of depth as shown typically by Figure 24. The resistance begins to decrease at approximately 40 cm and begins to level off at about 60 cm. The zone between 40 and 60 cm is one of transition where ice is being formed as well as being melted. In that super cooling can occur at less than the normal freezing point of 0 °C at normal atmospheric pressure it is likely that the depth of freezing, from an engineering viewpoint, occurs closer to the transition to lower resistance at 60 cm than the high transition at 40 cm. For this particular case the depth of freezing, referred to as the depth of frost, is approximately 55 cm. This is the zone of nucleation where frost heaving, caused by feeding water to an ice lens, would occur if the temperature did not drift up or down and capillary rise kept pumping water to the zone. The zone of saturation caused by capillary rise was easily identified by monitoring the resistance change as water was added to the reservoir via the fill pipe. As the moisture content of a soil at a given depth increases the resistance between the rings at that location drops and approaches zero at saturation due to the presence of moisture. Readings from the thermocouples and rings together gave a very good indication of the depth of frost and the moisture state of the soil.

Average daily air temperatures, defined as the average of the lowest and the highest daily air temperatures, were used to approximate the freezing index for the 1992 /1993 and 1993/1994 test years. The freezing index is defined as the difference between the highest and lowest cumulated degree days for a given year. A degree day is defined as one day when the average temperature is one degree below freezing (a day with an average temperature of 22 °F would be equal to 10 degree days as would ten days with an average temperature of 31 °F). Figures 25 and 26 sow the cumulated degree days for the 1992-93 and 1003-94 test years respectively. The freezing index for the 1992-93 season and 1993-94 season was approximately 800 and 1,000 degree days respectively.

The Magna-rule heave probe equipment was monitored for a short period before unexpected field conditions made its use impossible. The units were not properly sealed to prevent water from entering into the electronic portion of the units. Upon filling the reservoir with water the heave probe chambers acted as air vents and the hydrostatic pressure of the water in the fill pipe was transferred through the lower reservoir and forced water up the heave probes and submerged the Magna-rule deformation probes. The probes were shorted out and destroyed by the water. The frost heaving was measured by inserting a calibrated probe into the heave probes and recording the deformation manually.

These measurements were performed weekly on each Flowable Fill case of trenches 1 and 3 during the winter season.

frost heaving

The frost heaving measurements taken from each of the 5 heave probe assemblies in trenches 1 and 3 are presented in Table 9 and are plotted on Figure 27. Figure 27 shows the extent of frost heaving that occurred under the conditions of the winter of 1993/94. Reference to Figure 4 which shows the 5 different cases is helpful in trying to relate the frost heaving to each case. Depth of frost penetration in the frost susceptible material was approximately 55 cm (22"). The frost heave probe assemblies precision of measurement was 0.25 mm (0.01"). Any reading of 0.25 mm or less was not plotted so that only the cases which unquestionably heaved could be easily seen. These data show that movement was observed in every case of the conventional Flowable Fill except for case 4. Only case 3 of the fly ash Flowable Fill frost heaved. Case 3 as shown on Figure 4 is the most likely candidate to frost heave because its depth was only slightly deeper than the depth of frost (60 cm versus 55 cm respectively). The freezing ice lenses on and around the side walls of the Flowable Fill trenches were such that the forces could actually lift them as the frost heave developed. The actual frost heaving was relatively small and insignificant at 4 to 8 mm. The trenches, within the measurement of precision, all returned to their starting elevations except for trench 3 case 3. This is most probably due to the lack of traffic on the test facility.

The frost heaving of the pavement adjacent to the trenches is presented in Table 10 and plotted on Figure 28. The elevation data were taken on 4 lines (Y) running parallel to and half way between the trenches. The first line with X = 0 m was to the left of trench 1 and the last line X = 6.9 m was half way between trenches 3 and 4. These data show the pavement frost heaved uniformly from about 10 mm (0.5 ") on the left side of the facility to around 25 mm (1.0 ") on the right side of the test facility. The interesting aspect of the pavement frost heaving was that only about 50% of the total frost heaving was recouped when the soil thawed, as shown by the data labeled "Permanent Deformation" in Table 10. Again as with the trench observations this was probably due to the lack of traffic on the test facility. These limited data show that a Flowable Fill trench can move with a pavement that is frost heaving but with less magnitude. In an actual pavement the effect of traffic may be to overcome this observation.

freeze thaw durability

The exposed surfaces of case number 2 as shown on Figure 4 were inspected for freeze-thaw damage. Some breakdown of the surface of the concrete sand mixes occurred to a depth of 1" to 2" however the Flowable Fill appeared to remain intact from that level down. The fly ash mixes, especially the Merrimack fly ash had the tendency to break up in fist sized particles on the surface which was exposed. Stresses from freeze thaw and wetting and drying cycles are excessive at the exposed surface. Destruction of the surface of Flowable Fill exposed to the elements is consistent with the results of the laboratory freeze thaw testing if the material becomes critically saturated. In reality this will never happen unless the Flowable Fill is exposed to the environment, which is beyond the design expectation of the material. Excavation of the material showed all mixes, conventional as well as both fly ash mixes, to be in excellent condition and not damaged from freezing and thawing. Based on these observations it seems reasonable that Flowable Fill should have its surface protected to prevent critical saturation if it is to be used in a freezing environment.

SUMMARY

Flowable Fill is truly a remarkable material! It can be made of almost any aggregate material available, providing the material does not drastically effect hydration of the cementious binder used to hold the matrix together. A Flowable Fill must be flowable to be a viable mix. Flowability may be achieved in a variety of ways: it may achieve its flowability from small diameter particles like fly ash or finely ground slag cement or it may be achieved by specifying high air content by increasing the dosage of conventional air entraining admixture or it may be achieved by specifying a high range air entraining agent. Each of these methods has advantages and disadvantages but all most certainly have one thing in common, they are capable of producing a good Flowable Fill mix. Although the Flowable Fill which was placed as backfill material in the simulated abutment on the heavy traffic haul road held up well and was even superior to conventional granular material, it is not recommend that asphaltic concrete be placed immediately on top of Flowable Fill in a cold climate. A better design is to place the material then remove a thin portion of it the next day and apply a base material similar to the surrounding existing material. It is essential the material be of equal quality to the adjacent material to assure equal response to the effect of traffic and climate. The major advantage of removing a portion of the Flowable Fill is that it doesn't matter what environmental conditions exist during and after placement. The mix can literally be allowed to freeze in the winter or allowed to dry out and undergo plastic shrinkage in the summer because the underlying Flowable Fill is protected by the surface that is to be removed. It truly is a unique material which, unlike conventional concrete, can not be abused relative to adding too much water, not protecting it from freezing, not properly curing it , and not consolidating it.

Recommended trial batches based on the work herewithin are presented in Table 11. These mixes are to be considered starting point for trial mixes and must be adjusted according to local available materials and placement conditions. These mixes are expected to set in a reasonable time (2 to 3 hours) and develop strengths approximately as shown.

CONCLUSIONS

The following conclusions are based upon the work described herein and may not necessarily apply to other materials. However it seems reasonable that in most cases the results should apply to similar aggregates, waste materials, and ASTM C 618 fly ashes as well as non ASTM C 618 fly ashes. The conclusions are as follows:

1. Schiller fly ashes, except for low iron contents and increased LOI's, have major elemental compositions similar to Merrimack fly ashes. The low iron content is made up by increased aluminum and silicon.
2. Merrimack fly ash was found to be an ASTM C 618 fly ash and was typical of the Merrimack fly ashes tested over the last 7 years.
3. High carbon fly ash mixes require more water and portland cement than ASTM C 618 fly ashes The increased carbon (LOI) negatively affects hydration of portland cement and more cement must be used to overcome the effect. The increased particle size (fineness) negatively affects the plastic properties of Flowable Fill and more water must be used to achieve adequate fluidity.
4. When the LOI of a fly ash increases above approximately 25% the small fly ash particles coalesce into very large conglomerates rendering the fly ash impractical for use as Flowable Fill.
5. Ashes with LOI's smaller than 25% have increased surface areas similar to the ASTM C 618 Merrimack ash and are good candidates for use in Flowable Fill
6. For a given fly ash more cement is required with decreasing ash pH and increasing ash LOI.

7. Flowable Fill showed superior settlement properties under heavy traffic as compared to conventional backfill.
8. Flowable Fill could not be shown to be durable under laboratory freeze thaw testing conditions, however field mixes were found to be durable for all portions except the top 5 cm (2") when exposed to severe freeze thaw conditions, including letting it freeze while still plastic.
9. For placement of Flowable Fill in a freezing climate zone it is recommended the top 5 to 15 cm (2 to 6") of a Flowable Fill trench be removed after set and backfilled with a frost heave compatible base material to assure uniform heaving of pavement and trench.
10. Recommended trial mixes are as presented in table 11.

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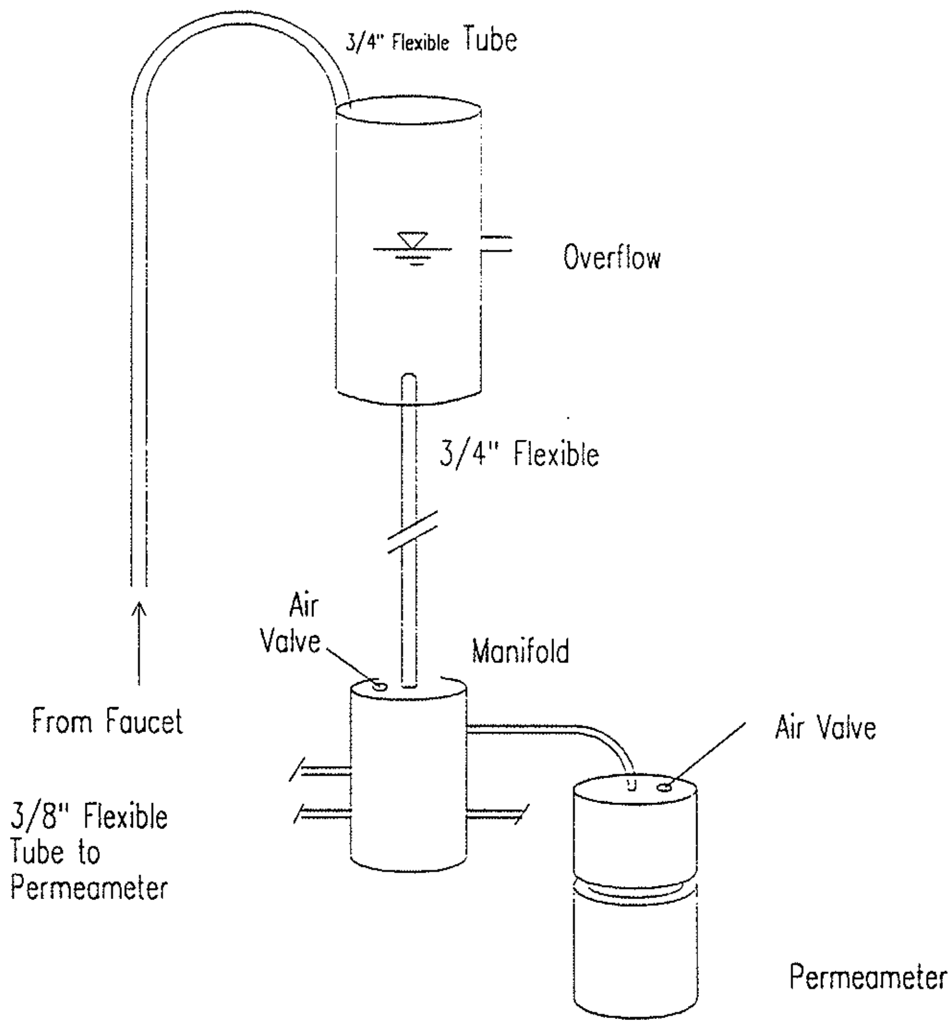


FIGURE 1 PERMEABILITY TEST APPARATUS

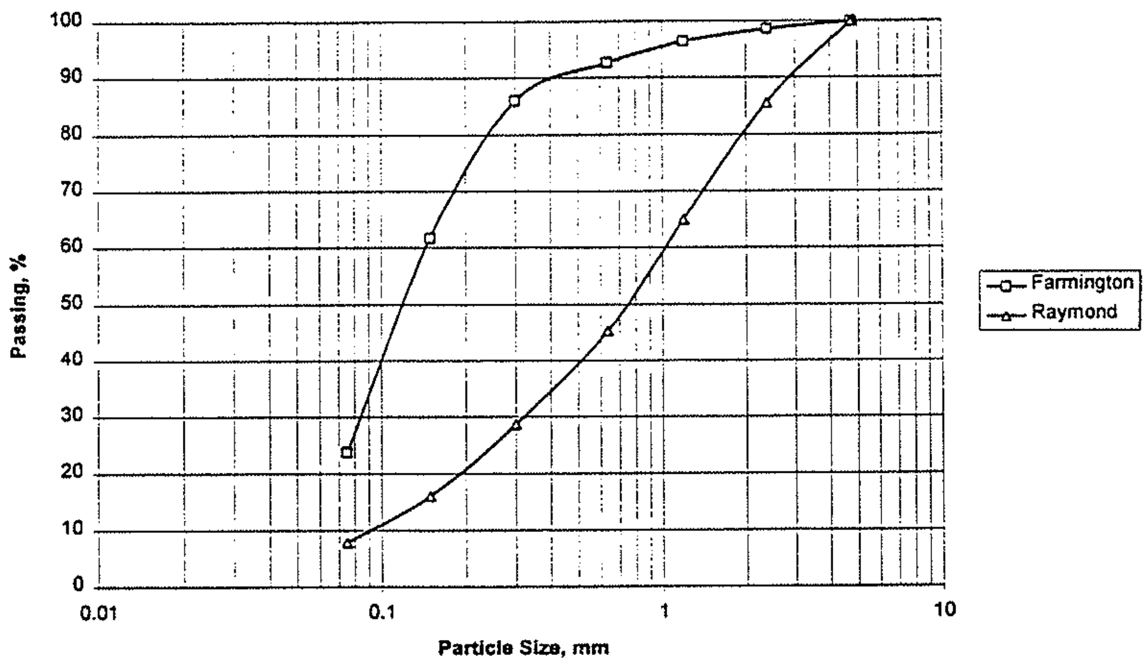


FIGURE 2 PARTICAL SIZE DISTRUBITION OF WASTE MATERIALS

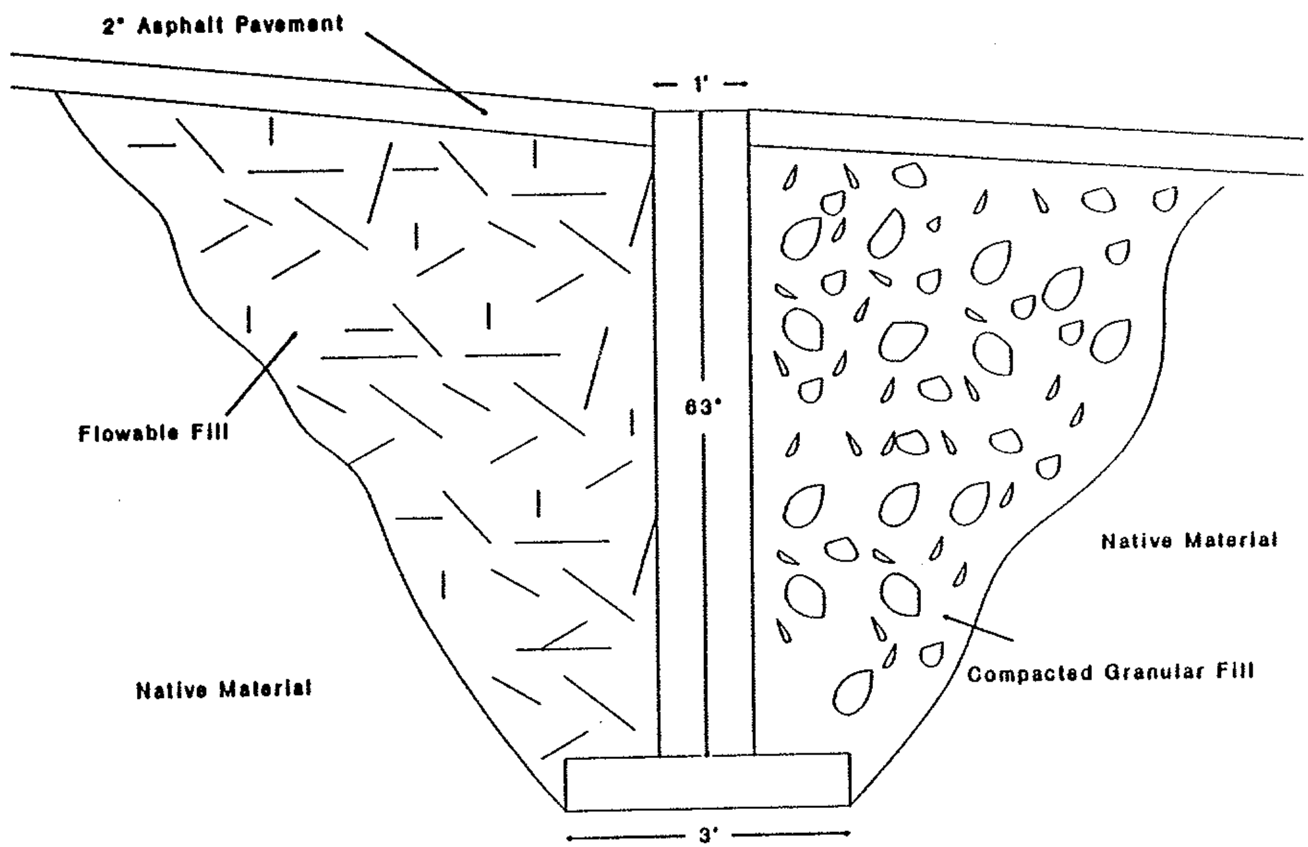


FIGURE 3 SIMULATED BRIDGE ABUTMENT

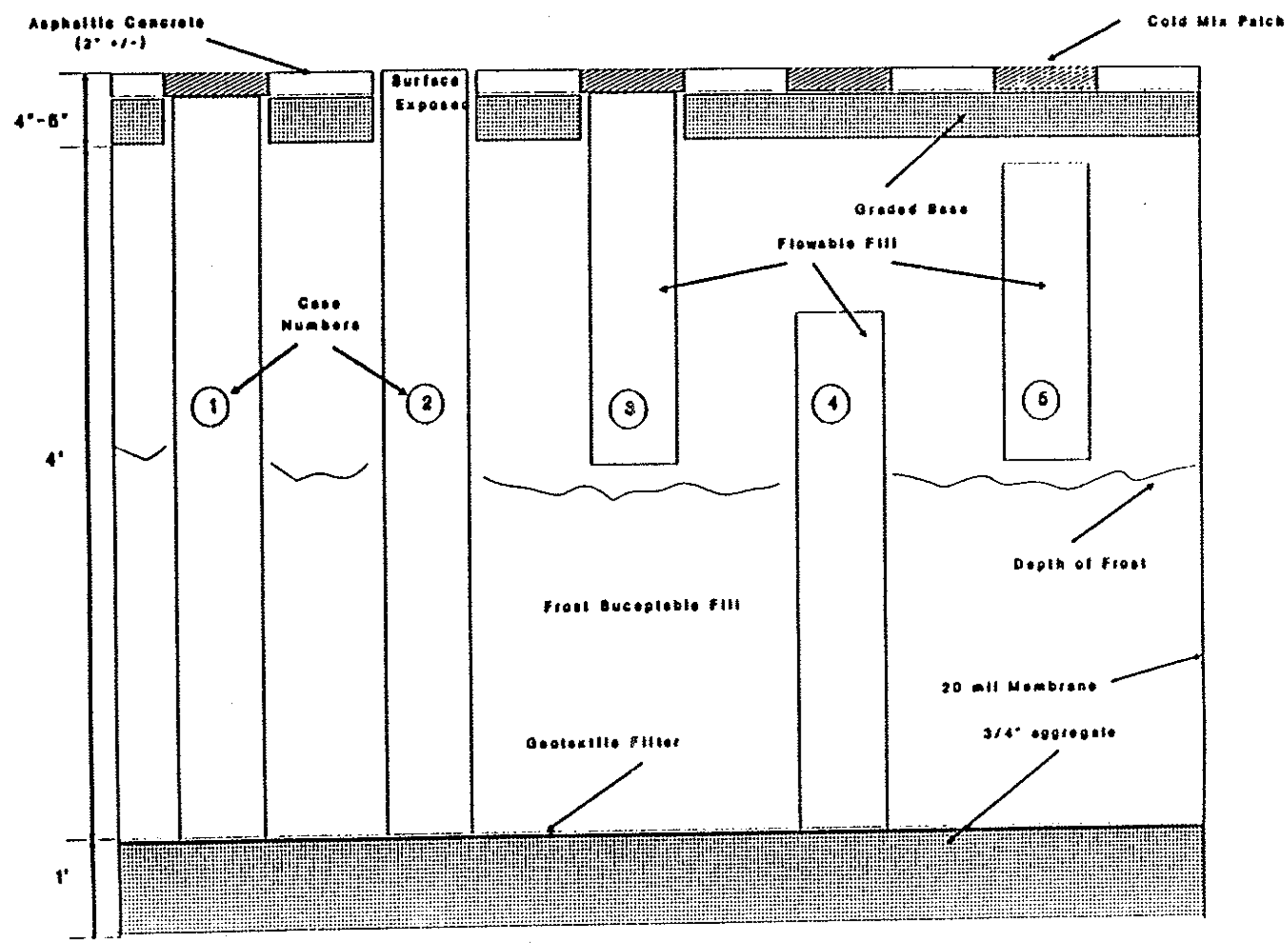


FIGURE 4 TRENCH CASE CROSS SECTIONS

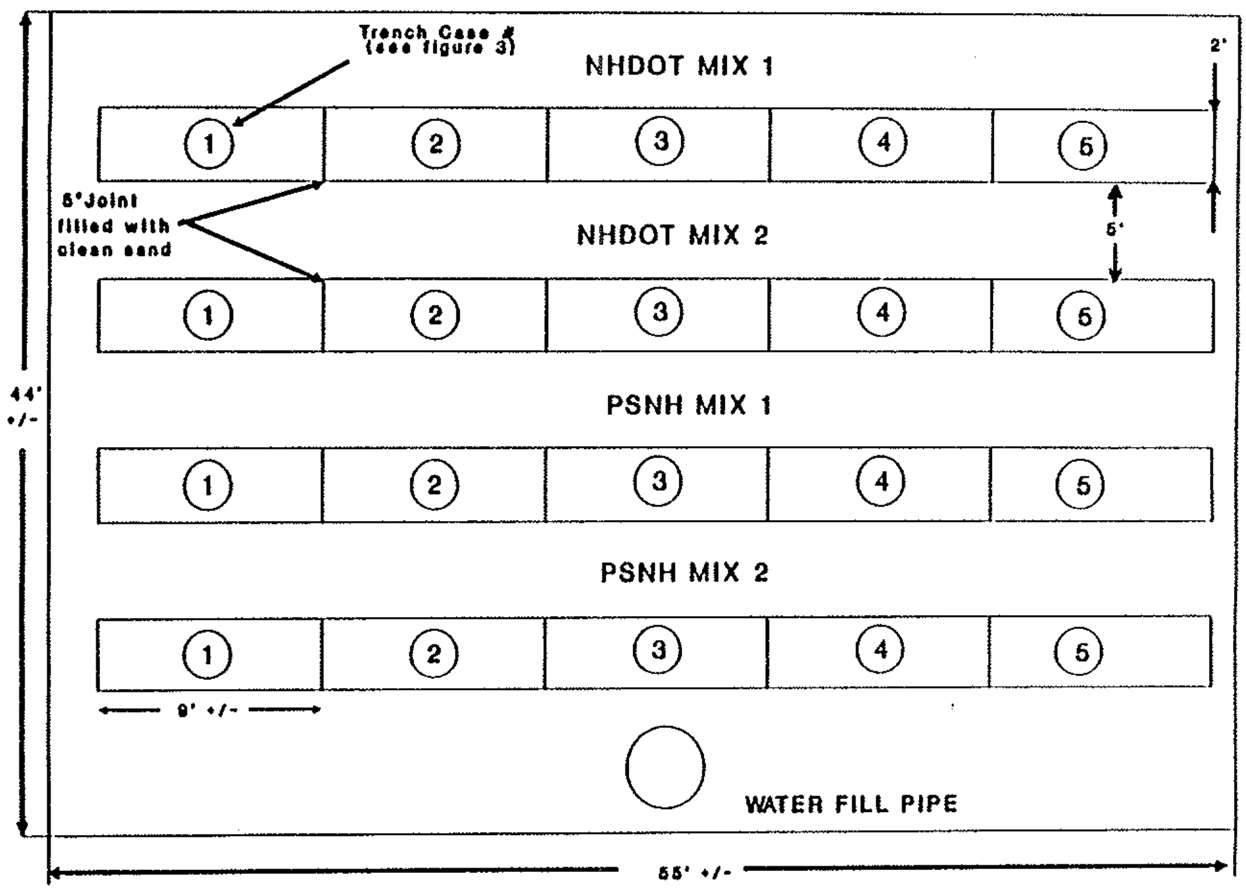


FIGURE 5 TRENCH BACKFILL TEST FACILITY

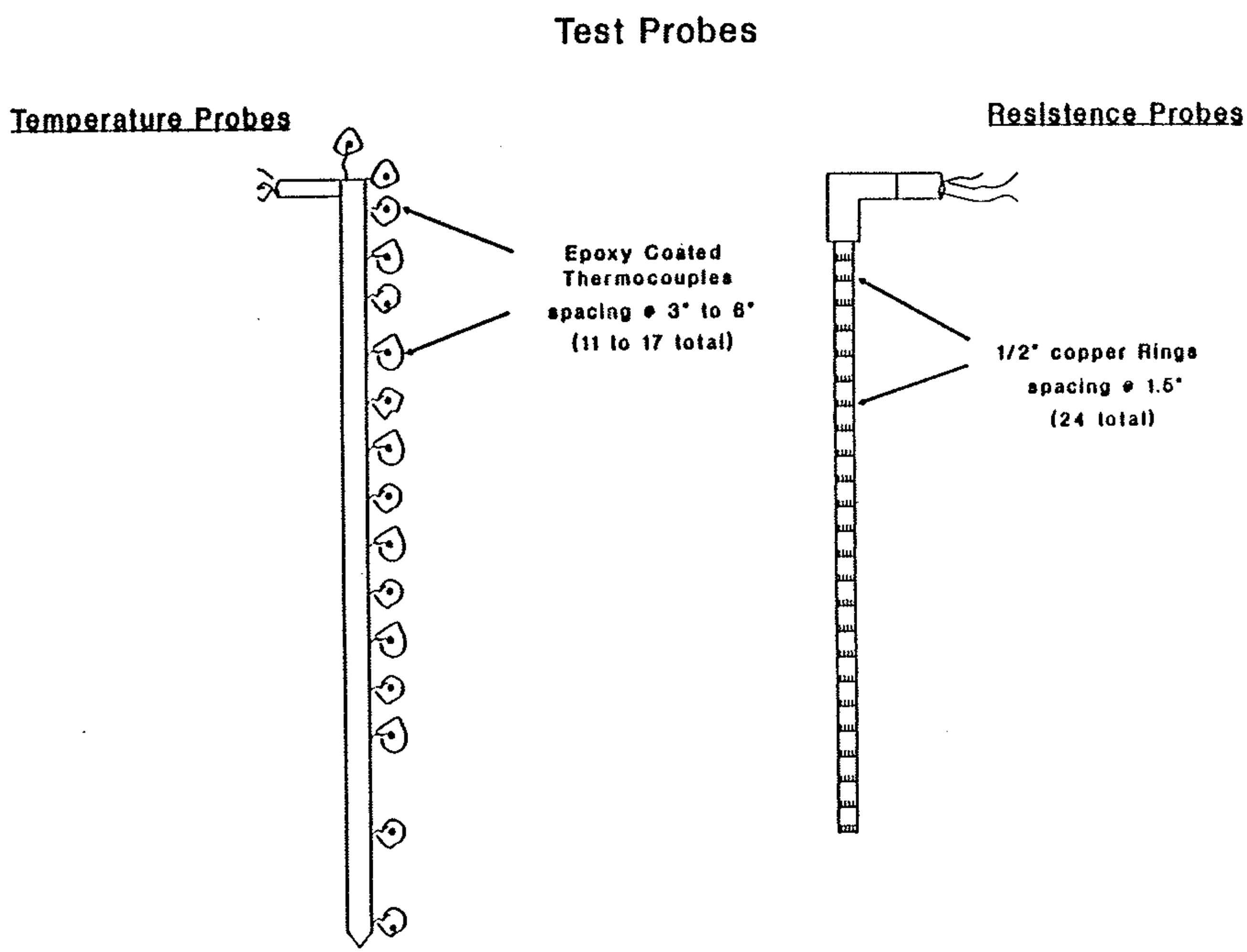


FIGURE 6 TEST PROBES

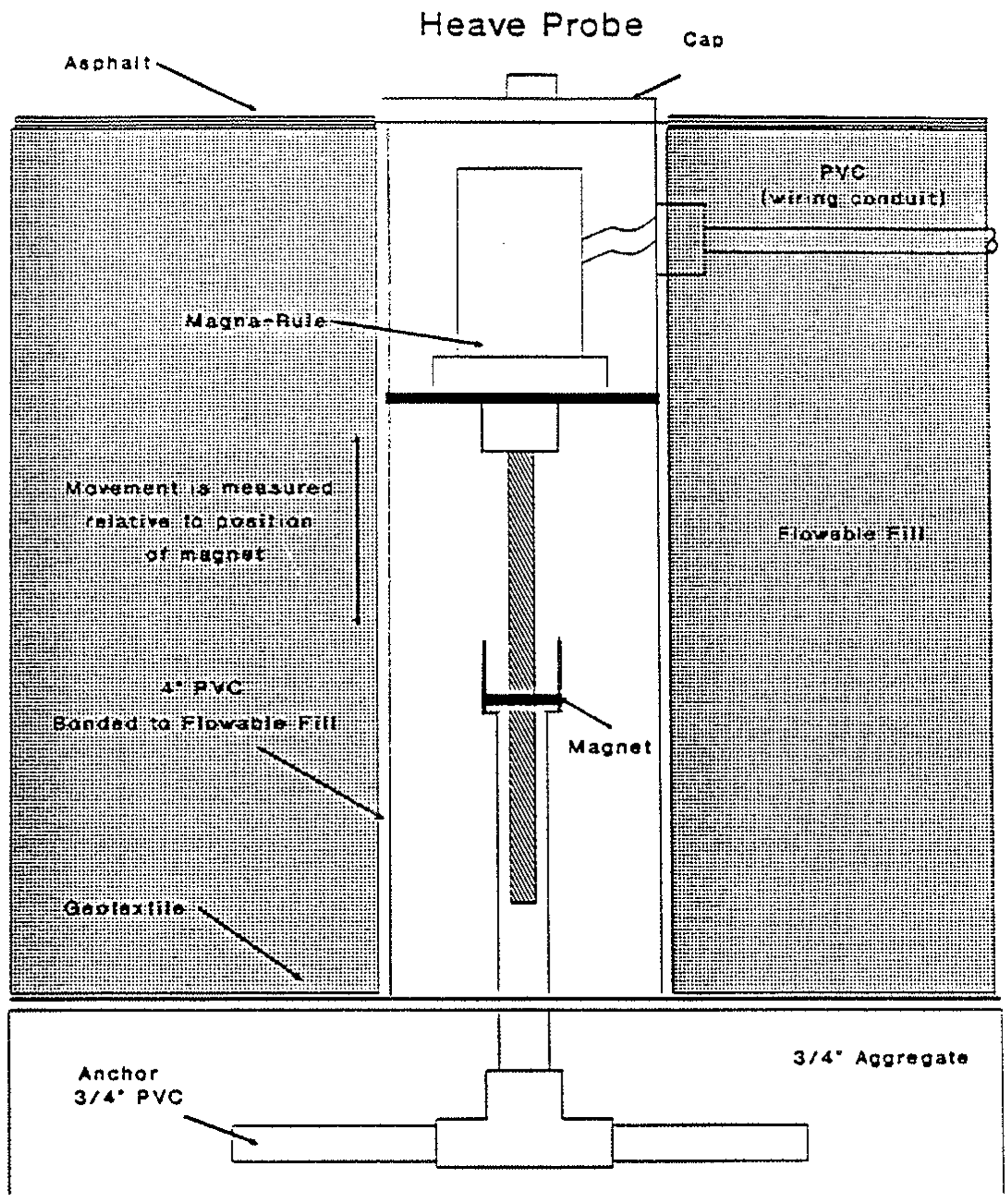


FIGURE 7 HEAVE PROBE

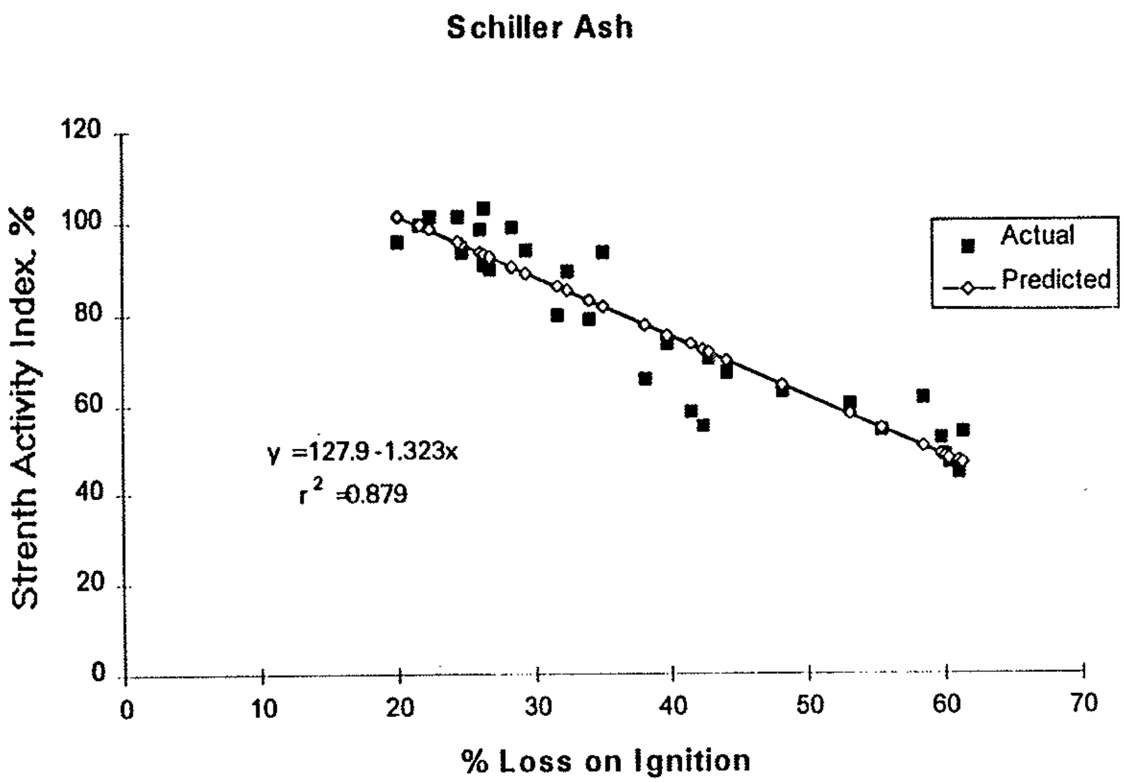


FIGURE 8 SAI VERSUS LOSS ON IGNITION

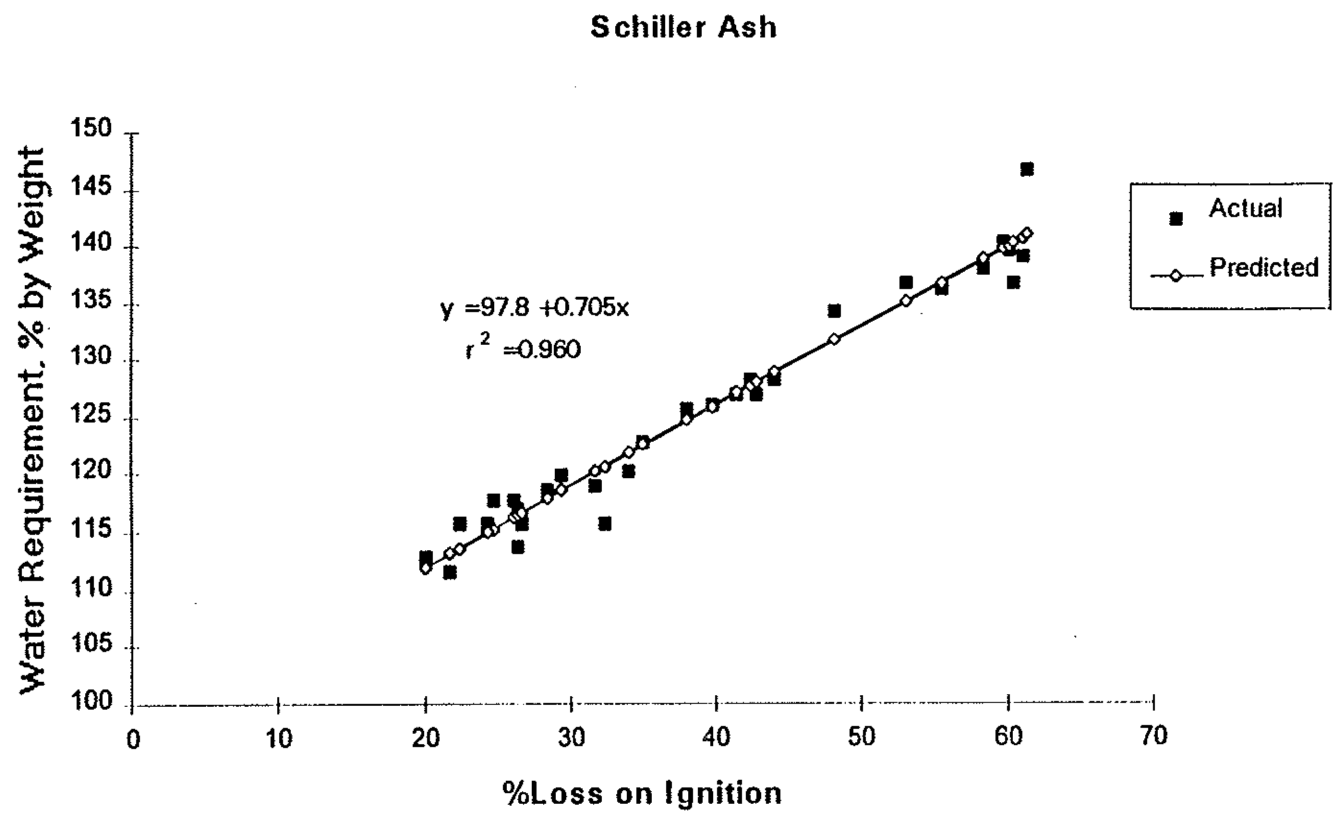


FIGURE 9 WATER REQUIREMENT VERSUS LOSS ON IGNITION

F 9

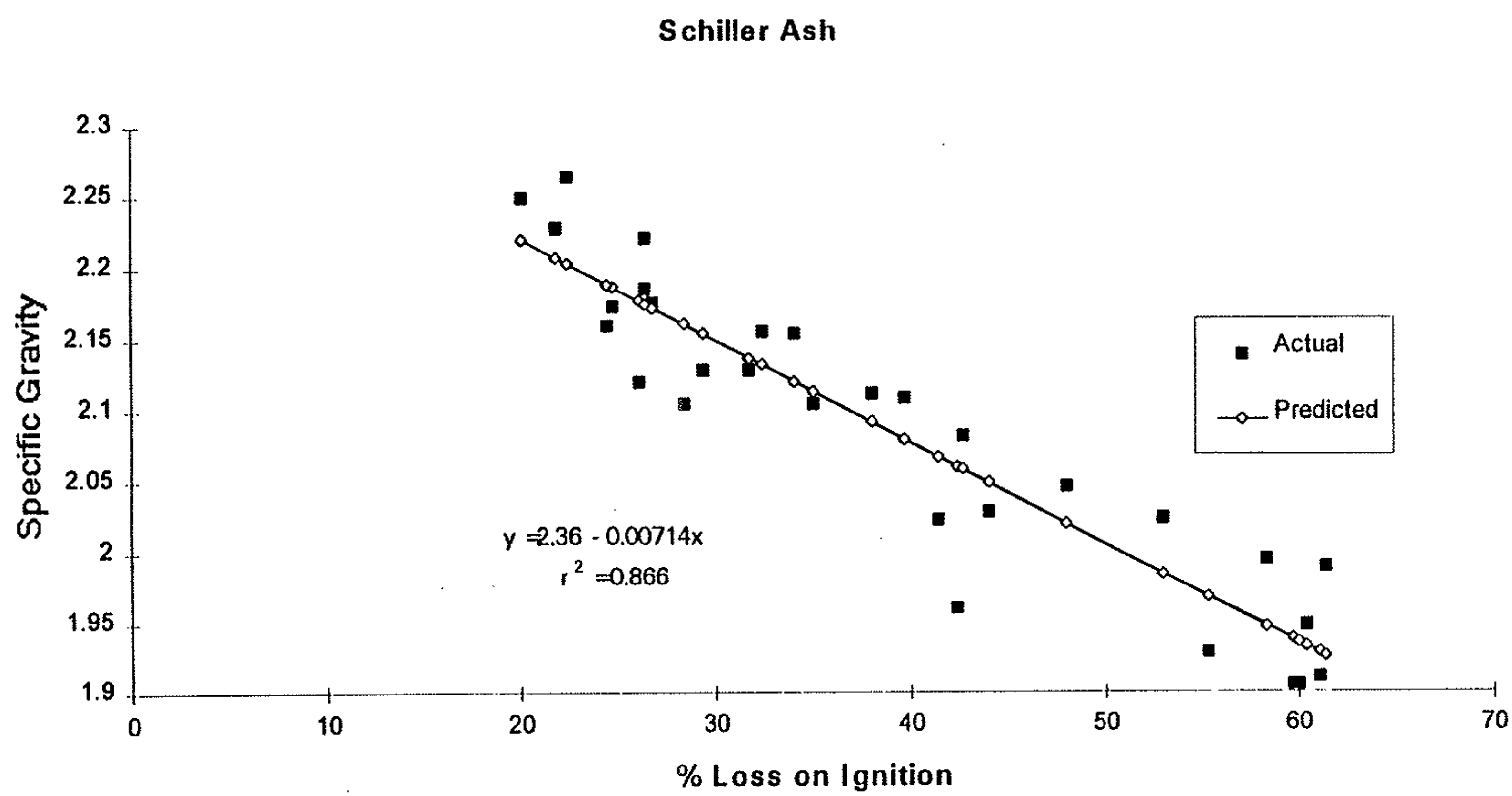


FIGURE 10 SPECIFIC GRAVITY VERSUS LOSS ON IGNITION

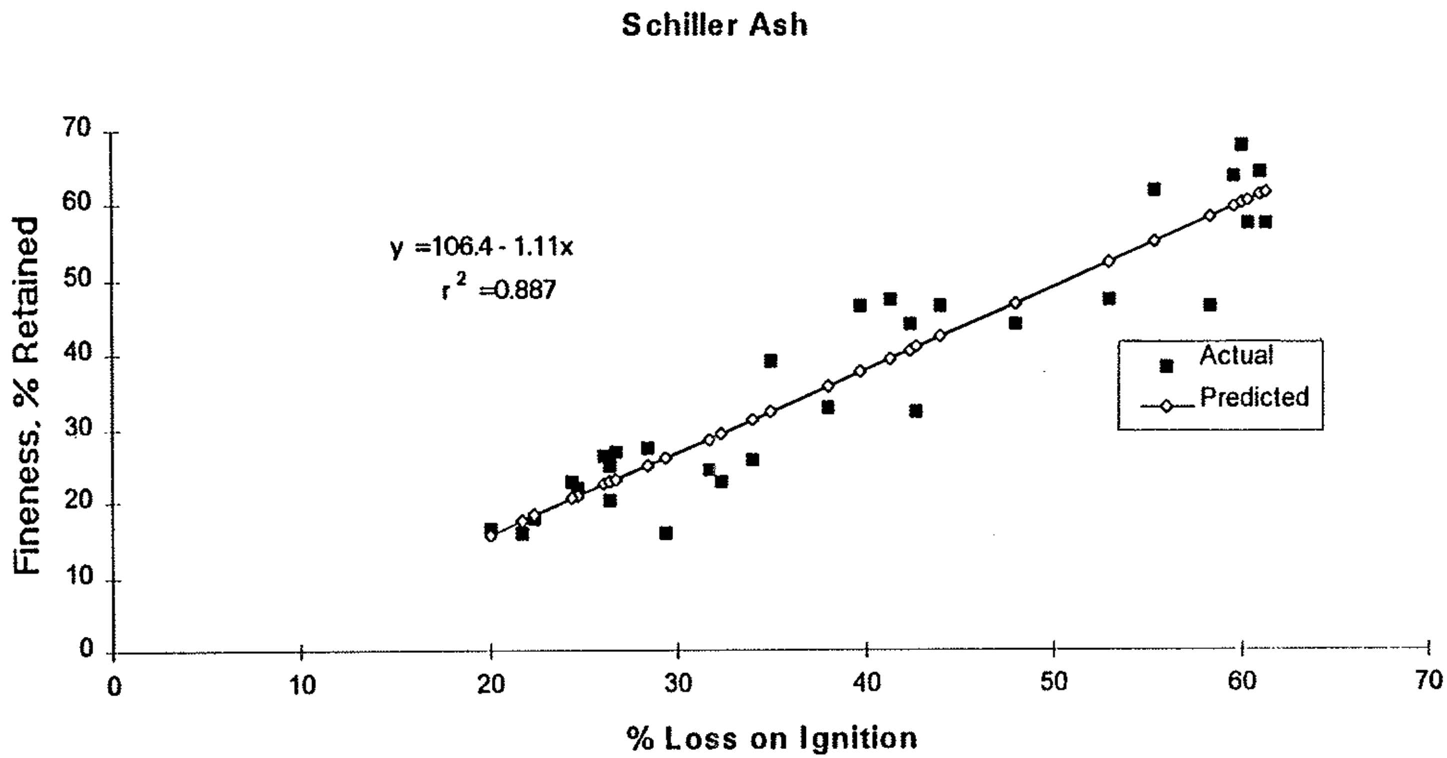
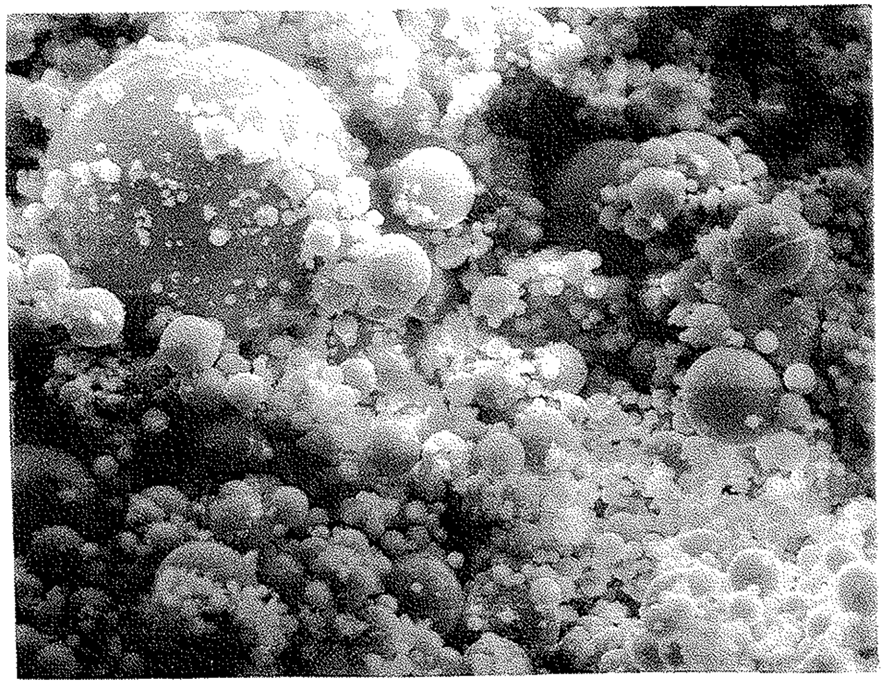


FIGURE 11 FINENESS VERSUS LOSS ON IGNITION

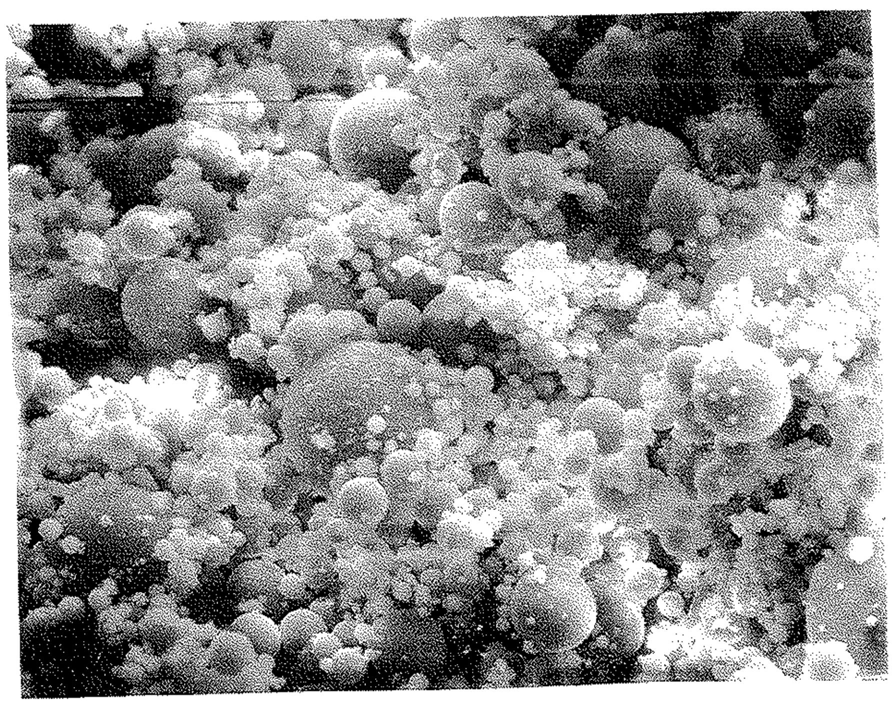
MAC 1



LOI = 3.67%

Scale: 10μm

MAC 2

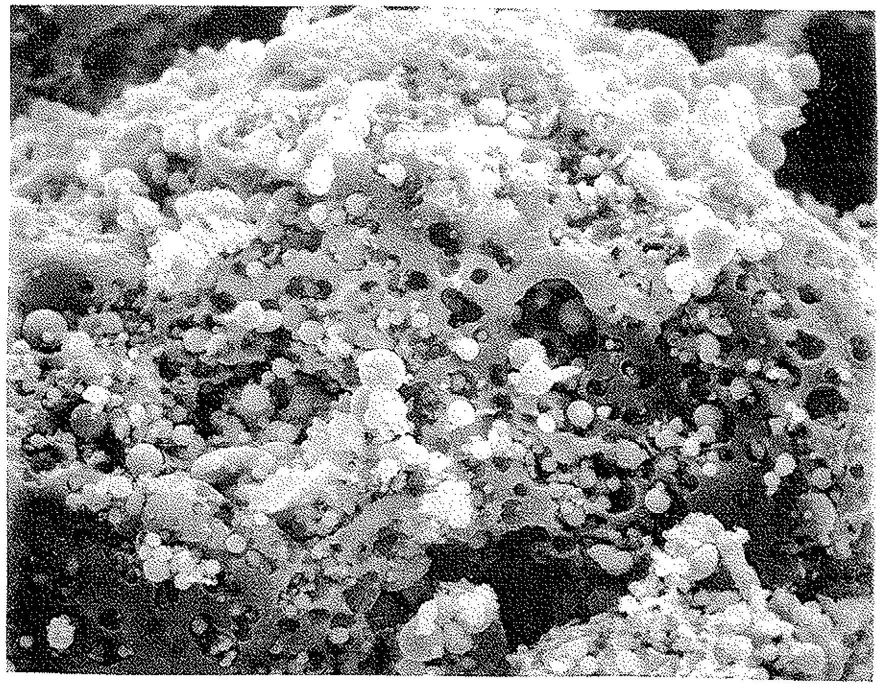


LOI = 3.33%

Scale: 10μm

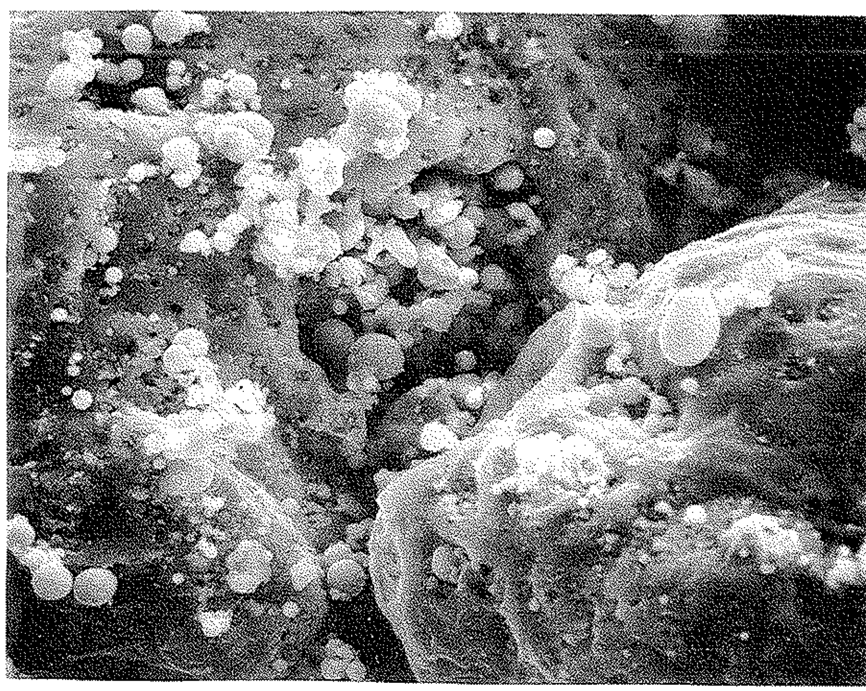
FIGURE 12 SEM PHOTOGRAPHS FOR MAC 1 AND MAC 2

S9



LOI = 48.0%   Scale: 10μm

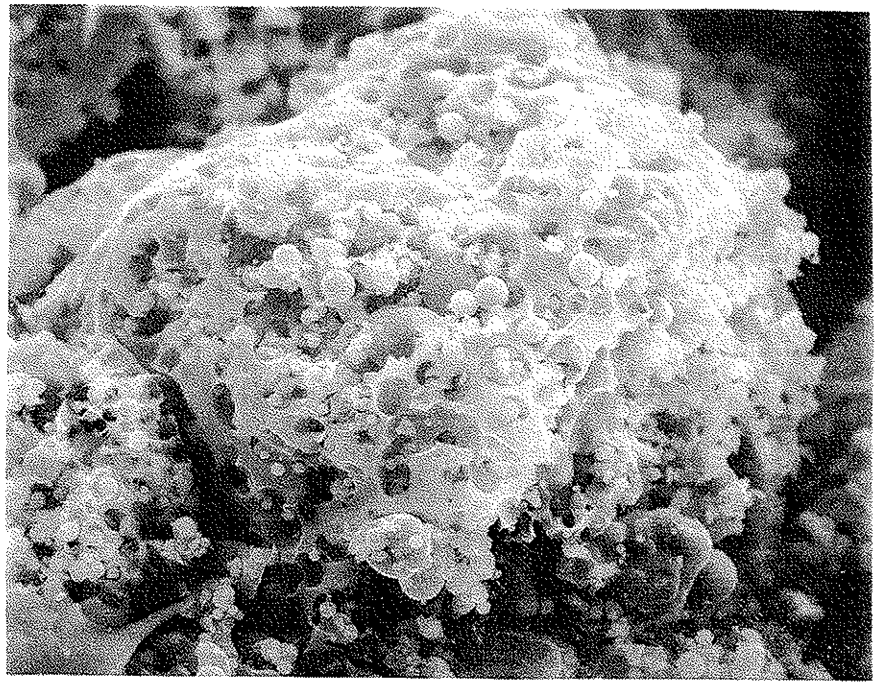
S10



LOI = 39.67   Scale: 10μm

FIGURE 13 SEM PHOTOGRAPHS FOR S9 AND S10

S30



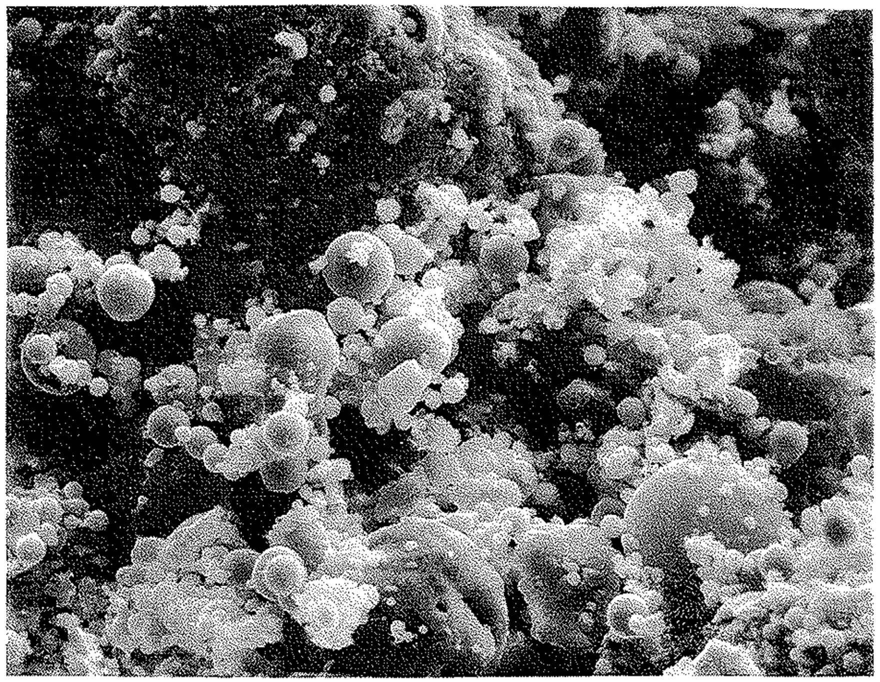
LOI = 34.0% Scale: 10μm

S31

LOI = 61.33% Scale: 10μm

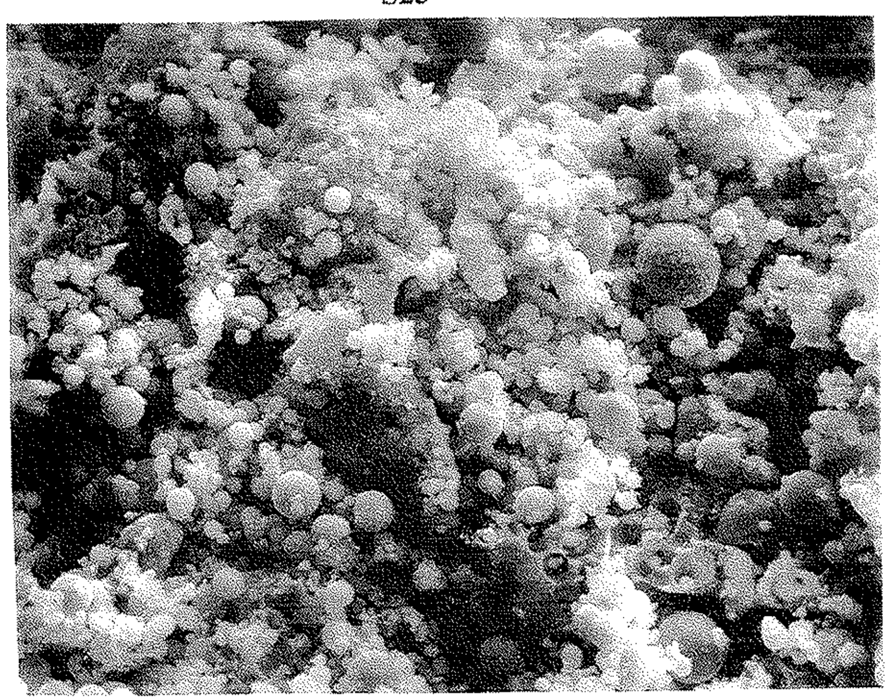
FIGURE 14 SEM PHOTOGRAPHS FOR S30 AND S31

S22



LOI = 24.67%   Scale: 10μm

S23



LOI = 20.0%   Scale: 10μm

FIGURE 15 SEM PHOTOGRAPHS FOR S22 AND S23

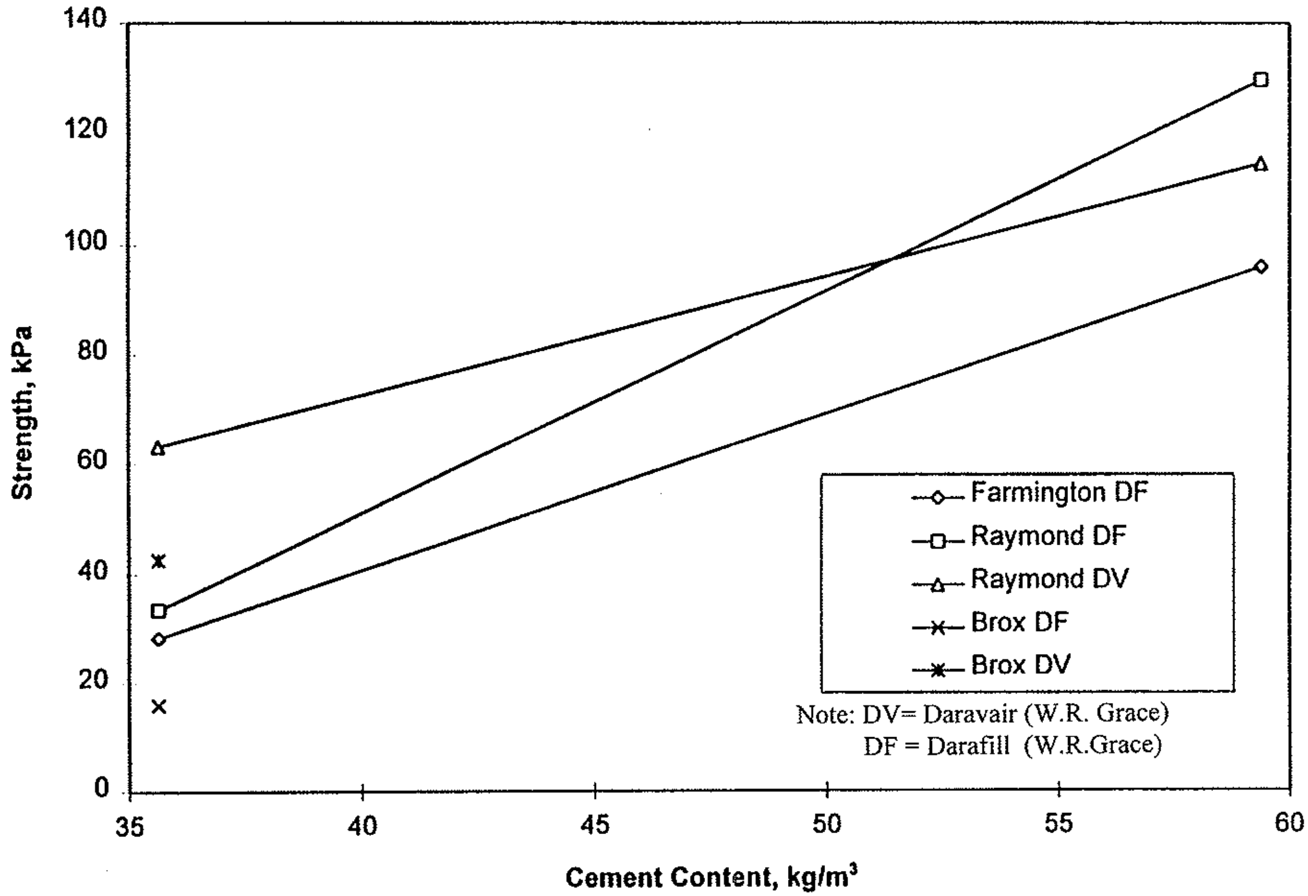


FIGURE 16 STRENGTH VERSUS CEMENT CONTENT FOR FARMINGTON, RAYMOND AND BROX AGGREGATES

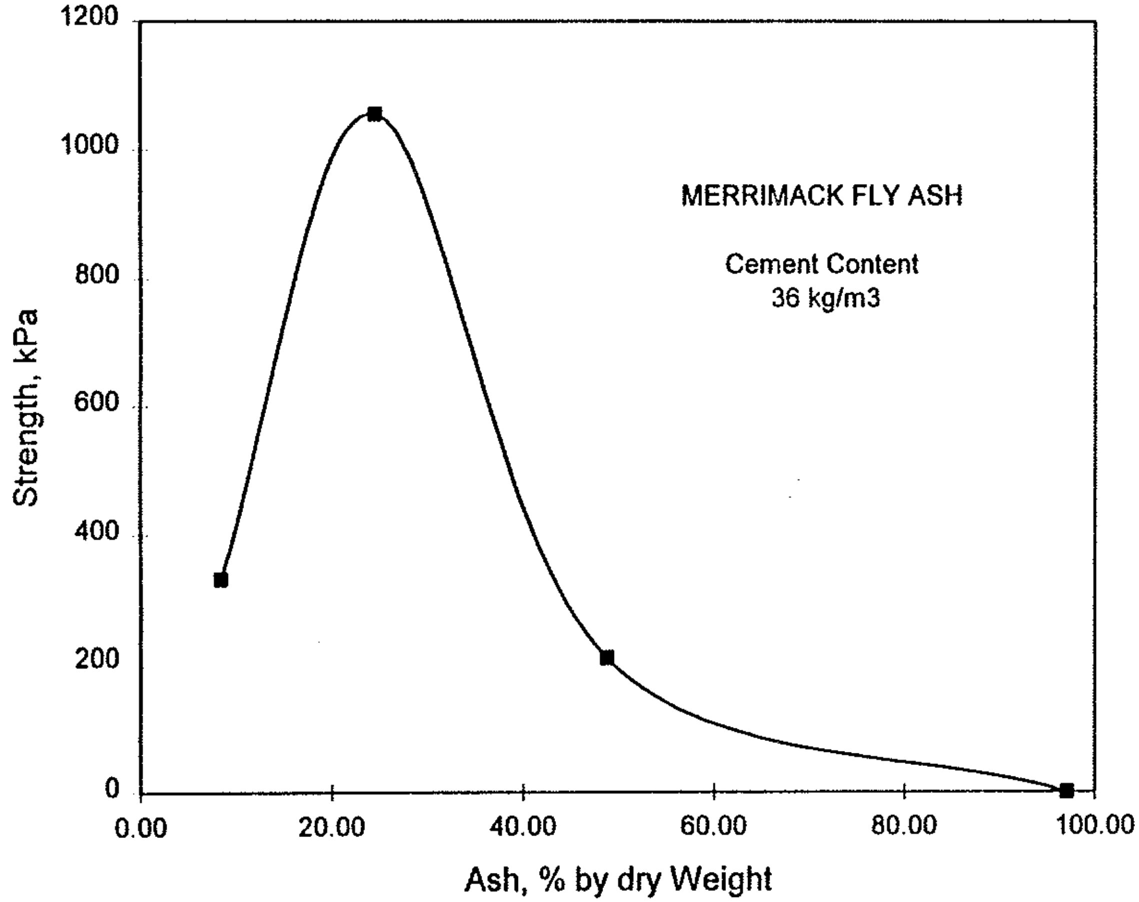


FIGURE 17 STRENGTH VERSUS ASH CONTENT

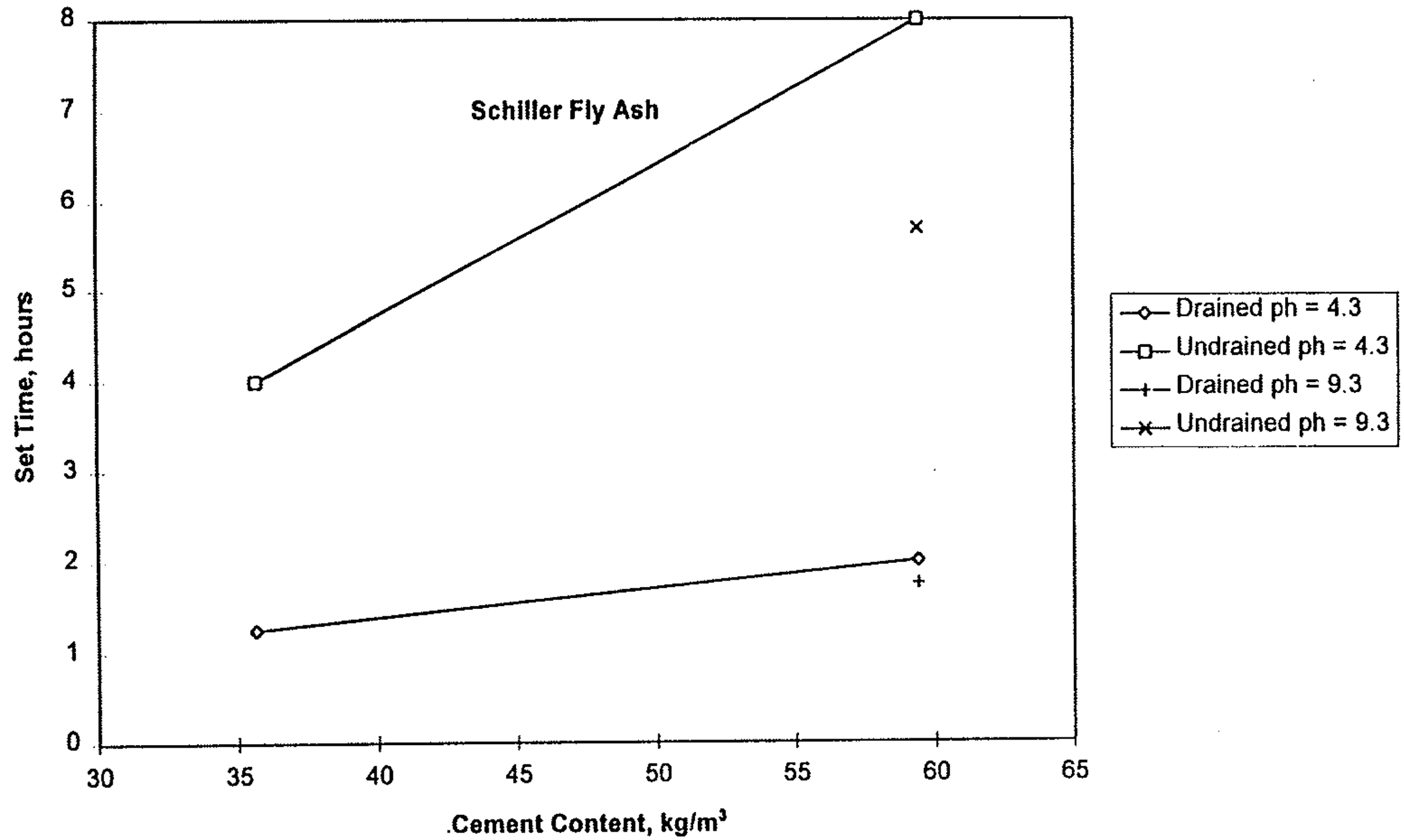


FIGURE 18 SET TIME VERSUS CEMENT CONTENT FOR TWO SCHILLER ASH

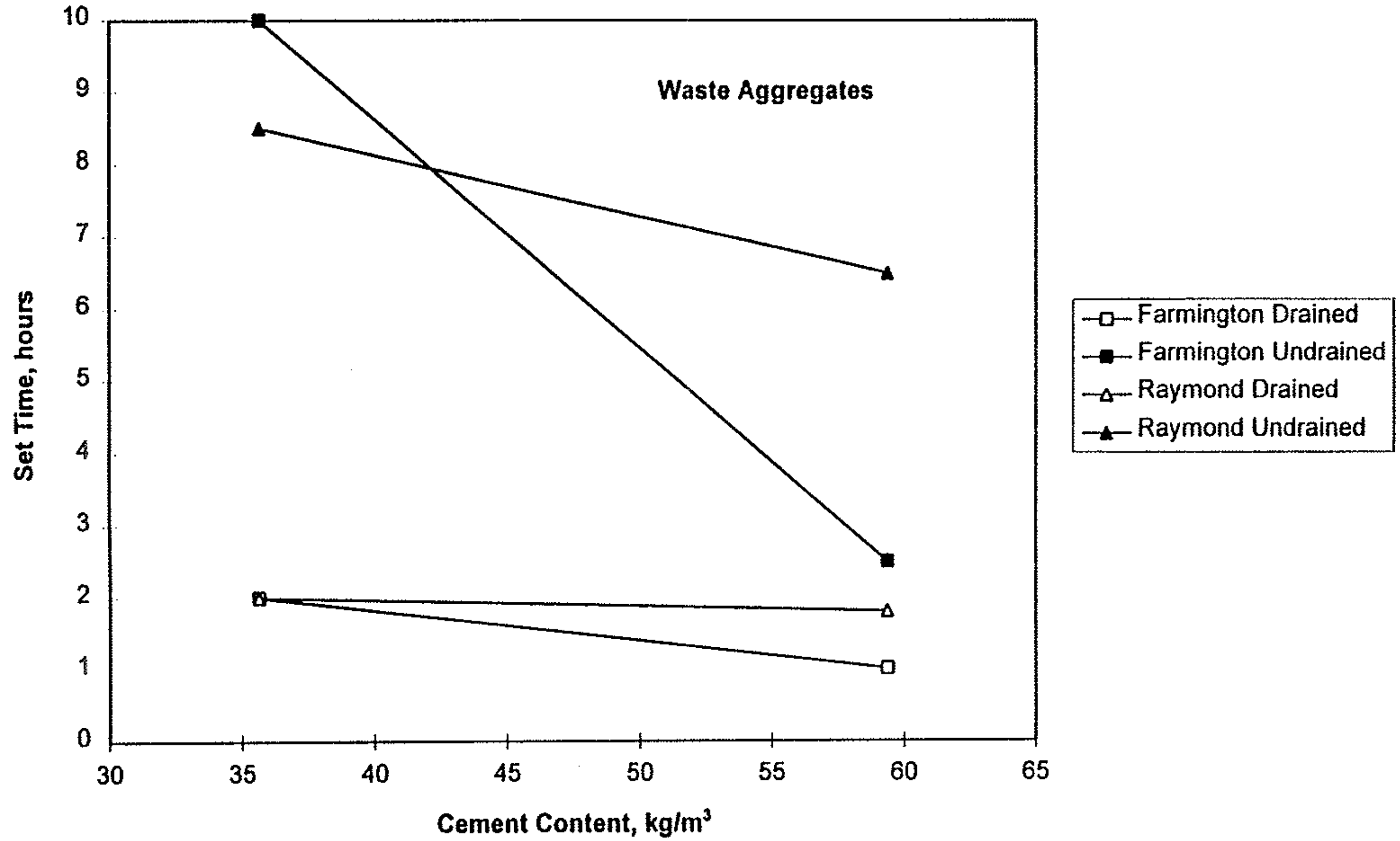


FIGURE 19 SET TIME VERSUS CEMENT CONTENT FOR FARMINGTON AND RAYMOND AGGREGATES

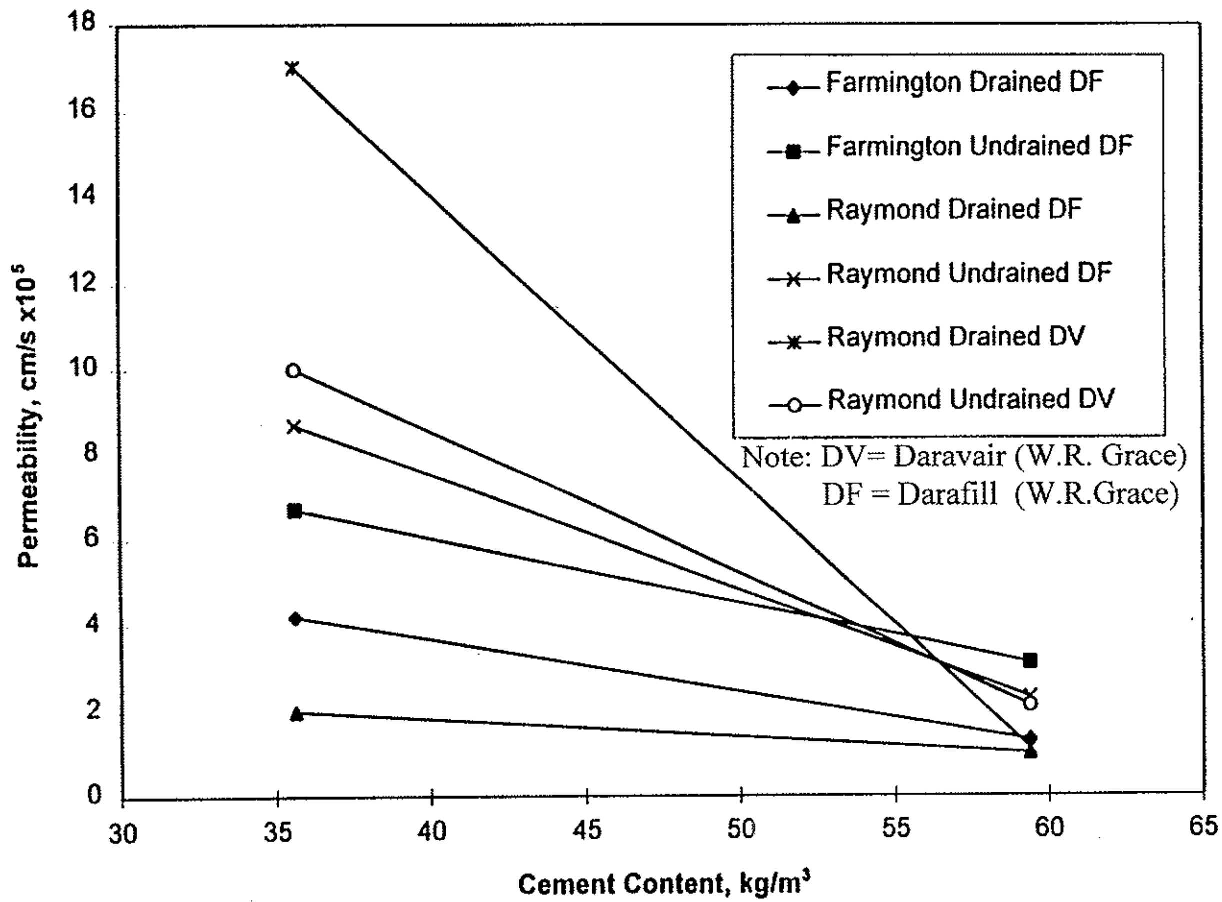


FIGURE 20 PERMEABILITY VERSUS CEMENT CONTENT

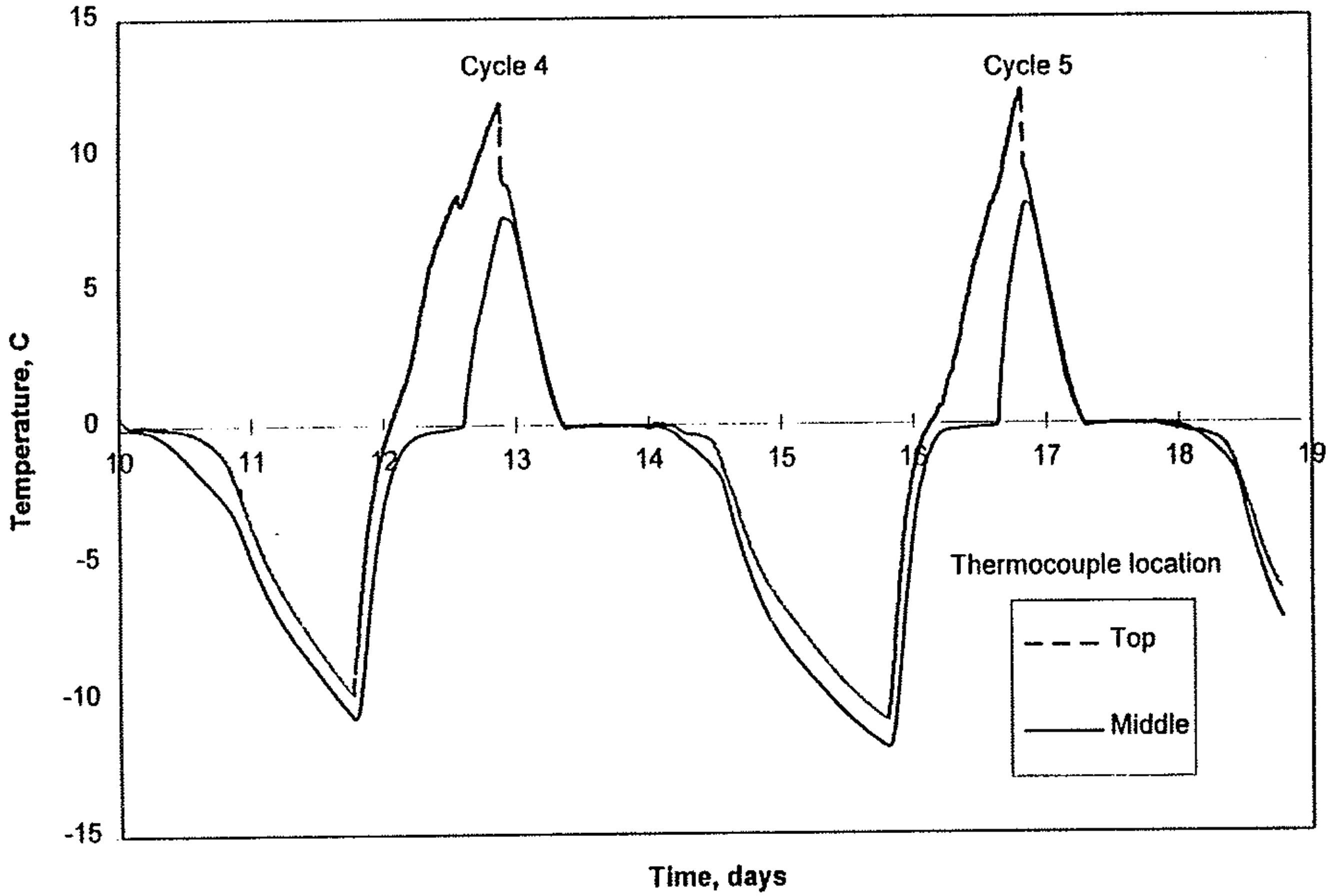


FIGURE 21 TYPICAL LABORATORY SLOW FREEZE THAW CYCLES

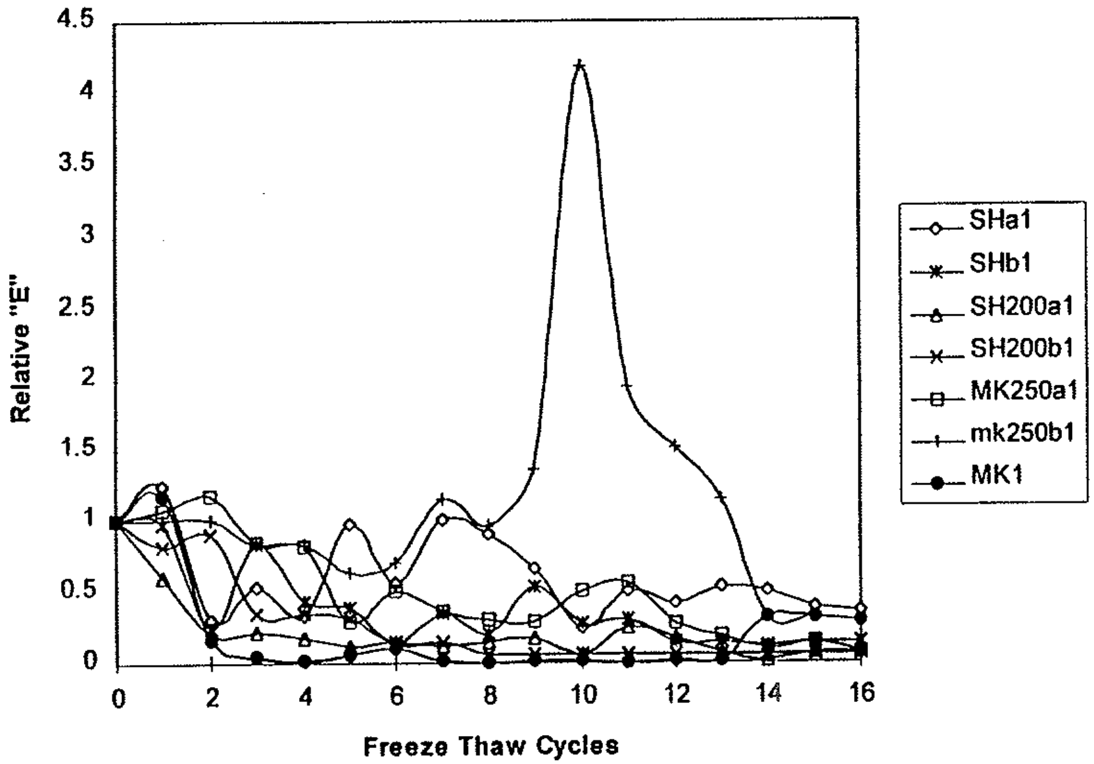


FIGURE 22 RELATIVE "E" VERSUS FREEZE THAW CYCLES

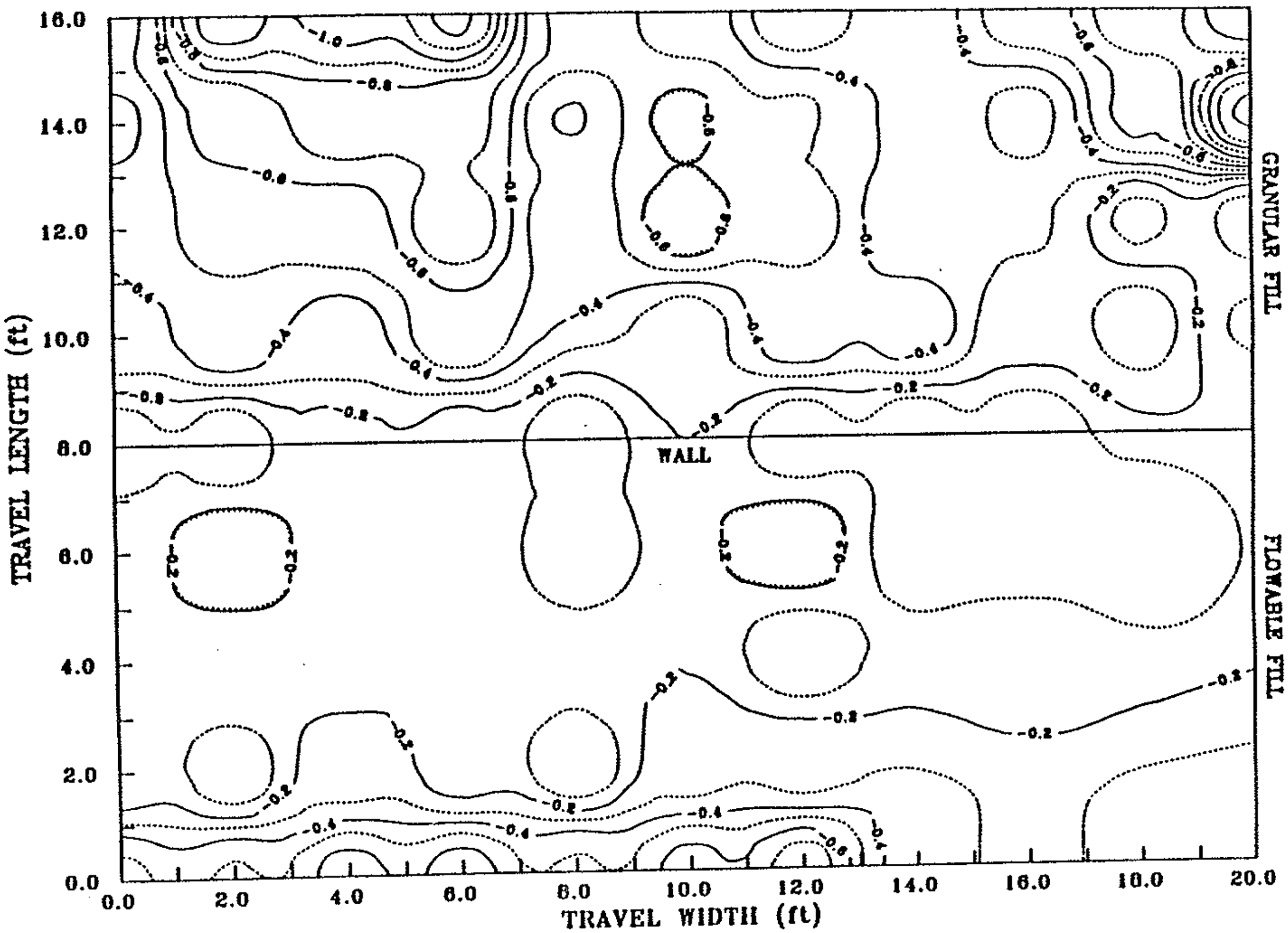


FIGURE 23 SIMULATED ABUTMENT SURFACE SETTLEMENT

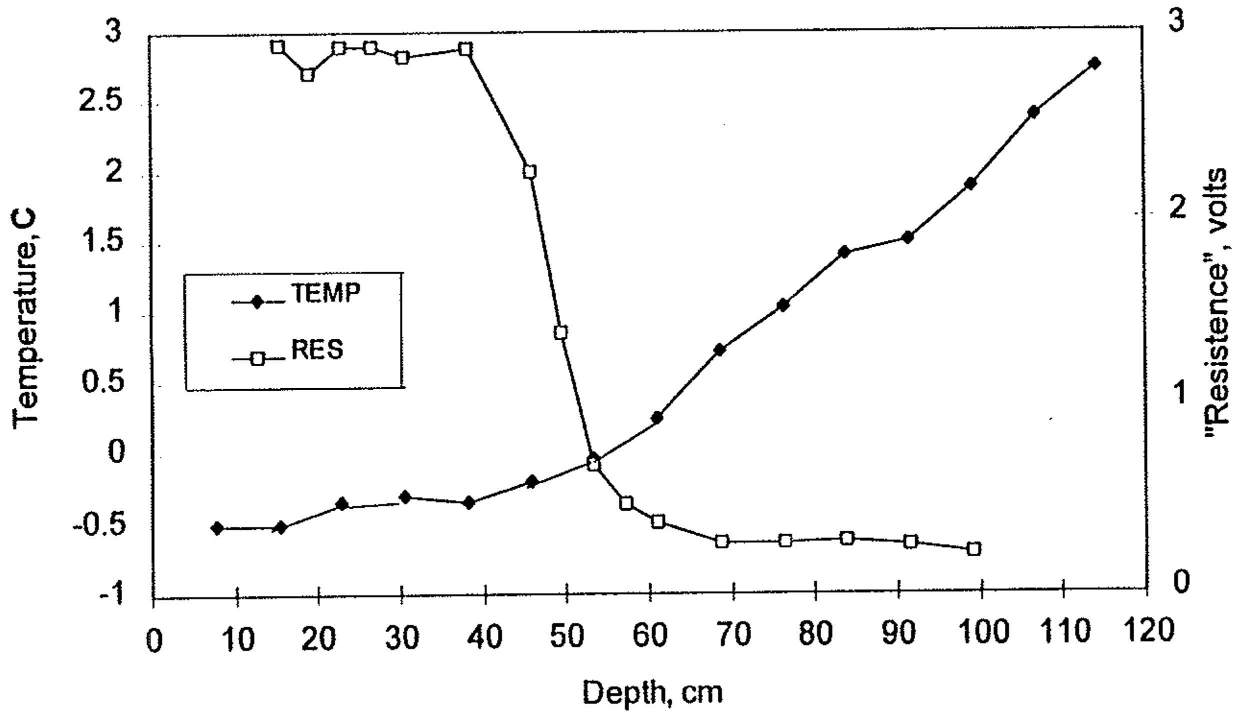


FIGURE 24 TEMPERATURE AND RESISTANCE VERSUS DEPTH

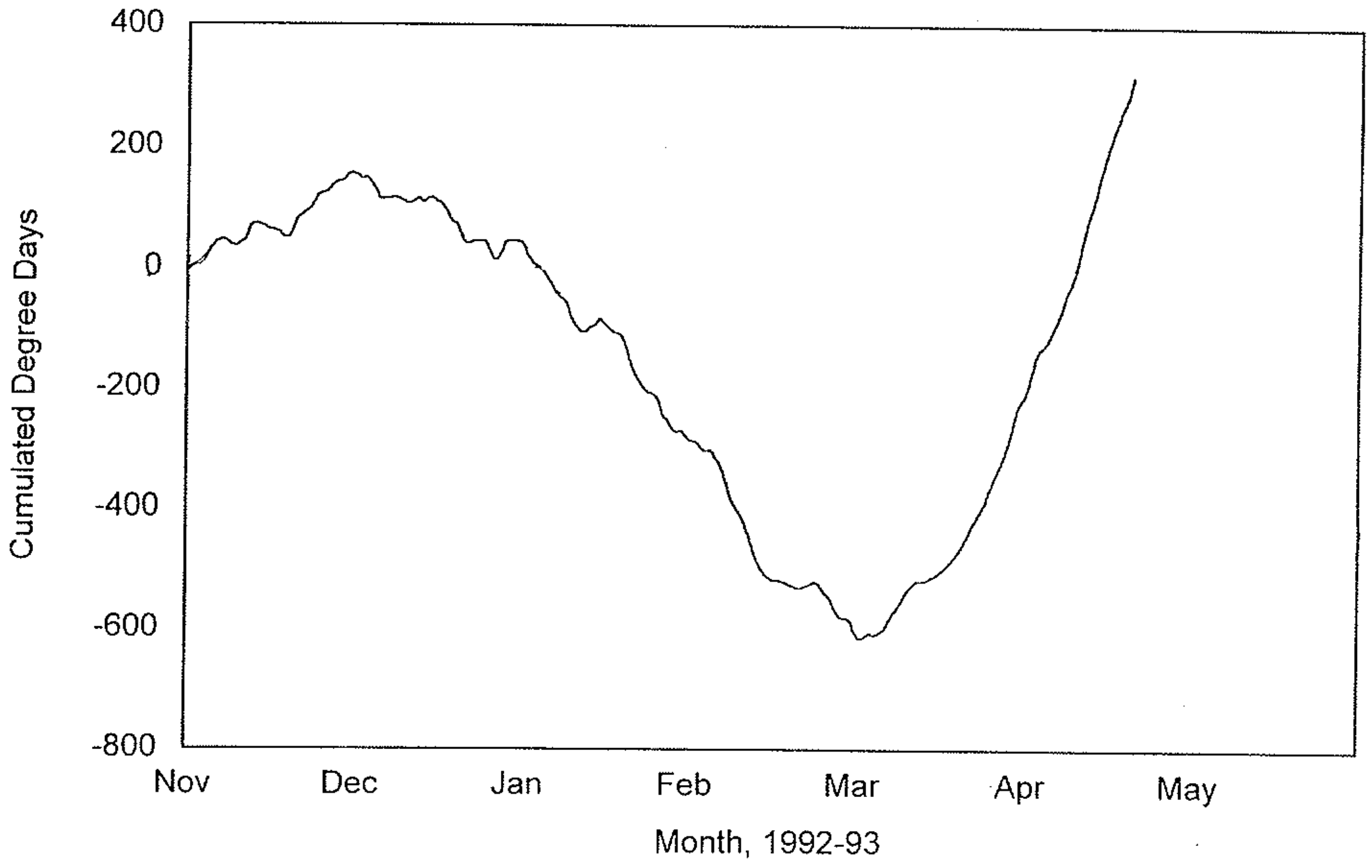


FIGURE 25 CUMULATED DEGREE DAYS VERSUS TIME FOR 1992-93

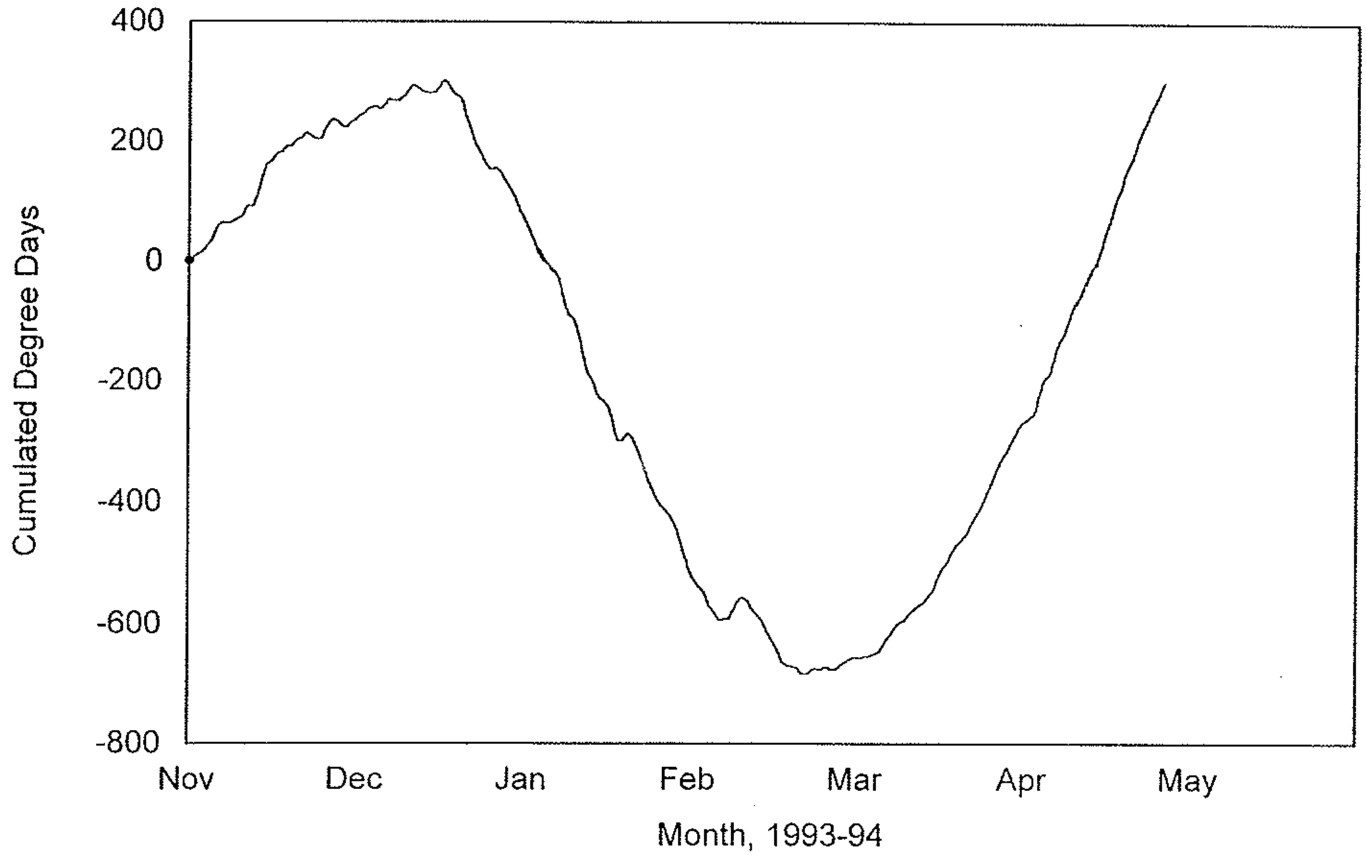


FIGURE 26 CUMULATED DEGREE DAYS VERSUS TIME FOR 1993-94

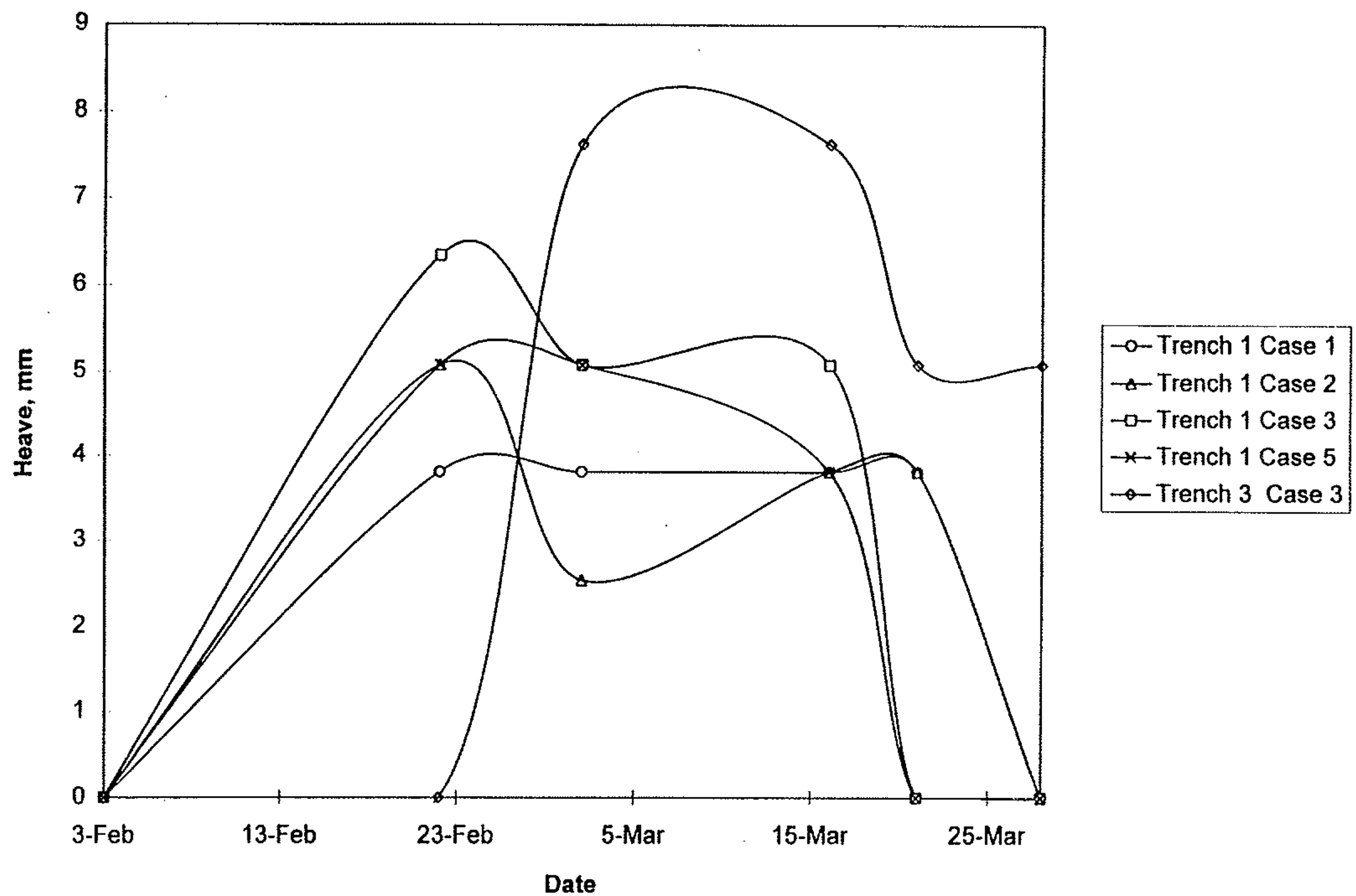


FIGURE 27 FROST HEAVING VERSUS DATE FOR TRENCHES 1 AND 3

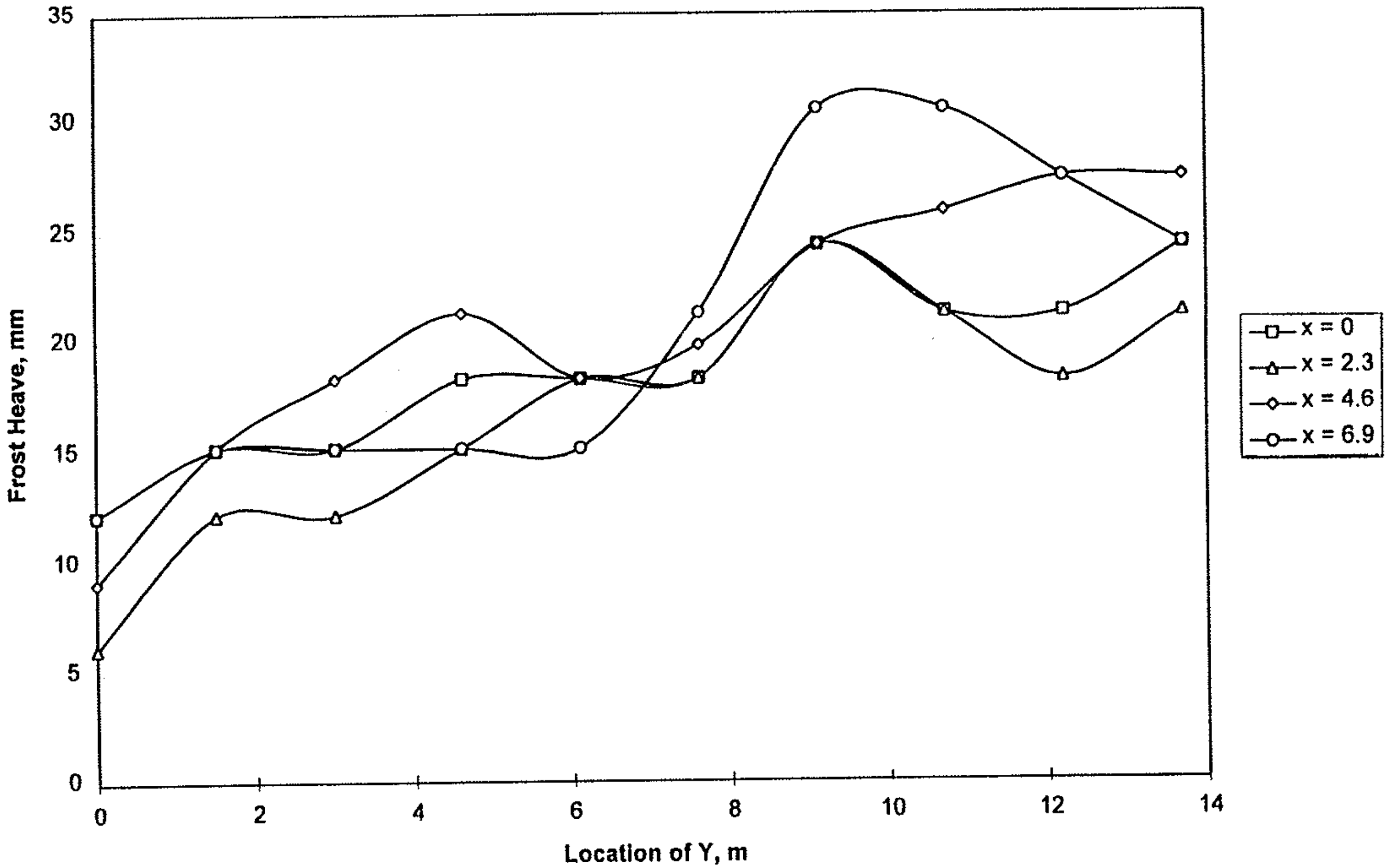


FIGURE 28 FROST HEAVING OF PIT PAVEMENT VERSUS LOCATION

TABLE 1 SCHILLER AND MERRIMACK ASH AVERAGE ASTM 618 PROPERTIES

FLY ASH	MOISTURE %	LOI %	FINENESS %	WATER %	SAI %	SPECIFIC GRAVITY
SCHILLER	0.29	39.1	62.9	125.5	76.2	2.09
MERRIMACK	0.33	2.89	100.0	96.3	116.	2.70

NOTE: Schiller data based on 30 independent samples
Merrimack data based on 3 independent samples

TABLE 2 AVERAGE ELEMENTAL ANALYSIS OF SCHILLER AND MERRIMACK ASH

ELEMENT	AVERAGE COMPOSITIONS MERRIMACK	SCHILLER
CARBON	0.46	8.47
OXYGEN	14.30	11.40
SODIUM	0.54	0.37
MAGNESIUM	0.62	0.57
ALUMINUM	19.10	26.10
SILICON	33.9	40.70
SULFUR	2.10	1.31
POTASSIUM	5.00	2.84
CALCIUM	3.79	2.05
TITANIUM	1.35	1.46
VANADIUM	0.25	0.41
IRON	17.56	4.32

TABLE 3 LABORATORY FLY ASH MIX DATA

ASH	MIX	pH	CEMENT kg/m^3	SAND kg/m^3	ASH kg/m^3	WATER kg/m^3	ADMIXTURE	AIR %	YIELD m^3
Schiller	AA	4.3	59.38	0	704	673	0	0	1.02
Schiller	FA	4.3	35.63	0	669	663	0	0	0.98
Schiller	BA	4.3	11.88	0	723	723	0	0	1.06
Schiller	T	9.3	59.38	0	677	667	0	0	0.99
Schiller	CA	4.3	29.69	1663	119	356	0	0	1.08
Schiller	DA	4.3	29.69	1366	119	255	280 ml/m^3 DF	15	.99
Schiller	U	4.3	59.38	568	568	495	0	0	.99
Merrimack	HA	4.2	35.63	1603	148	245	58 ml/m^3 DF	12.3	1.03
Merrimack	K	4.2	35.63	1143	380	258	155 ml/m^3 DF	10.5	0.94
Merrimack	L	4.2	35.63	677	677	346	658 ml/m^3 DF	1.5	.88
Merrimack	J	4.2	35.63	0	1178	480	697 ml/m^3 DF	0	.89

SAND = Brox concrete sand
DF = Darafill manufactured by W.R. Grace Inc.

TABLE 3 LABORATORY FLY ASH MIX DATA continued

ASH	MIX	DENSITY	SPREAD	FLOW	PERMEABILITY cm/s x10^{-5}		SET TIME hr		STRENGTH
		kg/m^3	cm	sec	Undrained	Drained	Undrained	Drained	kPa
Schiller	AA	1410	20.3	N/A	4.7	2. 7	8	2	179.3
Schiller	FA	1390	27.9	90	14.0	6. 2	4	1.25	75.8
Schiller	BA	1380	33.0	47	6.0	NA	NA	NA	27.6
Schiller	T	1460	30.5	58	3.0	2. 4	5.7	1.75	248.2
Schiller	CA	2030	NA	NA	7.6	11	2.0	NA	124.1
Schiller	DA	1800	22.9	NA	1.3	6.0	2.0	NA	82.7
Schiller	U	1710	27.9	88	3.0	6.5	4.0	1.3	441.3
Merrimack	HA	1940	21.6	NA	1.4	4.5	2.5	1.0	331
Merrimack	K	1930	25.4	NA	.29	.53	4.5	2.0	1054.9
Merrimack	L	1980	30.5	26	2.1	3.3	15.0	4.8	206.8
Merrimack	J	1833	33.0	28	Mix Did Not Set				

TABLE 4 LABORATORY MIX DATA

AGGREGATE	MIX	CEMENT kg/m^3	SAND kg/m^3	ASH kg/m^3	WATER kg/m^3	ADMIXTURE	AIR %	YIELD m^3
Brox Sand	EA	35.63	1663	0	254	116 ml/m^3 DF	27.4	1.23
Brox Sand	GA	35.63	1663	0	336	542 ml/kg DV	14.6	1.12
Farmington	M	35.63	1170	0	396	116 ml/m^3 DF	13.7	.98
Farmington	N	59.38	1189	0	405	348 ml/m^3 DF	4.7	.91
Raymond	P	35.63	1318	0	270	116 ml/m^3 DF	29.3	1.11
Raymond	R	35.63	1473	0	321	4 ml/kg DV	6.4	.96
Raymond	Q	59.38	1253	0	249	116 ml/m^3 DF	26.5	1.02
Raymond	S	59.38	1473	0	342	10 ml/kg DV	15.0	1.12

NOTE:
Brox Sand = Concrete sand from Brox at Rochester
Farmington = wash waste from Coastal Materials at Farmington
Raymond = crusher waste from Coastal Materials at Raymond
DV = Daravair from W.R. Grace
DF = Darafill from W.R. Grace
1 lb/yd = .5938 kg/m^3 1 oz/yd = 38.7 ml/m^3 1 oz/100 lb = 0.652 ml/kg

TABLE 4 LABORATORY MIX DATA continued

AGGREGATE	MIX	DENSITY	SPREAD	PERMEABILITY cm/s $x10^{-5}$		SET TIME hr		STRENGTH
		kg/m^3	cm	Undrained	Drained	Undrained	Drained	Kpa
Brox Sand	EA	1600	21.6	NA	4.0	2.5	6.5	15.9
Brox Sand	GA	1780	20.3	3.4	1.5	1.8	5	42.7
Farmington	M	1640	21.6	6.7	4.2	10.0	2.0	4.1
Farmington	N	1810	22.9	3.1	1.3	2.5	1.0	174.4
Raymond	P	1460	22.9	8.7	2.0	8.5	2.0	29.6
Raymond	R	1910	20.3	10.0	17.0	3.0	0.8	111
Raymond	Q	1530	21.6	2.3	1.0	6.5	1.8	129.6
Raymond	S	1730	22.9	2.1	1.1	5.0	1.0	114.5

NOTE:

Property	Farmington	Raymond
Absorption	1.5%	0.9%
Specific Gravity		
bssd	2.60	2.61
apparent	2.67	2.64

TABLE 5 FREEZE THAW MIX DATA

AGGREGATE	ASH	MIX	BATCH WEIGHTS					DENSITY		AIR	SLUMP	UCC*
			ASH kg/m3	CEMENT kg/m3	SAND kg/m3	WATER kg/m3	ADMIXTURE	wet kg/m3	dry kg/m3	%	cm	kPa
VIRGINIA	Merrimack	MK250 (HA)	148	35.63	1603	314	116 ml/m^3 DV 58 ml/m^3 DF	2100	1840	NM	14.0	434
VIRGINIA	Schiller	SH200	119	35.63	1360	299	116 ml/m^3 DV 271 ml/m^3 DF	2100	1840	2	NA	475
NONE	Schiller	SH (AA)	704	59.38	NA	671		2100	1840	NM	30.5	2101
NONE	Merrimack	MK	1188	89.07	NA	395		2100	1360	NM	30.5	1013
VIRGINIA	NA	SDV (GA)	NA	35.63	1663	297	174 ml/m^3 DV	2100	1540	12.5	14.0	83
VIRGINIA	NA	SDF (EA)	NA	35.63	1663	254	116 ml/m^3 DF	2100	1490	20	30.5	207

* UCC = unconfined compressive strength in kPa (1psi = 6.89 kPa)

Note: DV = Daravair manufactured by W.R. Grace
DF = Darafill manufactured by W.R. Grace

TABLE 6 ABUTMENT BACKFILL DENSITY DATA

STATION	LIFT THICKNESS	DEPTH	MOISTURE	WET DENSITY	DRY DENSITY	COMPACTION
number	cm	m	%	kg/m^3	kg/m^3	%
1	15	1.19	1.19	2260	2170	101.7
2	20	1.16	1.16	2240	2170	98.5
1	20	0.99	0.99	2200	2170	99.5
2	19	0.97	0.97	2170	2170	97.9
1	20	0.79	0.79	2170	2170	98.2
2	20	0.76	0.76	2160	2170	98.3
1	25	0.53	0.53	2170	2170	98.1
2	25	0.51	0.51	2170	2170	98.4
1	23	0.30	0.30	2230	2170	99.5
2	20	0.30	0.30	2240	2170	100.8
1	25	0.05	0.05	2200	2170	98.7
2	25	0.05	0.05	2170	2170	97.8

NOTE: $\gamma_{d\ opt}$ = 2130 kg/m^3 W_{opt} = 8.0 %

TABLE 7 ABUTMENT ELEVATION SURVEY

11/21/92
Bench = -3.47 feet

8/4/93
Bench = -3.99 feet

ROW	COLUMN	EL. (ft)	Bench - El (ft)	EL. (ft)	Bench - El (ft)	MOVEMENT (in.)
1	1	-3.83	-0.36	-4.40	-0.41	-0.55
1	2	-3.82	-0.35	-4.44	-0.45	-1.15
1	3	-3.83	-0.36	-4.45	-0.46	-1.15
1	4	-3.83	-0.36	-4.46	-0.47	-1.33
1	5	-3.81	-0.34	-4.39	-0.40	-0.67
1	6	-3.81	-0.34	-4.38	-0.39	-0.55
1	7	-3.82	-0.35	-4.37	-0.38	-0.31
1	8	-3.82	-0.35	-4.38	-0.39	-0.43
1	9	-3.85	-0.39	-4.43	-0.44	-0.65
1	10	-3.88	-0.41	-4.47	-0.48	-0.88
1	11	-3.92	-0.45	-4.49	-0.50	-0.63
2	1	-3.74	-0.27	-4.30	-0.31	-0.47
2	2	-3.71	-0.24	-4.29	-0.30	-0.72
2	3	-3.71	-0.24	-4.30	-0.31	-0.84
2	4	-3.73	-0.26	-4.32	-0.33	-0.84
2	5	-3.70	-0.23	-4.26	-0.27	-0.49
2	6	-3.70	-0.23	-4.28	-0.29	-0.73
2	7	-3.70	-0.23	-4.27	-0.28	-0.61
2	8	-3.70	-0.23	-4.26	-0.27	-0.49
2	9	-3.72	-0.25	-4.27	-0.28	-0.36
2	10	-3.72	-0.25	-4.30	-0.31	-0.72
2	11	-3.70	-0.23	-4.33	-0.34	-1.33
3	1	-3.66	-0.19	-4.22	-0.23	-0.51
3	2	-3.63	-0.16	-4.20	-0.21	-0.65
3	3	-3.64	-0.17	-4.21	-0.22	-0.64
3	4	-3.63	-0.16	-4.22	-0.23	-0.88
3	5	-3.63	-0.16	-4.19	-0.20	-0.53
3	6	-3.60	-0.14	-4.19	-0.20	-0.78
3	7	-3.60	-0.14	-4.18	-0.19	-0.65
3	8	-3.60	-0.14	-4.16	-0.17	-0.42
3	9	-3.61	-0.15	-4.17	-0.18	-0.41
3	10	-3.63	-0.16	-4.16	-0.17	-0.16
3	11	-3.67	-0.20	-4.20	-0.21	-0.15
4	1	-3.54	-0.07	-4.10	-0.11	-0.44
4	2	-3.52	-0.05	-4.09	-0.10	-0.57
4	3	-3.53	-0.06	-4.09	-0.10	-0.45
4	4	-3.54	-0.07	-4.12	-0.13	-0.69
4	5	-3.61	-0.15	-4.10	-0.11	0.43
4	6	-3.52	-0.05	-4.07	-0.08	-0.33
4	7	-3.52	-0.05	-4.09	-0.10	-0.57
4	8	-3.52	-0.05	-4.09	-0.10	-0.57
4	9	-3.52	-0.05	-4.07	-0.08	-0.33
4	10	-3.54	-0.07	-4.10	-0.11	-0.44
4	11	-3.58	-0.11	-4.12	-0.13	-0.18
5	1	-3.47	0.00	-4.00	-0.01	-0.12

TABLE 7 ABUTMENT ELEVATION SURVEY continued

5	2	-3.47	0.00	-4.00	-0.01	-0.12
5	3	-3.46	0.01	-4.00	-0.01	-0.24
5	4	-3.46	0.01	-4.00	-0.01	-0.24
5	5	-3.47	0.00	-4.00	-0.01	-0.12
5	6	-3.47	0.00	-3.99	0.00	0.00
5	7	-3.47	0.00	-4.00	-0.01	-0.12
5	8	-3.47	0.00	-4.00	-0.01	-0.12
5	9	-3.47	0.00	-4.00	-0.01	-0.12
5	10	-3.48	-0.01	-3.99	0.00	0.12
5	11	-3.48	-0.01	-4.00	-0.01	0.01
6	1	-3.44	0.03	-3.98	0.01	-0.25
6	2	-3.44	0.03	-3.99	0.00	-0.38
6	3	-3.44	0.03	-3.98	0.01	-0.25
6	4	-3.44	0.03	-3.98	0.01	-0.25
6	5	-3.46	0.01	-3.99	0.00	-0.12
6	6	-3.44	0.03	-3.96	0.03	-0.01
6	7	-3.44	0.03	-3.99	0.00	-0.38
6	8	-3.44	0.03	-3.97	0.02	-0.14
6	9	-3.45	0.02	-3.98	0.01	-0.13
6	10	-3.48	-0.01	-4.01	-0.02	-0.11
6	11	-3.49	-0.02	-4.00	-0.01	0.13
7	1	-3.47	0.00	-4.01	-0.02	-0.24
7	2	-3.46	0.01	-4.00	-0.01	-0.24
7	3	-3.46	0.01	-4.00	-0.01	-0.24
7	4	-3.46	0.01	-4.00	-0.01	-0.24
7	5	-3.48	-0.01	-4.00	-0.01	0.01
7	6	-3.48	-0.01	-4.00	-0.01	0.01
7	7	-3.48	-0.01	-4.01	-0.02	-0.11
7	8	-3.48	-0.01	-3.99	0.00	0.12
7	9	-3.48	-0.01	-4.02	-0.03	-0.23
7	10	-3.48	-0.01	-4.00	-0.01	0.01
7	11	-3.50	-0.03	-4.02	-0.03	0.02
8	1	-3.48	-0.01	-4.02	-0.03	-0.23
8	2	-3.48	-0.01	-4.01	-0.02	-0.11
8	3	-3.48	-0.01	-4.03	-0.04	-0.36
8	4	-3.48	-0.01	-4.02	-0.03	-0.23
8	5	-3.50	-0.03	-4.03	-0.04	-0.11
8	6	-3.50	-0.03	-4.05	-0.06	-0.34
8	7	-3.52	-0.05	-4.07	-0.08	-0.33
8	8	-3.53	-0.06	-4.05	-0.06	0.03
8	9	-3.53	-0.06	-4.06	-0.07	-0.09
8	10	-3.53	-0.06	-4.04	-0.05	0.15
8	11	-3.53	-0.06	-4.06	-0.07	-0.09
9	1	-3.43	0.04	-4.00	-0.01	-0.62
9	2	-3.45	0.02	-4.02	-0.03	-0.61
9	3	-3.44	0.03	-4.02	-0.03	-0.73
9	4	-3.44	0.03	-4.02	-0.03	-0.73
9	5	-3.45	0.02	-4.02	-0.03	-0.61
9	6	-3.46	0.01	-4.04	-0.05	-0.72
9	7	-3.48	-0.01	-4.07	-0.08	-0.84
9	8	-3.50	-0.03	-4.06	-0.07	-0.46
9	9	-3.50	-0.03	-4.05	-0.06	-0.34
9	10	-3.49	-0.02	-4.05	-0.06	-0.47

TABLE 8 FLOWABLE FILL FIELD MIX DESIGN DATA

Mix Component	Abutment Mix NHDOT 1	NHDOT 1 (1)	NHDOT 2 (2)	Trench Mix (Trench) PSNH 1 (3)	PSNH 2 (4)	
Cementious Materials						
Slag Cement	59.4 kg/m^3	59.4 kg/m^3	59.4 kg/m^3		truck 1	truck 2
Portland Cement	11.9 kg/m^3	11.9 kg/m^3	11.9 kg/m^3	89.1 kg/m^3	36.8 kg/m^3	38.6 kg/m^3
Merrimack Fly Ash						
G_s				2.63		
LOI				12.7 %		
pH				9.1		
Schiller Fly Ash					730 kg/m^3	771 kg/m^3
G_s					2.17	2.17
LOI					19.0 %	19.0 %
pH					10.1	10.1
Aggregate (sand)						
Brox	1680 kg/m^3	1680 kg/m^3	1680 kg/m^3			
Water	246 l/m^3	246 l/m^3	197 l/m^3		632 l/m^3	607 l/m^3
Air Entrainment						
Daravair	484 ml/m^3	484 ml/m^3				
Darafill			1 egg			
Slump Spread	flowable	flowable	very flowable	22 cm	46 cm	ND
Mix G_s	ND	ND	ND		1.38	ND
Set Time	ND	ND	ND			
Drained	ND	ND	ND	1.7 hr	1.5 hr	
Undrained	ND	ND	ND	6.0 hr	24 hr	
Permeability	ND	ND	ND			
Drained	ND	ND	ND	1.38 x 10^{-6} cm/sec	8.38 x 10^{-5} cm/sec	ND
Undrained	ND	ND	ND	1.27 x10^{-6}	ND	ND
Strength						
28 days	ND	ND	ND	1786 kPa	ND	ND
6 months				2068 kPa	345 kPa	ND

TABLE 9 TRENCH ELEVATION SURVEY OF FROST HEAVING

DATE	FROST PROBE FROST HEAVING DATA, mm									
	TRENCH 1					TRENCH 3				
	CASE NUMBER									
	1	2	3	4	5	1	2	3	4	5
03-Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22-Feb	3.8	5.1	6.4	0.0	5.1	0.0	0.0	0.0	0.0	0.0
02-Mar	3.8	2.5	5.1	0.0	5.1	0.0	0.0	7.6	0.0	0.0
16-Mar	3.8	3.8	5.1	0.0	3.8	0.0	0.0	7.6	0.0	0.0
21-Mar	3.8	3.8	0.0	0.0	2.5	0.0	0.0	5.1	0.0	0.0
28-Mar	0.0	0.0	0.0	0.0	2.5	0.0	0.0	5.1	0.0	0.0

TABLE 10 PAVEMENT ELEVATION SURVEY OF FROST HEAVING

Frost Heaving, mm

Y	Position X: 0	2.3	4.6	6.9
.0	12.2	6.1	9.1	12.2
1.5	15.2	12.2	15.2	15.2
3.0	15.2	12.2	18.3	15.2
4.6	18.3	15.2	21.3	15.2
6.1	18.3	18.3	18.3	15.2
7.6	18.3	18.3	19.8	21.3
9.1	24.4	24.4	24.4	30.5
10.7	21.3	21.3	25.9 *	30.5
12.2	21.3	18.3	27.4	27.4
13.7	24.4	21.3	27.4	24.4

Permanent Deformation, mm

Y	Position X: 0	2.3	4.6	6.9
.0	9.1	.0	12.2	12.2
1.5	15.2		9.1	12.2
3.0	12.2	9.1	12.2	15.2
4.6	15.2	12.2	21.3	12.2
6.1	18.3	15.2	12.2	15.2
7.6	24.4	15.2	15.2	21.3
9.1	27.4	21.3	21.3	30.5
10.7	24.4	18.3	25.9 *	27.4
12.2	18.3	15.2	27.4	27.4
13.7	15.2	24.4	27.4	27.4

* ESTIMATED

TABLE 11 RECOMMENDED TRIAL MIXES

BATCH WEIGHTS in kg/m^3 (lb/yd^3)

MIX	SAND	ASH	CEMENT CEMENT	CEMENT SLAG	WATER	AIR ml/m^3 (oz/yd^3)	STRENGTH 28day/ult, psi (kPa)
1	1663 (2800)		35.6 (60)		336 (565)	DV 542 (14.0)	69/345 (10/50)
2	1663 (2800)		35.6 (60}		254 (428)	DF 1 egg	69/345 (10/50)
3	1680 (2830)		11.9 (20)	59.4 (100)	246 (414)	DV 484 (12.5)	345/689 (50/100)
4	1680 (2830)		11:9 (20)	59.4 (100)	197 (332)	DF 1 egg	300/600 (44/87)
5		Schiller 718 (1210)	35.6 (60)		671 (1130)	none	172/689 (25/100)
6		Merrimack 1200 (2020)	74.2 (125)		395 (665)	none	345/689 (50/100)

Note: DV = Daravair manufactured by W.R. Grace
DF = Darafill manufactured by W.R. Grace