PERMEABILITY CONTROL IN SELECTED SOILS USING ASPHALT EMULSION

by

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INTRODUCTION

A large number of soils throughout the United States are plagued with high permeabilities. Since this property is indicative of the ease with which gravitational water moves through a soil, it is one of the most important physical characteristics of a soil. This factor enters into the construction of dams, the stability of earth slopes, the construction of airports and highways, the design of sewage lagoons, and many other soil engineering problems (8).

Because of permeability limitations, many soils in the world have limited application for water-holding facilities. Some of the methods used to decrease the permeability of a soil include the addition of clay layers, plastic liners, asphalt layers, dispersion agents, grouting and others. This investigation deals with an attempt to add limited amounts of asphalt emulsions in order to control permeability by forming a semi-permeable membrane of the soil rather than a complete seal.

This study attempted to reduce the permeability of four differing soils (loess, silty-sand, blow sand, concrete sand) by adding asphalt emulsion to each soil. A relationship between asphalt emulsion and permeability was demonstrated for all four soils.

A procedure was introduced as a result of tests conducted. This procedure showed how to attain the same permeability test results consistently in replicated samples.

REVIEW OF LITERATURE

The review of literature for this investigation is very limited. With the exception of the thesis presented by Drumm (3), the concept of controlling permeability with asphaltic emulsions has never been studied as far as could be determined from the literature reviewed.

In Mr. Drumm's thesis, the bulk of the investigation was concerned with a development of the apparatus. He showed that the permeability of his samples decreased as the experiment proceeded. The solution to this dilemma can be found in the type of water used. Tap water was used by Drumm as opposed to de-aired water. The use of de-aired water as suggested by Lambe (4) should alleviate this decreasing permeability characteristic.

Also in Drumm's thesis, an exact process was never cited that could be used in mixing asphalt with soil water. This caused inconsistencies in his data which made each test unrelatable to the others and generally unreliable.

Other studies have been conducted in asphalt coating such as those done by Draper (2). Draper investigated complete seals with asphalt that could produce permeabilities of zero. This process worked well for small pond reservoirs, irrigation channels and in membranes under sandy crop fields. He also investigated the use of asphalt to stabilize soil before grass could grow and take root; this process is called asphalt "mulching".

In this study, asphalt emulsions were combined with soil and water to form a mixture. To ensure that emulsions are basically understood, a small section is included here for clarification.

The emulsions are prepared from paving grade asphalt cements dispersed in water and held in suspension with emulsifiers and stabilizers. These emulsifiers and stabilizers impart an electrical charge to the asphalt droplets (6). Because soil particles have an electrical charge, the inherent electro-chemical charges of the emulsion improve the asphalt-aggregate systems.

Cationic emulsion carries a positive electrical charge. This polar charge causes the asphalt to be attracted to negatively charged mineral particles and gives a superior adhesion. This is of particular value in seal coat construction and other special uses. Cationic emulsion must be used as received from the refinery. Dilution with water will cause the asphalt to drop out of the emulsion system.

Anionic emulsion carries a negative electrical charge which is attracted electro-chemically to positive charged minerals and other surfaces. Anionic emulsions can be diluted with potable water in practically every proportion.

The oil-in-water emulsions of both types are brown in color. As the water evaporates, the black color of the asphalt reappears. This is called "breaking" (6). The speed at which the asphalt breaks can be controlled by the use of either rapid break (RS) or slow break (SS) asphalt emulsions.

Most soils found in nature have a relatively high natural water content. This water will cause the cationic asphalt emulsion to drop its asphalt. Therefore, the study will deal strictly with anionic emulsions.

Procedures and Apparatus Used

The experiments follow Procedure I as discussed later in this section. The sample is combined with asphalt and water and molded to the dimensions of 2½ inches (6.35 cm) diameter by 2 inches (5.08 cm) in height. Once the sample is molded, it is placed on a 3 inch (7.62 cm) diameter by ½ inch (1.27 cm) porous disc. A plastic tube with an inside diameter of 3 inches (7.62 cm) and a height of 3 inches (7.62 cm) is placed as shown in Figure 1. The space between the sample and the plastic tube is filled with molten wax. Another porous disc is placed on top of the sample. This entire set-up is shown in Figure 1.

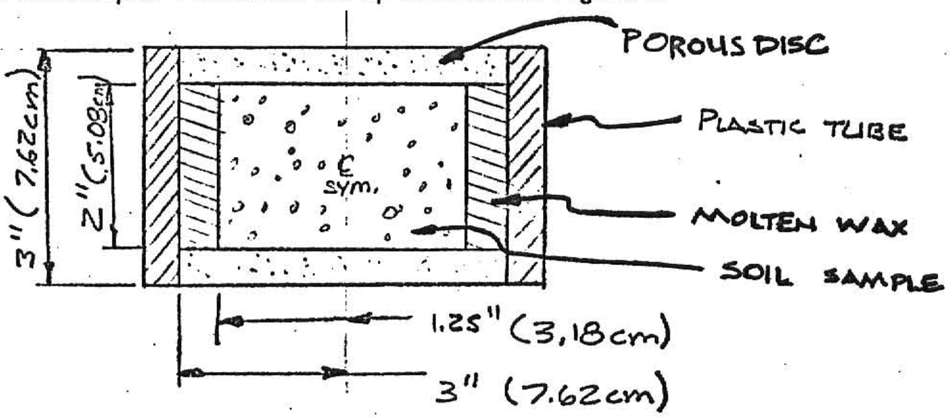


Figure 1. Half section of a permeameter.

This permeameter does not agree with ASTM standards since it is a recent development of the KSU Soils and Foundations group. (1) The difference is the size of the sample. The standard ASTM specifies a minimum of 6 inches (15.24 cm), whereas the equipment available limits these tests to 2½ inches (6.35 cm). It is assumed that although the values will not be as correct as they would be if 6 inches (15.24 cm) were used, they are relative to one another and should give a good representation of what would happen if ASTM standards were used.

The permeameter as shown in Figure 1 is then submerged in a water bath for thirty minutes. Six permeameters are run at a time. Once the sample has saturated, a metal cap is placed on three samples at a time. The six samples (2 sets of three) are then connected to water hoses as shown in Figure 2.

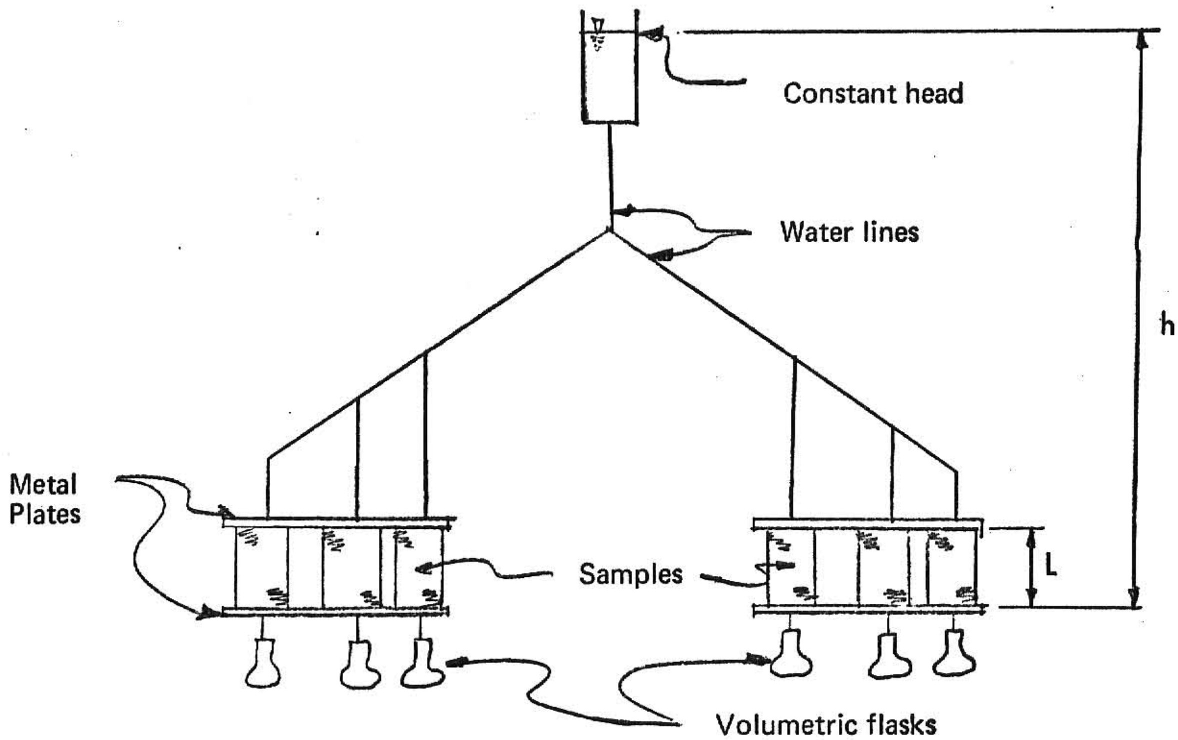


Figure 2. Schematic of permeability test set-up.

A constant head of 97 inches (246.38 cm) is established, and the discharge volume of water is measured for a specific period of time.

The permeability is calculated using Darcy's relation (5):

$$k_T = \frac{QL}{Ath} \tag{3.1}$$

where:

k_T = coefficient of permeability at temperature T

Q = quantity of water that flowed through the soil in time T

L = lengths of sample

A = cross-sectional area of specimen

t = total time of discharge

h = total head from top of water to outlet point.

A relative statement of the permeability is given by the equation (5):

$$k_{20^\circ C} = \frac{\mu_T}{\mu_{20^\circ C}} k_T$$

where:

$k_{20^\circ C}$ = the permeability at temperature 20°C

k_T = the permeability at temperature T

$\mu_{20^\circ C}$ = the viscosity of water at temperature 20°C

μ_T = the viscosity of water at temperature T

The limitations of Darcy's equation must also be considered in a study of this type (7). It is assumed that:

1. Flow is laminar and does not approach turbulent flow.
2. Boundary effects at the center and sides of the sample are considered negligible.
3. The water that percolates through the soil does not react with the soil either chemically or physically.
4. The fluid will act in a Newtonian behavior.
5. Interfacial tension between the water and the soil particles is negligible. (4).

With any laboratory work, a specified procedure must be followed. In this work, the procedure for determining permeabilities, as specified in ASTM D 2434-68, was followed whenever possible. Complication arose as to the method best suited to use in adding the asphalt. The three procedures which were tested are shown on page 7. Separate permeability tests were run for each of the three procedures.

Procedure I:

1. Oven dry raw soil. Calculate values for soil weight, water volume and asphalt weight and put on data work sheet (DWS).
2. Weigh out dry soil in mixing bowl according to DWS. Leave mixing bowl and soil on balance.
3. Add the required water according to DWS.
4. Add the required asphalt according to DWS.
5. Remove bowl from balance and mix thoroughly.
6. Place mixture in mold and compress to a height of 5.08 cm and a diameter of 6.35 cm.
7. Let mold air dry for 24 hours.
8. Place mold in permeameter. Pour molten wax around mold. Let wax harden.
9. Place mold in tank of water and let saturate for 30 minutes.
10. Place mold in permeameter. Let permeameter run for 5–10 minutes.
11. Record data.

Procedure II:

1. Oven dry raw soil. Calculate values for soil weight, water volume and asphalt weight. Record these values on DWS.
2. Weigh out dry soil in mixing bowl according to DWS. Leave mixing bowl and soil on balance.
3. Add the required water according to DWS.
4. Add the required asphalt according to DWS.
5. Remove bowl from balance and mix thoroughly.
6. Let mixture air dry for 24 hours.
7. Place mixture in mold and compress to a height of 5.08 cm and a diameter of 6.35 cm.
8. Same as 8, 9, 10, and 11 above.

Procedure III:

Same as procedure II, but omit step 6.

The results from the permeability tests performed by the three different procedures are condensed and presented in Table 1 for ease of discussion.

Table 1

k_{avg} (in/day)	Procedure No.	% Asphalt	Reference Page
0.52	I	5%	48
1.30	II	5%	42
2.10	III	5%	43
*3.59	III	0	44

It is seen from this table that Procedure 1 gives the lowest k_{avg} for a given asphalt percent as compared to the other two methods. The last row of numbers (denoted by the asterisk) contains no asphalt and is entered as a reference. Procedure 1 was adopted as the method used for the remainder of the investigation. The reason being that the less asphalt used to obtain a lower permeability, the lower the cost.

Another important part of the procedure was the determination of an average value for k. Six tests were run at a time on one soil sample. The highest value and lowest value was deleted. The remaining four values were averaged.The average k value (k_{avg}) was converted into the relative permeability at 20° C ($k_{20\,°C}$).

DESIGN OF THE EXPERIMENT

A *microscopic look at a soil structure* (Figure 3) shows that it is a combination of soil, water, and air arranged in a random fashion.

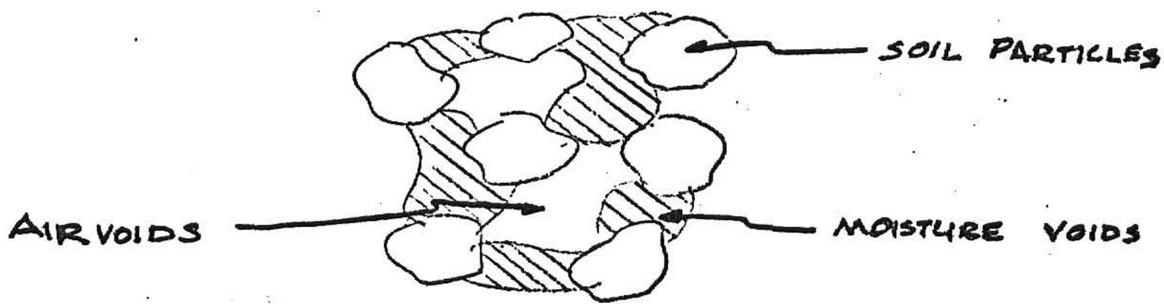


Figure 3. Microscopic look of a soil sample.

The permeability of a soil, such as that shown in Figure 3, is affected by the following:

1. Particle size
2. Void ratio
3. Composition
4. Fabric
5. Degree of Saturation (5).

All of the above factors were held constant for each soil investigated in this study. With the exception of the void ratio, the factors were different from one type of soil to the next; however, they did not change from one test to the next with the same soil.

The entire investigation is based on the above assumptions.

The design of this experiment followed ASTM D 2434-68 wherever possible. The following fundamental test conditions were observed:

1. The soil mixtures remain at a constant volume of 0.00568 ft^3 (160.84 cm^3).
2. The soil sample is saturated in water for a sufficient amount of time (30 minutes) to ensure no voids are occupied by air.
3. This test employs a constant head permeameter.

In this investigation, asphalt emulsion is combined with soil and water to form a mixture of constant density. The object is to combine the three at different concentrations of emulsion and still maintain a constant density. The following derivation is an analytical attempt to maintain the said density.

The emulsion that is to be used gives a percent residue which shall be termed R. Values for R can be found in Appendix H. Given the following diagram, (Figure 4), the moisture content of the asphalt (m_{asp}) and the dry density of the asphalt (γ_{asp}) can be found:

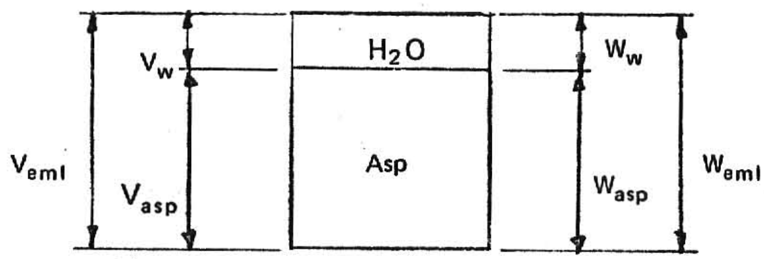


Figure 4. Schematic of an emulsion sample.

All symbols are defined in Appendix A.

$$m_{asp} = W_w/W_{eml} \tag{4.1a}$$

$$m_{asp} = (W_{eml} - W_{asp})/W_{eml} \tag{4.1b}$$

$$W_{asp} = (W_{eml})(R) \tag{4.1c}$$

$$m_{asp} = ((W_{eml} - (W_{eml})(R))/W_{eml} \tag{4.1d}$$

$$m_{asp} = W_{eml}(1 - R)/W_{eml} \tag{4.1e}$$

$$m_{asp} = 1 - R \tag{4.1f}$$

where R is the residue from distillation in percent.

$$G = \gamma_{asp}/\gamma_{water} \tag{4.2a}$$

$$\gamma_{asp} = G\gamma\omega \tag{4.2b}$$

where G is the specific gravity of the asphalt.

$$\omega = W_w/W_{asp} \tag{4.3a}$$

$$\omega = (W_{eml} - W_{asp})/W_{asp} \tag{4.3b}$$

$$\omega = ((1/R)\, W_{asp} - W_{asp})/W_{asp} \tag{4.3c}$$

$$\omega = ((1 - R) - 1) \tag{4.3d}$$

$$\omega = (1 - R)/R \tag{4.3e}$$

$$\gamma_{d_{asp}} = \gamma_{asp}/(1 + (\omega/100)) \tag{4.4a}$$

$$\gamma_{d_{asp}} = G\gamma\omega/(1 + (\omega/100)) \tag{4.4b}$$

$$\gamma_{d_{asp}} = G\gamma\omega/(1 + R/R\,(100))) \tag{4.4c}$$

where R is expressed in percent.

Maximum dry density of the soil ($\gamma_{d_{soil}}$) and the optimum moisture content of the soil ($\omega_{o_{soil}}$). Since the sample density is to remain constant and the amount of the asphalt is variable, let y represent the amount, (in grams) of asphalt used per cubic foot.

The weight of the soil (W_s) to run a normal permeability test is shown below where "Volume" is used to describe the volume of space that the sample will occupy:

$$W_s = (\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{Volume}) \tag{4.5}$$

The quantity of water needed for a normal permeability test (V_w) is defined as:

$$V_w = (\omega_{o_{soil}})\ (W_s) \tag{4.6}$$

therefore, the total weight (W_T) is:

$$W_T - V_w + W_s \tag{4.7a}$$

$$W_T = (1 + \omega_{o_{soil}})\ (\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{Volume}) \tag{4.7b}$$

Therefore, the weight of the soil can further be modified to include a reduction factor for the amount of asphalt in the mixture of soil and emulsion. Throughout this paper, the word asphalt and emulsion are used. The term asphalt is used to describe the solids within the emulsion. The emulsion therefore contains asphalt, water, and an emulsifier. The weight of the soil,including the factor for asphalt,is shown here:

$$W_s = ((\gamma_{d_{soil}})\ (\%\ \text{proctor}) - (\gamma_{d_{asp}})\ y)\ (\text{Volume}) \tag{4.8}$$

The above value can be worked with units of pounds or grams. This value must be multiplied times the appropriate conversion factor to convert from pounds to grams or vice versa.

With this reasoning, it follows that the weight of the asphalt (W_{asp}) in the emulsion should be:

$$W_{asp} = ((\gamma_{d_{asp}})\ y)\ (\text{Volume}) \tag{4.9}$$

The emulsion that is used contains a certain percentage of water (m_{asp}). This can be added into the equation to give the weight of emulsion (W_{eml}) that is required.

$$W_{eml} = W_{asp} + (\text{weight of water in emulsion}) \tag{4.10a}$$

The weight of water in the emulsion (W_{water}) is found by considering the following diagram (Figure 5):

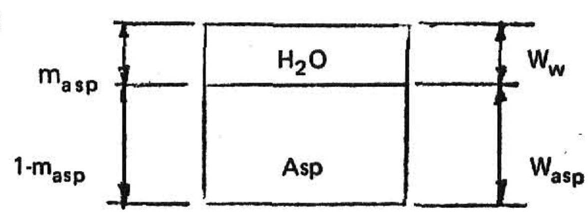


Figure 5. Schematic of asphalt emulsion.

$$W_{water} = (W_{asp})/(1 - m_{asp}) \qquad (4.10b)$$

$$W_{water} = (W_{asp})\ (m_{asp})/(1 - m_{asp}) \qquad (4.10c)$$

$$\text{recall that } 1 - m_{asp} = R \qquad (4.10d)$$

Therefore, by observing the above ratio, the weight of the emulsion can be defined as:

$$W_{eml} = ((\gamma_{d_{asp}})y(\text{Volume}) + ((W_{asp})\ (1 - R)/R)) \qquad (4.11)$$

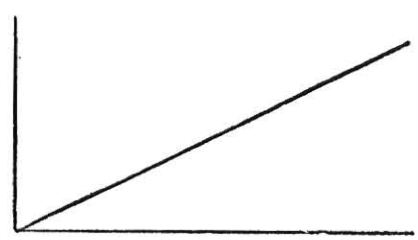
It would also seem that the weight of the water added to the soil (W_w) will be affected by the quantity of water in the emulsion:

$$W_w = V_w - W_{water} \qquad (4.12a)$$

$$W_w = ((\omega_{o_{soil}})\ (W_s)) - ((W_{asp})\ (m_{asp})/R) \qquad (4.12b)$$

The derivation thus far has used the variable y to describe the amount of asphalt used. It is advantageous to be able to know the percent asphalt by weight (x). It is felt that it can be found by the use of a graph of y-vs-x. This graph is shown below (Figure 6):

$$y = \frac{W_{asp}}{(\gamma_{d_{asp}})(\text{Vol})}$$



$$x = \frac{W_{asp}}{W_T}$$

Figure 6. Graph of y-vs-x.

W_{asp} is a constant. The values of $\gamma_{d_{asp}}$, Volume, and W_T are determined for each different situation. These values will be constant for that situation. The slope for the graph then will be:

$$\text{slope} = \ y/\ \ x = (W_{asp}/(\gamma_{d_{asp}})\ (\text{Volume}))/(W_{asp}/W_T) \qquad (4.13a)$$

$$\text{slope} = W_T/(\gamma_{d_{asp}})\ (\text{Volume}) \qquad (4.13b)$$

Therefore:

$$y = x\ (W_T)/(\gamma_{d_{asp}})\ (\text{Volume}) \qquad (4.13c)$$

This value then should be substituted back into the equations for W_s, W_{eml}, and W_w. Those substitutions and subsequent derivations are shown below:

$$W_s = ((\gamma_{d_{soil}})\ (\%\ \text{proctor}) - ((\gamma_{d_{soil}})\ x\ (W_T)/(\gamma_{d_{soil}})\ (\text{Volume})))\ (\text{Volume}) \qquad (4.14a)$$

$$W_s = ((\gamma_{d_{soil}})\ (\%\ \text{proctor})\ (\text{Volume}) - x(W_T)) \qquad (4.14b)$$

$$W_s = ((\gamma_{d_{soil}})\ (\%\ \text{proctor})\ (\text{Volume}) - x(1 + \omega_{o_{soil}})\ (\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{Volume})) \qquad (4.14c)$$

$$W_s = (1 - x\,(1 + \omega_{o_{soil}}))\,((\gamma_{d_{soil}})\,(\%\ \text{proctor})\,(\text{Volume})) \tag{4.14 d}$$

$$W_{eml} = ((\gamma_{d_{asp}})\ y\ \text{Volume} + (W_{asp}\ (1 - R)/R)) \tag{4.15a}$$

$$W_{eml} = (((\gamma_{d_{asp}})\ x\ (W_T)\ (\text{Volume})/(\gamma_{d_{asp}})\ (\text{Volume})) + ((\gamma_{d_{asp}})\ (\text{Volume})\ x\ (W_T))\ (1 - R)/(\gamma_{d_{asp}})\ ((\text{Volume})\ (R))) \tag{4.15b}$$

$$W_{eml} = (x\ (W_T) + (x\ (W_T)\ (1 - R)/R)) \tag{4.15c}$$

$$W_{eml} = (x\ (W_T))\ (1 + ((1 - R)/R)) \tag{4.15d}$$

$$W_{eml} = (x\ (1 + \omega_{o_{soil}})\ (\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{Volume}))\ (1/R) \tag{4.15e}$$

$$W_w = ((\omega_{o_{soil}})\ (W_s)) - ((W_{asp})\ (m_{asp})/R) \tag{4.16a}$$

$$W_w = ((\omega_{o_{soil}})\ (\gamma_{d_{soil}})\ (\%\ \text{proctor})\ (\text{Volume}) - ((\gamma_{d_{asp}})\ y\ (\text{Volume})\ (1\text{-}R)/R)) \tag{4.16b}$$

$$W_w = (((\omega_{o_{soil}})\ (\gamma_{d_{soil}})\ (\%\ \text{proctor})) - ((\gamma_{d_{asp}})\ (x)\ (W_T)\ (1 - R)/(\gamma_{d_{asp}})\ (\text{Volume})\ (R)))\ (\text{Volume}) \tag{4.16c}$$

$$W_w = (((\omega_{o_{soil}})\ (\gamma_{d_{soil}})\ (\%\ \text{proctor})\ (\text{Volume})) - ((x)\ (W_T)\ (1 - R)/R)) \tag{4.16d}$$

$$W_w = (((\omega_{o_{soil}})\ (\gamma_{d_{soil}})\ (\%\ \text{proctor})\ (\text{Volume})) - ((x)\ (1 - R)\ (1 + \omega_{o_{soil}})\ (\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{Volume}))) \tag{4.16e}$$

$$W_w = ((\omega_{o_{soil}}) - (x)\ (1 - R)\ (1 + \omega_{o_{soil}})/(R))\ ((\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{Volume})) \tag{4.16f}$$

PRESENTATION AND INTERPRETATION OF DATA

The basic information on each soil can be found in Appendix C (grain size analysis) and Appendix D (compaction tests). These values help correlate the soils to real situations and provide certain values used in the equations of this investigation.

Each soil sample was combined with water and asphalt emulsion. The process by which this operation was performed is shown in Procedure I on page 7. The weights for each element of a sample are calculated according to equations 4.14d (page 12), 4.15e (page 13), and 4.16f (page 13). Sample calculations for the soils used in this thesis are shown in Appendix G.

Values of the permeability were recorded on data work sheets. These work sheets are shown in Appendix I. Each data work sheet (DWS) has the date of the test, percent asphalt used in the equations (4.14d, 4.15e, and 4.16f), the procedure used, type of soil used and 8 major headings. Columns 1 through 5 display the weights used in the formation of each sample. Column 1 is the weight of the mixing bowl. To the value of Column 1 the values of Columns 2, 3, and 4 were added. This total is shown in Column 5. The values for Columns 2, 3, and 4 are found using equations 4.14d, 4.15e, and 4.16f, respectively.

Column 6 is the total elapsed time the permeability test was run. Column 7 shows the volume, Q, measured during the elapsed time. The last Column, 8, is the permeability for that particular permeameter. The permeability is calculated according to equation 3.1, page 5.

At the bottom of each page is the average permeability (k_{avg}) and the relative permeability at 20°C ($k_{20°C}$). The equation used to obtain $k_{20°C}$ is shown on page 6, equation (3.2). Values for water viscosity at different temperatures can be found in Appendix B. Calculation of sample volume and permeability constant are shown in Appendix H, page 41. Values of permeability are shown both in English and metric units. All other values are shown in metric units only.

Due to the large number of data work sheets, they will be discussed in four groups rather than individually. Those four groups represent all the tests run in this investigation. They are: silty sand, loess, river sand, and blow sand.

The first group, silty sand, seemed to show the best reaction to treatment with emulsion. A graph of the relative permeability at 20°C ($k_{20°C}$) versus the percent asphalt emulsion (x) shown on page 76 in Appendix J. Values for this graph can be found in Appendix I on pages 44 through 54. The calculations of weights can be found in Appendix G on page 37.

A close analysis of the curve on page 76 shows a depression around a percent asphalt emulsion of 4. It seems as though the asphalt and soil mixture reaches an optimum amount and then it starts to become more permeable. This phenomenon was not expected and no time was spent in trying to explain it. After 8%, the permeability once again begins to descend and does not go up again. Although this dip in the curve is an interesting academic question, it does not follow with the purpose of this study.

The second group, loess, also displays a positive reaction. The graph of relative permeability at 20°C ($k_{20\,°C}$) versus percent asphalt emulsion (x) is shown with silty sand for comparison on page 76 . Values for this part of the graph can be found on the data work sheets in Appendix I on pages 55 through 63. The *calculations* of weights can be found in Appendix C on page 38.

The graph of loess on page 76 is a very smooth plot decreasing somewhat constantly towards zero permeability. Tests were suspended after 16% emulsion. It seemed obvious at this point that the thesis had been proven with these two soils.

The last two groups did not display favorable results, but they did introduce some interesting points.

The river sand (concrete sand) has the unique property of most sands; that is, it attains maximum proctor at either zero moisture or total saturation. Since the asphalt emulsion contains moisture, the samples were prepared totally saturated. This process produced an extremely viscous material that had to be placed in metal containers to set up. The conventional procedure would not force the mixture into a stable mold of soil. Three of the samples were placed in an oven at 120°C for 1 day while the other three were left to air-dry for 5 days.

The three air dried samples (numbers 1, 2, and 3 on page 64) were too permeable to collect data. It was noted that the emulsion seemed to wash out of the mixture. Further investigation showed that the emulsion did not adhere to the sand grains at all and that the emulsion could be washed completely out of the sand.

The three samples that were oven dried (numbers 4, 5, and 6 on page 64) were less permeable than the original soil, but they were still too permeable to get readings. An interesting point observed on these three samples was that the emulsion did not "wash away" from the soil grains. Because this investigation does not deal with hot mix emulsion, the study of river sand was terminated.

The last group of soil investigated was the blow sand. Results from tests run on this soil can be found in Appendix I of pages 65 through 71. The calculations of weights can be found in Appendix G on page 40. It was found that the emulsion adhered to the soil. A close look at the data work sheet shows that the emulsion does not reduce the permeability. Tests were suspended after 30 percent emulsion due to the economic infeasibility.

The majority of the tests run for this investigation were done with a head of 108 inches (274.32 cm). Because the height of the head has a direct effect on the permeability, tests were performed on 6 soil samples at different heads. These values can be found in Appendix I on pages 72–74. The information on these data work sheets was condensedand is shown in Table 2.

TABLE 2

h (inches)	h/L (inches/feet)	Average V/At (milliliters/inches^2 x seconds)
108	54	59.45
97	48.5	50.21
67	33.5	36.07

A plot of the data contained in Table 2 is shown in Appendix E on page 33. This graph is very useful in designing systems that have a different head than the one used throughout this investigation.

SS-1h emulsion was used throughout this investigation. RS-1h emulsion produces the same results as can be seen by comparing page 75 and page 60. The difference lies in the workability of the soil. The RS-1h soil was very hard to mix because the asphalt "broke" so fast. The SS-1h emulsion was much easier to work with in this investigation. This would tend to indicate that the workability would be the controlling factor in the field.

CONCLUSIONS

The investigation conducted by this author has resulted in the following conclusions:

(1) A procedure for combining soil, water and asphaltic emulsion has been established that creates reproducible data.

(2) The permeability of a silty soil can be decreased at a controllable rate with the use of asphaltic emulsions.

(3) The permeability of sandy soils can be reduced only to a degree with asphaltic emulsions.

It has been shown in this investigation that silty soils are very adaptable to this process. A silty soil can be controlled by using 14–16% emulsion to get a permeability of approximately 0.2 inches/day (5.68×10^{-6} cm/sec).

This investigation introduces a procedure to be used when combining asphaltic emulsion, soil, and water. The procedure can be applied to further research or practical problems in engineering. This procedure will ensure reproducible results.

SS1-h emulsion cannot be used to control permeability in sands. The emulsion will wash out of a river sand. Economics do not allow this process to be applicable to blow sand because it requires too much asphalt.

RECOMMENDATIONS FOR FURTHER RESEARCH

Time limitations forced the author to limit his investigations to four soils. Only two soils produced favorable results. Other silty soils with different amounts of sand or clay should be investigated. It is assumed that an in-depth study of a large number of different silty soils will create an envelope of values that can be generalized into an equation.

Only one type of emulsion (cold mix anionic) was investigated. Further research should be conducted in the areas of hot mix and different electron bonds.

A last recommendation is to investigate sandy soils. It is the author's belief, however, that the addition of asphalt to sandy soils will be economically infeasible as compared to asphalt liners.

APPENDIX A

TERMS USED

A	=	Cross sectional area of specimen
G	=	Specific gravity of asphalt
h	=	Total head from top of water to outlet point
k	=	Coefficient of permeability
k_{avg}	=	Average permeability at temperature T
k_T	=	Permeability at temperature T
$k_{20°}$	=	Permeability at 20°C
l	=	Length of sample
m_{asp}	=	Moisture content of the asphalt emulsion
Q	=	Quantity of water that flows through a soil sample in a given amount of time
R	=	Percent residue of the asphalt emulsion
T	=	Temperature
t	=	Total time of discharge
V_ω	=	Volume of water
W_{eml}	=	Weight of asphalt emulsion in sample
W_s	=	Weight of soil in sample
W_T	=	Total weight of sample
W_w	=	Weight of water in sample
x	=	Variable asphalt content by weight
y	=	Amount of asphalt used per cubic foot
γ_{asp}	=	Unit weight of asphalt
$\gamma_{d_{asp}}$	=	Dry density of asphalt
$\gamma_{d_{soil}}$	=	Maximum dry density of the soil
γ_w	=	Unit weight of water
μ_T	=	Viscosity of water at temperature T
$\mu_{20°C}$	=	Viscosity of water at 20°C
ω	=	Water content
ω_{asp}	=	Weight of asphalt in the emulsion
$\omega_{o_{soil}}$	=	Optimum moisture content
% proctor	=	Percent of standard proctor density

APPENDIX B

Temperature (°C)	Viscosity of water $-\mu$ (lb-sec/ft^2 or grams-sec/cm^2)	
10	2.735×10^{-5}	(115.20)
11	2.673×10^{-5}	(112.40)
12	2.610×10^{-5}	(109.70)
13	2.548×10^{-5}	(106.90)
14	2.486×10^{-5}	(104.20)
15	2.424×10^{-5}	(101.40)
16	2.361×10^{-5}	(98.69)
17	2.299×10^{-5}	(95.94)
18	2.237×10^{-5}	(93.18)
19	2.174×10^{-5}	(90.43)
20	2.112×10^{-5}	(87.68)
21	2.072×10^{-5}	(86.08)
22	2.032×10^{-5}	(84.47)
23	1.992×10^{-5}	(82.87)
24	1.951×10^{-5}	(81.27)
25	1.911×10^{-5}	(79.66)
26	1.871×10^{-5}	(78.06)
27	1.831×10^{-5}	(76.46)
28	1.791×10^{-5}	(74.86)
29	1.751×10^{-5}	(73.26)
30	1.711×10^{-5}	(71.66)

APPENDIX C
GRAIN SIZE ANALYSIS

Soil: Silty sand   Hydrometer No: 87671

Location: Manhattan, Kansas   Mensicus Corr.: 0.2

Run By: Gordon Brest R_c = R_a - (Corr)

Date: 1 November 1976   % Finer = R_c/W_s

Soil Weight: 50 grams   NOTE: 1 gram Tripolyphosphate defloculant added

TIME	ELAPSED TIME	R_a	R_c	% FINER	T°C	$D_{(mm)}$
2:00	0	—	—	—	—	—
2:15	15	5.2	5.0	10.0	21	0.0148
2:30	30	5.1	4.9	9.8	21	0.0105
2:45	45	5.1	4.9	9.8	21	0.0080
3:00	60	5.1	4.9	9.8	21	0.0070
3:15	75	5.0	4.8	9.6	21	0.0063
3:30	90	4.9	4.7	9.4	21	0.0057
3:45	105	4.9	4.7	9.4	21	0.0055
4:00	120	4.1	3.9	7.8	21	0.0050

% Passing 200 Mesh Sieve:

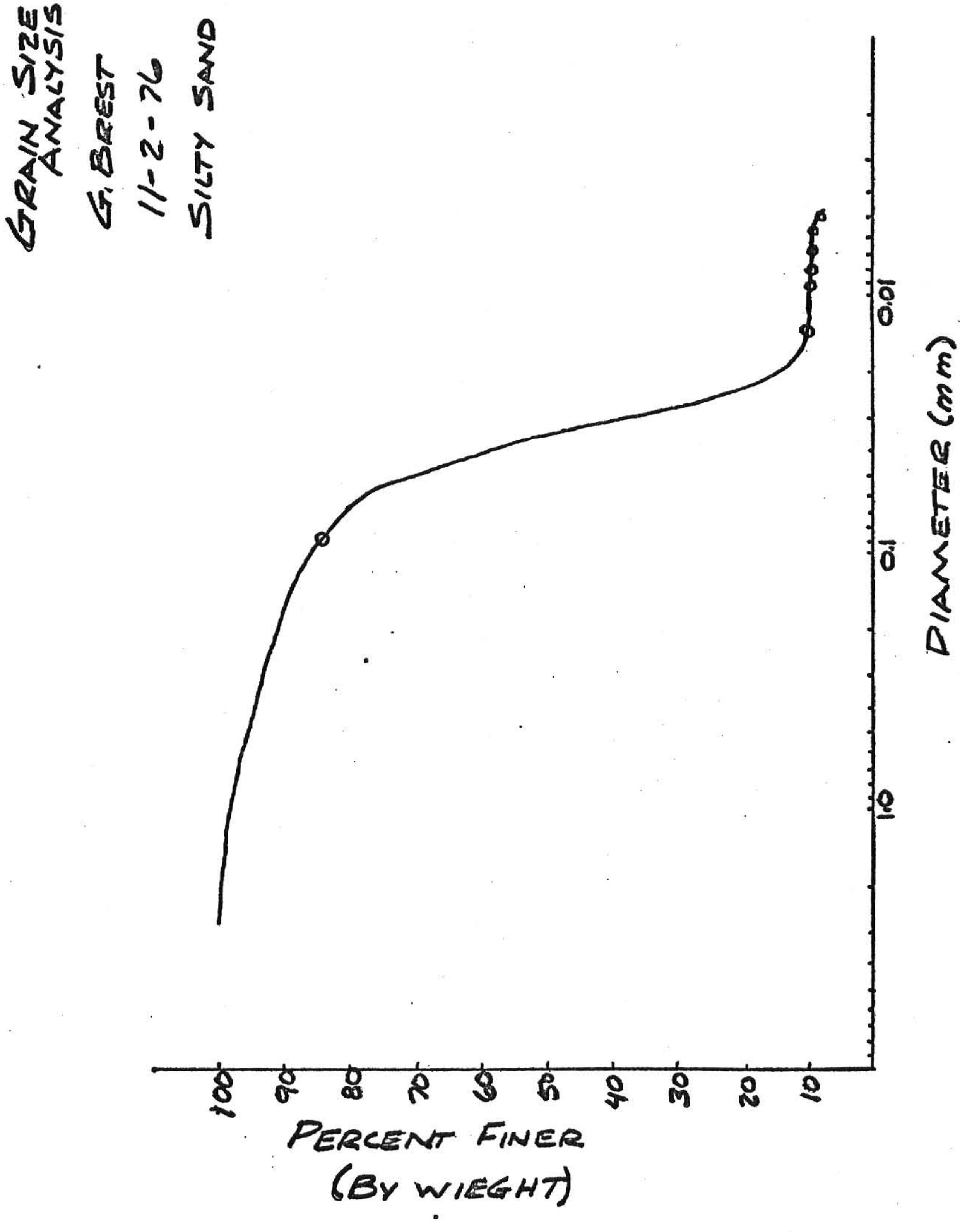
Wt. can + soil	64.60 grams
Wt. can	52.22 grams
Wt. soil	12.38 grams

% Sand = 12.38/50.0

% Sand = 24.8%

From Graph:

% Clay = 9%   % Silt = 66.24%


GRAIN SIZE ANALYSIS
G. BREST
11-2-76
SILTY SAND
100
90
80
70
60
50
40
30
20
10
PERCENT FINER
(BY WIEGHT)
1.0
0.1
0.01
DIAMETER (mm)

GRAIN SIZE ANALYSIS

Soil: Loess   Hydrometer No: 357810

Location : Kansas City, Kansas   Meniscus Corr.: 2.5

Run By: Gordon Brest $R_c = R_a$ - (Corr.)

Date: 15 November 1976   % Finer = R_c/W_s

Soil Weight: 50 grams   NOTE: 1 gram Tripolyphosphate defloculant added

TIME	ELAPSED TIME	R_a	R_c	% FINER	T°C	$D_{(mm)}$
2:00	0	—	—	—	—	—
2:15	15	10.5	8.0	16.0	20	0.0140
2:30	30	8.5	6.0	12.0	20	0.0105
2:45	45	6.5	4.0	8.0	20	0.0086
3:00	60	6.5	4.0	8.0	20	0.0075
3:15	75	5.0	2.5	5.0	20	0.0064
3:30	90	4.5	2.0	4.0	20	0.0056
3:45	105	4.0	1.5	3.0	20	0.0048
4:00	120	3.5	1.0	2.0	20	0.0042

% Passing 200 Mesh Sieve :

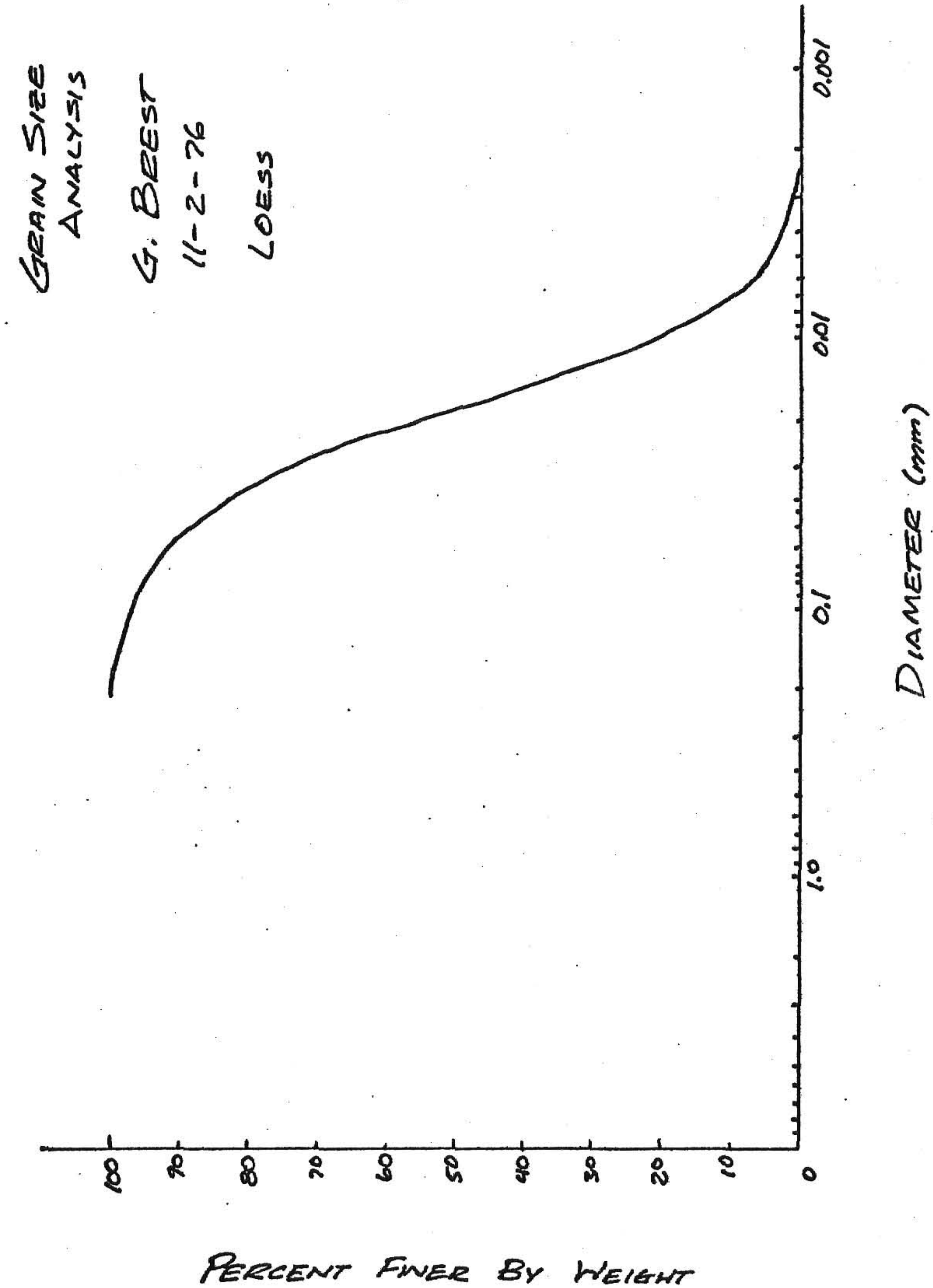
Wt. can + soil	55.69
Wt. can	53.19
Wt. soil	2.50

% Sand = 2.50/50.00

% Sand = 5 %

From Graph:

% Clay = 4%   % Silt = 91%


GRAIN SIZE ANALYSIS
G. BEEST
11-2-76
LOESS
PERCENT FINER BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
DIAMETER (mm)
1.0
0.1
0.01
0.001

SIEVE ANALYSIS

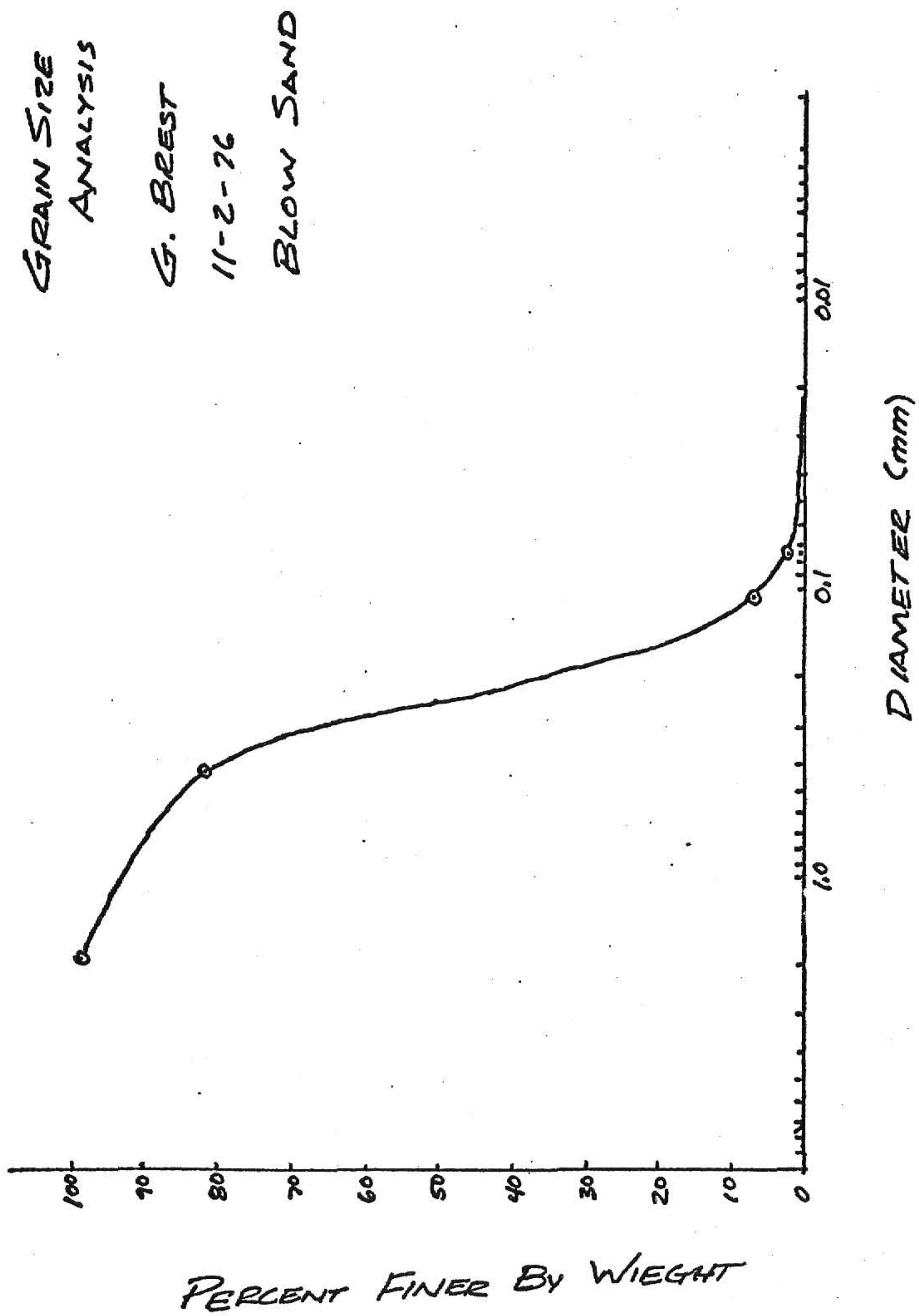
Soil: Blow Sand Run By: Gordon Brest

Location: Manhattan, Ks.

Date: 1 November 1976

SIEVE NO.	SIEVE OPENING (mm)	CUMULATED % RETAINED	% FINER
4	4.760	0.0	100.00
10	2.000	0.0	100.00
20	0.840	1.6	98.40
40	0.420	18.2	81.80
140	0.105	93.6	6.40
200	0.074	97.9	2.10
Pan	—	100.0	—

% Sand = 97.9% % Silt = 2.1% % Clay = 0%


GRAIN SIZE ANALYSIS
G. BREST
11-2-76
BLOW SAND
DIAMETER (mm)
0.01
0.1
1.0
PERCENT FINER BY WIEGHT
100
90
80
70
60
50
40
30
20
10
0

SIEVE ANALYSIS

Soil: River Sand

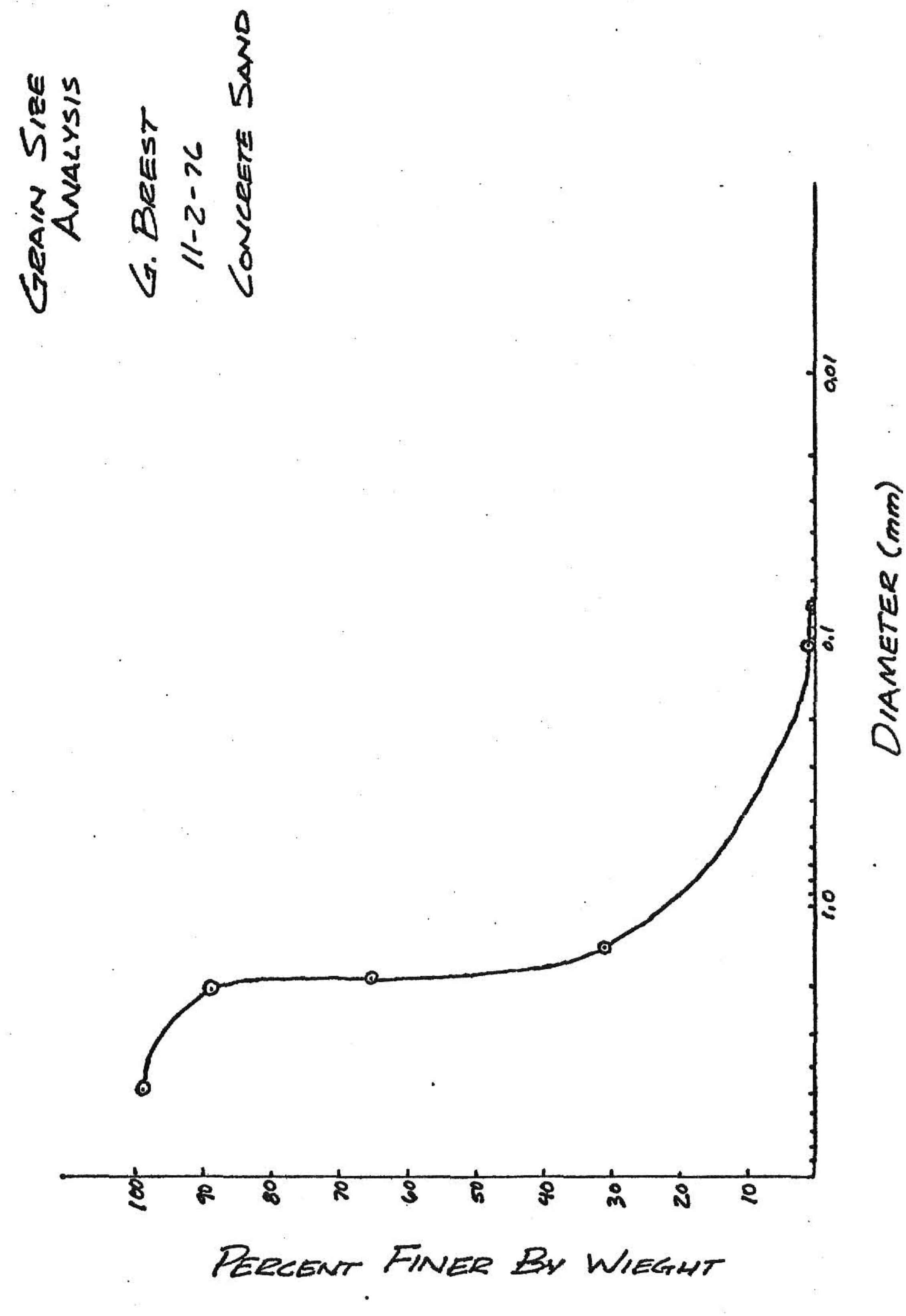
Run By: Gordon Brest

Location: Manhattan, Kansas

Date: 1 November 1976

SIEVE NO.	SIEVE OPENING (mm)	CUMULATED % RETAINED	% FINER
4	4.760	1.3	98.7
10	2.000	11.1	88.9
20	0.840	34.5	65.5
40	0.420	69.2	30.8
140	0.105	98.9	1.1
200	0.074	99.3	0.7
Pan	–	100.0	–

% Sand = 99.3% % Silt = 0.7% % Clay = 0%



Grain Sibe Analysis
G. Breest
11-2-76
Concrete Sand
0.01
0.1
1.0
Diameter (mm)
100
90
80
70
60
50
40
30
20
10
Percent Finer By Wieght

APPENDIX D

COMPACTION TEST

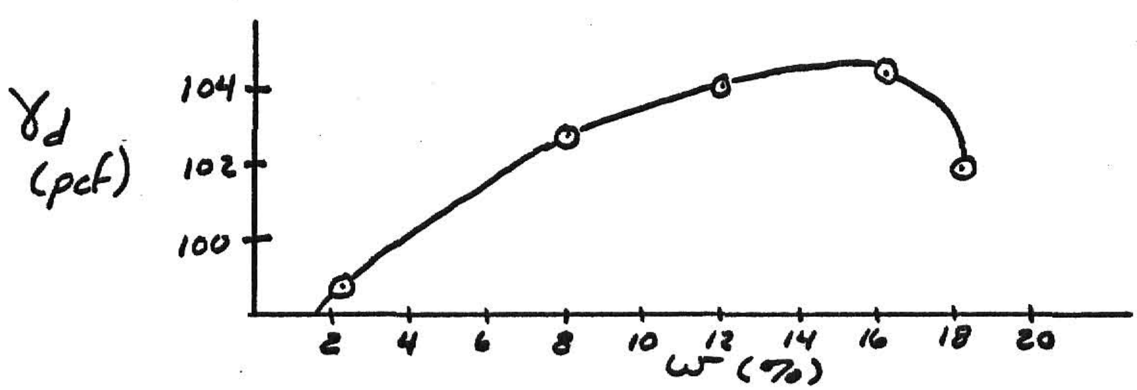
Project Asphalt Emulsions
Description of Soil Silt
Test Performed by Gordon Brest Date of Test 27 Aug 1976
Blows/Layer 25 No. of Layers 3 Wt. of Hammer 5.5 lb.
Mold Dimensions: Diam. 0.333 ft. Ht. 0.3833 ft. Vol. 1/30 cu. ft.

Water Content Determination

Sample no.	**1**	**2**	**3**	**4**	**5**	**6**
Moisture can no.	124	100	136	135	119	106
Wt. of can + wet soil	315.34	258.93	354.03	372.11	280.45	300.33
Wt. of can + dry soil	314.73	254.29	331.70	336.79	248.70	262.30
Wt. of water	0.61	4.64	22.33	35.32	31.75	38.03
Wt. of can	52.07	52.64	53.64	52.93	52.13	53.16
Wt. of dry soil	262.66	201.65	278.06	283.86	196.57	209.14
Water content, ω%	0.23	2.3	8.03	12.4	16.2	18.2

Density Determination

Assumed water content	1	2	5	10	15	20
Water content, ω%	0.23	2.3	8.03	12.4	16.2	18.2
Wt. of soil + mold	6110	6180	6328	6415	6480	6470
Wt. of mold	4650	4650	4650	4650	4650	4650
Wt. of soil in mold	1460	1530	1678	1765	1830	1820
Wet density, pcf	96.56	101.19	110.98	116.73	121.03	120.37
Dry density, γ pcf	96.34	98.92	102.73	103.86	104.16	101.84



Optimum moisture = 15% Maximum dry density = 10 4.4 pcf

COMPACTION TEST

Project Asphalt Emulsion

Description of Soil River sand

Test Performed by Gordon Brest Date of Test 20 October 1976

Blows/Layer 25 No. of Layers 3 Weight of Hammer 5.5 pounds

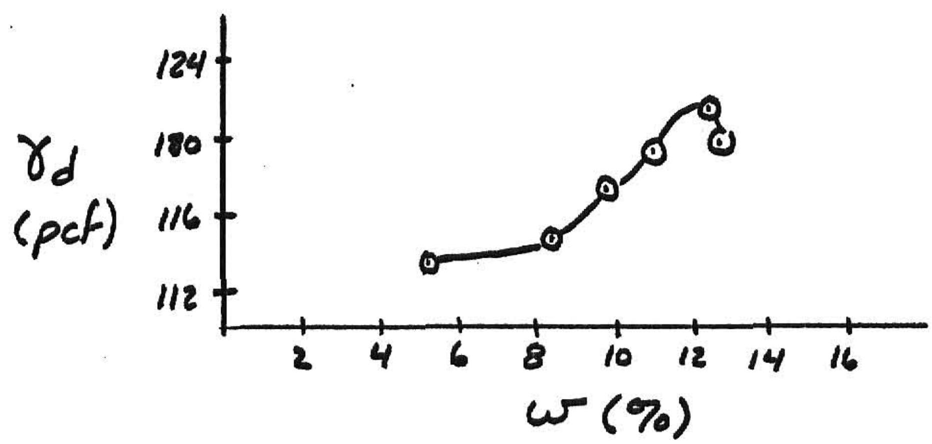
Mold Dimensions: Diameter 0.333 feet Ht. 0.3833 ft. Volume 1/30 cu. ft.

Water Content Determination

Moisture can no.	129	139	136	88	106	81
Wt. of can + wet soil	226.31	242.02	268.17	310.98	308.39	288.24
Wt. of can + dry soil	217.82	225.66	249.81	285.56	279.66	261.53
Wt. of water	8.49	16.36	18.36	25.42	28.73	26.71
Wt. of can	52.25	52.16	53.81	54.39	53.25	52.42
Wt. of dry soil	165.57	173.50	196.00	231.17	226.41	209.11
Water content, ω%	5.13	9.43	9.37	11.00	12.67	12.77

Density Determination

Wt. of soil + mold	6423	6523	6580	6630	6700	6673
Wt. of mold	4631	4631	4631	4631	4631	4631
Wt. of soil	1792	1892	1949	1999	2069	2042
Wet density, pcf	118.52	125.13	128.90	132.21	136.84	135.05
Dry density, γ pcf	112.74	114.35	117.86	119.11	121.45	119.76



Optimum moisture = 12.7% Maximum dry density = 121.5 pcf

COMPACTION TEST

Project Asphalt Emulsions

Description of Soil Blow Sand

Test Performed By Gordon Brest Date of Test 20 October 1976

Blows/Layer 25 No. of Layers 3 Wt. of Hammer 5.5 pounds

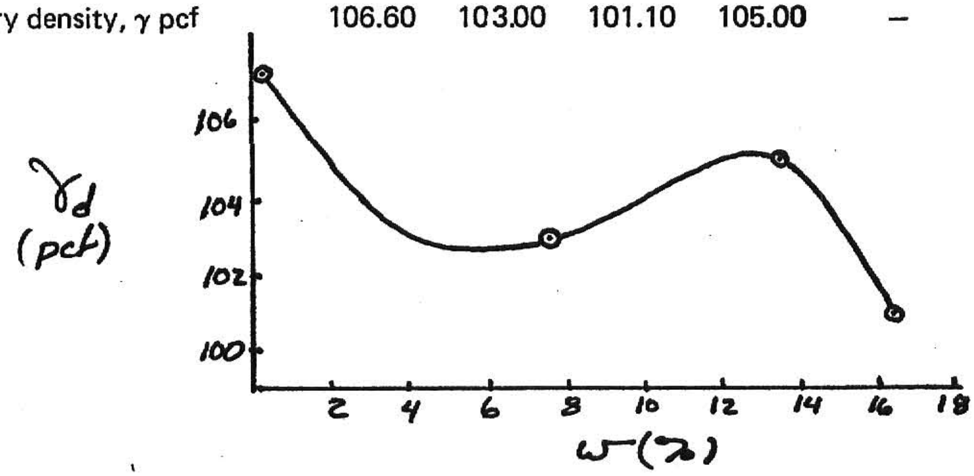
Mold Dimensions: Diam. 0.3333 ft. Ht. 0.3833 ft Vol. 1/30 cu. ft.

Water Content Determination

Sample no.	**1**	**2**	**3**	**4**	**5**	**6**
Moisture can no.	C3	22	12	3	–	–
Wt. of can + wet soil	143.29	146.27	137.22	155.23	–	–
Wt. of can + dry soil	142.95	138.39	123.11	140.96	–	–
Wt. of water	.34	7.88	14.11	14.27	–	–
Wt. of can	35.42	35.31	36.01	35.29	–	–
Wt. of dry soil	107.53	103.08	87.10	105.67	–	–
Water content, ω%	0.32	7.64	16.20	13.50	–	–

Density Determination

Sample no.	**1**	**2**	**3**	**4**	**5**	**6**
Assumed water content	0%	10%	15%	12%	–	–
Water content, ω%	0.32	7.64	16.20	13.50	–	–
Wt. of soil + mold	6.32	6.38	6.48	6.43	–	–
Wt. of mold	4.70	4.70	4.70	4.70	–	–
Wt. of soil in mold	3.56	3.70	3.92	3.97	–	–
Wet density, pcf	106.92	110.88	117.48	119.18	–	–
Dry density, γ pcf	106.60	103.00	101.10	105.00	–	–



Optimum moisture = 6.5% Maximum dry density = 103.00 pcf

COMPACTION TEST

Project Asphalt Emulsions

Description of Soil Concrete Sand

Test Performed By Gordon Brest Date of Test 20 October 1976

Blows/Layer 25 No. of Layers 3 Wt. of Hammer 5.5 pounds

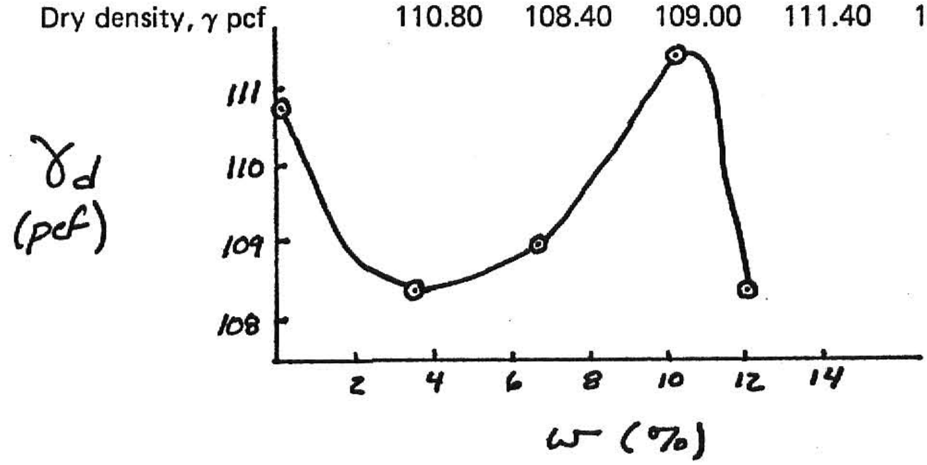
Mold Dimensions: Diam. 0.333 ft. Ht. 0.3833 ft. Vol. 1/30 cu. ft.

Water Content Determination

Sample no.	1	2	3	4	5	6
Moisture can no.	CS	12	22	20	C	—
Wt. of can + wet soil	191.15	137.30	124.00	129.92	129.77	—
Wt. of can + dry soil	190.39	133.80	118.53	121.13	119.18	—
Wt. of water	0.26	3.50	5.47	8.71	10.59	—
Wt. of can	34.46	36.02	35.35	34.83	35.14	—
Wt. of dry soil	156.43	97.73	83.18	86.30	84.04	—
Water content, ω%	.166	3.50	6.60	10.20	12.00	—

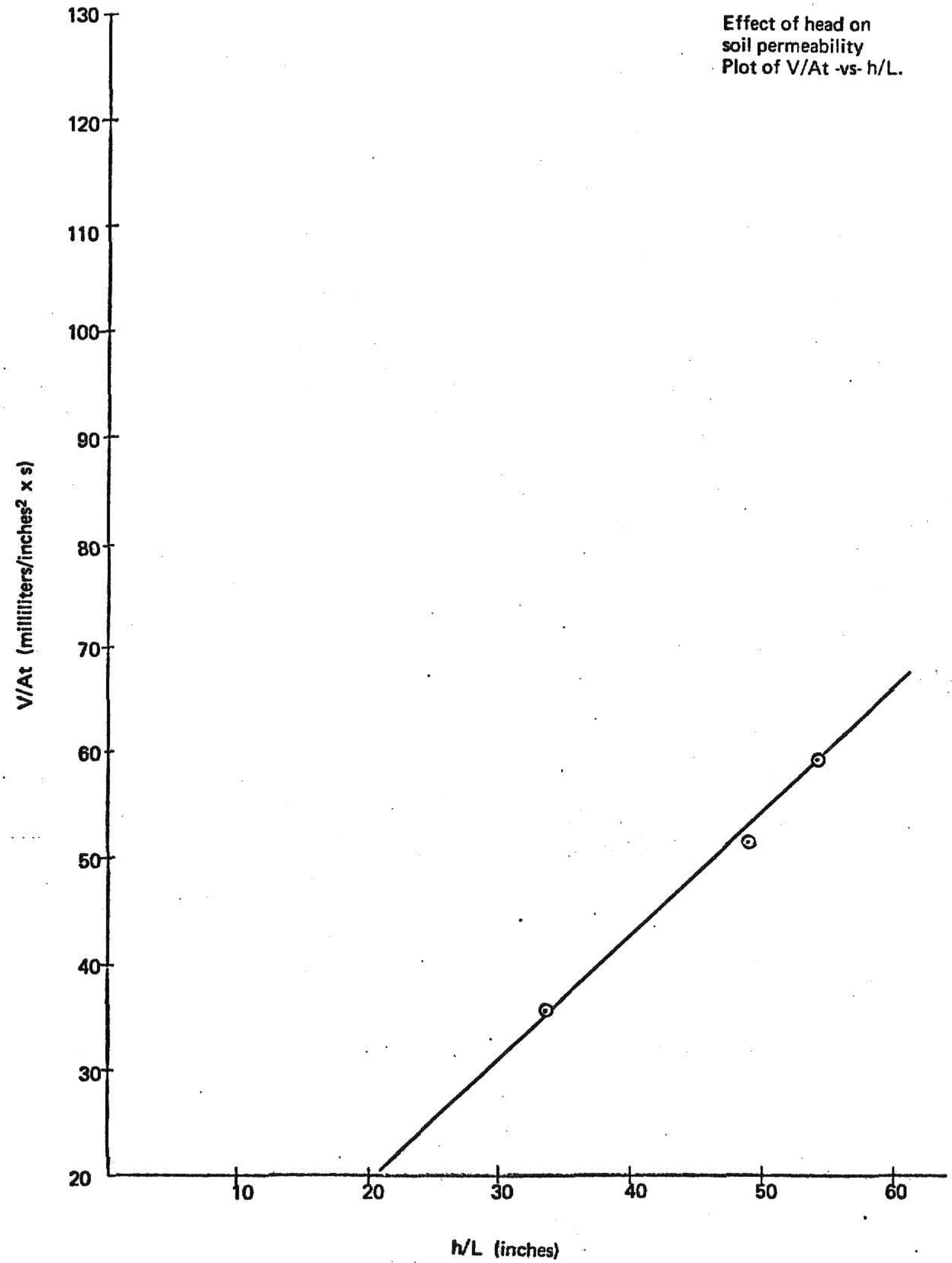
Density Determination

Sample no.	1	2	3	4	5	6
Assumed water content	0%	5%	10%	15%	20%	—
Water content, ω%	.166	3.50	6.60	10.20	12.00	—
Wt. of soil + mold	6.40	6.42	6.48	6.58	6.56	—
Wt. of mold	4.72	4.72	4.72	4.72	4.72	—
Wt. of soil in mold	3.70	3.74	3.87	4.09	4.05	—
Wet density, pcf	110.90	112.20	116.16	122.30	121.44	—
Dry density, γ pcf	110.80	108.40	109.00	111.40	108.40	—



Optimum moisture = 3.0% Maximum dry density = 108.4 pcf

APPENDIX E


Effect of head on
soil permeability
Plot of V/At -vs- h/L.
130
120
110
100
90
80
70
60
50
40
30
20
V/At (milliliters/inches² x s)
10
20
30
40
50
60
h/L (inches)

APPENDIX F

By drying a certain volume of emulsion, the percent residue of the SS-1h emulsion can be ascertained:

Wt. of Can	53.60 grams
Volume of emulsion	37.00 milliliters
Wt. of can + emulsion	86.65 grams
Wt. of emulsion	33.05 grams
Wt. of can + dry asphalt	75.80 grams
Wt. of asphalt	22.20 grams
Wt. of water	10.85 grams

R = percent residue = 1 - Wt. of water/Wt. of emulsion

$R = 1 - (10.85)/(33.05)$

$R = 67.17\%$

KANSAS SPECIFICATION SS-1H

TEST RESULTS

Specific Gravity 60°/60°F.			1.0059
Viscosity Saybolt Rurol at	122	°F., sec.	97
Residue from Distillation, per cent			66.5
Oil Distillate, per cent by volume			trace
Settlement, 5 days, per cent difference			0.1
Demulsibility:			
50 ml. of 0.1 N Calcium Chloride, per cent			
35 ml. of 0.02 N Calcium Chloride, per cent			89.5
Sieve test, per cent retained			0,01
Coating test			
Cement Mixing Test, per cent			
Modified Miscibility with water, maximum per cent difference			
Particle charge			
pH			
CHARACTERISTICS OF DISTILLATION RESIDUE:			
Penetration 77°F., 100 grams, 5 sec.			94
Ductility at 77°F., cm.			100+
Float test at 140°F., sec.			
Soluble in Trichloroethylene, percent			99.84
Viscosity, S. F.	77	°F., Sec.	31.5

KANSAS SPECIFICATION RS-1H

TEST RESULTS

Specific Gravity 60°/60°F.			1.0059
Viscosity Saybolt Rurol at	122	°F., sec.	97
Residue from Distillation, per cent			68.25
Oil Distillate, per cent by volume			trace
Settlement, 5 days, per cent difference			0.1
Demulsibility:			
50 ml. of 0.1 N Calcium Chloride, per cent			
35 ml. of 0.02 N Calcium Chloride, per cent			89.5
Sieve test, per cent retained			0.01
Coating test			
Cement Mixing Test, per cent			
Modified Miscibility with water, maximum per cent difference			
Particle charge			
pH			
CHARACTERISTICS OF DISTILLATION RESIDUE:			
Penetration 77°F., 100 grams, 5 sec.			94
Ductility at 77°F., cm.			100+
Float test at 140°F., sec.			
Soluble in Trichloroethylene, percent			99.84
Viscosity, S. F.		°F., Sec.	

APPENDIX G

CALCULATION OF WEIGHTS FOR SILTY-SAND

Given:

x = variable asphalt content

$\omega_{o_{soil}}$ = 15%

$\gamma_{d_{soil}}$ = 104.4 pcf

% proctor = 90%

volume = 0.00568 ft^3 (1.608 x 10^{-4} m^3)

R = 67.2% (SS-1h anionic)

W_s = [1 - x (1 + $\omega_{o_{soil}}$)] [($\gamma_{d_{soil}}$) (% proctor) (volume)]

W_s = [1 - x (1.15)] [(104.5) (0.90) (0.00568) (453.6)]

W_s = (242.31 - 278.66 (x)) grams

W_{eml} = [x (1 + $\omega_{o_{soil}}$) (% proctor) ($\gamma_{d_{soil}}$) (volume)] [1/R]

W_{eml} = [x (1.15) (0.90) (104.5) (0.00568) (453.6)] [1/0.672]

W_{eml} = (414.68 x) grams

W_w = [($\omega_{o_{soil}}$) - ((x) (1 - R) (1 + $\omega_{o_{soil}}$)/R)] (% proctor) ($\gamma_{d_{soil}}$) (volume)

W_w = [(0.15) - (x (0.328) (1.15)/(0.672))] (0.90) (104.5) (0.00568) (453.6)

W_w = (36.35 - 136.01 x) grams

@x = 0

W_s = 0.5342 lb. (242.31 grams)

W_w = 0.0801 lb. (36.35 grams)

W_T = 0.6143 lb. (278.66 grams)

CALCULATION OF WEIGHTS FOR LOESS:

Given:

x = variable asphalt content

$\omega_{o_{soil}}$ = 12.0%

$\gamma_{d_{soil}}$ = 104.5 pcf

% proctor = 90%

volume = 0.00568 ft^3 ($1.608 \times 10^{-4} m^3$)

R = 67.2% (SS-1h anionic)

$W_s = [1 - x\,(1 + \omega_{o_{soil}})]\ [(\gamma_{d_{soil}})\ (\%\ \text{proctor})\ (\text{volume})]$

$W_s = [1 - x\,(1.12)]\ [(104.5)\ (0.90)\ (0.00568)\ (453.6)]$

$W_s = (242.31 - 271.39\,x)$ grams

$W_{eml} = [x\,(1 + \omega_{o_{soil}})\ (\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{volume})]\ [1/R]$

$W_{eml} = [x\,(1.12)\ (0.90)\ (104.5)\ (0.00568)\ (453.6)]\ [1/0.672]$

$W_{eml} = (403.86\,x)$ grams

$W_w = [(\omega_{o_{soil}}) - ((x)\,(1 - R)\,(1 + \omega_{o_{soil}})/R)]\ (\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{volume})$

$W_w = [(0.12) - ((x)\,(1 - 0.672)\,(1.12)/(0.672))]\ (0.90)\ (104.5)\ (0.00568)\ (435.6)$

$W_w = (29.08 - 132.47\,x)$ grams

@x = 0

W_s = 0.5342 lb. (242.31 grams)

W_w = 0.0641 lb. (29.08 grams)

W_T = 0.5983 lb. (271.39 grams)

CALCULATION OF WEIGHTS FOR RIVER SAND

Given:

x = variable

$\omega_{o_{soil}}$ = 12.67%

$\gamma_{d_{soil}}$ = 121.45 pcf

% proctor = 90%

volume = 0.00568 ft^3 ($1.608 \times 10^{-4} m^3$)

R = 67.2% (SS-1h anionic)

W_s = [1 - x (1 + $\omega_{o_{soil}}$)] [($\gamma_{d_{soil}}$) (% proctor) (volume)]

W_s = [1 - x (1.1267)] [(121.45) (0.90) (0.00568) (453.6)]

W_s = [1 - x (1.1267)] [281.62]

W_{eml} = [x (1 + $\omega_{o_{soil}}$) (% proctor) ($\gamma_{d_{soil}}$) (volume)] [1/R]

W_{eml} = [x (1.1267) (0.9) (121.45) (0.00568) (453.6)] [1/0.672]

W_{eml} = (472.17) x

W_w = [($\omega_{o_{soil}}$) - ((x) (1 - R) (1 + $\omega_{o_{soil}}$)/R)] (% proctor) ($\gamma_{d_{soil}}$) (volume)

W_w = [(0.1267) - (x (1 - 0.672) (1.1267)/(0.672))] (0.90) (121.45) (0.00568) (453.6)

W_w = [(0.1267) - (0.55) x] [281.62]

@x = 0

W_s = 0.6209 lb. (281.62 grams)

W_w = 0.0787 lb. (35.68 grams)

W_T = 0.6995 lb (317.30 grams)

VALUES FOR WEIGHTS USING BLOW SAND:

Given:

x = variable asphalt content

$\omega_{o_{soil}}$ = 2% (not using optimum due to difficulty in forming molds.)

$\gamma_{d_{soil}}$ = 100 pcf

% proctor = 90%

volume = 0.00568 ft^3 (1.608 x 10^{-4} m^3)

R = 67.2% (SS-1h anionic)

$W_s = [1 - x\,(1 + \omega_{o_{soil}})]\ [(\gamma_{d_{soil}})\ (\%\ \text{proctor})\ (\text{volume})]$

$W_s = [1 - x\,(1.02)]\ [(100)]\ (0.90)\ (0.00568)\ (453.6)]$

$W_s = [231.88 - 236.52\,x]$ grams

$W_{eml} = [x\,(1 + \omega_{o_{soil}})\ (\%\ \text{proctor})\ (\gamma_{d_{soil}})\ (\text{volume})]\ [1/R]$

$W_{eml} = [x\,(1.02)\ (0.90)\ (100)\ (0.00568)\ (453.6)]\ [1/0.672]$

$W_{eml} = (351.96\,x)$ grams

$W_w = [(\omega_{o_{soil}}) - ((x)\,(1 - R)\,(1 + \omega_{o_{soil}})/R)]\ (\%\text{proctor})\ (\gamma_{d_{soil}})\ (\text{volume})$

$W_w = [(0.02 - (x\,(1 - 0.672)\,(1.02)/(0.672))]\ (0.90)\ (100)\ (0.00568)\ (453.6)$

$W_w = (4.64 - 115.44\,(x))$ grams

@x = 0

W_s = 0.5112 lb. (231.88 grams)

W_w = 0.0102 lb. (4.64 grams)

W_T = 0.5214 lb. (236.52 grams)

APPENDIX H

Permeability Constant Determination:

$k = VL/thA$

$k = (V\ ml)\ (2\ inches)\ (4)\ (1l/1000\ ml)\ (1728\ inches^3/feet^3)\ (24\ hrs/day)/$

$(t\ min)\ (97\ inches)\ (\pi)\ (2.5\ inches)^2\ (28.316l/feet^3)\ (1\ hr/60\ min)$

$k = (V\ ml/t\ min)\ (0.3691)$

Volume of sample:

$(2\ inches) \times \pi\ (2.5\ inches)^2/4) \times (1\ foot^3/1728\ inches^3) = 0.00568\ feet^3\ (1.608 \times 10^{-4}\ m^3)$

DATA WORK SHEET

SILTY SAND

4 OCT 1976 5% ASPHALT 26°C PROCEDURE II

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	473.55	228.17	29.52	20.70	751.94	10.0	77.5	2.86 (8.41)
2	473.55	228.17	29.52	20.70	751.94	10.0	37.5	1.38 (4.06)
3	473.58	228.17	29.52	20.70	751.97	10.0	40.5	1.49 (4.38)
4	473.50	228.17	29.52	20.70	751.89	10.0	42.0	1.55 (4.56)
5	473.45	228.17	29.52	20.70	751.84	10.0	39.6	1.46 (4.29)
6	473.53	228.17	29.52	20.70	751.92	10.0	36.2	1.34 (3.94)

k_{avg} = 1.47 (4.32)
k_{20} = 1.30 (3.83)

DATA WORK SHEET

SILTY SAND

2 OCT 1976   5% ASPHALT   22°C   PROCEDURE III

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	473.44	228.17	29.52	20.70	751.83	6.15	93	5.49 (16.14)
2	473.44	228.17	29.52	20.70	751.87	6.15	7	0.41 (1.21)
3	473.44	228.17	29.52	20.70	751.84	6.15	28	1.48 (4.35)
4	473.44	228.17	29.52	20.70	751.87	6.10	39	2.33 (6.85)
5	473.44	228.17	29.52	20.70	751.89	6.10	42	2.51 (7.38)
6	473.44	228.17	29.52	20.70	751.92	6.10	40	2.39 (7.03)

k_{avg} = 2.18 (6.41)
k_{20} = 2.10 (6.17)

DATA WORK SHEET

SILTY SAND

8 SEPT 1976   0% ASPHALT   27°C   PROCEDURE III

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	53.68	242.14	36.32	0	332.14	16.0	123.8	2.86 (8.41)
2	52.61	242.14	36.32	0	331.07	15.72	149	3.50 (10.49)
3	52.12	242.14	36.32	0	330.58	15.01	187	4.60 (13.52)
4	52.59	242.14	36.32	0	331.05	15.34	174.2	4.19 (12.32)
5	53.69	242.14	36.32	0	332.15	15.17	205.7	5.00 (14.70)
6	52.08	242.14	36.32	0	330.54	14.83	170.09	4.25 (12.49)

k_{avg} = 4.14 (12.17)
k_{20} = 3.59 (10.55)

DATA WORK SHEET

SILTY SAND

29 OCT 1976 | 2% ASPHALT | 24°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	474.00	236.52	33.59	8.28	752.39	5.0	35.5	2.62 (7.70)
2	474.10	236.52	33.59	8.28	752.49	5.0	35.8	2.64 (7.76)
3	474.20	236.52	33.59	8.28	752.59	5.0	38.7	2.86 (8.41)
4	474.30	236.52	33.59	8.28	752.69	5.0	33.3	2.46 (7.23)
5	474.20	236.52	33.59	8.28	752.59	5.0	33.7	2.49 (7.32)
6	474.10	236.52	33.59	8.28	752.49	5.0	35.8	2.64 (7.76)

k_{avg} = 2.60 (7.64)
k_{20} = 2.40 (7.06)

DATA WORK SHEET

SILTY SAND

8 NOV 1976 3% ASPHALT 26°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	474.00	233.73	32.24	12.42	752.39	5.0	23.2	1.71 (5.03)
2	474.00	233.73	32.24	12.42	752.39	5.0	18.6	1.37 (4.03)
3	474.00	233.73	32.24	12.42	752.39	5.0	31.5	2.33 (6.85)
4	474.00	233.73	32.24	12.42	752.39	5.0	25.2	1.86 (5.47)
5	474.00	233.73	32.24	12.42	752.39	void	void	void
6	474.00	233.73	32.24	12.42	752.39	void	void	void

k_{avg} = 1.82 (5.35)
k_{20} = 1.61 (4.74)

DATA WORK SHEET

SILTY SAND

29 OCT 1976 4% ASPHALT 22°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	473.87	230.95	30.88	16.56	752.26	void	void	void
2	473.87	230.95	30.88	16.56	752.26	5.0	3.7	0.27 (0.79)
3	473.87	230.95	30.88	16.56	752.26	5.0	2.5	0.18 (0.53)
4	473.87	230.95	30.88	16.56	752.26	5.0	8.9	0.66 (1.94)
5	473.87	230.95	30.88	16.56	752.26	5.0	7.3	0.54 (1.59)
6	473.87	230.95	30.88	16.56	752.26	void	void	void

k_{avg} = 0.41 (1.21)
k_{20} = 0.39 (1.16)

DATA WORK SHEET

SILTY SAND

7 OCT 1976 5% ASPHALT 25 °C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	473.48	228.17	29.52	20.70	751.87	17.0	31.9	0.69 (2.03)
2	473.48	228.17	29.52	20.70	751.79	17.0	21.5	0.47 (1.38)
3	473.48	228.17	29.52	20.70	751.85	17.0	23.0	0.50 (1.47)
4	473.48	228.17	29.52	20.70	751.83	17.0	43.2	0.94 (2.76)
5	473.48	228.17	29.52	20.70	751.90	17.0	21.9	0.48 (1.41)
6	473.48	228.17	29.52	20.70	751.90	17.0	29.0	0.63 (1.85)

k_{avg} = 0.58 (1.71)
k_{20} = 0.52 (1.54)

DATA WORK SHEET

SILTY SAND

13 OCT 1976 6% ASPHALT 21°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	473.56	225.38	28.16	24.85	751.95	2.31	9.6	1.41 (4.15)
2	473.56	225.38	28.16	24.85	752.01	2.27	9.0	1.36 (4.00)
3	473.56	225.38	28.16	24.85	751.97	2.23	15.2	2.35 (6.91)
4	473.56	225.38	28.16	24.85	751.92	2.20	9.4	1.49 (4.38)
5	473.56	225.38	28.16	24.85	752.03	2.16	6.4	1.04 (3.06)
6	473.56	225.38	28.16	24.85	751.95	void	void	void

k_{avg} = 1.32 (3.88)
k_{20} = 1.30 (3.81)

DATA WORK SHEET

SILTY SAND

14 OCT 1976 7% ASPHALT 23°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	471.44	222.60	26.80	28.99	749.83	5.0	33.1	2.44 (7.71)
2	471.44	222.60	26.80	28.99	749.83	5.0	21.9	1.62 (4.76)
3	471.44	222.60	26.80	28.99	749.83	5.0	19.5	1.44 (4.23)
4	471.44	222.60	26.80	28.99	749.79	5.0	21.9	1.62 (4.76)
5	471.44	222.60	26.80	28.99	749.88	5.0	22.9	1.69 (4.97)
6	471.44	222.60	26.80	28.99	749.84	5.0	14.0	1.03 (3.03)

k_{avg} = 1.59 (4.67)
k_{20} = 1.50 (4.41)

DATA WORK SHEET

SILTY SAND

14 FEB 1977 8% ASPHALT 21°C PROCEUDRE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	219.81	25.09	33.50	750.40	5.0	20.5	1.51 (4.44)
2	472.00	219.81	25.09	33.50	750.40	5.0	25.5	1.88 (5.53)
3	472.00	219.81	25.09	33.50	750.40	5.0	90.0	6.64 (19.5)
4	472.00	219.81	25.09	33.50	750.40	5.0	23.2	1.71 (5.03)
5	472.00	219.81	25.09	33.50	750.40	5.0	19.6	1.45 (4.26)
6	472.00	219.81	25.09	33.50	750.40	5.0	22.1	1.63 (4.79)

k_{avg} = 1.68 (4.94)
k_{20} = 1.64 (4.82)

DATA WORK SHEET

SILTY SAND

15 FEB 1977 | 10% ASPHALT | 20°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	214.24	22.29	41.87	750.40	5.0	35.5	2.62 (7.70)
2	472.00	214.24	22.29	41.87	750.40	5.0	17.9	1.32 (3.88)
3	472.00	214.24	22.29	41.87	750.40	5.0	18.2	1.34 (3.94)
4	472.00	214.24	22.29	41.87	750.40	5.0	6.8	0.50 (1.47)
5	472.00	214.24	22.29	41.87	750.40	5.0	17.3	1.28 (3.76)
6	472.00	214.24	22.29	41.87	750.40	5.0	17.1	1.26 (3.70)

k_{avg} = 1.30 (3.82)
k_{20} = 1.30 (3.82)

DATA WORK SHEET

SILTY SAND

15 FEB 1977 14% ASPHALT 20°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	203.11	16.68	58.61	750.40	5.0	4.5	0.33 (0.97)
2	472.00	203.11	16.68	58.61	750.40	5.0	5.3	0.39 (1.15)
3	472.00	203.11	16.68	58.61	750.40	5.0	13.5	1.00 (2.94)
4	472.00	203.11	16.68	58.61	750.40	5.0	0.8	0.06 (0.02)
5	472.00	203.11	16.68	58.61	750.40	5.0	5.6	0.41 (1.21)
6	472.00	203.11	16.68	58.61	750.40	5.0	4.7	0.35 (1.03)

k_{avg} = 0.37 (1.09)
k_{20} = 0.37 (1.09)

DATA WORK SHEET

SILTY SAND

14 FEB 1977 | 16% ASPHALT | 21°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	197.54	13.87	66.99	750.40	5.0	3.0	0.22 (0.65)
2	472.00	197.54	13.87	66.99	750.40	5.0	3.1	0.23 (0.68)
3	472.00	197.54	13.87	66.99	750.40	5.0	3.4	0.25 (0.73)
4	472.00	197.54	13.87	66.99	750.40	5.0	14.2	1.05 (3.09)
5	472.00	197.54	13.87	66.99	750.40	5.0	0.3	0.12 (0.35)
6	472.00	197.54	13.87	66.99	750.40	5.0	3.1	0.23 (0.68)

k_{avg} = 0.23 (0.68)
k_{20} = 0.23 (0.68)

DATA WORK SHEET

LOESS

23 NOV 1976 2% ASPHALT 25°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	236.88	26.43	8.08	743.39	5.0	16.9	1.25 (3.67)
2	472.00	236.88	26.43	8.08	743.39	5.0	19.2	1.42 (4.17)
3	472.00	236.88	26.43	8.08	743.39	5.0	155.0	11.44 (3.36)
4	472.00	236.88	26.43	8.08	743.39	5.0	12.0	0.89 (2.62)
5	472.00	236.88	26.43	8.08	743.39	5.0	5.5	0.41 (1.21)
6	472.00	236.88	26.43	8.08	743.39	5.0	16.3	1.20 (3.53)

k_{avg} = 1.19 (3.50)
k_{20} = 1.08 (3.17)

DATA WORK SHEET

LOESS

23 NOV 1976 4% ASPHALT 29°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	231.45	23.78	16.15	743.39	5.0	8.6	0.63 (1.85)
2	472.00	231.45	23.78	16.15	743.39	5.0	13.0	0.96 (2.82)
3	472.00	231.45	23.78	16.15	743.39	5.0	12.8	0.94 (2.76)
4	472.00	231.45	23.78	16.15	743.39	5.0	9.5	0.70 (2.06)
5	472.00	231.45	23.78	16.15	743.39	5.0	13.0	0.96 (2.82)
6	472.00	231.45	23.78	16.15	743.39	5.0	11.8	0.87 (2.56)

k_{avg} = 0.87 (2.56)
k_{20} = 0.72 (2.12)

DATA WORK SHEET

LOESS

23 NOV 1976 6% ASPHALT 27°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	226.03	21.13	24.23	743.39	5.0	8.2	0.61 (1.79)
2	472.00	226.03	21.13	24.23	743.39	5.0	12.1	0.89 (2.62)
3	472.00	226.03	21.13	24.23	743.39	5.0	13.9	1.03 (3.03)
4	472.00	226.03	21.13	24.23	743.39	5.0	9.2	0.68 (2.00)
5	472.00	226.03	21.13	24.23	743.39	5.0	14.2	1.05 (3.09)
6	472.00	226.03	21.13	24.23	743.39	5.0	13.2	0.97 (2.85)

k_{avg} = 0.89 (2.85)
k_{20} = 0.77 (2.26)

DATA WORK SHEET

LOESS

3 DEC 1976 | 8% ASPHALT | 26°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability inches/day (cm/sec x 10^{-5}) (9)
1	472.00	220.60	18.48	32.31	743.39	5.0	6.1	0.45 (1.32)
2	472.00	220.60	18.48	32.31	743.39	5.0	20.5	1.51 (4.44)
3	472.00	220.60	18.48	32.31	743.39	5.0	11.1	0.82 (2.41)
4	472.00	220.60	18.48	32.31	743.39	5.0	6.0	0.44 (1.29)
5	472.00	220.60	18.48	32.31	743.39	5.0	9.0	0.66 (1.94)
6	472.00	220.60	18.48	32.31	743.39	5.0	10.0	0.74 (2.18)

k_{avg} = 0.67 (1.97)
k_{20} = 0.59 (1.73)

DATA WORK SHEET

LOESS

3 DEC 1976 | 10% ASPHALT | 28°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	215.17	15.83	40.39	743.39	5.0	5.6	0.41 (1.21)
2	472.00	215.17	15.83	40.39	743.39	5.0	7.0	0.52 (1.53)
3	472.00	215.17	15.83	40.39	743.39	5.0	6.1	0.45 (1.32)
4	472.00	215.17	15.83	40.39	743.39	5.0	6.1	0.46 (1.35)
5	472.00	215.17	15.83	40.39	743.39	–	–	–
6	472.00	215.17	15.83	40.39	743.39	–	–	–

k_{avg} = 0.46 (1.35)
k_{20} = 0.39 (1.15)

DATA WORK SHEET

LOESS

7 JAN 1977 | 10% ASPHALT | 22°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	473.00	215.18	15.41	40.81	744.40	5.0	3.0	0.22 (0.65)
2	473.00	215.18	15.41	40.81	744.40	5.0	6.6	0.49 (1.44)
3	473.00	215.18	15.41	40.81	744.40	5.0	6.5	0.48 (1.41)
4	473.00	215.18	15.41	40.81	744.40	5.0	3.5	0.26 (0.76)
5	473.00	215.18	15.41	40.81	744.40	5.0	5.9	0.44 (1.29)
6	473.00	215.18	15.41	40.81	744.40	5.0	4.9	0.36 (1.06)

k_{avg} = 0.38 (1.12)
k_{20} = 0.36 (1.06)

DATA WORK SHEET

LOESS

7 JAN 1977   12% ASPHALT   19°C   PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	473.00	209.75	12.67	48.97	744.40	10.0	15.3	0.56 (1.65)
2	473.00	209.75	12.67	48.97	744.40	10.0	14.9	0.55 (1.62)
3	473.00	209.75	12.67	48.97	744.40	10.0	21.0	0.76 (2.23)
4	473.00	209.75	12.67	48.97	744.40	10.0	7.0	0.26 (0.76)
5	473.00	209.75	12.67	48.97	744.40	10.0	20.0	0.74 (2.18)
6	473.00	209.75	12.67	48.97	744.40	10.0	16.0	0.59 (1.73)

$k_{avg} = 0.61$ (1.79)
$k_{20} = 0.63$ (1.85)

DATA WORK SHEET

LOESS

9 FEB 1977 14% ASPHALT 20°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	204.32	9.94	57.14	743.40	10.0	3.8	0.14 (0.41)
2	472.00	204.32	9.94	57.14	743.40	10.0	2.8	0.10 (0.29)
3	472.00	204.32	9.94	57.14	743.40	10.0	1.9	0.07 (0.21)
4	472.00	204.32	9.94	57.14	743.40	10.0	3.4	0.13 (0.38
5	472.00	204.32	9.94	57.14	743.40	10.0	5.6	0.21 (0.62)
6	472.00	204.32	9.94	57.14	743.40	10.0	3.1	0.11 (0.32)

k_{avg} = 0.12 (0.35)
k_{20} = 0.12 (0.35)

DATA WORK SHEET

LOESS

9 FEB 1977 16% ASPHALT 19°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	198.89	7.21	65.30	743.40	10.0	1.2	0.04 (0.12)
2	472.00	198.89	7.21	65.30	743.40	10.0	0.8	0.03 (0.09)
3	472.00	198.89	7.21	65.30	743.40	10.0	1.1	0.04 (0.12)
4	472.00	198.89	7.21	65.30	743.40	10.0	0.6	0.02 (0.06)
5	472.00	198.89	7.21	65.30	743.40	10.0	2.3	0.08 (0.24)
6	472.00	198.89	7.21	65.30	743.40	10.0	0.1	0.004 (0.01)

k_{avg} = 0.03 (0.09)
k_{20} = 0.03 (0.09)

DATA WORK SHEET

RIVER SAND

12 NOV 1976 — 2% ASPHALT — 20°C — PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	474.00	275.27	32.58	9.44	791.30	Asphalt did not break		
2	474.00	275.27	32.58	9.44	791.30	Asphalt did not break		
3	474.00	275.27	32.58	9.44	791.30	Asphalt did not break		
4	474.00	275.27	32.58	9.44	791.30	Asphalt did not break		
5	474.00	275.27	32.58	9.44	791.30	Asphalt did not break		
6	474.00	275.27	32.58	9.44	791.30	Asphalt did not break		

$k_{avg} = \infty$
$k_{20} = \infty$

DATA WORK SHEET

BLOW SAND

23 NOV 1976 — 2% ASPHALT — 25°C — PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	227.15	2.33	7.04	708.52	Too permeable to collect data		
2	472.00	227.15	2.33	7.04	708.52	Too permeable to collect data		
3	472.00	227.15	2.33	7.04	708.52	Too permeable to collect data		
4	472.00	227.15	2.33	7.04	708.52	Too permeable to collect data		
5	472.00	227.15	2.33	7.04	708.52	Too permeable to collect data		
6	472.00	227.15	2.33	7.04	708.52	Too permeable to collect data		

$k_{avg} = \infty$
$k_{20} = \infty$

DATA WORK SHEET

BLOW SAND

2 DEC 1976 | 4% ASPHALT | 20°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	222.05	9.12	14.63	717.80	Too permeable to collect data		
2	472.00	222.05	9.12	14.63	717.80	Too permeable to collect data		
3	472.00	222.05	9.12	14.63	717.80	Too permeable to collect data		
4	472.00	222.05	9.12	14.63	717.80	Too permeable to collect data		
5	472.00	222.05	9.12	14.63	717.80	Too permeable to collect data		
6	472.00	222.05	9.12	14.63	717.80	Too permeable to collect data		

$k_{avg} = \infty$
$k_{20} = \infty$

DATA WORK SHEET

BLOW SAND

2 DEC 1976 | 6% ASPHALT | 20°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	217.13	6.72	21.95	717.80	Too permeable to collect data		
2	472.00	217.13	6.72	21.95	717.80	Too permeable to collect data		
3	472.00	217.13	6.72	21.95	717.80	Too permeable to collect data		
4	472.00	217.13	6.72	21.95	717.80	Too permeable to collect data		
5	472.00	217.13	6.72	21.95	717.80	Too permeable to collect data		
6	472.00	217.13	6.72	21.95	717.80	Too permaable to collect data		

$k_{avg} = \infty$
$k_{20} = \infty$

DATA WORK SHEET

BLOW SAND

2 DEC 1976 8% ASPHALT 20°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,I}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	212.22	4.32	29.26	717.80	Too permeable to collect data		
2	472.00	212.22	4.32	29.26	717.80	Too permeable to collect data		
3	472.00	212.22	4.32	29.26	717.80	Too permeable to collect data		
4	472.00	212.22	4.32	29.26	717.80	Too permeable to collect data		
5	472.00	212.22	4.32	29.26	717.80	Too permeable to collect data		
6	472.00	212.22	4.32	29.26	717.80	Too permeable to collect data		

$k_{avg} = \infty$
$k_{20} = \infty$

DATA WORK SHEET

BLOW SAND

2 DEC 1976   10% ASPHALT   20°C   PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	297.30	1.92	36.58	717.80	Too permeable to collect data		
2	472.00	207.30	1.92	36.58	717.80	Too permeable to collect data		
3	472.00	207.30	1.92	36.58	717.80	Too permeable to collect data		
4	472.00	207.30	1.92	36.58	717.80	Too permeable to collect data		
5	472.00	207.30	1.92	36.58	717.80	Too permeable to collect data		
6	472.00	207.30	1.92	36.58	717.80	Too permeable to collect data		

$k_{avg} = \infty$
$k_{20} = \infty$

DATA WORK SHEET

BLOW SAND

2 DEC 1976 | 20% ASPHALT | 20°C | PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	182.70	–	43.90	698.60	Too permeable to collect data		
2	472.00	182.70	–	43.90	698.60	Too permeable to collect data		
3	472.00	182.70	–	43.00	698.60	Too permeable to collect data		
4	472.00	182.70	–	43.00	698.60	Too permeable to collect data		
5	472.00	182.70	–	43.00	698.60	Too permeable to collect data		
6	472.00	182.70	–	43.00	698.60	Too permeable to collect data		

$k_{avg} = \infty$

$k_{20} = \infty$

DATA WORK SHEET

BLOW SAND

2 DEC 1976 30% ASPHALT 20°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	$W_{em\,l}$ in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	472.00	158.10	–	51.22	681.32	Too permeable to collect data		
2	472.00	158.10	–	51.22	681.32	Too permeable to collect data		
3	472.00	158.10	–	51.22	681.32	Too permeable to collect data		
4	472.00	158.10	–	51.22	681.32	Too permeable to collect data		
5	472.00	158.10	–	51.22	681.32	Too permeable to collect data		
6	472.00	158.10	–	51.22	681.32	Too permeable to collect data		

$k_{avg} = \infty$
$k_{20} = \infty$

DATA WORK SHEET

SILTY SAND

27 OCT 1976 7% ASPHALT 21°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	471.44	222.60	26.80	28.99	749.83	6.0	40.0	2.21 (6.50)
2	471.44	222.60	26.80	28.99	749.83	6.0	12.1	0.67 (1.97)
3	471.44	222.60	26.80	28.99	749.83	6.0	14.4	0.80 (2.35)
4	471.44	222.60	26.80	28.99	749.83	6.0	28.5	1.57 (4.62)
5	471.44	222.60	26.80	28.99	749.83	6.0	23.7	1.31 (3.85)
6	471.44	222.60	26.80	28.99	749.83	6.0	13.1	0.72 (2.12)

k_{avg} = 1.10 (3.23)
k_{20} = 1.08 (3.17)

DATA WORK SHEET

SILTY SAND

27 OCT 1976   7% ASPHALT   27°C   PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{emI} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	471.44	222.60	26.80	28.99	749.83	5.0	20.3	2.17 (6.38)
2	471.44	222.60	26.80	28.99	749.83	5.0	5.7	0.61 (1.79)
3	471.44	222.60	26.80	28.99	749.83	5.0	7.0	0.75 (2.20)
4	471.44	222.60	26.80	28.99	749.83	5.0	14.9	1.59 (4.67)
5	471.44	222.60	26.80	28.99	749.83	5.0	11.3	1.21 (3.56)
6	471.44	222.60	26.80	28.99	749.83	5.0	7.1	0.76 (2.23)

k_{avg} = 1.08 (3.17)
k_{20} = 0.94 (2.75)

DATA WORK SHEET

SILTY SAND

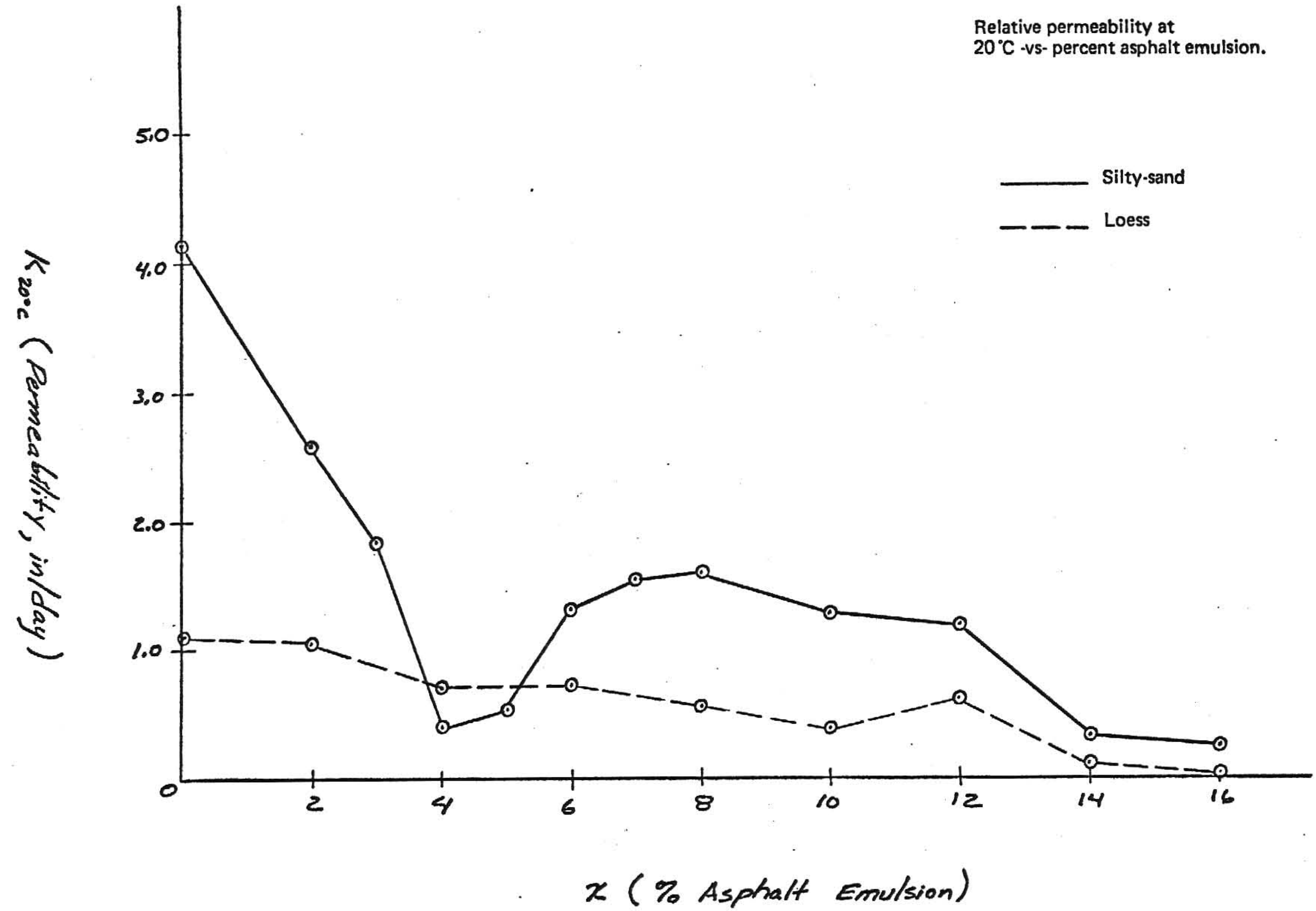
27 OCT 1976 7% ASPHALT 25°C PROCEDURE I

Permeameter Number (1)	Weight of Can in grams (2)	W_s in grams (3)	W_w in grams (4)	W_{eml} in grams (5)	Total Weight in grams (6)	Elapsed Time in minutes (7)	Volume in milliliters (8)	Permeability in inches/day (cm/sec x 10^{-5}) (9)
1	471.44	222.60	26.80	28.99	749.83	5.0	26.1	1.93 (5.67)
2	471.44	222.60	26.80	28.99	749.83	5.0	8.0	0.59 (1.73)
3	471.44	222.60	26.80	28.99	749.83	5.0	9.9	0.73 (2.15)
4	471.44	222.60	26.80	28.99	749.83	5.0	20.0	1.48 (4.35)
5	471.44	222.60	26.80	28.99	749.83	5.0	16.0	1.18 (3.47)
6	471.44	222.60	26.80	28.99	749.83	5.0	10.2	0.75 (2.20)

k_{avg} = 1.04 (3.06)
k_{20} = 0.94 (2.77)

APPENDIX J

Relative permeability at
20°C -vs- percent asphalt emulsion.



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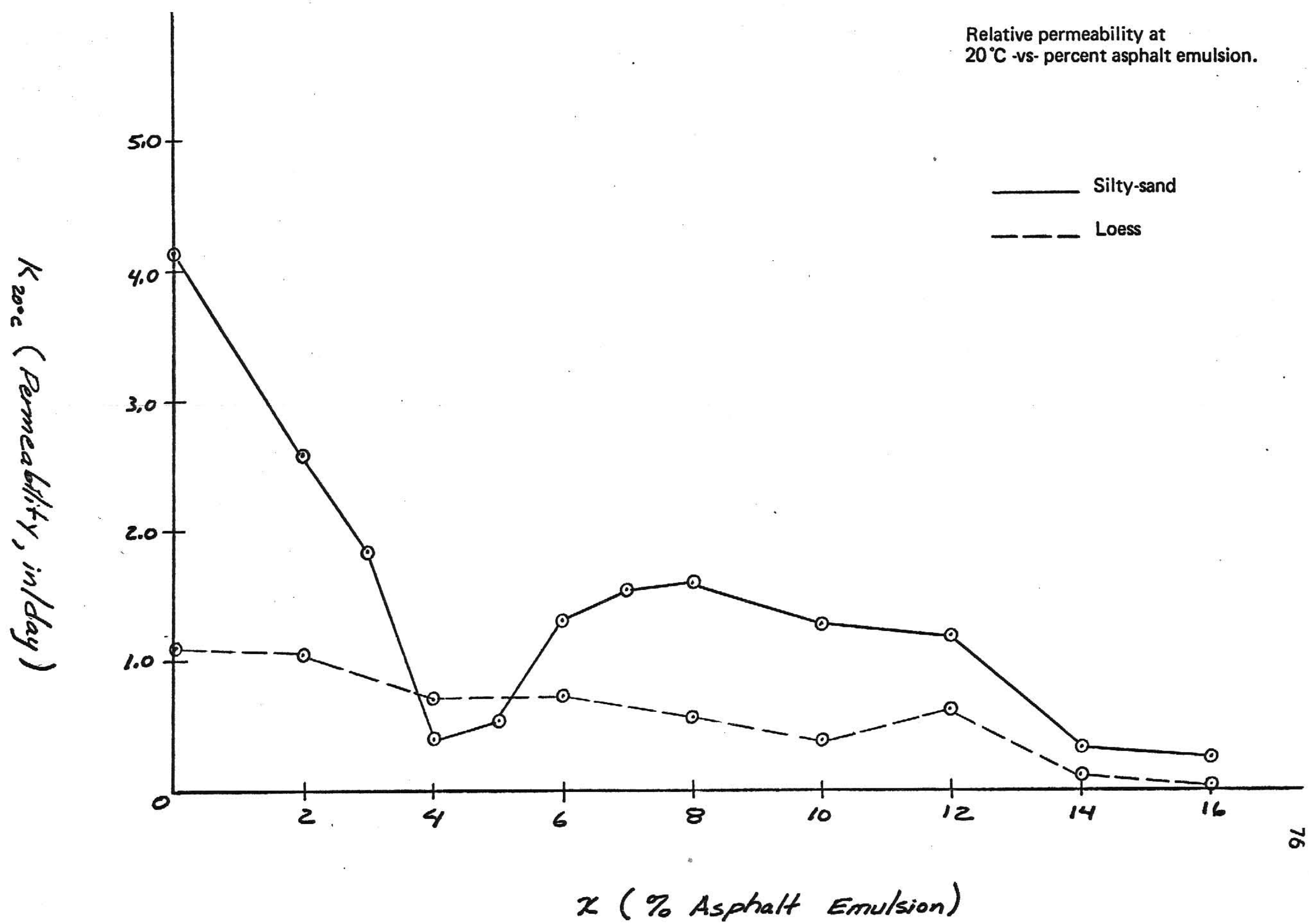
APPENDIX J

Relative permeability at
20°C -vs- percent asphalt emulsion.



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PERMEABILITY CONTROL IN SELECTED SOILS USING ASPHALT EMULSION

by

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B.S., Kansas State University, 1976

AN ABSTRACT OF
A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1977

The study was undertaken to determine the effect of asphalt emulsions on soil permeability. A slow curing anionic asphalt emulsion was used with a loess, a silty-sand, a blow sand, and a river sand.

The emulsion was mixed with soil and water to form soil samples. The samples were tested over a range of asphalt contents to determine which content decreased the soil permeability the most. Permeabilities and asphalt contents were recorded for all soils. Testing was conducted at the Kansas State University Civil Engineering Soils Laboratory.

The study introduces a procedure to combine soil, water, and asphalt emulsion. It is shown that asphalt emulsion does reduce permeability for silty soils. Equations were derived in the investigation that determine amounts of soil, water, and emulsion to be used in each sample.