SCHOOL OF
CIVIL ENGINEERING

INDIANA

DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-96/13

Final Report

REMEDICATION OF HAZARDOUS EFFLUENT
EMITTED FROM BENEATH NEWLY
CONSTRUCTED ROAD SYSTEMS AND
CLOGGING OF UNDERDRAIN SYSTEMS

R. Wukasch
A. Siddiqui

PURDUE UNIVERSITY

FHWA/IN/JHRP-96/13
Final Report

**REMEDIATION OF HAZARDOUS EFFLUENT EMITTED FROM BENEATH NEWLY
CONSTRUCTED ROAD SYSTEMS AND CLOGGING OF UNDERDRAIN SYSTEMS**

by

Ronald F. Wukasch
and
Adil Siddiqui
School of Civil Engineering
Purdue University

Project No. SPR-2116
File No. 4-7-3

Conducted by the
Joint Highway Research Project

In Cooperation with the the
Indiana Department of Transportation
and the
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration and the Indiana Department of Transportation. This report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, Indiana
May, 1996
November, 1996 (Revised)

Digitized by the Internet Archive
in 2011 with funding from
LYRASIS members and Sloan Foundation; Indiana Department of Transportation

1. Report No. FHWA/TN/JHRP-96/13	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Remediation of Hazardous Effluent Emitted from Beneath Newly Constructed Road Systems and Clogging of Underdrain Systems		5. Report Date May, 1996; Revised November, 1996	
		6. Performing Organization Code	
7. Author(s) Ronald F. Wukasch and Adil Siddiqui		8. Performing Organization Report No. FHWA/TN/JHRP-96/13	
9. Performing Organization Name and Address Joint Highway Research Project 1284 Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284		10. Work Unit No.	
		11. Contract or Grant No. SPR-2116	
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.			
16. Abstract The Indiana Department of Transportation uses recycled concrete pavement as aggregate for the construction of highways. The effluent from these pavements has a high pH. The high pH effluent can cause clogging of drains and vegetative kill around the outlet. This project looks into the source of the effluent water, its chemical composition and the approximate duration the problem can be expected to persist. The project also investigates possible methods for reduction of the problem in future installation. The approximate additional cost of these solutions and the problems associated with them are discussed as well.			
17. Key Words remediation, recycled concrete, pavement.		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 82	22. Price

ACKNOWLEDGEMENTS

We would like to thank the Study Advisory Committee which consists of Don Arnold, Youlanda Bewel, Barry Partridge, Tom Vandenpool, David Ward, and Tommy Nantung of the Indiana Department of Transportation, Merritt Hoffmann of the Federal Highway Administration and Rebecca McDaniel of Purdue University.

We also wish to thank the Joint Highway Research Project for funding this project.

TABLE OF CONTENTS

List of Figures	i
List of Tables	ii
Introduction	1
The Problem	2
Objectives	3
The Cause of the Problem	4
A Typical Pavement Structure	4
Composition of the # 53 Recycled Concrete	5
Hypothesis	5
Experimental Results	6
Confirmation of the Hypothesis	14
Expected Duration of the Problem	14
Leachability	14
Test Method	15
Results of Leachability Test	16
Field Investigation	17
In-Situ Permeability Test	17
Remediation of the Site	19
Prevention of the Problem in Future Installations	20
Pretreatment	21
Additives to the Recycled Concrete	22
Sealing the Recycled Concrete Layer	24
Reduction in the Permeability of the # 53 Layer	26
Conclusions	37
Bibilography	39
Appendix A	
Appendix B	
Appendix C	
Appendix D	

LIST OF FIGURES

- Figure 1 : Section detailing the placement of # 53 recycled concrete.
- Figure 2 : Hydroxide Alkalinity variation with pH.
- Figure 3 : The carbonate system.
- Figure 4 : Alkalinity of the recycled concrete
- Figure 5 : Calcium ion Concentration in different grades of concrete
- Figure 6 : EDTA-Na Complex molecular structure.
- Figure 7 : EBT-Mg Complex
- Figure 8 : Leachability of materials
- Figure 9 : Sulfur additives
- Figure 10 : Cross-section of pavement with lean concrete
- Figure 11 : Cross-section of pavement with flexible membrane liner
- Figure 12 : Permeameter
- Figure 13 : Sieve analysis of the # 53 recycled concrete
- Figure 14 : Variation in Permeability with % Fines
- Figure 15 : Variation in Permeability with the void ratio
- Figure 16 : Variation in void ratio with % fines

LIST OF TABLES

Table 1	: Alkalinity calculations
Table 2	: Calcium ion concentration
Table 3	: Leachability calculations
Table 4	: Comparison of available acids
Table 5	: Estimate of cost of pretreatment with acid
Table 6	: Estimate of cost of pretreatment by leaching with water
Table 7	: Change in pH with addition of sulfur powder
Table 8	: Sieve Analysis of the # 53 grade concrete
Table 9	: Permeability test data
Table 10	: Coefficient of permeability

INTRODUCTION

With increased landfill costs, reduction in available land space and stringent permitting regulations the Indiana Department of Transportation (INDOT) looked into ways to reduce waste and reuse waste in construction and repair of roads. The push for reuse of waste material was provided by federal and state legislative acts. In 1991, the United States Congress passed the Intermodal Surface Transportation Act. This Act requires the U.S. Department of Transportation and the Environmental Protection Agency to conduct studies on the reuse of recycled materials in highway construction. The 107th Indiana General Assembly mandated INDOT and Purdue University to examine the reuse of waste materials in construction and repair of highways.

INDOT has experimented with various ways of recycling and reuse to cut disposal and construction cost. One such innovative step INDOT has tried is to recycle concrete pavements as aggregates in new highway systems. However, the effluent from drains underneath these highway systems caused environmental and maintenance problems. It was found that the effluent from underneath these road systems had a high pH that can cause vegetative kill around the drain opening and clogging of the drains.

THE PROBLEM

Effluent from beneath new road construction using # 53 grade recycled concrete has been found to have a high pH. An investigation done by INDOT shows that of the 51 samples taken from drains located on I-70, I-465 and I-65 most had a pH above 11 and only 15 were below pH 9. These results are attached in Appendix A. Due to its high pH the effluent from these drains was causing vegetative kill at the opening. In addition the drains were clogged due to depositions causing the water to back up in the drains.

The problems investigated in this project are;

1. The below pavement drainage from highways constructed using recycled concrete as base aggregate have a pH of about 12, higher than permitted for discharge.
2. The effluent is causing vegetative kill around the outlet. There is deposition on the screens resulting in the clogging of the drains and the water is backing up in the drains.
3. It is possible that similar deposits and scales may be forming in the underdrain filter cloth, # 8 stone causing problems in the free flow of water.

OBJECTIVES

The objectives of this project are;

1. Find out the source and composition of the high pH effluent.
2. Figure out the chemical mechanisms involved in the formation of the water, the scale and the deposits.
3. Determine the ultimate extent of the leachability of the chemicals and the duration the problem can be expected to last.
4. Investigate methods to remedy the existing problem.
5. Investigate methods to prevent the problem in future installations.

THE CAUSE OF THE PROBLEM

A Typical pavement section is shown in Figure 1:

A typical pavement cross-section as shown in Figure 1, has a sub-base of # 53 grade aggregate of about 12" followed by a 4" base layer of # 8 crushed stone. the base if over lain by " of concrete. When it rains the water flows through the # 8 layer of crushed stone and is collected in the side drains. A filter fabric is provided around the drain to prevent erosion of the sub-base.

Figure 1: Section detailing placement of # 53 recycle concrete

Composition of the # 53 recycled concrete:

The primary reactive component in the recycled concrete is Portland cement. Portland cements are made from limestone and other minerals, which are ground up, mixed and burnt in a kiln, and subsequently ground up into a fine powder. This powder hardens when mixed with water.

The main constituents used in the production of cement are lime (CaO), silica (SiO₂), alumina (Al₂O₃) and iron oxide (Fe₂O₃). Lime makes up 60-65% of these materials. The compounds that result from the treatment are;

- 3CaO.SiO ₂	abbreviated C ₃ S
- 2CaO.SiO ₂	abbreviated C ₂ S
- 3CaO.Al ₂ O ₃	abbreviated C ₃ A
- 4CaO.Al ₂ O ₃ .Fe ₂ O ₃	abbreviated C ₄ AF

The relative amounts of these four chemicals in the final product depend on the desired properties such as rate of hardening, the amount of heat given off and the *resistance to chemical attack. The chemical strength gained by the cement is due to its reaction with 3CaO.SiO₂.3H₂O, *calcium silicate hydrate* or *tobermorite*.

Hypothesis:

The recycled concrete aggregate contains Portland cement concrete, the main constituent of which is calcium oxide, CaO. The cement gains strength through the reaction of CaO with H₂O. A typical reaction of water with 3CaO.SiO₂ is;

The unreacted CaO and products from reaction with water like, $3\text{CaO} \cdot \text{SiO}_2 \cdot 3\text{H}_2\text{O}$, are exposed when the concrete is crushed for recycling. The CaO reacts with water and forms $\text{Ca}(\text{OH})_2$;

The $\text{Ca}(\text{OH})_2$ formed is sparingly soluble in water and the saturated solution has a pH of 12.45 at 25°C. The water in the underdrains has sufficient quantities of $\text{Ca}(\text{OH})_2$ to have a pH of 11-12. The earth's atmosphere has 0.003 % CO_2 by volume, which dissolves in water. At equilibrium water has 10^{-5}M aqueous CO_2 . When the water reaches the outlet it comes into contact with atmospheric CO_2 and precipitates out as calcium carbonate, CaCO_3 .

The CaCO_3 (limestone) is not very soluble in water and precipitates out thus forming depositions at the screen. This hypothesis explains the problems associated with the reuse of concrete in pavements.

Experimental Results:

A sample of recycled concrete used in the construction of the highways was collected on the 16th of October from Burns Construction at Raymond & Harding Street, Indianapolis for experimentation. An extract of water from the recycled concrete was taken to determine the characteristics of the effluent water.

Alkalinity is the measure of the capacity of water to neutralize acids. Although many materials may contribute to the alkalinity of water major causes are ;

1. Hydroxides
2. Carbonates
3. Bicarbonates

Therefore, a measure of the alkalinity of water can reveal the concentration of carbonate ions present in it. Alkalinity was measured volumetrically by titration with 1/100 N HCl and is reported in terms of equivalents of CaCO_3 . For samples whose initial pH is above 8.3 (like the effluent from the recycled concrete), the titration is made in two steps. In the first step the titration is conducted until the pH is lowered to 8.2, the point at which the phenolphthaleine indicator turns from pink to colorless. The second phase of the titration is complete when the pH is lowered to pH 4.5 corresponding to the methyl orange end point.

The value of pH 8.3 also corresponds to the equivalence point for the conversion of carbonate ion to bicarbonate ion;

The pH of about 4.5 (the end point for the second part of the titration) corresponds to the equivalence point for the conversion of bicarbonate ion to carbonic acid;

The hydroxide alkalinity has a dependence on the temperature. Figure 2 gives the variation in the Hydroxide alkalinity with pH and temperature.

Figure 2: Hydroxide Alkalinity variation with pH

The carbonate alkalinity is due to the presence of carbonate and bicarbonates. The three forms of alkalinity and carbon dioxide are a part of one system in equilibrium. The concentration of each species is dependent on the other. The

following figure illustrates the carbonates system. The values differ with total alkalinity and temperature.

Figure 3 : The carbonate system

The results from these titration are given in Table 1 and Figure 4.

Table 1: Alkalinity Calculations

Sample Number	Contact Time (Hrs)	HCl Added (ml)		Alkalinity (mg/L as CaCO_3)		
		Phenolphthaleine	Methylorange	Carbonate	Hydroxide	Total
1	72	65	77	650	120	770
2	2.5	53	67	530	140	670
3	2.0	52	68	520	160	680
4	1.5	57	66	570	90	660
5	1.0	55	68	550	130	680
6	0.25	59	80	590	210	800

Figure 4: Alkalinity of the recycled concrete

The concentration of calcium oxide in different grades of the recycled concrete was determined. The results are given in Figure 5. The results show that unreacted calcium oxide is found in significant quantities in all grades of the concrete.

Figure 5: Calcium ion Concentration in different grades of concrete

The calcium ion concentration can be measured by the titration with ethylenediamine-tetra acetic acid (EDTA). EDTA is a chelating agent and forms an extremely stable complex ions with Ca^{2+} , Mg^{2+} and other divalent compounds.

The Ca^{2+} -EDTA complex (Figure 6 shows the EDTA-Na complex molecular structure) is more stable than the Mg^{2+} -EDTA complex by two orders. To estimate the Calcium ion concentration a Eriochrome Black T (EBT) indicator is used, the EBT forms a complex with Mg^{2+} ions and has a wine red color. When the EDTA reacts fully with the Ca^{2+} ions present the Mg^{2+} -EBT complex (Figure 7) is broken in favor of the Mg^{2+} -EDTA complex. The free EBT has a blue coloration indicating the exhaustion of the Ca^{2+} ions present.

Figure 6: EDTA-Na Complex molecular structure

Figure 7: EBT-Mg Complex

The results of the EDTA titration to determine the Ca^{2+} ion concentration are given in Table 2.

Table 2: Calcium Ion Concentration

Sample Number	EDTA used (ml)	$[\text{Ca}^{2+}]$ (molar)	$[\text{Ca}^{2+}]$ (as CaCO_3)
1	200	0.01	500
2	189	0.0095	473
3	191	0.0096	478
4	211	0.0106	530

Confirmation of the Hypothesis:

The experimental results confirm the initial hypothesis. The results from the titration for carbonate alkalinity and calcium ion concentration show that CaCO_3 is present in significant quantities.

Average calcium ion conc	= 495 mg/L as CaCO_3
	= 9.9 meq/L
Average carbonate ion conc	= 568 mg/L as CaCO_3
	= 11.36 meq/L

The presence of such high concentrations of calcium and carbonate ions confirms the presence of CaCO_3 in the effluent water. The high hydroxide alkalinity (Figure 2) of the effluent water suggests the presence of $\text{Ca}(\text{OH})_2$.

EXPECTED DURATION OF THE PROBLEM

Leachability:

The leachability of a chemical from a material is the amount of ease with which the chemical can be extracted. Leachability of a chemical is an indicator of the duration the problem can be expected to persist in the field. However, the leachability is not a measure of the chemical expected to be emitted, because the test is done by fully stirring the material in water for a short time. Depending on the path of water flow across the recycled concrete layer some of it will get more exposed than the other.

Test Method:

To 100 grams of the recycled concrete 1 liter of water was added and stirred for 5 minutes. The water was then filtered and titrated against 0.01 N HCl. The residual material was further stirred with 1 liter of water and extracted. Sixteen such extractions were made and the alkalinity of each extract was determined.

Table 3: Leachability Calculations

All alkalinity in mg/L as CaCO_3

Water Added (L)	Vol _{water} : Vol _{aggregate}	Carbonate Alkalinity	Hydroxide Alkalinity	Total Alkalinity %	
1	5.71	415	170	585	0.585
2	11.43	422	150	570	1.155
3	17.14	491	165	555	1.710
4	22.86	422	120	542	2.252
5	28.57	421	102	523	2.775
6	34.28	416	89	505	3.280
7	40.00	399	83	480	3.760
8	45.71	342	69	412	4.172
9	51.43	317	69	386	4.558
10	57.14	300	66	366	4.924
11	62.86	276	66	342	5.266
12	68.57	238	62	300	5.566
13	74.29	224	57	281	5.847
14	80.00	222	54	270	6.117
15	85.71	196	47	243	6.360
16	91.43	178	42	220	6.580

Results of leachability test:

The results from leachability test on the # 53 recycled concrete are given in Table 3 and Figure 8. The data can be extrapolated to show that there is significant extractable alkalinity even after about 200 bed volumes of water.

Figure 8: Leachability of the Material

FIELD INVESTIGATION

A section of I-70 (East, just past Minnesota St., Indianapolis) was cut and the state of the underdrains was investigated. Investigations reveal that the calcium carbonate depositions are clogging the underdrains and water is backing up in them. A section of the drain was cut out and it showed deposits of calcium carbonate at the bottom of the drain pipes. There was visible vegetative kill around the outlet of the drain pipes. Further, the filter fabric around the drain had calcium carbonate depositions.

Boroscope study of the excavated drain was also done. The video did not reveal severe clogging beyond the mouth of the pipe. This is consistent with the theory that the depositions occur only where the effluent comes into contact with atmospheric air.

In-situ permeability test:

An in-situ field permeability test was done on site to determine the permeability of the base and sub-base. The test was done according to the specifications of INDOT, given in Appendix B.

The tests were done by Mr. Frank Tom John, of the Indiana Department of Transportation, Green Field District Materials and Test. The results were submitted in his report on, "Sample of Coarse Aggregate Crushed Stone Productivity Quality." A copy of his report is attached in Appendix C.

Standpipe Falling Head Permeability Test

k = Mean coefficient of permeability (inches/minute)

h = Drop of water level within standpipe at the end of 10 minute test period

H_2 = $H_1 - h$ (inches)

Location : I-70 (Near Airport Expressway, 701+00)						
Test Site Number : 1						
Date : 8-16-1995						
Length of standpipe (H_1) : 48"						
Inside diameter of standpipe : 4.73"						
Shoulder Thickness : 14.5"						
Trial Number	Sub-base Depth of standpipe installation = 9.5" below bottom of concrete			Shoulder base Depth of standpipe installation = 6" below bottom of concrete		
	Δt (min)	h	H_2	Δt (min)	h	H_2
1	10	6.50	41.50	10	*	
2	10	6.25	41.75	10	*	
3	10	6.00	42.00	10	*	

* water drains through the shoulder base within a few seconds. Very high permeability.

Mean coefficient of permeability for the shoulder base;

$$k = 0.0393 D \ln\left(\frac{H_1}{H_2}\right)$$

Mean coefficient of permeability for the sub base;

$$k = 0.0286 D \ln\left(\frac{H_1}{H_2}\right)$$

The INDOT procedure states that a calculated mean coefficient of permeability (k) greater than or equal to 0.036 inches/minute is considered to exhibit an adequate drainage condition and may be given "pass" designation. A calculated mean coefficient of permeability (k) less than 0.024 inches/minute may be given "fail" designation. A calculated mean coefficient of permeability between 0.036 inches/minute and 0.024 inches/minute must be evaluated before a "pass" or "fail" judgement is made. Consideration may be given to consistency of the readings and the quality of the standpipe installation.

From the in-situ test performed the permeability of the sub-base was found to be 0.0188 inches/minute and the permeability of the base was found to be greater than 0.036 inches/minute. Hence, both the base and the sub-base may be designated as "fail" for permeability.

REMEDIATION OF THE PROBLEM

Neutralizing the high pH water using acid has been studied. Low concentrated acetic acid would be best suited. The use of stronger acids like HCl and H_2SO_4 is not recommended due to the problems with the workers safety and the possibility of the pH going too low.

The frequency of flushing required will depend on the amount of rainfall in a given area and the permeability of the recycled concrete layer. It is estimated that 1.5 gallons of acetic acid would be sufficient to flush out a section of the drain. The clogged drain sections need to be isolated. The acid introduced at one end collected

at the other outlet. The clogged screens can be replaced periodically and recycled after treatment with acetic acid. A comparison of the effectiveness of the different acids and the issues related to their use is given in Table 4.

Table 4: Comparison of available acids

Acid	pH	Cost/lb	Issues
Hydrochloric	0	\$ 0.034	Low pH, worker safety !
Phosphoric	1	\$ 0.29	Low pH, worker safety, high deposition
Sulfuric	0	\$ 0.0375	Low pH, gypsum formation and deposition
Acetic	4	\$ 0.33	BOD
Citric	3	\$ 0.82	BOD
Oxalic	2	\$ 0.40	BOD, poison, vegetative kill

PREVENTION OF THE PROBLEM IN FUTURE INSTALLATIONS

Several methods for the prevention of this problem in future installations were considered. Most of the methods are not economically feasible since the cost of not recycling concrete at present is only just slightly higher than the cost of recycling. Increase in landfill disposal costs may make some more methods of prevention feasible. The methods studied are;

1. Pretreatment of # 53 grade recycled concrete.
2. Additives in the concrete.
3. Sealing of the recycled layer
4. Gradation of the recycled concrete layer to reduce its permeability.

Pretreatment:

The recycled concrete can be pretreated before it is used as aggregate. The pretreatment can be done by adding acid to neutralize the $\text{Ca}(\text{OH})_2$ in the recycled concrete or it can be done by treatment of the water after leaching with the recycled concrete. From experiments done to determine the alkalinity of the recycled concrete it is estimated that around 40 ml of 0.1 N HCl is required to neutralize 1 gram of the material to pH 8. The recycled concrete requires 4 meq of acid/gram.

The pretreatment to neutralize the concrete is costly because of the acid required, the mechanism for mixing of the concrete, and the determination of the exact amount of acid required. An approximate calculation of the total cost of each method of pretreatment is shown in Table 5

Table 5: Estimate of cost of pretreatment with acid

Material	Unit cost	Quantity	Cost(\$)/ton of concrete
HCl used	0.034 \$/lb	300 lb/ton	10 \$
Water used	1 \$/1000gal	1000gal/ton	1 \$
Wastewater Treatment	1 \$/1000gal	1000gal/ton	1 \$
Equipment & labor	10 \$/ton		10 \$
Total cost			22 \$

This method is also time consuming and requires investment in developing a facility for treatment.

The leaching out of $\text{Ca}(\text{OH})_2$ by treating with excess water is not economical because of the high leachability of the concrete. The treatment of the waste water

would require a small treatment plant and that would mean significant investment of capital into the process. An estimate of cost for treatment by leaching is given in Table 6.

Table 6: Estimate of cost of pretreatment by leaching with water

	Unit cost	Quantity	Cost(\$)/ton of concrete
Water used	1 \$/1000gal	20000gal/ton	20 \$
Wastewater Treatment	1 \$/1000gal	20000gal/ton	20 \$
Total cost			40 \$

Hence, the methods of treatment of the recycled concrete are not economically feasible. The methods considered require investments to treat the concrete and the waste water from the process. Given the low cost effectiveness of recycling the concrete none of these methods seem feasible.

Additives to the recycled concrete:

Sulfur reacts with water and oxygen to produce sulfuric acid. Addition of sulfur in small quantities in the recycled concrete might produce sufficient acid to neutralize the lime present in it. The addition of sulfur powder during the crushing of concrete or at the time of construction can be easily incorporated into the process. The cost of sulfur is relatively low. To determine the amount of sulfur required, the sulfur powder was added in increments of 10 grams and the pH of the extract water was determined for four bed volumes. The results from these experiments are given in Table 7 and Figure 9. It is estimated that to reduce the pH to below 8, approximately 50 grams of

sulfur is required per pound of the concrete (11% by weight). The relative density of the recycled concrete was found to be 2.32, thus it would require 430 pounds of sulfur to neutralize one per cubic yard of the recycled concrete. At a cost of 18 \$/ton of sulfur this method would cost a additional cost of \$ 4 per cubic yard of the recycled concrete used.

Table 7: Change in pH with addition of sulfur powder

Sulfur Added (grams)	pH of the water extracted			
	1st bed volume	2nd bed volume	3rd bed volume	4th bed volume
10	9.98	9.84	9.90	10.10
20	9.09	9.21	9.34	9.48
30	8.84	8.94	9.10	9.26
40	7.41	7.74	8.21	8.94
50	7.04	7.13	7.75	8.23
60	6.67	6.82	6.98	7.58
70	6.21	6.52	6.75	7.06
80	6.10	6.24	6.31	6.56
90	5.83	5.91	6.11	6.24
100	5.42	5.55	5.83	6.13

In this study the effect of sulfur additives on the structural properties of the aggregates or the pavement has not been investigated. Also there is a possibility of a low pH effluent in the first flush because the sulfur is not bound and is easily dissolved.

Once the sulfur is flushed out the pH might go up due to the lime form the concrete. Instead of adding sulfur powder a cheaper alternative may be adding materials rich in sulfur such as high sulfur coal. However, any such material added may have its own environmental problems.

Figure 9: Sulfur Additives

Sealing the recycled concrete layer:

The recycled concrete possibly could be sealed from water so that the lime present cannot leach out. The sealing can be done by;

1. Lean concrete
2. Sealers

Some water proofing can be achieved by adding a layer of lean concrete and fly ash between the # 8 and # 53 layers, Figure 10. The application of the layer is simple to incorporate in the over all design of the pavement. However, the concrete may develop cracks when the road bends due to loads. The layer would allow the water to flow through. The method also means an added cost to the construction of the road.

Figure 10: Cross-section of pavement with lean concrete

The recycled aggregate layer may also be sealed with a layer of shot (sp.gr = 2.5), which is an emulsion of oil and other adhesives. After the #53 concrete aggregate is laid a layer of oil emulsion must be applied and immediately followed by a flexible membrane liner, Figure 11. It is estimated that 2.5 to 3.5 gallons/sq.yard of oil emulsion would be required. The water proofing fabric could cost 0.40 - 0.50 \$/ft² and a additional 1 \$/sq. yard for installation.

Figure 11: Cross-section of pavement with waterproofing fabric

Reduction in the permeability of the # 53 layer:

In-situ permeability tests done on the 16th of August 1995 at a site on I-70 (Appendix C) indicate that the # 53 layer is more permeable than the # 8 layer. This causes the water to drain through the recycled concrete layer instead of the # 8 layer. The design is such that the water drains mainly through the # 8 layer. The high permeability of the recycled concrete layer may be due to the poor Gradation of the recycled concrete.

Tests were performed to determine the change in permeability of the # 53 layer of concrete with the addition of fines.

TEST:

ASTM Designation; D 2434-68 (Appendix D)

"This test method covers the determination of coefficient of permeability by a constant head method for laminar flow of water through granular soils. The procedure is to establish representative values of the coefficient of permeability of granular soils that may occur in deposits as placed in embankments, or when used as a base course under pavements. In order to limit consolidation influences during testing, the procedure is limited to disturbed granular soils containing no more than 10% soil passing the 75- μm (# 200) sieve".

The coefficient of permeability is a constant of proportionality relating to the ease with which a fluid passes through the porous medium. The permeability constant is known to be function of the soil void ratio, e . Darcy's law gives the relationship between the hydraulic gradient and the velocity of the water flow as,

$$v = ki$$

The relationship in terms of flow rate may be written as,

$$q = kiA$$

where, q = quantity of fluid flow in a unit time

k = coefficient of permeability

i = hydraulic gradient

A = cross-sectional area of soil mass

METHODS & MATERIALS

Permeameter:

A permeameter calibrates the permeability of soil samples, it consists of,

1. A porous disk or suitable reinforced screen at the bottom with a permeability greater than that of the soil specimen, but with opening sufficiently small to prevent movement of particles.
2. Manometer outlets for measuring the head loss, h , over the length, l . Equivalent to atleast the diameter of the cylinder.
3. A porous disk or a suitable reinforcement screen to apply a pressure of 5 to 10 lbf, to maintain a constant volume of sample during the test.
4. A constant head filter, to supply water and remove most of the air from tap water, fitted with suitable control valves.

Figure 12: Permeameter

Sample:

The sample must be air dried granular soil, containing less than 10% of the material passing through the 75- μm (# 200) sieve. Further, a sieve analysis must be done on the soil sample before the test and any particle larger than 19 mm must be separated out by sieving. The oversize material is not used but its percentage in the sample must be recorded.

A sieve analysis of the # 53 recycled concrete was done and the results are given in Table 8 and Figure 13. Most of the # 53 recycled concrete had particle sizes between 3/4th inch and 3/8th inch sieve sizes. The number of fines, 75- μ m (# 200) sieve is negligible. For the purposes of the experiment the % of fines were varied by adding particles passing 75- μ m (# 200) sieve. The percentage of such particles was varied from 5 to 12. The maximum number of fines allowable under the test conditions is 10%, however a wider range of up to 12% was considered.

Table 8: Sieve Analysis of the # 53 grade concrete

Sieve Size/Number	Percentage of sample passing the sieve		
	In sample	In-situ*	Recommended**
2-1/2 inches	100	100	100
2 inches	100	100	100
1-1/2 inches	100	100	100
1 inches	96.3	98.4	80-100
3/4 inches	85.4	88.5	70-90
1/2 inches	52.8	56.4	55-80
3/8 inches	44.2	39.9	----
Sieve # 4	10.1	12.6	35-60
Sieve # 8	5.9	7.4	25-50
Sieve # 30	----	----	12-30
Sieve # 200	----	----	5-10
Removal by decantation	0.5	2.4	----

* From report by Mr. Frank Tom John, Appendix C.

** From the INDOT Specification

Test procedure:

The procedure involves mixing the recycled concrete with the fines to achieve the required percentage of fines. The mixture is then placed into the metal cylinder through a constant head filter tank and the time taken for the 600 ml of water to flow through the sample is noted. Two more runs are taken for more accurate value. the average time required for 600 ml of water to flow through is used to calculate the permeability constant.

Figure 13: Sieve Analysis of the # 53 recycled concrete.

Location:

The test was conducted in the soil testing laboratory at the School of Civil Engineering, Purdue University.

Results from test:

Diameter of the permeameter = 8" (20.32 cm)

Height of the permeameter = 12" (30.48 cm)

Cross-sectional area = 15.96 cm²

Table 9: Permeability test data

% Fines	Void Ratio	Length L (cm)	Manometer(cm) In Out		Head h,(cm)	h/L	Q (cm ³)	Mean Time
0	0.65	25.3	67.3	1.5	68.8	2.72	600	306.67
5	0.55	24.3	63.6	1.2	65.1	2.68	600	1323.33
6	0.51	26.7	81.4	1.9	83.3	3.12	600	2256.67
7	0.45	25.5	71.4	1.8	73.2	2.87	600	3363.33
8	0.39	24.4	69.8	1.4	71.2	2.92	600	4326.67
9	0.38	24.8	74.5	2.1	76.6	3.09	600	5493.33
10	0.35	25.8	74.3	1.8	76.1	2.95	600	6226.67
11	0.32	26.0	72.1	1.5	73.6	2.83	600	7643.33
12	0.28	26.2	74.0	1.5	75.5	2.88	600	8646.67

Table 10: Coefficient of permeability

% Fines	Void ratio, e	Coeff. of Permeability (cm/s)	k * 10⁵ (cm/s)
0	0.65	0.000555	55.5
5	0.55	0.000130	13.05
6	0.51	0.0000657	6.57
7	0.45	0.0000479	4.79
8	0.39	0.0000366	3.66
9	0.38	0.0000273	2.72
10	0.35	0.0000252	2.52
11	0.32	0.0000214	2.14
12	0.28	0.0000186	1.86

Figure 14: Variation in Permeability with % Fines

Figure 15: Variation in Permeability with Void ratio, e

Figure 16: Variation in Void ratio with % fines

The variation in the permeability of the soil sample as a function of the percentage of fines added to the sample is exponential. From Figure 14 clearly the permeability becomes almost flat at around 7 to 8% fines. The addition of 7 % fines results in the reduction of the permeability from $55 \times 10^{-5} \text{ cm/s}$ to $4.8 \times 10^{-5} \text{ cm/s}$. This, however is still relatively permeable and would not prevent water from flowing through the recycled concrete.

CONCLUSIONS

Pavements with recycled concrete used as aggregate have a high pH from underdrains. The high pH effluent can cause vegetative kill around the drain opening and causes clogging of the drain screens.

Experiments show that the recycled concrete contains unreacted calcium oxide. When water passes through the recycled concrete layer it reacts with the calcium oxide present to form calcium hydroxide. The calcium hydroxide is highly soluble in water and has a pH of above 12 at equilibrium.

When the calcium hydroxide laden water is exposed to atmospheric carbon dioxide it reacts to form calcium carbonate. The calcium carbonate produced is sparingly soluble in water and forms precipitates. The precipitate depositions at the screens clog the drains and cause the water to backup.

Leachability studies done with the material indicate that there would be significant alkalinity present even after 200 bed volumes of water, at an average rainfall in Indiana that would take more than 60 years. In the pavement the leachability may last for a shorter duration depending on the amount of aggregate exposed to water. However, it is likely to be a long term problem rather than a short one.

The possible solutions to this problem in future installations are not promising. These solutions are based on the preventing water to flow through the recycled concrete layer or to neutralize it before installation. Neutralization of the concrete before it is used as aggregate requires treatment with acid or leaching out of the alkalinity by washing. Both these methods involve development of treatment facilities.

Additives which reacts with water to form acids such as sulfur can be used to neutralize the lime in the water as water passes through the recycled concrete. This method however is risky because the sulfur may be flushed out in the first rain storm causing low pH and subsequently the pH may be high due to the leaching of lime.

The other methods of prevention of the problem are based on waterproofing of the recycled layer. Some water proofing can be attained by placing a water-proofing fabric or by decreasing the permeability of the aggregate layer to prevent water flow through it. Lower permeability can be achieved by better gradation of the aggregate, but the reduction in permeability is not sufficient to prevent water from entering this layer.

The solutions to this problem require some added cost. Unfortunately, waste materials currently do not compete favorably with virgin materials. The cost of recycling concrete barely covers the cost of crushing, transporting and working with it. Any additional cost associated with the recycling of concrete would make it less favorable.

The current practice could be continued if an understanding is reached with the regulatory agencies that the problem is minor and no public health is endangered. This would require a formal letter of variance from the concern agency. In case such an understanding is not possible the recycling of the concrete may be stopped till the cost of not recycling it raises and there is justification for additional cost of reusing it.

BIBLIOGRAPHY

1. "Concrete and its Chemical Behaviour", Eglinton M. S., Telford, London 1987.
2. "The Chemistry of Cement and Concrete", Lea F. M., London 1970.
3. "The Manual of soil laboratory testing", Head K. H., Pentech Press, London 1992.
4. "Permeability of Concrete", Publication # 108; American Concrete Institute, Detroit, 1988.
5. "Determination of the in-situ permeability of base and subbase courses", Moulton L. K., Federal Highway Administration: Washington 1979.
6. ASTM Standards on bituminous materials for highway construction, waterproofing and roofing., Philadelphia, ASTM 1962.
7. "Recycling of structural materials", Speare R. S., *Structural Engineer* v 73 n 13 July 4 1995, pg 220-222.
8. "Using waste concrete as aggregate", Topcu I. B & Guncan N. F., *Cement and Concrete Research* v 25 n 7 Oct 1995, pg 1385-1390.
9. "Recycling portland cement concrete pavement at the contractors option", Reusser R. R., Proceedings of the 23rd Air Transport Conference 1994, Published by ASCE.
10. "Recycling Concrete Pavements", Mark J. W., Solberg C. E. & Voigt G. F., *Aberdeen's Concrete Construction* v 38 n 7 July 1993, pg 470-473.
11. "Concrete Recycled", De Vries, Peter, *Concrete* v 27 n 3 May-June 1993, pg 9-13.

APPENDIX A

The following is sampling data collected locations on I-70, I-465 and I-65.

These samples were collected between February to August of 1994.

Sampling was done on 6 occasions and a total of 133 samples were collected and there pH was determined.

Sampling date	Total # of samples	pH 12-10	pH 10-8	pH below 8
2-22-94	24	11	9	4
5-26-94	14	12	1	1
6-1-94	6	4	2	0
6-13-94	30	14	11	5
6-27-94	26	17	8	1
8-12-94	31	17	9	5
Total	131	75	40	16
% of total		57.25	30.53	12.22

As the table shows more than 57% of the samples have a pH of above 10 and the maximum recorded pH was 13.0.

Site #1 I-70 Eastbound, Hancock County
Just West of Mt. Comfort Rd.

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
1-1	2-22-94	I-70-(430+00)-EB from rectangular culvert.	Cloudy, overcast, 34°F temp.	94-1607	11.75
1-2	5-26-94	I-70-(430+00)-EB. Sample from culvert. Flow: 1 to 2 GPM, est screen clogged, clear water.	Clear-Cool. Rain on May 24 evenings. Culverts and ground mostly dry.	94-5371	12.20
1-3	6-13-94	I-70-(430+00)-EB. Sample from culvert. Culvert mostly plugged. Flow: 5-10 GPM, est. Water: Clear.	Intermittent showers on June 12. Approx. 1 inch rain. On June 13, hot (90°F), high humidity. Flow thru culverts was significant.	94-5913	11.61
1-4	6-27-94	I-70-(430+00)-EB. Sample from culvert. Water clear, running well @ 5+GPM. Culvert limey and half-blocked	The sampling was conducted after two days of rain totalling 2-3 inches locally. Temperatures were seasonably cool, sky hazy to clear. Ground damp/saturated with water.	94-6555	12.70
1-5	8-12-94	I-70-(430+00)-EB. Sample from culvert. Screen blocked. Water clear and running @ 4-5 GPM.	High humidity; clear sky, temp. 70-80s. Approx. 1 inch rain on 11th.	94-8619	11.31

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
2-1	2-22-94	I-70-(430+00)-EB. Sample taken from puddle 10' below culvert.	Same as No. 1-1	94-1608	9.35
2-2	5-26-94	I-70-(430+20)-EB. Sample taken from ditch.	Same as No. 1-2	94-5372	12.20
2-3	6-13-94	I-70-(430+20)-EB. Sample taken from ditch. Water: clean. No precipitates.	Same as No. 1-3	94-5914	11.59
2-4	6-27-94	I-70-(430+20)-EB. Sample taken from ditch. Some ppts. at the bottom of ditch.	Same as No. 1-4	94-6556	12.60
2-5	8-12-94	I-70-(430+20)-EB. Sample taken from ditch. Some limey precipitates.	Same as No. 1-5	94-8620	11.56

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
3-1	2-22-94	I-70-(430+60)-EB. Sample from ditch.	Same as No. 1-1	94-1609	9.89
3-2	5-26-94	I-70-(430+60)-EB. Round culvert emptying directly into ditch. Mostly clear, but stagnant water in the ditch. Some discoloration seen in water.	Same as no. 1-2	94-5373	11.50
3-3	6-13-94	I-70-(432+50)-EB. Sampled from ditch-immediately in front of culvert. Water: clean. No precipitates.	Same as No. 1-3	94-5915	8.88
3-4	6-27-94	I-70-(432+20)-EB> Sampled from same ditch as 94-6556. Large puddle of water in front of another culvert. Culvert is partially immersed in water, water appears clean.	Same as No. 1-4	94-6557	9.80
3-5	8-12-94	I-70-(432+50)-EB. Sample from standing water in ditch immediately in front of a culvert. Culvert is partially submerged. Water about 5" deep and is clear.	Same as No. 1-5	94-8621	9.11

Site #2 I-70 Westbound, Hancock Co.
Just West of Sugar Creek

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
4-1	2-22-94	I-70-(638+90)-WB. Sampled from culvert lip.	Same as No. 1-1	94-1610	10.38
4-2	5-26-94	I-70-(638+90)-WB. Sampled from culvert. Water: clear. Slimy precipitates on culvert. Screen almost clogged with ppt. deposits.	Same as No. 1-2	94-5365	11.60
4-3	6-13-94	I-70-(638+90)-WB. Sampled from culvert. Culvert still mostly blocked. Flow estimated @ 2-5 GPM. Water is washing out some precipitates.	Same as No. 1-3	94-5918	10.96
4-4	5-26-94	I-70-(638+90)-WB. Samples of water and sludge dammed inside culvert.	Same as No. 1-2	94-5367 (water) 94-5368 (sludge)	11.50 11.60
4-5	6-27-94	I-70-(638+90)-WB. Sample taken from culvert. Flow approx. 5 GPM. Culvert mostly blocked. Flow is clear.	Same as No. 1-4	94-6558	11.80
4-6	8-12-94	I-70-(638+90)-WB. Sample taken from culvert. Screen is blocked. Bottom of culvert limey. Flow @ 1/2 GPM.	Same as No. 1-5	94-8622	11.60

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
5-1	2-22-94	I-70-(630+20)-WB. Sampled from concrete portion of ditch. Screen on pipe completely clogged with precipitants. Precipitant from ground to ditch line.	Same as No. 1-1	94-1611	7.83
5-2	6-13-94	I-70-(630+20)-WB. Sampled from flowing water out of concrete-lined ditch.	Same as No. 1-3	94-5919	7.60
5-3	5-26-94	I-70-(639+50)-WB. Sampled from concrete portion of the ditch. Slow flow approx. 2GPM.	Same as No. 1-2	94-5366	7.40
5-4	6-27-94	I-70-(623+20)-WB. Sampled from concrete portion of ditch.	Same as No. 1-4	94-6559	8.20
5-5	8-12-94	I-70-(639+20)-WB. Sampled from concrete apron at the end of ditch. Water clear, flow approx. 1 GPM.	Same as No. 1-5	94-8623	7.82

Site #3 I-70 Westbound
Just West of Westbound Ramp from
Mt. Comfort Rd.

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
6-1	2-22-94	I-70-(428+90)-WB. Sampled from culvert. Outlet blocked by precipitant.	Same as No. 1-1	94-1612	11.65
6-2	5-26-94	I-70-(428+90)-WB. Sampled from puddle at the lip of culvert. No flow. Heavy lime ppts. on surface. Visible discoloration extends 5-10 ft downhill from culvert.	Same as No. 1-2	94-5369	11.9
6-3	6-13-94	I-70-(428+90)-WB. Sample from culvert. Water: clean. Culvert: barely flowing. Heavily limed.	Same as No. 1-3	94-5916	10.94
6-4	6-27-94	I-70-(428+90)-WB. Sampled from culvert. Culvert almost blocked. Water clear, flow approx. 1-2 GPM.	Same as No. 1-4	94-6560	12.70
6-5	8-12-94	I-70-(428+90)-WB. Sampled from culvert. Screen blocked. Algae starting to cover discoloration.	Same as No. 1-5	94-8624	7.72

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
7-1	2-22-94	I-70-(428+90)-WB. Small puddle 10ft. below culvert.	Same as No. 1-1	94-1613	11.31
7-2	5-26-94	I-70-(428+90)-WB. Sampled from ditch 10-15 ft. below culvert.	Same as No. 1-2	94-5370	8.3
7-3	6-13-94	I-70-(428+90)-WB. Sampled from standing water in ditch directly below culvert.	Same as No. 1-3	94-5917	9.13
7-4	2-22-94	I-70-(429+30)-WB. Sampled from ditch - approx. 40 ft. east of culvert outlet in the ditch.	Same as No. 1-1	94-1614	7.87
7-5	6-27-94	I-70-(429+30)-WB. Sampled from ditch, looks clean.	Same as No. 1-4	94-6561	8.00
7-6	8-12-94	I-70-(429+30)-WB. Sampled from ditch. Very little amount of water present. No limey ppt. in sight.	Same as No. 1-5	94-8626	7.52
7-7	8-12-94	I-70-(428+90)-WB. Sampled from ditch. No ppt in sight. No significant water present.	Same as No. 1-5	94-8625	7.48

Site #4 I-465-WB @ US-31 NB
Marion Co. (just East of
Northbound Ramp to US 31)

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
8-1	2-22-94	I-465-(467+10)-WB. Sampled from center culvert (there are 3 culverts at this location). Culvert barely running. Screen partly blocked.	Same as No. 1-1	94-1615	11.61
8-2	5-26-94	I-465-(467+10)-WB. Sampled from culvert. Water barely running. Screen mostly plugged. Heavy stain of ppts. for about 6 ft. from culvert.	Same as No. 1-2	94-5374	11.60
8-3	6-13-94	I-465-(467+10)-WB. SE culvert. Flow: approx. 1 GPM. Ditch was dry.	Same as No. 1-3	94-5921	8.07
8-4	6-13-94	I-465-(467+10)-WB. NW culvert. No running flow. Approx. 1/4 GPM.	Same as No. 1-3	94-5920	9.56
3-5	6-27-94	I-465-(467+10)-WB. NW culvert. Culvert running approx. 1 GPM.	Same as No. 1-4	94-6567	11.30
8-6	6-27-94	I-465-(467+10)-WB. Sampled out of SE culvert. Culvert running approx. 1 GPM.	Same as No. 1-4	94-6568	8.90
8-7	8-12-94	I-465-(467+10)-WB. (SE) East culvert. Screen blocked. Little discoloration. Flow @ 1/2 GPM.	Same as No. 1-5	94-8627	8.13

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
9-1	2-22-94	I-465-(467+00)-WB. Sampled from ditch (running water) about 20 ft. west of 3 culverts at (467+10) location.	Same as No. 1-1	94-1616	8.15
9-2	2-22-94	I-465-(466+00)-WB. Sampled from running water in ditch. Stains extend approx. 125 ft. discoloration ends after about 350 ft length.	Same as No. 1-1	94-1617	8.04

Site #5 I-465-EB, just west of
Madison Ave. Overpass

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
10-1	6-13-94	I-465-(450+50)-EB. (Three culverts here at this location. Central culvert is about 3ft. lower than side culverts). Sampled from east culvert running approx. 2-5 GPM. Water is clear, but lime stains on cement visible.	Same as No. 1-3	94-5925	11.73
10-2	6-13-94	Same as above. Sampled at central culvert. Culvert running about 5 GPM. Water clear but limey ppts on concrete.	Same as No. 1-3	94-5926	12.15
10-3	2-22-94	Same as above. Sampled in puddle.	Same as No. 1-1	94-1618	11.94
10-4	6-1-94	Same as above. Sampled in puddle. Culvert mostly blocked. Heavy ppts. No running flow.	Mostly Clear; ground mostly dry and very hot and humid.	94-5401	12.70
10-5	6-1-94	I-465-(450+50)-EB. Sample taken 3 ft. directly below upper east culvert.	Same as No. 10-4	94-5400	12.30
10-6	6-13-94	I-465-(450+50)-EB. Puddle about 12 ft. below culverts at bank of Lick Creek.	Same as No. 1-3	94-5927	12.05
10-7	6-13-94	I-465-(449+50)-EB. Sample taken from lower culvert. Upper culvert was clean and dry; lower culvert had screen and was seeping.	Same as No. 1-3	94-5928	7.89
10-8	2-22-94	I-465-(449+10)-EB. Sampled from puddle about 25 ft. below culvert.	Same as No. 1-1	94-1619	7.48
10-9	6-27-94	Three culverts at I-465-(450+50)-EB. Central culvert is about three feet lower than side culverts. Sampled from east culvert. Flow @ 2 GPM Culvert blocked.	Same as No. 1-4	94-6569	12.60

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
10-10	6-27-94	I-465-(450+50)-EB. Sampled from center culvert. Flow @ 5 GPM. Culvert partly blocked.	Same as No. 1-4	94-6570	12.90
10-11	6-27-94	I-465-(449+50)-EB. Two additional culverts. Eastern culvert dry. Sampled from western culvert. Water Clean.	Same as No. 1-4	94-6571	8.80
10-12	8-12-94	I-465-(450+50)-EB. Sampled from East culvert. Screen is blocked. Limey ppts. in area, water flow @ 1/2 GPM.	Same as No. 1-5	94-8631	11.73
10-13	8-12-94	I-465-(450+50)-EB. Sampled from Central culvert.	Same as No. 1-5	94-8632	12.34
10-14	8-12-94	I-465-(450+50)-EB. Puddle @ 12' below culverts, at bank of creek.	Same as No. 1-5	94-8633	11.85

Site #6 I-465-EB, just West of Carson Ave
Overpass. Marion Co.

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
11-1	2-22-94	I-465-(464+97)-EB. Sampled from culvert. Culvert not running and approx. 1 1/2" of lime clogging screen	Same as No. 1-1	94-1620	11.19
11-2	6-13-94	I-465-(464+97)-EB. Sampled out of culvert. Culvert flowing approx. 2 GPM.	Same as No. 1-3	94-5922	12.02
11-3	2-22-94	I-465-(464+99)-EB. Sampled from standing water about 15" below culvert.	Same as No. 1-1	94-1621	10.39
11-4	6-13-94	I-465-(464+99)-EB. Round culvert emptying below standing water. Little flow. Sampled at the mouth of culvert.	Same as No. 1-3	94-5923	8.59
11-5	2-22-94	I-465-(465+30)-EB. Sampled from standing water in ditch. Water looks clean.	Same as No. 1-1	94-1622	8.10
11-6	6-1-94	I-465-(465+03)-EB. Sampled from standing water in ditch.	Same as No. 10-4	94-5402	8.10
11-7	6-13-94	Same location. Small puddle in the ditch.	Same as No. 1-3	94-5924	11.48
11-8	6-27-94	I-465-(464+97)-EB. West (box) culvert sampled from culvert. Culvert running @ 5GPM. Water clear, culvert limey.	Same as No. 1-4	94-6572	13.00
11-9	6-27-94	I-465-(464+99)-EB. East (round) culvert. Barely running-dripping. White ppts. at bottom below the culvert. Sample taken from puddle at front of culvert.	Same as No. 1-4	94-6573	12.00
11-10	6-27-94	I-465-(465+60)-EB. Sampled from running water in ditch. Water looks clean.	Same as No. 1-4	94-6574	12.40
11-11	8-12-94	I-465-(464+97)-EB. Sampled from rectangular (WB) culvert.	Same as No. 1-5	94-8628	8.46
11-12	8-12-94	I-465-(464+99)-EB. Sampled from standing water 15" below culvert.	Same as No. 1-5	94-8629	8.13
11-13	8-12-94	I-465-(465+60)-EB. From Ditch.	Same as No. 1-5	94-8630	8.28

Site #7 I-65 Northbound on exit ramp to
Keystone Ave. near 107 mile marker

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
12-1	6-13-94	I-65-(152+75)-NB. North culvert Sample taken from culvert. Clear screen, Culvert seeping.	Same as No. 1-3	94-5929	7.22
12-2	6-13-94	I-65-(152+71)-NB. Sample taken from culvert. Southern of the two culverts. Culvert seeping. Small quantity of lime.	Same as No. 1-3	94-5930	7.27
12-3	6-13-94	I-65-(152+80)-NB. Sample taken from puddle in the ditch.	Same as No. 1-3	94-5931	6.89
12-4	2-22-94	I-65-(148+75)-NB. Three culverts emptying below the water line. Southleg of I-465, just south of 107 mile marker.	Same as No. 1-1	94-1623	11.56
12-5	6-13-94	I-65-(148+75)-NB. Northernmost of three culverts. Sampled at the lip of culvert.	Same as No. 1-3	94-5932	11.92
12-6	2-22-94	I-65-(148+70)-NB. Sampled from ditch at lip of culvert.	Same as No. 1-1	94-1624-	8.07
12-7	6-1-94	I-65-(148+70)-NB. Sampled from ditch.	Same as No. 10-4	94-5403	12.20
12-8	6-13-94	I-65-(148+70)-NB. Center of three culverts. Sampled out of ditch at lip of culvert.	Same as No. 1-3	94-5933	11.75
12-9	6-1-94	Sample taken from ditch. There are three additional culverts at approx. I-65-(148+25)NB. These culverts are blocked with mud.	Same as No. 10-4	94-5404	12.05
12-10	6-13-94	I-65-(148+65)-NB. Southernmost of three culverts. Sampled out of ditch at lip of culvert.	Same as No. 1-3	94-5934	11.83
12-11	6-13-94	I-65-(148+00)-NB. Sampled from ditch.	Same as No. 1-3	94-5935	10.47
12-12	6-1-94	I-65-(147+25)-NB. Sampled from ditch. Three additional culverts at approx. I-65-(148+25)NB. These culverts are blocked with mud.	Same as No. 10-4	94-5405	8.00

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
12-13	2-22-94	I-65-(147+00)-NB. East of 5th culvert standing water is continuous from west of (148+75) Water is just clearing of limey scum.	Same as No. 1-1	94-1625	9.59
12-14	6-13-94	I-65-(147+00)-NB. Sampled from ditch.	Same as No. 1-3	94-5936	8.62
12-15	6-27-94	I-65-(148+75)-NB. Sampled out of ditch water, just at mouth of northern culvert.	Same as No. 1-4	94-6562	12.70
12-16	6-27-94	I-65-(148+70)-NB. Sampled out of ditch water, just at mouth of central culvert.	Same as No. 1-4	94-6563	12.70
12-17	6-27-94	I-65-(148+65)-NB. Sampled out of ditch water, just at mouth of southern culvert.	Same as No. 1-4	94-6564	12.80
12-18	6-27-94	I-65-(148+00)-NB. Sampled from ditch.	Same as No. 1-4	94-6565	11.20
12-19	6-27-94	I-65-(147+00)-NB. Sampled from ditch.	Same as No. 1-4	94-6566	9.70
12-20	8-12-94	I-65-(148+75)-NB. North culvert. Sampled from ditch at tip of culvert.	Same as No. 1-5	94-8634	11.92
12-21	8-12-94	I-65-(148+70)-NB. Center culvert. Sampled from ditch at lip of culvert.	Same as No. 1-5	94-8635	11.11
12-22	8-12-94	I-65-(148+65)-NB. South culvert. Sampled from ditch at the lip of culvert.	Same as No. 1-5	94-8636	11.86
12-23	8-12-94	I-65-(148+00)-NB. Sampled from ditch.	Same as No. 1-5	94-8637	8.16
12-24	8-12-94	I-65-(147+25)-NB. Sampled from ditch.	Same as No. 1-5	94-8638	8.01
12-25	8-12-94	I-65-(147+00)-NB. Sampled from ditch.	Same as No. 1-5	94-8639	7.91

Site #8 Eastbound I-70, Marion Co.
Between I-465 & Airport Expressway
 (Across from Goodyear)

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
13-1	2-22-94	I-70-(612+50)-EB. Sampled out of 15" metal culvert. Water lightly running; relatively clean.	Same as No. 1-1	94-1627	11.82
13-2	5-26-94	I-70-(612+50)-EB. Standing water below culvert. Some precipitation. Discoloration starts at culvert.	Same as No. 1-2	94-5376	12.20
13-3	6-13-94	I-70-(612+50)-EB. Western culvert. Running about 2-5 GPM. Clean water.	Same as No. 1-3	94-5937	12.62
13-4	2-22-94	I-70-(612+70)-EB. Standing water in ditch. Water has limey precipitants.	Same as No. 1-1	94-1628	10.51
13-5	6-13-94	I-70-(613+10)-EB. Sampled from ditch. Slow running. Loose, limey material at bottom of water.	Same as No. 1-3	94-5938	12.63
13-6	6-13-94	I-70-(613+70)-EB. Sampled from same ditch. Severe decoloration at this point.	Same as No. 1-3	94-5939	12.58
13-7	5-26-94	I-70-(612+50)-EB. Sample was taken 5 ft. below culvert. Significant precipitants.	Same as No. 1-2	94-5377	12.20
13-8	2-22-94	I-70-(616+50)-EB. Sampled from 15" culvert. Lightly running water. Precipitants visible in running water from culvert.	Same as No. 1-1	94-1629	11.78
13-9	5-26-94	I-70-(614+50)-EB. No running water. Discoloration extends about 100 yards to rip-rap above creek.	Same as No. 1-2	94-5378	12.20
13-10	6-13-94	I-70-(616+50)-EB. Metal 15" culvert. Running 2-5 GPM. Water: Clean.	Same as No. 1-3	94-5940	12.57

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
13-11	6-13-94	I-70-(617+40)-EB. Sampled from same ditch about 70 ft. west of small stream. Water: clear. Lots of loose precipitates on bottom.	Same as No. 1-3	94-5941	12.30
13-12	2-22-94	I-70-(617+60)-EB. Sampled out of ditch near exit to small stream. Precipitates extend from (612+50) to ditch exit into stream.	Same as No. 1-1	94-1630	8.24
13-13	6-27-94	I-70-(612+50)-EB. Sampled from culvert. Flow 2-3 GPM.	Same as No. 1-4	94-6575	13.20
13-14	6-27-94	I-70-(617+60)-EB. Sampled from small pond at eastern extremity of ditch.	Same as No. 1-4	94-6576	12.60
13-15	6-27-94	I-70-(611+50)-EB. Sampled from ditch.	Same as No. 1-4	94-6577	8.50
13-16	8-12-94	I-70-(612+50)-EB. Sampled from culvert.	Same as No. 1-5	94-8640	12.21
13-17	8-12-94	I-70-(613+10)-EB. Sampled from ditch.	Same as No. 1-5	94-8641	11.62
13-18	8-12-94	I-70-(613+70)-EB. Sampled from ditch.	Same as No. 1-5	94-8642	11.13
13-19	8-12-94	I-70-(616+50)-EB. also (616+45) Sampled from culvert.	Same as No. 1-5	94-8643	12.38
13-20	8-12-94	I-70-(617+60)-EB. Sampled from ditch.	Same as No. 1-5	94-8644	11.70

Site #9 Eastbound I-70, Between
Minnesota and Holt Rd. Across from
Lester Sales. Marion Co.

<u>Sample No.</u>	<u>Date</u>	<u>Location Description</u>	<u>Weather Condition</u>	<u>Lab I.D. #</u>	<u>pH</u>
14-1	2-22-94	I-70-(711+50)-EB. Two culverts Western culvert dry. Sample from eastern culvert. Very little volume of water running some lime ppts.	Same as No. 1-1	94-1626	11.81
14-2	5-26-94	I-70-(711+50)-EB. Sampled from rectangular culvert. Culvert almost plugged. Some precipitates.	Same as No. 1-2	94-5379	12.20
14-3	6-13-94	I-70-(711+50)-EB. Culvert high on bank. Running about one GPM. Sampled from culvert.	Same as No. 1-3	94-5942	12.02
14-4	6-13-94	About I-70-(712+50)-EB. Sampled from culvert just above ditch.	Same as No. 1-3	94-5943	12.06
14-5	6-13-94	I-70-(715)-EB	Same as No. 1-3	94-5944	10.94
14-6	6-27-94	I-70-(711+50)-EB. Sampled from culvert high on the bank. Marked culvert. Water running @ 1/4 gal/min.	Same as No. 1-4	94-6578	13.00
14-7	6-27-94	I-70-715(approx.) Sampled from large puddle at eastern end of the ditch.	Same as No. 1-4	94-6579	9.40
14-8	6-27-94	I-70-(709+50)-EB. Sampled from ditch.	Same as No. 1-4	94-6580	9.10
14-9	6-27-94	Comparison sample of saturated CaCO ₃ from above location.	Same as No. 1-4	94-6581	10.40
14-10	8-12-94	I-70-(711+50)-EB. Sampled from culvert high on the bank.	Same as No. 1-5	94-8645	10.51
14-11	8-12-94	I-70-(709+50)-EB. Sampled from ditch.	Same as No. 1-5	94-8646	10.64
14-12	8-12-94	@I-70-(712+50)-EB. Sampled from culvert just above ditch.	Same as No. 1-5	94-8647	8.40
14-13	8-12-94	@I-70-(715)-EB. Sampled at Eastern limit of ditch.	Same as No. 1-5	94-8648	9.63
14-14	8-12-94	I-70-(714+50). Box culvert near top of embankment.	Same as No. 1-5	94-8649	12.60

APPENDIX B

INDOT Specifications: Field Tests for Evaluating Pavement Underdrains.

The specifications include,

1. Equipment and Materials
2. Test Frequency and General Location
3. Test site preparation
4. Test Procedures
5. Interpretation of test results
6. Exploratory excavation of existing underdrains

APPENDIX B

FIELD TEST FOR EVALUATING PAVEMENT UNDERDRAINS

The work shall be the preparation of locations for a field test which evaluates the mean coefficient of permability of the shoulder base and pavement subbase material near the critical location of the longitudinal pavement-shoulder joint.

EQUIPMENT AND MATERIAL. The following is a basic list of equipment and testing apparatus required in order to set up the field test and shall be provided by the Contractor:

- 1) A coring rig and bit for drilling a 5 inch diameter hole through a bituminous shoulder.
- 2) A steel standpipe which is cut to a length of 4 feet. It is important to note that the inner diameter and the length of the standpipe will greatly influence the interpretation of the test results. Specific dimensions of the standpipe are shown in a detail drawing at the end of this special provision.
- 3) A supply of dry bentonite of fine granulation which is to be used to provide a seal around the standpipe and joint cracks.
- 4) A minimum of 55 gallons of clear water in appropriate containers such as to promote ease of handling during testing.
- 5) A 6 foot long folding ruler having divisions indicating tenths or eighths of an inch.
- 6) A clock or watch indicating minutes and seconds.
- 7). A large sponge or suction tube to empty water from test hole.
- 8) A long chisel (14 inches long) and hammer to be used to deepen and clean out test hole for standpipe installation.
- 9) A small metal scoop or large spoon to be used to remove material from hole.
- 10) Clean rags for drying sides of cored hole and sides of standpipe prior to installation.
- 11) A flashlight for use in inspecting inside of standpipe prior to conducting test.
- 12) Siphoning equipment or other approved method of gradually filling standpipe with water without disturbing seal.
- 13) Patching material to repair cored holes.
- 14) 12" - 14" long 5" diameter steel tube to act as casing while the test hole is deepened to the subbase material.

TEST FREQUENCY AND GENERAL LOCATION. A minimum of one field test shall be conducted for every 2 miles of roadway which is to be evaluated for existing or proposed underdrain performance. Additional field tests or altering the spacing of test locations should be done in order to investigate known or suspected problem areas. Such problem areas may be located at the low point in a vertical curve or at a superelevated pavement where only one side of the pavement section has an underdrain installed and the slope of subgrade is the same as the pavement. Another such potential problem area may be present where a fine sand or silt like material may be present near a pavement joint, possibly indicating a pumping condition.

When evaluating interstate or divided highway, the test sites shall be for each directional set of traffic lanes or as directed by the Engineer.

TEST SITE PREPARATION. Once the general location of the test site has been selected, 2 holes should be drilled through the shoulder using a 5 inch diameter core bit. The center location of each hole shall be 6 inches from the longitudinal pavement shoulder joint and the cored holes shall be spaced approximately 7 feet apart. Clean water shall be used during the coring operations. Cutting oil shall not be added to the water.

Prior to the coring operations, the joint and cracks within the shoulder shall be inspected to assure adequate sealing within the vicinity of the core. If the joint or cracks appear inadequately sealed, then a joint sealer shall be used within 5 feet of each test hole.

The first test hole shall be drilled through the shoulder and cleaned out by hand to a depth of 1 to 2 inches into the shoulder base material. The second hole shall be drilled through the shoulder and deepened by hand tool digging to a depth of 1 to 2 inches into the subbase material. A 12"-14" length of 5" diameter steel tubing shall be used as casting to keep the hole open while deepening the test holes to the required depth. This is especially important when preparing the test hole within the deeper subbase material.

A standpipe shall be placed in each of the prepared holes and partially seated into the shoulder base and subbase material by driving the standpipe down into the material using a wooden block as padding and a small sledge hammer. The dry granulated bentonite shall be worked down into the gap between the bituminous shoulder and outer surface of the standpipe. This is accomplished by tapping and rotating the standpipe within the hole as the dry bentonite is slowly placed in the gap. It is important that each of the prepared holes, as well as the standpipes, be as dry as possible to allow the granulated bentonite to work its way into the gaps between the hole and the standpipe in order to provide an adequate seal. The inside of each standpipe shall be inspected to confirm that no bentonite has worked its way into the standpipe. The installation of the standpipe in the subbase material is the critical and difficult to perform properly, because the bentonite will have to penetrate deeper to fill the void between the outside of the standpipe and the sides of the test hole. An improper seal will result in data which may be inconsistent or not representative of the material encountered.

A plastic squeeze bottle shall be used to squirt water in the gap to allow the upper portion of the bentonite to swell and seal the standpipe. The addition of water into the standpipe at the start of the test will seep to the lower bentonite and complete the seal.

A sketch of a typical standpipe installation in the shoulder base and subbase material is presented at the end of this special provision.

The test hole which is deepened into the subbase material shall be used by the Contractor to obtain a sample of the shoulder base and subbase material. Each sample shall be approximately 2.5 Kg in weight and placed in appropriate containers and properly labeled. The sample of shoulder base material shall be obtained as the test hole is deepened prior to the standpipe installation. The sample of subbase material is obtained after completion of the permeability test. The hole shall be cleared of water and the casing reinserted prior to obtaining the sample. It is imperative that extreme care be used in obtaining a sample of the subbase so as not to contaminate it with the bentonite sealer. The Engineer will receive the samples and will deliver to the district test laboratory for a gradation determination.

TEST PROCEDURE. The test procedure shall be performed by the Engineer.

1. To initiate the test, each of the two standpipes are filled to the top with water. When initially filling the standpipes, it is important that the water not be dumped into the standpipe. Such action could scour out the material at the base of the standpipe and damage the seal along the outside edge. The water will be added slowly, at least until the standpipe is half full. Use of a siphon, extending from a water reservoir to the standpipe base, is the recommended way to initially fill the standpipe.

At the end of 10 minutes the drop in water level is measured from the top of each standpipe and recorded to the nearest 1/10 or 1/8 inch. Observations are to be made of the longitudinal pavement joint as well as the bentonite seal to assure that no seepage develops. If water is observed to be seeping up through the joint or seal, it will be noted and shall be repaired by the Contractor, as this will affect the interpretation of the test results. If a leak develops in the standpipe, it shall be reinstalled.

The standpipe installed in the shoulder base material will be filled first and wait several minutes before starting the test for the second standpipe installed in the deeper subbase material. This will enable the Engineer to easily record the test data as the test progresses at each standpipe installation.

2. Each standpipe is refilled to its top after the first measurement is obtained. The water level is again allowed to drop for 10 minutes at which time the water level is measured from the top of standpipe and recorded. These operations are repeated in order to obtain at least a total of 3 readings for each of the standpipe installations in the shoulder base and subbase material. If a consistent reading cannot be determined, then additional readings will be obtained until consistency is

apparent. An approximate guideline to use in determining consistency of readings is, if the last reading is within 1/2 inch of the previous one, provided that there have not been any drastic changes between the first and last reading obtained.

3. After recording the test readings for each standpipe, the standpipe shall be drained and removed by the Contractor. Any pertinent observations or comments regarding the standpipe installations or test results obtained will be recorded by the Engineer in order to provide any necessary information for use in interpreting the test data.
4. A form for recording the test data is presented at the end of this special provision.

INTERPRETATION OF TEST RESULTS. The interpretation of the test results will be performed by the Engineer. The following formulas will be used to calculate the mean coefficient of permeability of the shoulder base and subbase material at each test site.

FORMULAS

VARIABLES: k = MEAN COEFFICIENT OF PERMEABILITY (INCHES/MINUTE)
 D = INSIDE DIAMETER OF STANDPIPE (INCHES)
 H_1 = LENGTH OF STANDPIPE (INCHES)
 h = DROP OF WATER LEVEL WITHIN STANDPIPE
 AT END OF 10 MINUTE TEST PERIOD (INCHES)

H_2 = $H_1 - h$ (INCHES)
 $\ln$ = NATURAL LOG

DETERMINATION OF MEAN COEFFICIENT
OF PERMEABILITY FOR SHOULDER BASE MATERIAL

$$K = 0.0393 D \times \ln \frac{(H_1)}{(H_2)} \quad (\text{INCHES/MINUTE})$$

DETERMINATION OF MEAN COEFFICIENT
OF PERMEABILITY FOR SUBBASE MATERIAL

$$K = 0.0286 D \times \ln \frac{(H_1)}{(H_2)} \quad (\text{INCHES/MINUTE})$$

A calculated mean coefficient of permeability (k) greater than or equal to 0.036 inches/minute is considered to exhibit an adequate drainage condition and may be given a "pass" designation. A calculated mean coefficient of permeability (k) less than 0.024 inches/minute will be given a "fail" designation.

A calculated mean coefficient of permeability between 0.036 inches/minute and 0.024 inches/minute ($0.036 > k > 0.024$) will be evaluated before a "pass" or

"fail" judgment is made. Consideration will be given to the consistency of the water level readings and the quality of the standpipe installation. Observations will also be made as to the degree of distress exhibited in the shoulder and pavement. A standpipe (where $H_1 = 48"$, $D = 4.78"$) installed in the shoulder base material would have to exhibit a drop in water level of 5.8 to 8.4 inches to define the mean coefficient of permeability (k) between 0.024 and 0.036 inches/minute, respectively. For a similar standpipe installed in the subbase material, a drop in water level of 7.7 to 11.1 inches would define the same marginal limits of permeability stated previously.

Below is a list of conditions which describe the possible results of a field test and the following conclusions and/or recommended action.

Condition 1 - The shoulder base and subbase mean coefficient of permeability both pass, thus exhibiting an adequate drainage condition.

This condition will not require additional tests.

Condition 2 - The shoulder base mean coefficient of permeability fails, thus indicating a poor drainage condition within the shoulder base adjacent to the joint. Yet the subbase permeability passes, thus indicating an adequate drainage condition in the subbase.

Additional investigation of the shoulder base is warranted in order to explain the reason of failure. A retest of the shoulder base may need to be made as determined by the Engineer.

Condition 3 - The shoulder base mean coefficient of permeability passes, thus indicating an adequate drainage condition. However, the subbase permeability fails, indicating a poor drainage condition in the subbase.

Additional investigation of the shoulder subbase is warranted in order to explain the reason of failure. A retest of the shoulder subbase may need to be made as determined by the Engineer.

Condition 4 - The shoulder base and subbase mean coefficients of permeability both fail, indicating poor drainage conditions within the shoulder base material adjacent to the longitudinal joint and within the subbase material.

Sections of roadway which encountered Test Site Condition Nos. 3 and/or 4 shall require the installation of new underdrains, as specified elsewhere herein. If Condition No. 1 and/or 2 exist between such sections of the roadway under consideration, the Engineer will decide as to whether the new underdrain installation remains continuous or segmented. Isolated occurrences of Conditions Nos. 3 or 4 will require field examination by the Engineer of the conditions concerning the profile grade or distress conditions indicative of drainage problems in order to obtain information to establish the recommended limits of new underdrain installation.

If Condition No. 2 is consistently encountered, then installation of the new underdrains shall be made. However, if it is sporadically encountered

along with Conditions No. 1, then the Engineer will not require new underdrain installation.

If Condition No. 1 is consistently encountered along a portion of the roadway under evaluation, then installation of underdrains will not be required by the Engineer.

It should be noted that the gradation test results of the shoulder base and subbase material can assist the Engineer in determining actual limits of new underdrain installation.

EXPLORATORY EXCAVATION OF EXISTING UNDERDRAINS. If weather conditions permit, it would be advisable for the Engineer to inspect the outlets of the existing pavement underdrains during a heavy rain storm to locate non functioning drains. If such a malfunctioning drain is located, then exploratory excavation of the existing underdrain may be required. This work shall consist of excavating a hole (located above the existing underdrain trench) to the top of the underdrain pipe, at the locations specified by the Engineer, and flushing a sufficient amount of water (approx. 25 gallons) into trench to determine if the underdrain is functioning. After the test has been performed, the excavation shall then be backfilled with aggregate suitable for underdrains.

BASIS OF PAYMENT. Work completed and accepted under this item will be paid for at the contract unit price bid per each for **FIELD TEST FOR EVALUATING PAVEMENT UNDERDRAINS**, which price shall be full compensation for excavation and backfill, for furnishing all materials, and for all labor, tools, equipment and incidentals necessary to complete the work. The item of **FIELD TEST FOR EVALUATING PAVEMENT UNDERDRAINS** as shown on the Itemized Proposal is an estimated quantity and the actual quantity shall be determined after all field tests for underdrains have been completed.

The work performed for exploratory excavation of existing underdrains will not be paid for directly, but shall be included in the cost for **FIELD TEST FOR EVALUATING PAVEMENT UNDERDRAINS** and shall be full compensation for excavation, backfill material, all labor, tools, equipment and incidentals necessary to complete the work.

STANDPIPE FALLING HEAD PERMEABILITY TEST

DATE : _____
TEST SITE No. : _____
LOCATION : _____

LENGTH OF STANDPIPE (H_1) = _____
DIAMETER OF STANDPIPE (D) = _____

SHOULDER THICKNESS: DEPTH OF STANDPIPE INSTALLATION	10 MINUTE INTERVAL	(h) DROP IN WATER LEVEL FROM TOP OF STANDPIPE	$H_1 - h$
	1 ST		
	2 ND		
	3 RD		
	4 TH		
	5 TH		
	6 TH		
STABILIZED VALUE			

COMMENTS

DEPTH OF STANDPIPE INSTALLATION	10 MINUTE INTERVAL	(h) DROP IN WATER LEVEL FROM TOP OF STANDPIPE	$H_1 - h$
	1 ST		
	2 ND		
	3 RD		
	4 TH		
	5 TH		
	6 TH		
STABILIZED VALUE			

DIMENSIONS OF STEEL STANDPIPE

TYPICAL INSTALLATION OF STANDPIPE

APPENDIX C

The following is a report on the field test conducted to determine the permeability of the # 8 and # 53 aggregate material on 1-70 Eastbound (near the Airport Expressway). The test was done the 16th of August 1995. The test was conducted by Mr. Frank Tom John of the Green District Materials and Test Laboratory, INDOT. The test includes the sieve analysis of the sample obtained from the site and aggregate materials collected from the construction company of Mr. Martin Marietta. The company is located at 2801 Kentucky Avenue, Indianapolis, Indiana.

INDIANA DEPARTMENT OF TRANSPORTATION 3GREEN 00
DISTRICT MATERIALS AND TESTS

08-18-95

REPORT ON SAMPLE OF
COARSE AGGREGATE
CRUSHED STONE PRODUCTION QUALITY

CONTRACT NO.	R - 20511	MATERIAL CODE	2856
LABORATORY NO.	95-3-0719-20576	DATE SAMPLED	08-16-95
SUBMITTED BY	JOHN, FRANK TOM		
PURPOSE	INFORMATION		
SAMPLED FROM	IN PLACE		
SAMPLED AT	JOB SITE	(9998)	
QUANTITY REPRESENTED	2994		
SAMPLE MARKING	26531		
SOURCE OF MATERIAL	MARTIN MARIETTA	(2314)	
	2801 KENTUCKY AVENUE INDIANAPOLIS, IN.		46200
REMARKS	LEDGES 2-4		

*** TEST RESULTS ***

TOTAL WEIGHT OF SAMPLE, GRAMS
 AMOUNT PASSING 2 1/2-INCH SIEVE, PCT.---
 AMOUNT PASSING 2-INCH SIEVE, PCT.-----
 AMOUNT PASSING 1 1/2-INCH SIEVE, PCT.--- 100.0
 AMOUNT PASSING 1-INCH SIEVE, PCT.----- 98.4
 AMOUNT PASSING 3/4-INCH SIEVE, PCT.----- 88.5
 AMOUNT PASSING 1/2-INCH SIEVE, PCT.----- 56.4
 AMOUNT PASSING 3/8-INCH SIEVE, PCT.----- 39.9
 AMOUNT PASSING NO.4 SIEVE, PCT.----- 12.6
 AMOUNT PASSING NO.8 SIEVE, PCT.----- 7.4
 AMOUNT PASSING NO.30 SIEVE, PCT.-----
 AMOUNT PASSING NO.200 SIEVE, PCT.-----
 REMOVAL BY DECANTATION, PCT.----- 2.4
 CLAY LUMPS & FRIABLE PARTICLES, PCT.-----
 SOFT AND NON-DURABLE PARTICLES, PCT.-----
 CHERT, LESS THAN 2.45 SP. GR., PCT.-----
 CHERT, TOTAL PCT.-----
 APPARENT SPECIFIC GRAVITY-----
 BULK SPECIFIC GRAVITY-----
 WATER ABSORPTION, PCT.-----
 L.A. WEAR LOSS, PCT.-----
 S.S. SOUNDNESS LOSS, PCT.-----
 F & T SOUNDNESS LOSS, PCT.-----
 NACL BRINE F & T SOUNDNESS LOSS, PCT.-----
 BITUMEN RETENTION INDEX-----
 AVERAGE F & T BEAM EXPANSION PCT.-----
 AVERAGE F & T BEAM CONTRACTION, PCT.-----
 AGGREGATE SIZE TESTED

REMARKS:

INFORMATION ONLY.
 PERMEABILITY TEST - I-70EB NEAR AIRPORT EXPRESSWAY
 STA. 701+00 SHOULDER 15-17"

INDIANA DEPARTMENT OF TRANSPORTATION 3GREEN 00
DISTRICT MATERIALS AND TESTS

08-18-95

REPORT ON SAMPLE OF
COARSE AGGREGATE
CRUSHED STONE PRODUCTION QUALITY

CONTRACT NO.	R - 20511	MATERIAL CODE	2856
LABORATORY NO.	95-3-0719-20578	DATE SAMPLED	08-16-95
SUBMITTED BY	JOHN, FRANK TOM		
PURPOSE	INFORMATION		
SAMPLED FROM	IN PLACE		
SAMPLED AT	JOB SITE	(9998)	
QUANTITY REPRESENTED	2355		
SAMPLE MARKING	26541		
SOURCE OF MATERIAL	MARTIN MARIETTA	(2314)	
	2801 KENTUCKY AVENUE INDIANAPOLIS, IN.		48200
REMARKS	LEDGES 2-4		

*** TEST RESULTS ***

TOTAL WEIGHT OF SAMPLE, GRAMS

AMOUNT PASSING 2 1/2-INCH SIEVE, PCT.---	
AMOUNT PASSING 2-INCH SIEVE, PCT.-----	
AMOUNT PASSING 1 1/2-INCH SIEVE, PCT.---	100.0
AMOUNT PASSING 1-INCH SIEVE, PCT.-----	98.6
AMOUNT PASSING 3/4-INCH SIEVE, PCT.-----	91.3
AMOUNT PASSING 1/2-INCH SIEVE, PCT.-----	61.9
AMOUNT PASSING 3/8-INCH SIEVE, PCT.-----	44.2
AMOUNT PASSING NO.4 SIEVE, PCT.-----	22.9
AMOUNT PASSING NO.8 SIEVE, PCT.-----	15.6
AMOUNT PASSING NO.30 SIEVE, PCT.-----	9.9
AMOUNT PASSING NO.200 SIEVE, PCT.-----	6.0
REMOVAL BY DECANTATION, PCT.-----	5.7
CLAY LUMPS & FRIABLE PARTICLES, PCT.---	
SOFT AND NON-DURABLE PARTICLES, PCT.---	
CHERT, LESS THAN 2.45 SP. GR., PCT.-----	
CHERT, TOTAL PCT.-----	
APPARENT SPECIFIC GRAVITY-----	
BULK SPECIFIC GRAVITY-----	
WATER ABSORPTION, PCT.-----	
L.A. WEAR LOSS, PCT.-----	
S.S. SOUNDNESS LOSS, PCT.-----	
F & T SOUNDNESS LOSS, PCT.-----	
NaCl BRINE F & T SOUNDNESS LOSS, PCT.---	
BITUMEN RETENTION INDEX-----	
AVERAGE F & T BEAM EXPANSION PCT.-----	
AVERAGE F & T BEAM CONTRACTION, PCT.---	
AGGREGATE SIZE TESTED	

REMARKS:

INFORMATION ONLY.

PERMEABILITY TEST - I-70 EB NEAR AIRPORT EXPRESSWAY
STA. 701+00 SHOULDER 18-21"

INDIANA DEPARTMENT OF TRANSPORTATION 3GREEN 00
DISTRICT MATERIALS AND TESTS

08-18-95

REPORT ON SAMPLE OF
COARSE AGGREGATE
CRUSHED STONE PRODUCTION QUALITY

CONTRACT NO.	R - 20511	MATERIAL CODE	2856
LABORATORY NO.	95-3-0719-20577	DATE SAMPLED	08-16-95
SUBMITTED BY	JOHN, FRANK TOM		
PURPOSE	INFORMATION		
SAMPLED FROM	IN PLACE		
SAMPLED AT	JOB SITE	(9998)	
QUANTITY REPRESENTED	2355		
SAMPLE MARKING	26551		
SOURCE OF MATERIAL	JOB SITE	(9998)	

*** TEST RESULTS ***

TOTAL WEIGHT OF SAMPLE, GRAMS
 AMOUNT PASSING 2 1/2-INCH SIEVE, PCT.---
 AMOUNT PASSING 2-INCH SIEVE, PCT.-----
 AMOUNT PASSING 1 1/2-INCH SIEVE, PCT.--- 100.0
 AMOUNT PASSING 1-INCH SIEVE, PCT.----- 98.2
 AMOUNT PASSING 3/4-INCH SIEVE, PCT.----- 87.8
 AMOUNT PASSING 1/2-INCH SIEVE, PCT.----- 73.7
 AMOUNT PASSING 3/8-INCH SIEVE, PCT.----- 61.7
 AMOUNT PASSING NO.4 SIEVE, PCT.----- 44.5
 AMOUNT PASSING NO.8 SIEVE, PCT.----- 33.0
 AMOUNT PASSING NO.30 SIEVE, PCT.----- 25.3
 AMOUNT PASSING NO.200 SIEVE, PCT.----- 10.3
 REMOVAL BY DECANTATION, PCT.-----
 CLAY LUMPS & FRIABLE PARTICLES, PCT.-----
 SOFT AND NON-DURABLE PARTICLES, PCT.-----
 CHERT, LESS THAN 2.45 SP. GR., PCT.-----
 CHERT, TOTAL PCT.-----
 APPARENT SPECIFIC GRAVITY-----
 BULK SPECIFIC GRAVITY-----
 WATER ABSORPTION, PCT.-----
 L.A. WEAR LOSS, PCT.-----
 S.S. SOUNDNESS LOSS, PCT.-----
 F & T SOUNDNESS LOSS, PCT.-----
 NAEL BRINE F & T SOUNDNESS LOSS, PCT.---
 BITUMEN RETENTION INDEX-----
 AVERAGE F & T BEAM EXPANSION PCT.-----
 AVERAGE F & T BEAM CONTRACTION, PCT.-----
 AGGREGATE SIZE TESTED

REMARKS:

INFORMATION ONLY.

PERMEABILITY TEST - I-70EB NEAR AIRPORT EXPRESSWAY
 STA. 701+00 SHOULDER 21-24"

APPENDIX D

ASTM Method D 2434-68: Standard Test Method for permeability of granular soils (constant head)

Standard Test Method for Permeability of Granular Soils (Constant Head)¹

This standard is issued under the fixed designation D 2434; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

^{ε1} NOTE—Editorial changes were made and Section 10 added editorially in September 1993.

1. Scope

1.1 This test method covers the determination of the coefficient of permeability by a constant-head method for the laminar flow of water through granular soils. The procedure is to establish representative values of the coefficient of permeability of granular soils that may occur in natural deposits as placed in embankments, or when used as base courses under pavements. In order to limit consolidation influences during testing, this procedure is limited to disturbed granular soils containing not more than 10 % soil passing the 75- μ m (No. 200) sieve.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

D 422 Test Method for Particle-Size Analysis of Soils²

D 2049 Test Method for Relative Density of Cohesionless Soils³

3. Fundamental Test Conditions

3.1 The following ideal test conditions are prerequisites for the laminar flow of water through granular soils under constant-head conditions:

3.1.1 Continuity of flow with no soil volume change during a test,

3.1.2 Flow with the soil voids saturated with water and no air bubbles in the soil voids,

3.1.3 Flow in the steady state with no changes in hydraulic gradient, and

3.1.4 Direct proportionality of velocity of flow with hydraulic gradients below certain values, at which turbulent flow starts.

3.2. All other types of flow involving partial saturation of soil voids, turbulent flow, and unsteady state of flow are transient in character and yield variable and time-dependent coefficients of permeability; therefore, they require special

test conditions and procedures.

4. Apparatus

4.1 *Permeameters*, as shown in Fig. 1, shall have specimen cylinders with minimum diameters approximately 8 or 12 times the maximum particle size in accordance with Table 1. The permeameter should be fitted with: (1) a porous disk or suitable reinforced screen at the bottom with a permeability greater than that of the soil specimen, but with openings sufficiently small (not larger than 10 % finer size) to prevent movement of particles; (2) manometer outlets for measuring the loss of head, h , over a length, l , equivalent to at least the diameter of the cylinder; (3) a porous disk or suitable reinforced screen with a spring attached to the top, or any other device, for applying a light spring pressure of 22 to 45-N (5 to 10-lbf) total load, when the top plate is attached in place. This will hold the placement density and volume of soil without significant change during the saturation of the specimen and the permeability testing to satisfy the requirement prescribed in 3.1.1.

4.2 *Constant-Head Filter Tank*, as shown in Fig. 1, to supply water and to remove most of the air from tap water, fitted with suitable control valves to maintain conditions described in 3.1.2.

NOTE 1—De-aired water may be used if preferred.

4.3 *Large Funnels*, fitted with special cylindrical spouts 25 mm (1 in.) in diameter for 9.5-mm ($\frac{3}{8}$ -in.) maximum size particles and 13 mm ($\frac{1}{2}$ in.) in diameter for 2.00-mm (No. 10) maximum size particles. The length of the spout should be greater than the full length of the permeability chamber—at least 150 mm (6 in.).

4.4 *Specimen Compaction Equipment*²—Compaction equipment as deemed desirable may be used. The following are suggested: a vibrating tamper fitted with a tamping foot 51 mm (2 in.) in diameter; a sliding tamper with a tamping foot 51 mm (2 in.) in diameter, and a rod for sliding weights of 100 g (0.25 lb) (for sands) to 1 kg (2.25 lb) (for soils with a large gravel content), having an adjustable height of drop to 102 mm (4 in.) for sands and 203 mm (8 in.) for soils with large gravel contents.

4.5 *Vacuum Pump or Water-Faucet Aspirator*, for evacuating and for saturating soil specimens under full vacuum (see Fig. 2).

4.6 *Manometer Tubes*, with metric scales for measuring head of water.

4.7 *Balance*, of 2-kg (4.4-lb) capacity, sensitive to 1 g (0.002 lb).

4.8 *Scoop*, with a capacity of about 100 g (0.25 lb) of soil.

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.04 on Hydrologic Properties of Soil and Rocks.

Current edition approved Sept. 13, 1968. Originally issued 1965. Replaces D 2434 - 65 T.

² *Annual Book of ASTM Standards*, Vol 04.08.

³ Discontinued—See 1983 *Annual Book of ASTM Standards*, Vol 04.08.

FIG. 1 Constant-Head Permeameter

4.9 *Miscellaneous Apparatus*—Thermometers, clock with sweep second hand, 250-mL graduate, quart jar, mixing pan, etc.

5. Sample

5.1 A representative sample of air-dried granular soil, containing less than 10 % of the material passing the 75- μ m (No. 200) sieve and equal to an amount sufficient to satisfy the requirements prescribed in 5.2 and 5.3, shall be selected by the method of quartering.

5.2 A sieve analysis (see Method D 422) shall be made on a representative sample of the complete soil prior to the permeability test. Any particles larger than 19 mm ($\frac{3}{4}$ in.) shall be separated out by sieving (Method D 422). This oversize material shall not be used for the permeability test, but the percentage of the oversize material shall be recorded.

NOTE 2—In order to establish representative values of coefficients of permeabilities for the range that may exist in the situation being investigated, samples of the finer, average, and coarser soils should be obtained for testing.

5.3 From the material from which the oversize has been removed (see 5.2), select by the method of quartering, a

sample for testing equal to an amount approximately two times that required for filling the permeameter chamber.

6. Preparation of Specimens

6.1 The size of permeameter to be used shall be prescribed in Table 1.

6.2 Make the following initial measurements in centimetres or square centimetres and record on the data sheet (Fig. 3); the inside diameter, D , of the permeameter; the length, L , between manometer outlets; the depth, H , measured at four symmetrically spaced points from the upper surface of the top plate of the permeability cylinder to the top of the upper porous stone or screen temporarily placed on the lower porous plate or screen. This automatically deducts the thickness of the upper porous plate or screen from the height measurements used to determine the volume of soil placed in the permeability cylinder. Use duplicate top plate containing four large symmetrical spaced openings through which the necessary measurements can be made to determine the average value for H . Calculate the cross-sectional area, A , of the specimen.

6.3 Take a small portion of the sample selected as prescribed in 5.3 for water content determinations. Record

TABLE 1 Cylinder Diameter

Maximum Particle Size Lies Between Sieve Openings	Minimum Cylinder Diameter			
	Less than 35 % of Total Soil Retained on Sieve Opening		More than 35 % of Total Soil Retained on Sieve Opening	
	2.00-mm (No. 10)	9.5-mm ($\frac{3}{8}$ in.)	2.00-mm (No. 10)	9.5-mm ($\frac{3}{8}$ in.)
2.00-mm (No. 10) and 9.5-mm ($\frac{3}{8}$ in.)	76 mm (3 in.)	...	114 mm (4.5 in.)	...
9.5-mm ($\frac{3}{8}$ in.) and 19.0-mm ($\frac{3}{4}$ in.)	...	152 mm (6 in.)	...	229 mm (9 in.)

FIG. 2 Device for Evacuating and Saturating Specimen

the weight of the remaining air-dried sample (see 5.3), W_1 , for unit weight determinations.

6.4 Place the prepared soil by one of the following procedures in uniform thin layers approximately equal in thickness after compaction to the maximum size of particle, but not less than approximately 15 mm (0.60 in.).

6.4.1 For soils having a maximum size of 9.5 mm ($\frac{3}{8}$ in.) or less, place the appropriate size of funnel, as prescribed in 4.3, in the permeability device with the spout in contact with the lower porous plate or screen, or previously formed layer, and fill the funnel with sufficient soil to form a layer, taking soil from different areas of the sample in the pan. Lift the funnel by 15 mm (0.60 in.), or approximately the unconsolidated layer thickness to be formed, and spread the soil with a slow spiral motion, working from the perimeter of the device toward the center, so that a uniform layer is formed. Remix the soil in the pan for each successive layer to reduce segregation caused by taking soil from the pan.

6.4.2 For soils with a maximum size greater than 9.5 mm ($\frac{3}{8}$ in.), spread the soil from a scoop. Uniform spreading can be obtained by sliding a scoopful of soil in a nearly horizontal position down along the inside surface of the device to the bottom or to the formed layer, then tilting the scoop and drawing it toward the center with a single slow motion; this allows the soil to run smoothly from the scoop in a windrow without segregation. Turn the permeability cylinder sufficiently for the next scoopful, thus progressing around the inside perimeter to form a uniform compacted layer of a thickness equal to the maximum particle size.

6.5 Compact successive layers of soil to the desired relative density by appropriate procedures, as follows, to a height of about 2 cm (0.8 in.) above the upper manometer outlet.

6.5.1 *Minimum Density (0 % Relative Density)*—Continue placing layers of soil in succession by one of the procedures described in 6.4.1 or 6.4.2 until the device is filled to the proper level.

6.5.2 *Maximum Density (100 % Relative Density)*:

6.5.2.1 *Compaction by Vibrating Tamper*—Compact each layer of soil thoroughly with the vibrating tamper, distrib-

uting the light tamping action uniformly over the surface of the layer in a regular pattern. The pressure of contact and the length of time of the vibrating action at each spot should not cause soil to escape from beneath the edges of the tamping foot, thus tending to loosen the layer. Make a sufficient number of coverages to produce maximum density, as evidenced by practically no visible motion of surface particles adjacent to the edges of the tamping foot.

6.5.2.2 *Compaction by Sliding Weight Tamper*—Compact each layer of soil thoroughly by tamping blows uniformly distributed over the surface of the layer. Adjust the height of drop and give sufficient coverages to produce maximum density, depending on the coarseness and gravel content of the soil.

6.5.2.3 *Compaction by Other Methods*—Compaction may be accomplished by other approved methods, such as by vibratory packer equipment, where care is taken to obtain a uniform specimen without segregation of particle sizes (see Test Method D 2049).

6.5.3 *Relative Density Intermediate Between 0 and 100 %*—By trial in a separate container of the same diameter as the permeability cylinder, adjust the compaction to obtain reproducible values of relative density. Compact the soil in the permeability cylinder by these procedures in thin layers to a height about 2.0 cm (0.80 in.) above the upper manometer outlet.

NOTE 3—In order to bracket, systematically and representatively, the relative density conditions that may govern in natural deposits or in compacted embankments, a series of permeability tests should be made to bracket the range of field relative densities.

6.6 Preparation of Specimen for Permeability Test:

6.6.1 Level the upper surface of the soil by placing the upper porous plate or screen in position and by rotating it gently back and forth.

6.6.2 Measure and record: the final height of specimen, $H_1 - H_2$, by measuring the depth, H_2 , from the upper surface of the perforated top plate employed to measure H_1 to the top of the upper porous plate or screen at four symmetrically spaced points after compressing the spring lightly to seat the porous plate or screen during the measurements; the

PERMEABILITY TEST ON GRANULAR SOIL

Test No. _____		Date of Test _____
Location of Sample _____	Date Sampled _____	Report _____
Boring— _____	Sample— _____	Depth— _____

(a) DESCRIPTION OF SOIL _____

MATERIALS USED: _____

(b) UNIT WEIGHT DETERMINATION:

Diameter, D , cm	Height Before, H_1	Weight Before, W_1
Area, A , cm ²	Height After, H_2	Weight After, W_2
Length, L , cm	Height Net, cm	Weight Net, g

Moisture Content (air-dried) _____
W (max) _____
Dry Unit Weight, lb/ft ³ W _____
W (min) _____
Void Ratio, e _____
Relative Density, RD _____

(c) PERMEABILITY TEST (DEGREE OF COMPACTNESS)

Test No.	Manometers		Head, h cm	Q cm ³	t s	Q/At	h/L	Temperature, °C	k cm/s
	H_1	H_2							
1									
2									
3									
4									
5									
6									

FIG. 3 Permeability Test Data Sheet

final weight of air-dried soil used in the test ($W_1 - W_2$) by weighing the remainder of soil, W_2 , left in the pan. Compute and record the unit weights, void ratio, and relative density of the test specimen.

6.6.3 With its gasket in place, press down the top plate against the spring and attach it securely to the top of the permeameter cylinder, making an air-tight seal. This satisfies the condition described in 3.1.1 of holding the initial density without significant volume change during the test.

6.6.4 Using a vacuum pump or suitable aspirator, evacuate the specimen under 50 cm (20 in.) Hg minimum for 15 min to remove air adhering to soil particles and from the voids. Follow the evacuation by a slow saturation of the specimen from the bottom upward (Fig. 2) under full vacuum in order to free any remaining air in the specimen. Continued saturation of the specimen can be maintained more adequately by the use of (1) de-aired water, or (2) water maintained in an in-flow temperature sufficiently high to cause a decreasing temperature gradient in the specimen

during the test. Native water or water of low mineral content (Note 4) should be used for the test, but in any case the fluid should be described on the report form (Fig. 3). This satisfies the condition described in 3.1.2 for saturation of soil voids.

NOTE 4—Native water is the water occurring in the rock or soil *situ*. It should be used if possible, but it (as well as de-aired water) may be a refinement not ordinarily feasible for large-scale production testing.

6.6.5 After the specimen has been saturated and the permeameter is full of water, close the bottom valve on the outlet tube (Fig. 2) and disconnect the vacuum. Care should be taken to ensure that the permeability flow system and the manometer system are free of air and are working satisfactorily. Fill the inlet tube with water from the constant-head tank by slightly opening the filter tank valve. Then connect the inlet tube to the top of the permeameter, open the inlet valve slightly and open the manometer outlet cocks slightly to allow water to flow, thus freeing them of air. Connect the water manometer tubes to the manometer outlets and

with water to remove the air. Close the inlet valve and open the outlet valve to allow the water in the manometer tubes to reach their stable water level under zero head.

7. Procedure

7.1 Open the inlet valve from the filter tank slightly for the first run to conditions described in 3.1.3, delay measurements of quantity of flow and head until a stable head condition without appreciable drift in water manometer levels is attained. Measure and record the time, t , head, h (the difference in level in the manometers), quantity of flow, Q , and water temperature, T .

7.2 Repeat test runs at heads increasing by 0.5 cm in order to establish accurately the region of laminar flow with velocity, v (where $v = Q/At$), directly proportional to hydraulic gradient, i (where $i = h/L$). When departures from the linear relation become apparent, indicating the initiation of turbulent flow conditions, 1-cm intervals of head may be used to carry the test run sufficiently along in the region of turbulent flow to define this region if it is significant for field conditions.

NOTE 5—Much lower values of hydraulic gradient, h/L , are required than generally recognized, in order to ensure laminar flow conditions. The following values are suggested: loose compactness ratings, h/L from 0.2 to 0.3, and dense compactness ratings, h/L from 0.3 to 0.5, the lower values of h/L applying to coarser soils and the higher values to finer soils.

7.3 At the completion of the permeability test, drain the specimen and inspect it to establish whether it was essentially homogeneous and isotropic in character. Any light and dark alternating horizontal streaks or layers are evidence of segregation of fines.

8. Calculation

8.1 Calculate the coefficient of permeability, k , as follows:

$$k = QL/At h$$

where:

k = coefficient of permeability,

Q = quantity of water discharged,

L = distance between manometers,

A = cross-sectional area of specimen,

t = total time of discharge,

h = difference in head on manometers.

8.2 Correct the permeability to that for 20°C (68°F) by multiplying k (see 8.1) by the ratio of the viscosity of water at test temperature to the viscosity of water at 20°C (68°F).

9. Report

9.1 The report of permeability test shall include the following information:

9.1.1 Project, dates, sample number, location, depth, and any other pertinent information,

9.1.2 Grain size analysis, classification, maximum particle size, and percentage of any oversize material not used,

9.1.3 Dry unit weight, void ratio, relative density as placed, and maximum and minimum densities,

9.1.4 A statement of any departures from these test conditions, so the results can be evaluated and used,

9.1.5 Complete test data, as indicated in the laboratory form for test data (see Fig. 3), and

9.1.6 Test curves plotting velocity, Q/At , versus hydraulic gradient, h/L , covering the ranges of soil identifications and of relative densities.

10. Keywords

10.1 constant head; granular; permeability; soils

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.

COVER DESIGN BY ALDO GIORGINI