DEVELOPMENT AND EVALUATION OF A FIELD DRAINABILITY TEST METHOD

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MICHIGAN DEPARTMENT OF
STATE HIGHWAYS AND TRANSPORTATION

DEVELOPMENT AND EVALUATION OF A FIELD DRAINABILITY TEST METHOD

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INTRODUCTION

This report has been prepared at the request of the Department's Porous Materials Research Committee which requested that the Research Laboratory ". . . establish a consistent drainability test procedure" (1). The objective of this study was to establish a field test method that would be rugged, provide reliable drainability data, and be comparable to other field tests in simplicity and time required to perform the test. Development of the test method was to include trial field use to demonstrate its performance ability under construction conditions.

Permeability is a property of the soil alone, and is a measure of the ability of soil to conduct water. Drainability, however, is a property of soil masses--such as a pavement subbase layer--and is a measure of the ability of the soil mass to drain water. The suitability of a subbase material depends on its drainability properties, permeability being only one of the subbase properties needed to determine drainability. Casagrande (2) developed a method for determining the drainability of airfield pavement bases, and Hsia (3) adopted Casagrande's method and determined the subbase drainability requirements of Michigan's standard pavement cross-sections. Drainability requirements are based on a knowledge of the geometry of the subbase layer and the permeability (k) and effective porosity (N_e) of the subbase material. Acceptability of a subbase layer also depends on its percent saturation when gravity-drained.

Drainability test results can be used to accept or reject subbase and porous backfill materials. In addition, if drainability test results indicate inadequate subbase drainability, the data can be used to determine the size and location of drains needed to improve drainability to acceptable limits. However, if drainability criteria are to replace existing acceptance methods, test results should be quickly and easily determined in the field so that construction delays are avoided. This report describes such a field drainability test method, the equipment needed, testing procedures, and a description of how drainability data may be used.

Several established field permeability tests were considered for use in this study. However, all of these were developed for agricultural purposes, where soil permeability is generally low, and were not applicable to sandy subbase materials whose permeabilities are relatively high. Using the schematic diagram of the permeameter system shown in Figure 1 as a basic guide, a permeameter was constructed which appeared to be suitable

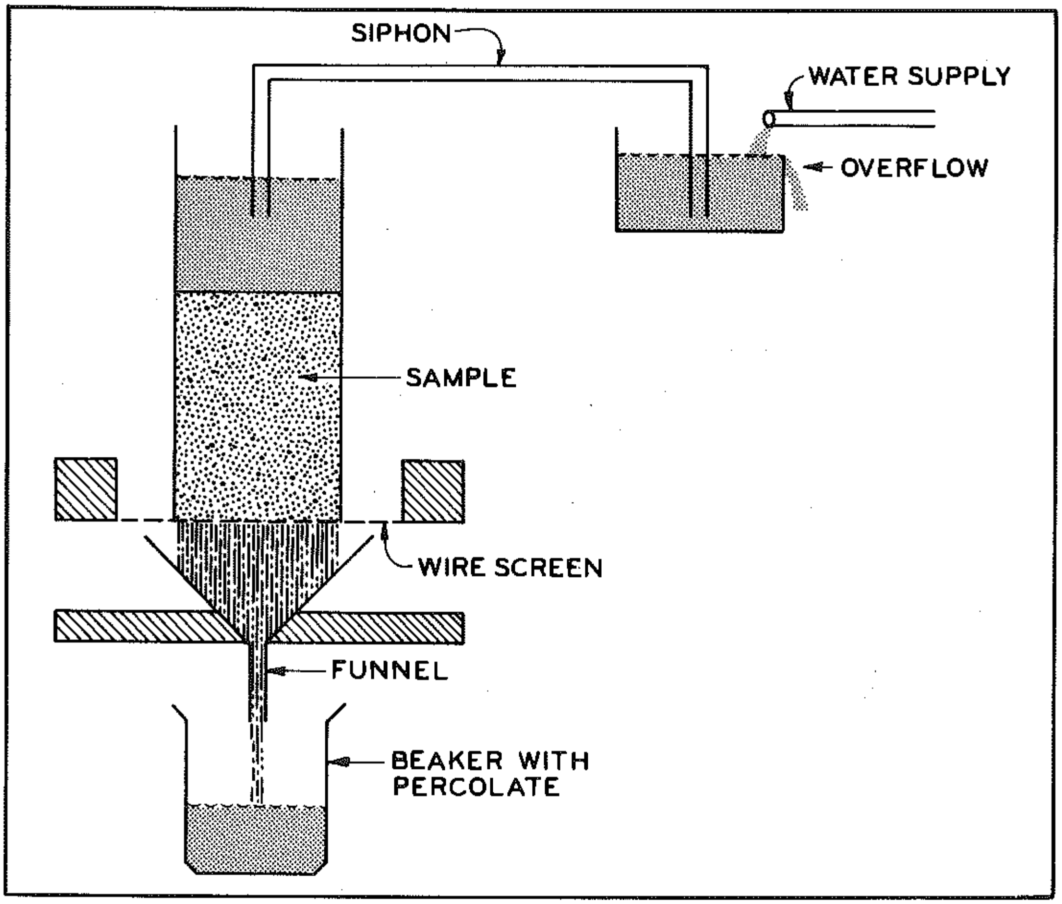

Figure 1. Schematic of the basic constant head system for permeability measurement.

for use with granular materials (4). Results obtained with this device compared favorably with those obtained using the standard ASTM D 2434-68 method. The method was developed further so the test could be conducted on undisturbed subbase samples collected from a compacted grade, resulting in the permeability apparatus shown in Figure 2. As finally refined through field testing, the procedure proved to be easy to perform in a rapid manner and the results were considered to be about the same as those obtained using standard ASTM test procedures. The test procedures developed fulfill the objectives of the study and, in addition, can be performed in less time than is required for the standard laboratory test. The complete field test procedure is outlined in Appendix A.

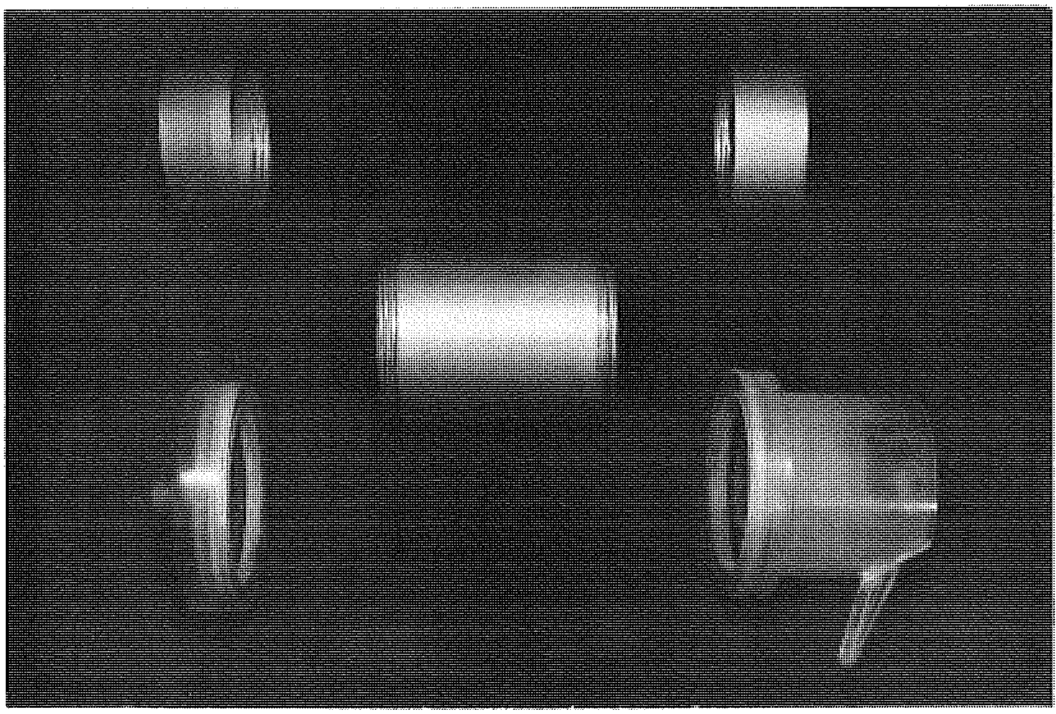

Figure 2. Basic components of the field permeameter.

TEST METHODS AND RESULTS

Laboratory Study Method

Three large sand samples were collected from US 10 near Clare, at sites having low, medium, and high permeabilities. Each sample was thoroughly mixed and quartered into 10 samples, each of which were then split in half. One half was tested using the field drainability test method the other half the Standard ASTM Method D 2434-68, in order to compare permeability results.

The use of tap water instead of de-aired water can result in lower permeability values. The magnitude of this influence was studied by determining the permeability of 10 samples of medium permeability, using cold tap water (which has a very high air content) and comparing these values with those obtained for 10 paired samples using de-aired water. The intent of this part of the study was to determine whether tap water could be used for field testing in place of de-aired water, which would be difficult to provide in the field.

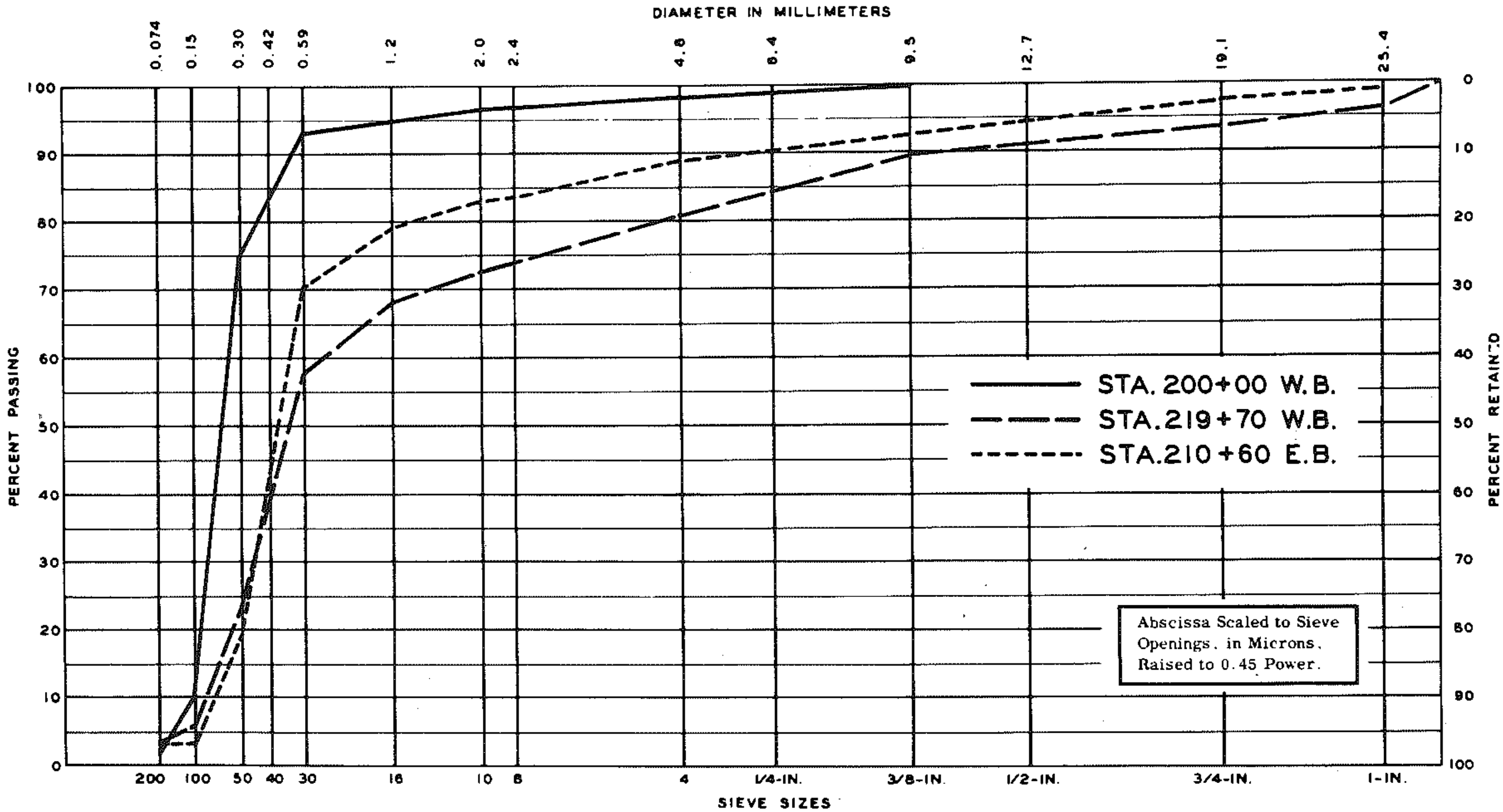

Figure 3. Gradation of materials used for laboratory permeability tests.

Saturation of the sample can be accomplished from the bottom of the sample upward or from the top downward. Downward saturation can cause air to be trapped in the voids, thus reducing the sample's permeability. Some idea of the magnitude of this effect was studied by saturating 10 sand samples from the bottom up, determining permeability, draining the sample, then resaturating from the top down and redetermining permeability. This procedure was repeated on 10 paired samples by first saturating from the top down and then resaturating from the bottom up.

Field Study Method

The field performance of the field drainability test was evaluated during construction of a six mile segment of US 10 located northwest of Clare. Drainability tests were made at 200-ft intervals for both subgrade and subbase, and more than 300 field drainability tests were made. This study was to provide information concerning the number of tests that could be completed per day, the suitability of the test to the field testing environment and the general durability of the equipment under field test conditions.

Laboratory Study Results

Results of the study, which compares permeability results obtained using the standard ASTM with the field test method, are summarized in Table 1. Gradations of the three basic materials used are shown in Figure 3.

According to statistical analysis of the data, discussed in detail in Appendix B, the field and ASTM test results are significantly different at the 95 percent confidence level, in most comparisons. In reviewing the results of each test series, however, it is noted that the numerical differences in results obtained by the two methods are not large for the range of permeability values on which a decision must be made to accept or reject materials 3 to 10 ft per day. From a practical standpoint, results obtained by either the field or the ASTM test method are such that decisions to accept or reject materials would be essentially the same regardless of the test method used.

The consistency of drainability test results obtained in this study is shown by the variance data presented in Appendix B. In general, the data collected indicate that both test methods have similar variance characteristics. Permeability data are very consistent, and the k/N_e ratio, though less consistent, is still reasonable. Just how consistent a test method must be in order to be acceptable is a matter of judgement.

TABLE 1
SUMMARY OF LABORATORY TEST RESULTS

Test Description	Permeability k, ft/day	Effective Porosity, N_e	$\frac{k}{N_e}$ Ratio	Percent Saturation	Density, lb/cu ft
(High Permeability Station 200+00)					
Field Test Method	25.4	0.08	347.8	78.1	104.2
ASTM Test Method	18.4	0.10	166.3	73.4	103.9
(Medium Permeability Station 210+60)					
Field Test Method (de-aired water)	10.0	0.06	249.5	81.7	113.2
Field Test Method (tap water)*	7.7	0.09	95.0	71.4	113.2
ASTM Test Method	11.7	0.09	143.8	71.9	113.2
(Low Permeability Station 219+70)					
Field Test Method	2.5	0.07	36.7	75.8	119.3
ASTM Test Method	4.0	0.08	48.4	72.1	118.8

Note: Each of the results listed is the mean of 10 tests except as noted.

* Results listed for tap water is the mean of nine tests.

TABLE 2
EFFECT OF SATURATION METHOD ON DRAINABILITY CHARACTERISTICS

Direction of Saturation	Density, lb/cu ft	Percent Saturation	Mean Effective Porosity, N_e	Mean Permeability k, ft/day	Mean $\frac{k}{N_e}$
(1st Saturation) Top-Down	104.4	75.0	0.09	38.4	414
(Resaturation) Bottom-Up	104.4	77.1	0.09	42.5	499
(1st Saturation) Bottom-Up	104.2	84.4	0.06	57.7	974
(Resaturation) Top-Down	104.2	85.6	0.06	57.7	1,041

Note: Each of the results listed is the mean of five tests.

A study of the effect of using tap water indicates that there is a significant drop in permeability when fresh tap water is used in place of de-aired water (Table 1).

A study of the effect of direction of saturation, upward as opposed to downward, is summarized in Table 2. These results indicate that saturation from the bottom upward will trap less air and result in higher permeability values.

Field Study Results

The field study indicated that a Research Technician working alone could easily complete six tests per eight-hour day, and when assisted by another Technician, 10 tests per eight-hour day. On days free of interruption one Technician could complete 10 tests in eight hours and with an assistant, 16 tests could be completed.

Information obtained from each drainability test enables calculation of the following soil properties: in-place dry density, permeability, effective porosity, moisture content, and the percent saturation when gravity drained. The data sheet used in the field to record test results is shown in Figure 4. Several calculations are needed to determine effective porosity and percent saturation; however, these calculations should be easy to make in the field. Appropriate revisions and additional instructions would be incorporated in the form in Figure 4 to facilitate its use by field personnel.

A standard density kit was used during this study to store the testing equipment (Fig. 5). Several other arrangements could be inexpensively developed which might be even more efficient.

The field drainability test proved to be a reliable field test method, comparable to the standard density control test in simplicity, adaptability to field conditions, and in the number of tests completed per man-day.

DISCUSSION OF RESULTS

Previous studies by the Research Laboratory indicate that drainability characteristics of subbase materials are not well controlled by present specifications which are based on gradation alone (5). When using these specifications it has been observed that satisfactory materials have been rejected and unsatisfactory accepted. In fact, it has been shown that present specifications have, on occasion, accepted subbase materials whose drainage time exceeds a year and have rejected materials whose drainage

MDSH T 1005 (N 6/75)

FIELD PERMEABILITY TEST

Date: ____________

Operator: ____________

Project No.: ____________

Sample ____________

Wt. of Mold and Soil (wet) ____________ gm

Wt. of Mold ____________ gm

Wt. of Wet Soil ____________ gm

Dry Density ____________ lb/cu ft

Vol. of Mold ____________ cu ft

Wet Density ____________ lb/cu ft

Percent H_2O (speedy) ____________ percent

Dry Density ____________ gm/cc

Time, min.	Graduate Reading	Q in c.c.	Time, min.	Graduate Reading	Q in c.c.

Qt = ____________ cc A = ____________ cm^2 Tt = ____________ min

h = ____________ cm L = ____________ cm

$$k = \frac{(Qt)\ (L)}{(h)\ (A)\ (Tt)} =$$

Percent H_2O after drained ____________ %

Vs ____________ Vw ____________ Vv ____________

E = ____________ % Sat ____________ Ne ____________ k/Ne ____________

Figure 4. Experimental field permeability test form.

Figure 5. Complete field drainability test kit.

time is less than 10 days. Moreover, drainable materials have been replaced by less drainable materials. Although the frequency of such occurrences cannot be determined from available data, the fact that they exist is clearly established.

The drainability test described in this report has been evaluated statistically and shows no such extreme variation as does the gradation based method. In fact, at the 67 percent confidence level, the drainability test varies within a range of plus or minus 3.5 days drainage time, based on controlled laboratory tests. The test also limits the acceptance of materials, in extreme cases, to those that will drain within 20 days. Therefore, in comparison with the gradation method of control for which drainage times might exceed a year, the direct measuring field drainability method for acceptance of subbase materials appears to offer a much greater control of subbase drainability.

The air content of the permeating water does reduce permeability results by about 25 percent; however, the air content of the water used in this study was extremely high being cold and directly from the tap. Under normal field conditions, if warmer than air temperature tap water were drawn at least 12 hours before being used for test purposes, it would have a lower air content to start with and much of this would be lost in the 12 hours before use. Hence, the use of tap water should normally have less effect on permeability than was observed in this study. In addition, a tendency toward lower permeabilities caused by using tap water makes the test results conservative thus helping to reduce the likelihood of accepting materials of inadequate drainability. It is suggested that the use of warm or hot tap water drawn at least 12 hours before it is to be used for drainability test purposes would be an acceptable practice.

Saturation of the sample from the bottom upward results in higher permeability values than does saturating from the top downward; however, the direction of saturation of the subbase in the field is not clear. Surface water infiltrating cracks and joints can saturate the subbase from the top downward and laterally. Saturation of field drainability test samples can be accomplished in either direction. When saturated from the top down, however, the results tend to be somewhat more conservative and the test easier to perform. It was decided, therefore, that saturating from the top downward would be the preferred procedure.

An additional capability of the field test apparatus is that porous backfill materials can be compacted in the permeameter in accordance with AASHTO test method T-99 requirements and their permeability determined. Therefore, the field test could also be used for acceptance testing of porous backfill and filter materials on the basis of minimum allowable permeability limits at T-99 density.

Field drainability tests are made on essentially undisturbed samples collected at the test site, after the subbase has been compacted. Permeability determinations, therefore, are realistic as their values apply to in-place material conditions.

APPLICATION OF FIELD DRAINABILITY TEST RESULTS

Field drainability test results can be used to accept or reject sources of subbase materials; determine if the subgrade is adequately drainable so that it may be left in place for the subbase layer; determine acceptability of porous backfill materials; determine in-place density; determine if in-place subbases are adequately drainable; and design acceptable subbase drainage systems in cases where drainability of subbase materials is below acceptable limits.

The acceptability of an in-place subbase can be easily determined by inspectors on the basis of field drainability test results. Table 2 of Ref. (3) lists the minimum allowable k/N_e ratio for each of Michigan's Standard cross-sections. The project Engineer, using this Table and the project plan sheets, can determine the minimum drainage (k/N_e) requirements for all parts of his projects and inform his inspectors of requirements. The inspector can then check to see that both the k/N_e ratio of the subbase material is equal to or larger than that required and that it does not exceed 90 percent saturation when gravity drained. He can accept or reject on that basis. In performing the field drainability test the dry density can be calculated; providing a quick method of checking if compacted subbases meet density requirements. There is a possibility that density inspectors could be used to conduct the field testing required for checking drainability.

In some areas, such as Detroit, fine sand subgrades occur but fail to meet subbase gradation specifications. They must therefore be removed and replaced with material which meets gradation specifications. In many cases such subgrades may actually meet drainability requirements or could be inexpensively modified to do so by the addition of subbase drains. The same is true of in-place subbase where all or portions are found to be inadequately drainable. In most, if not all cases, where subbase materials meet gradation specifications, drainability can be improved to exceed the requirements by the addition of subbase drains. Because subbase drains are an inexpensive method of improving drainability, they offer considerable economic advantages over the standard remove and replace method. In addition, because marginally and poorly drainable subbase material sources can be improved by the addition of subbase drains, to exceed drainability requirements, there would be an increase in the quantity of suitable materials available for subbase use.

CONCLUSIONS

1) The field drainability test method and equipment described in this report are well suited to field test conditions.

2) Permeability values obtained with the field test and standard ASTM test methods are essentially the same from a practical point of view although the differences noted are, in most cases, statistically significant at the 95 percent confidence level.

3) The permeability results obtained with field test and laboratory test methods are both consistent, based on the coefficient of variation of test results.

4) One inspector should be able to perform 6 to 10 drainability tests per day. Two inspectors working with the same equipment can perform 10 to 16 tests per day.

5) The field drainability test method is easy to perform in the field and comparable with standard density control tests in complexity and time required to perform the tests.

6) The use of drainage criteria and the proposed field drainability test method for accepting porous materials and in designing supplementary subbase drainage should result in considerable cost savings and increased availability of porous materials suitable for subbase use.

RECOMMENDATIONS

It is recommended that subbase and porous backfill drainage materials be accepted for highway construction on the basis of their drainability as previously discussed rather than their gradation. This should result in considerable cost savings because more granular material sources can be used and because lower maintenance costs should result since poorly drained materials could be identified during construction and appropriate corrective action taken to insure adequate drainability.

Subbases that do not meet drainability requirements can be improved to an acceptable drainability by the addition of subbase drains but the drain size, spacing, and location must be determined for each standard pavement cross-section. Because the most efficient placement of subbase drains requires complex analytical analysis it is recommended that the Research Laboratory be authorized to develop subbase drain designs for each of Michigan's Standard Pavement Cross-Sections.

Although the field drainability test method can be used to accept or reject like any other standard acceptance test method, a study should be conducted to develop a most efficient acceptance procedure which can take into account the characteristic variability of test results and accept or reject areas of subbase of sufficient length to make correction economically practical and of importance to overall pavement performance. For example, it should be possible to develop an acceptance procedure which assures that at least 95 percent of the subbase is adequately drainable and that no segment of inadequately drainable subbase shall exceed a specified unit of length such as 200 ft. Development of such an acceptance test method by the Research Laboratory is also recommended.

REFERENCES

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2. Casagrande, A., Shannon, W. L., "Base Course Drainage for Airport Pavements," Proceedings ASCE, June 1951.

3. Hsia, F. T., "Subbase Drainage Criteria," Michigan Department of State Highways and Transportation, Research Report R-991, March 1976.

4. Methods of Soil Analysis, Agronomy No. 9, Part 1, American Society of Agronomy, 1965.

5. Novak, E. C., "Permeability Characteristics of Various Subbase Materials," Michigan Department of State Highways and Transportation, Research Report R-781, August 1971.

APPENDIX A

APPENDIX A

The testing procedure for the field drainability test is described below in the order of occurrence of each step.

Step 1. The cutting edge and top extension are screwed to the main sample barrel.

Step 2. The sample barrel is then driven into the subbase until the top extension is almost flush with the subbase surface. It is very important to maintain good straight vertical alignment while driving the sample barrel (Fig. A-1).

Step 3. A shovel is used to remove the sample barrel as shown in Figure A-2, and another sample is removed from the side of the hole for use in determining in-place moisture content (Fig. A-3). The Speedy Moisture Meter is used for all moisture content determinations.

Step 4. The cutting edge and top extension of the sample mold are carefully removed one at a time and each surface struck smooth and the threads carefully cleaned as shown in Figure A-4. The wet weight of the sample is determined.

Step 5. The permeameter base and top shown in Figure A-5 are then screwed in place. The assembled permeameter (Fig. A-6) is then placed in a permeameter mounting, located at the side of a step-van pick-up truck, and the top of the sample flooded with water as shown in Figure A-7. The water used may either be de-aired or hot or warm tap water drawn at least 12 hours prior to its use for testing purposes.

Step 6. While the sample is saturating, the pick-up truck is moved to the next test site and a second undisturbed sample collected as indicated in the above described steps and placed next to the first sample to saturate, as shown in Figure A-8.

Step 7. The first sample is checked to determine if the rate of discharge is constant. This is done by measuring the quantity of water discharged in one minute, and repeating the measurement until the maximum and minimum quantity of water discharged in three consecutive checks does not vary by more than 2 percent from the mean value. The mean discharge value Q, is used to calculate permeability (k) from the equation $k = CQ$ where C is a constant for each different permeameter mold.

All samples which do not drain within 30 minutes from the time they are first saturated are, for practical purposes, impervious and must be recorded as such. All impervious subbase material must be removed from the grade.

Step 8. On completing the permeability test, the excess water is poured off the top of the sample and the permeameter replaced and allowed to complete gravity drainage. Gravity drainage is considered complete when no water drips from the bottom of the permeameter for a one-minute period.

Step 9. The permeameter is disassembled and the drained water content determined from a sample taken from the center of the soil cylinder (Fig. A-9). The effective porosity of the sample, N_e, is calculated on the basis of the drained water content and an assumed specific gravity of 2.68 g/cc using the equation:

$$N_e = 1 - V_s (2.68 W_e + 1)$$

where: V_s = volume of the solids, g/cc
W_e = effective water content expressed as a decimal fraction relative to dry weight.

Step 10. The percent saturation is computed and recorded.

Step 11. The k/N_e ratio of the test site must be equal to or larger than the minimum value required by Table 4 of Ref. (3) and the percent saturation must be no greater than 90 percent.

Figure A-1. Driving sample barrel.

Figure A-2. Subbase is dug away from one side of the sample barrel and the top pulled toward the hole to remove.

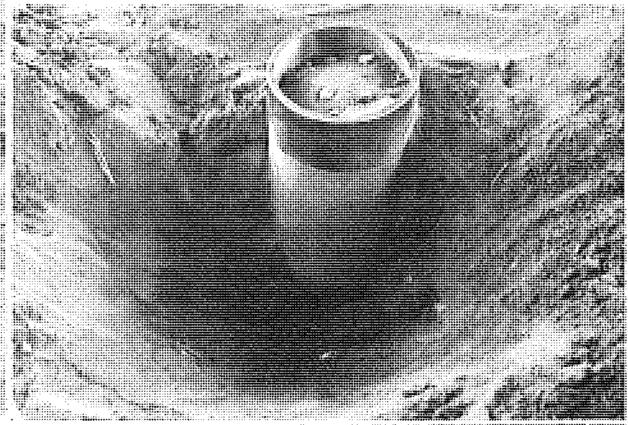
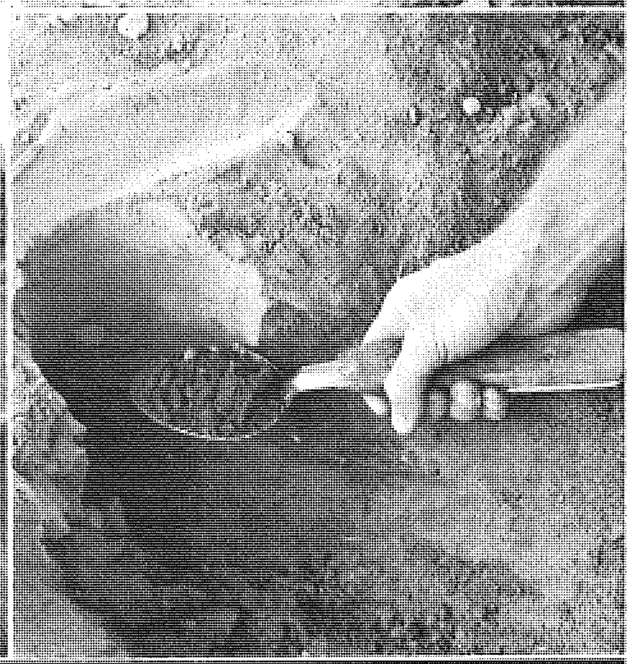


Figure A-3. A moisture content sample is taken from the side of the hole.



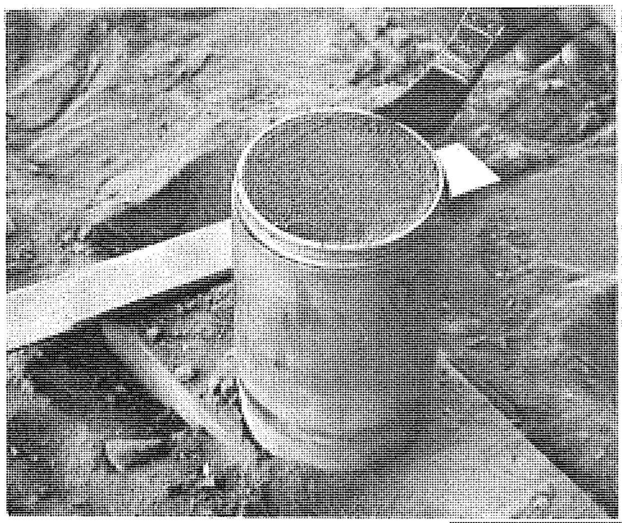
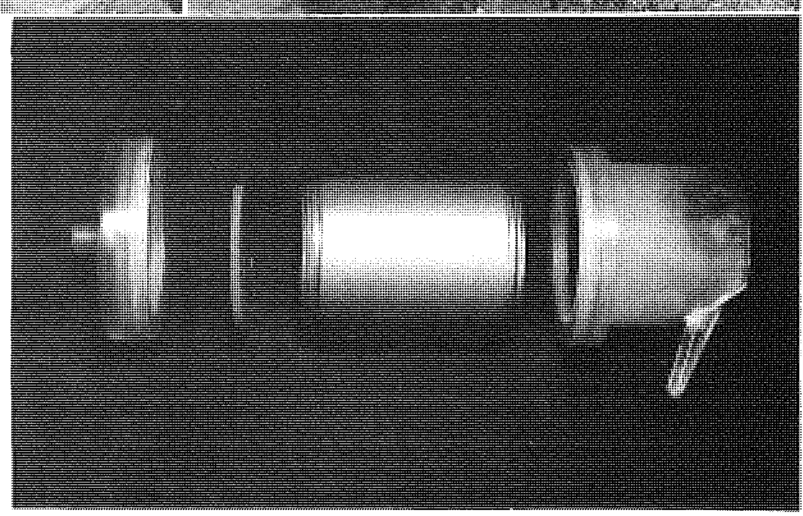


Figure A-4. Top extension and cutting edge are removed in order that the surface canbe struck smooth and the threads cleaned.

Figure A-5. Permeameter components - prior to assembly.



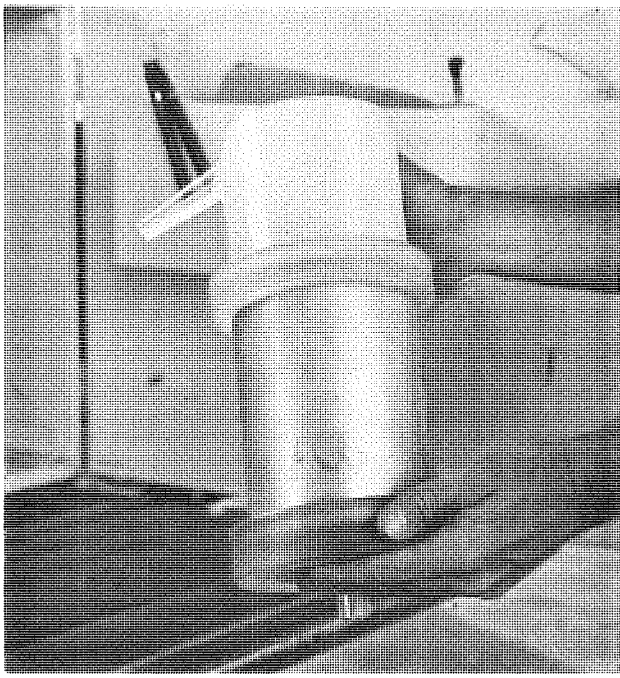


Figure A-6. Assembled permeameter.

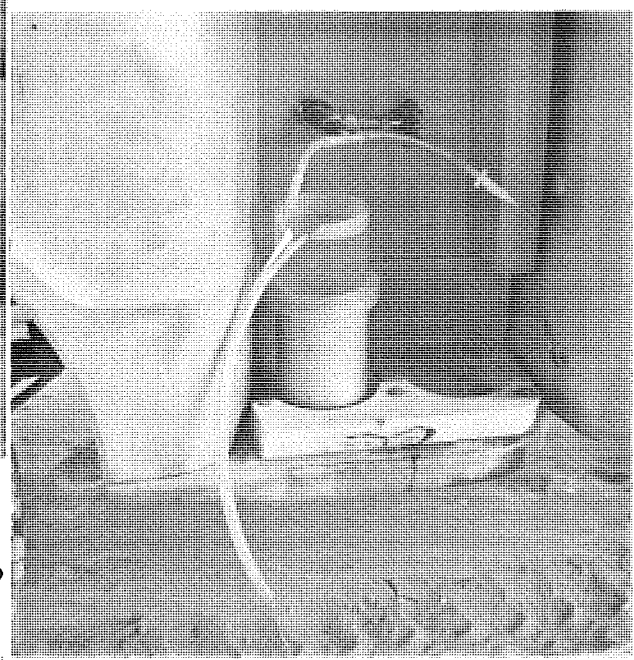


Figure A-7. Permeameter mounted for testing. Sample is being saturated.

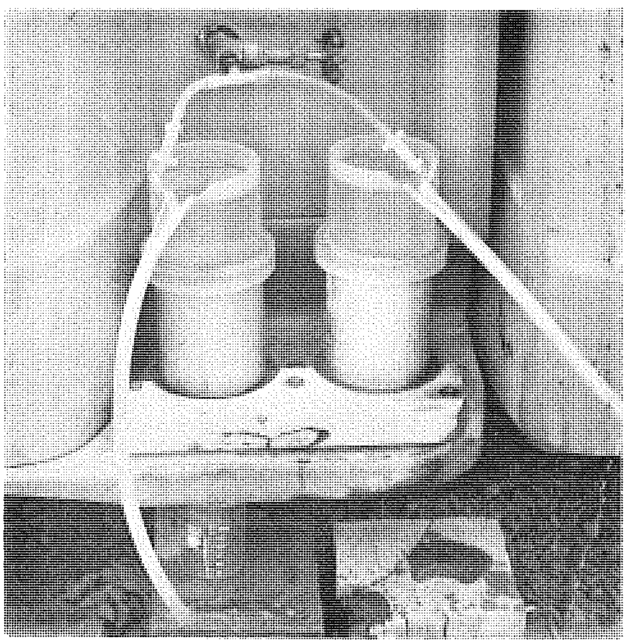


Figure A-8. In the sample on the left the quantity of water discharged in one minute is being measured. Sample on right is saturating.

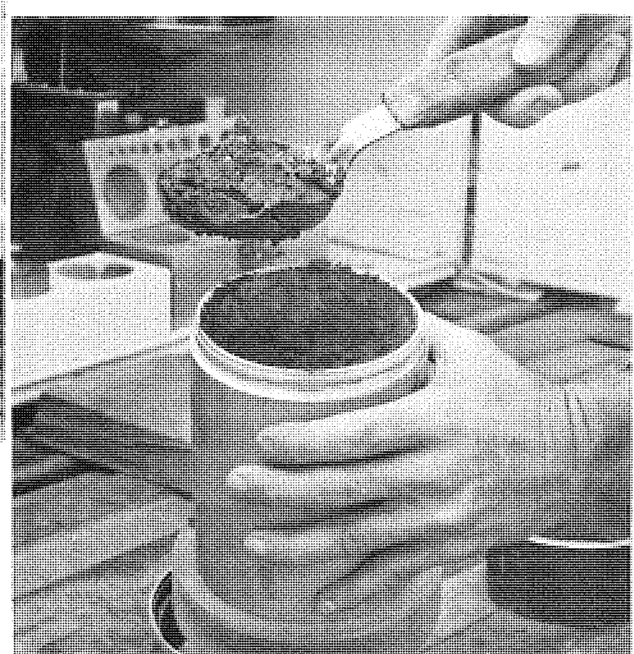


Figure A-9. Removing moisture sample to determine gravity-drained moisture content.

APPENDIX B

APPENDIX B

From a practical standpoint, the difference in results obtained by the field test method and the ASTM Standard laboratory method are small. A statistical analysis was made to determine if both test methods could be considered as producing the same results. The t-test for paired observations was used to test if the difference in results obtained by the two methods can be considered equal to zero. The results are summarized in Table B-1. To interpret Table B-1 note that for values of t greater than 2.26 one can be confident at the 0.05 level, there is a difference.

The normal variation in results obtained by the two test methods was evaluated on the basis of the standard deviation of the mean, $\sigma / \sqrt{n}$, and coefficient of variation, $\sigma / \bar{x}$. These data, summarized in Table B-2, show that the variation in mean values obtained is relatively small compared to the mean value and that the coefficient of variation for the permeability data is reasonably small averaging around 17 percent. On the other hand, the k/N_e ratio is subject to larger variation. This is due principally to the fact that the k/N_e ratio is a function of two variables such that their individual variability is amplified in the ratio. Nevertheless, the coefficient of variation of k/N_e for the field test, although tending to be somewhat larger than for the laboratory test method, is reasonably small.

TABLE B1
SUMMARY OF t-TEST DATA FOR PAIRED OBSERVATIONS

Field vs. Laboratory Data	$\bar{d}$	S_d	t
Permeability, k			
Station 200+00	7.06	2.79	7.99
Station 210+60 [1]	1.53	2.94	1.64
Station 210+60 [2]	2.29	1.72	3.98
Station 219+70	1.47	1.02	4.49
Effective Porosity, N_e			
Station 200+00	0.04	0.02	5.84
Station 210+60 [1]	0.03	0.02	3.95
Station 210+60 [2]	0.05	0.06	2.27
Station 219+70	0.01	0.04	0.89
$\frac{k}{N_e}$ Ratio			
Station 200+00	190.60	113.90	5.02
Station 210+60 [1]	140.00	165.50	2.68
Station 210+60 [2]	47.50	58.60	2.43
Station 219+70	19.90	12.30	5.09

Definitions

$$\bar{d} = \frac{1}{n} \sum_{1}^{10} d_i$$

where: d_i = Field - Laboratory Results

n = Number of Observations

$$S_d = \sqrt{\frac{n}{n-1}\left[\frac{\sum d_i^2}{n} - (\bar{d})^2\right]}$$

$$t = \frac{\bar{d}}{\frac{S_d}{\sqrt{n}}}$$

C. V. = 2.262, $\alpha = 0.05$

[1] De-aired water used for both field and laboratory test methods.

[2] Tap water used for field test method, de-aired for the laboratory test method.

TABLE B2
SUMMARY OF VARIANCE DATA

	Field and Laboratory Data	$\bar{x}$	σ	$\sqrt{n}$	$\frac{\sigma}{\sqrt{n}}$	$\frac{\sigma}{\bar{x}} \times 100$	Definitions
Permeability, k	Station 200+00						$\bar{x}$ = mean
	Field	25.4	3.5	3.16	1.1	14	σ = standard deviation
	Lab	18.4	1.6	3.16	0.5	9	$\frac{\sigma}{\sqrt{n}}$ = standard deviation of the mean
	Station 210+60						
	Field (de-aired)	10.0	1.5	3.16	0.5	15	
	Field (tap)*	7.7	1.5	3.00	0.5	20	$\frac{\sigma}{\bar{x}}$ = coefficient of variation
	Lab	11.7	2.7	3.16	0.9	23	
	Station 219+70						n = number of samples = 10
	Field	2.5	0.7	3.16	0.2	27	
	Lab	4.0	0.8	3.16	0.2	19	*n = 9
$\frac{k}{N_e}$ Ratio	Station 200+00						
	Field	347.8	109.5	3.16	34.6	31	
	Lab	166.3	17.9	3.16	5.7	11	
	Station 210+60						
	Field (de-aired)	249.5	177.7	3.16	56.2	71	
	Field (tap)*	95.0	34.4	3.00	11.5	36	
	Lab	141.6	62.0	3.16	19.6	44	
	Station 219+70						
	Field	36.7	12.4	3.16	3.9	34	
	Lab	48.4	15.9	3.16	5.0	33	