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A METHOD OF DETERMINING SUBBASE DRAINABILITY

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Introduction

In a letter of February 10, 1971, J. C. Brehler, Engineer of Materials, requested that the Research Laboratory conduct studies comparing permeability characteristics of two materials falling within "Subbase Supplemental Specification 8.02(4)," a supplement to the "Specification for Granular Material Class II." A brief report (MDSH Research Report No. R-781) was prepared accomplishing this task. It was noted in that report, however, that there are several other factors, besides permeability, that determine the drainability of subbase layers and that further research would be forthcoming on this problem. This report is intended to describe the research performed concerning a method of determining acceptable drainage characteristics of subbase materials.

Since subbase materials meeting the Class II grading requirements are becoming scarce, in some areas (e.g., Detroit) supplemental Class II specifications--allowing materials with higher fines content--have been necessary. Because previous experience indicated that materials with fines contents greater than permitted by Class II requirements may not perform well as subbase layers, research was conducted to determine how much the fines content influences permeability characteristics of subbase materials. This research indicated that Class II and supplemental Class II grading requirements have lower permeability limits of 0.42 and 0.11 ft/day, respectively (1). These lower limits are exceeded, however, when the material is either densely graded or contains clay. In trying to determine if these lower permeability limits are sufficient to insure subbase materials of adequate drainability it was found that subbase drainability is dependent upon factors other than permeability alone, among which are: the length of the drainage path, the subgrade slope, and the thickness of the subbase layer (2). Therefore, unless these other factors are determined, permeability characteristics are not sufficient and cannot be used alone to distinguish the acceptable from the unacceptable subbase materials.

In the early 1950's Casagrande published a paper describing a theoretical base-subbase drainage design method he had developed for the U.S. Army Corps of Engineers (3). It is the purpose of this report to review Casagrande's drainage analysis method, and utilize it to determine the drainability requirements of various subbase layers and the drainability characteristics required of Class II and supplementary Class II materials. By satisfying drainability requirements of the subbase layer, and incorporating the characteristics of the subbase material, it should be possible to distinguish acceptable and unacceptable subbase materials.

Casagrande's Method of Subbase Drainage Design

The purpose of a subbase layer, in addition to distributing wheel loads and minimizing the effect of differential frost heave, is to prevent concentrations of water under a pavement. Since the subbase layer can be severely weakened by the presence of high concentrations of water, it is extremely important to insure adequate subbase drainability. In order to fulfill this purpose subbase materials must, in addition to being stable, have satisfactory drainability characteristics. In this study only drainability characteristics of subbase materials are discussed.

Subbase drainage occurs under either steady or transient flow conditions. Steady flow seepage should take place in the subbase of a pavement built below the ground water table, in which case upward flowing seepage water would be carried through the subbase to edge drains. Transient flow seepage occurs when the quantity of water seeping through the subbase layer varies during a given time interval. Thus, water entering the subbase layer during a rain storm would be drained away under transient flow conditions.

Because normal subbase layers drain only under transient flow conditions, the suitability of subbase materials will be determined on the basis of this type flow. For pavements built below the water table (steady flow conditions) the suitability of subbase materials are based on different criteria, which will be discussed in a future Research Report.

In general terms, subbase drainability is defined as the ability of a subbase layer to remove water from under a pavement. According to Cedergren (2) the water removing capacity of a subbase layer depends on a number of factors, such as length of the seepage path, slope of the subgrade-subbase interface, the permeability of the subbase material, and the thickness of the subbase layer.

Mathematical procedures required for the solution of transient flow seepage problems are now generally available. However, the method of analysis appears to be too cumbersome, and testing procedures too time consuming, for practical application. During the time Casagrande developed his method, mathematical procedures were not sufficiently developed to enable a rigorous solution of transient flow problems. His method, therefore, is based on several simplifying assumptions; these assumptions being:

a) the centerline and bottom of the subbase are impervious boundaries

b) the subbase is assumed to be 100 percent water saturated at the time drainage starts

c) no further water enters the subbase layer once drainage begins

d) open discharge is assumed at the right side (Fig. 1) which is suddenly open for free drainage

e) the phreatic surface is assumed to be a straight line as shown in Figure 1

f) the effective porosity, n_e is assumed to be independent of height above the impervious boundary.

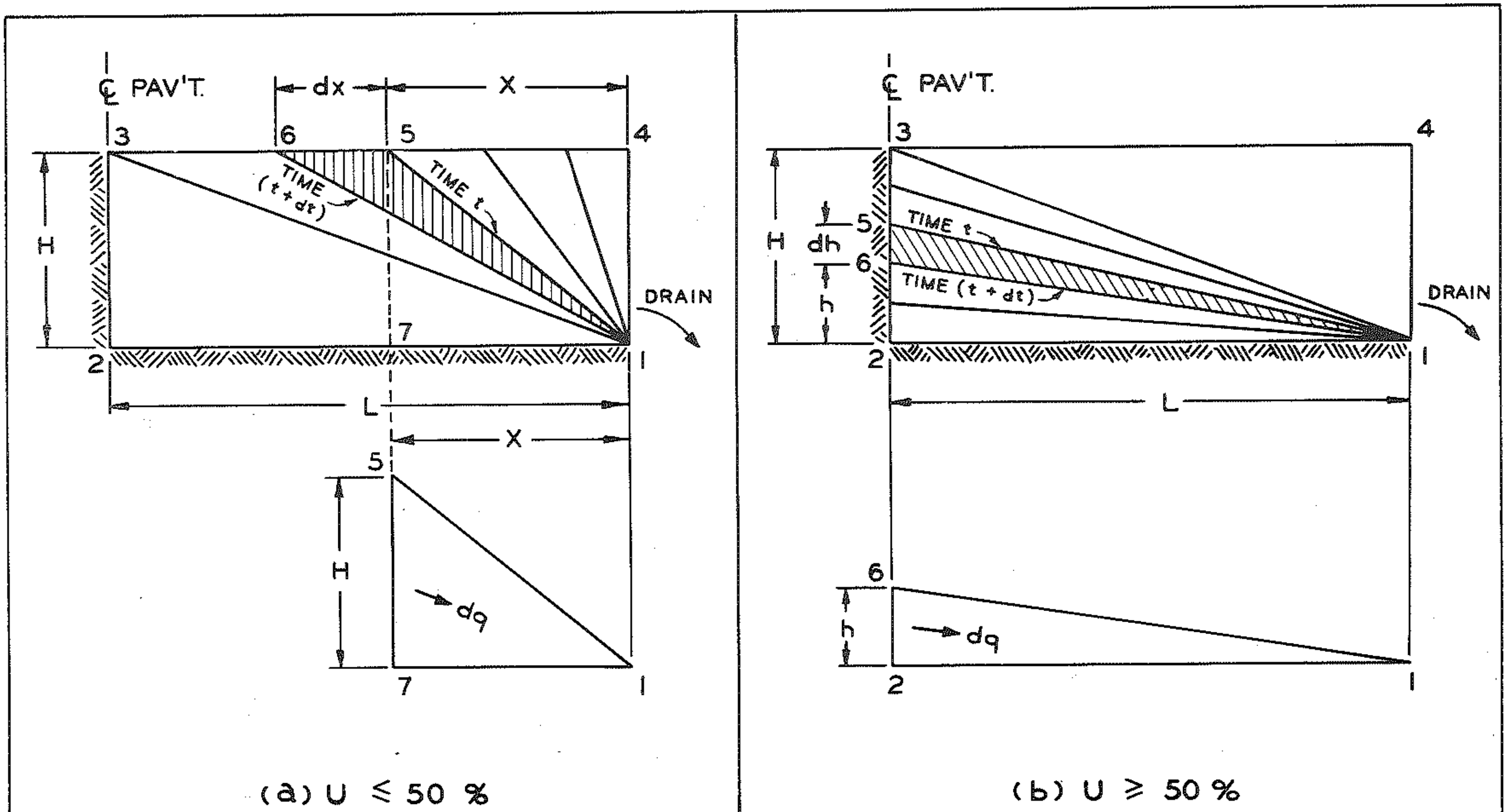
Pore water in granular materials can be divided into two basic categories: 1) gravity drainable water, and 2) non-gravity drainable water, normally referred to as capillary water. Casagrande's method deals only with the gravity drainable water contained in a base or subbase layer. The effective porosity, n_e, of the base or subbase material is considered to be the ratio of the volume of the voids drainable by gravity, to the total volume. This definition differs from the definition of porosity, n, which is the ratio of the volume of voids to the total volume.

The following is a basic outline of Casagrande's drainage method. Because of the geometry of Figures 1(a) and (b) it is convenient to divide the drainage process into two parts: first, Figure 1(a) in which the free surface gradually changes from position 1-4 to 1-3; and second, Figure 1(b) in which the free surface changes from position 1-3 to position 1-2. For brevity, only the equation for the first part of the drainage process is derived. A complete derivation is given in Casagrande's paper. In the first part of the drainage process, a differential equation can be set up by considering the position of the free water surface at elapsed time, t, and then at time (t + dt). In the time element, dt, the quantity of water discharge, dq, per unit width is equal to the area of the narrow, shaded triangle 1-5-6, multiplied by the effective porosity, n_e, previously defined. The quantity of discharge water, dq, is assumed to be independent of the moisture tension, that is, independent of the height above the subgrade - subbase interface at point 1. Geometrically then:

$$dq = \frac{Hn_e}{2} dx \qquad (1)$$

where the terms are as previously defined or are as indicated in Figure 1.

The flow through volume 1-5-7 is computed by means of Darcy's Law. The simplest assumption that could be made is to use $\frac{H}{2}$ as the average area



Note:

The progress of drainage is defined as the ratio of the drained area, triangle (1-4-5), to the total area rectangle (1-2-3-4). Thus $U = \frac{\text{drained area}}{\text{total area}}$.

Figure 1. Assumed progress of free water surface--horizontal subbase.

per unit of width through which flow takes place and to assume an average or effective hydraulic gradient of $\frac{H}{x}$. Then the rate of flow could be expressed by:

$$\frac{dq}{dt} = k\frac{H}{2} \cdot \frac{H}{x} = k\frac{H^2}{2x} \quad (2)$$

Combining Eqs. (1) and (2) and solving for t.

$$t = \frac{n_e}{2kH} \cdot x^2 \quad (3)$$

If t_{50} equals the time required to drain 50 percent of the gravity drainable water, x would equal L for this section and Eq. (3) becomes:

$$t_{50} = \frac{n_e L^2}{2kH} \quad (4)$$

Most subgrade - subbase interfaces are slopes, so this factor must also be considered in any subbase drainage analysis. The general derivation is similar to that presented in Eq. (1). The net result of introducing a sloping subgrade - subbase interface results in the modification of Eq. (4) to:

$$t_{50} = \frac{n_e L^2}{2k\,(H + LS)} \quad (5)$$

where S is the slope of the subgrade - subbase interface. For the working range of H, L, and S generally used in pavement design, Eq. (5) provides a good approximation of the time required for drainage of 50 percent of the subbase's gravity drainable water.

Casagrande recommended that subbases be designed so that the time required for 50 percent drainage would not exceed 10 days. Although it is possible to select other time-percent drainage criteria, that recommended by Casagrande appears reasonable. In this study, any material not capable of draining 50 percent of its gravity drainable water in 10 days will be considered insufficiently drainable for use as subbase material. No justification could be found for any other criteria.

Example of Casagrande's Method Applied to a Practical Design Problem

A four lane pavement is to be built having the cross-section shown in Figure 2 (1C). It is desired to know how permeable the subbase material

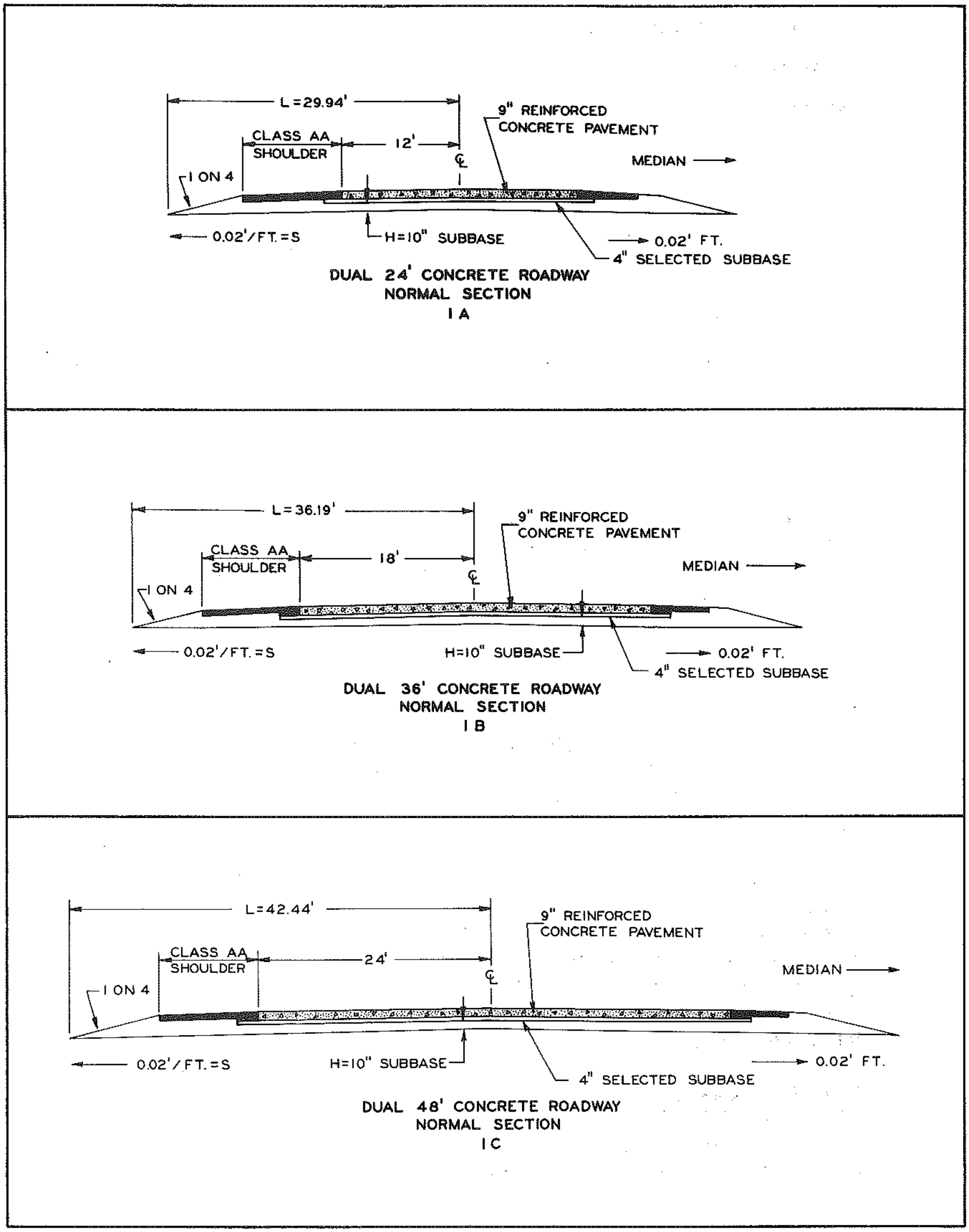


Figure 2. Typical cross-sections for rigid pavements.

should be in order to meet Casagrande's drainage criteria. Since the value of the effective porosity, n_e, is unknown it is not possible to solve Eq. (5) directly. Both k and n_e are material parameters which depend on the characteristics of the porous medium and the permeating fluid. The time required for drainage is a function of the $\frac{k}{n_e}$ ratio and the geometry of the drainage section which is characterized by $\frac{L^2}{(H + LS)}$. This indicates that in selecting subbase materials it is necessary to consider not only, k, the rate at which water can be conducted by the material, and the effective porosity, n_e, but also, the geometry of the pavement section. By combining the material parameters, the $\frac{k}{n_e}$ ratio, Eq. (5) could be rearranged in the following form.

$$\frac{k}{n_e} = \frac{L^2}{t_{50}\, 2(H + LS)} \qquad (6)$$

On the basis of Eq. (6) it is possible to determine the $\frac{k}{n_e}$ material requirements of pavement cross-section (1C) shown in Figure 2. From Figure 2 (1C), $L^2 = 1,800\ ft^2$, $(H + LS) = 1.68$ ft, and drainage time $t_{50} = 10$ days. Substituting these values in Eq. (6) we find that $\frac{k}{n_e}$ of the subbase material must be equal to 53.6, or more if its drainage time is to equal 10 days or less. The $\frac{k}{n_e}$ ratio of any prospective subbase material can easily be determined by the Ann Arbor Testing Lab.

It may be seen from Eq. (6) that not only is it possible to select materials which will satisfy the drainability requirements of pavement cross-sections, but it is also possible to alter the geometry of the cross-section so that the available material will provide 50 percent drainage in less than 10 days. The $\frac{k}{n_e}$ ratio required of the subbase material can be reduced with no resulting decrease in drainability by any combination of increasing the subbase thickness, increasing the subgrade slope, or decreasing the length of the drainage path, L, by placing edge drains.

Application of Casagrande's Method to Michigan's Subbases

At this point it should be clear why subbase drainability is dependent on more than just the permeability of the subbase material. Fortunately, all of the factors influencing subbase drainability fall into two categories:

1) Geometry of the subbase layer

   a) Length of the drainage path (L)
   b) Subbase thickness (H)
   c) Subgrade slope (S).

2) Subbase material drainability characteristics

   a) Permeability (k)
   b) Effective porosity (n_e).

The first step in applying Casagrande's method to Michigan's subbases is to determine the $\frac{k}{n_e}$ ratio required by each of the pavement cross-sections shown in Figures 2, 3, and 4. For some cross-sections, the subgrade slope may vary within a specified range as indicated in Figures 3 and 4. For these cross-sections, the $\frac{k}{n_e}$ ratios were computed, using Eq. (6), for both the maximum and minimum specified subgrade slopes. These results are summarized in Table 1.

The next step is to determine the $\frac{k}{n_e}$ ratios of materials meeting Class II and supplemental Class II grading requirements. To do this it is first necessary to clarify a point concerning the permeability of Class II materials. Class II specifications will accept granular materials containing clay or which are of dense gradation (such as 22A type gravels) and consequently can be of low permeability. Dense graded materials are usually too expensive to be used as Class II materials, and sources of Class II materials normally do not contain clay, so neither are likely to be used as subbase materials. If these materials are excluded from consideration because of their infrequent use we can develop a practical minimum permeability for Class II materials; that is, the minimum permeability of subbase materials which are not densely graded and do not contain clay. A description and gradation of the samples used for this study are summarized in Table 2. Based on a previous research study (1), the practical minimum permeability of Class II and supplemental Class II specifications are represented by Sample Nos. 6 and 4, respectively. The permeability, k, and effective porosity, n_e, of these materials are shown in Table 3, taken from MDSH Research Report R-781. Similar data are included for a number of other samples to show the variability of $\frac{k}{n_e}$ ratios possible for a group of materials meeting Class II grading requirements.

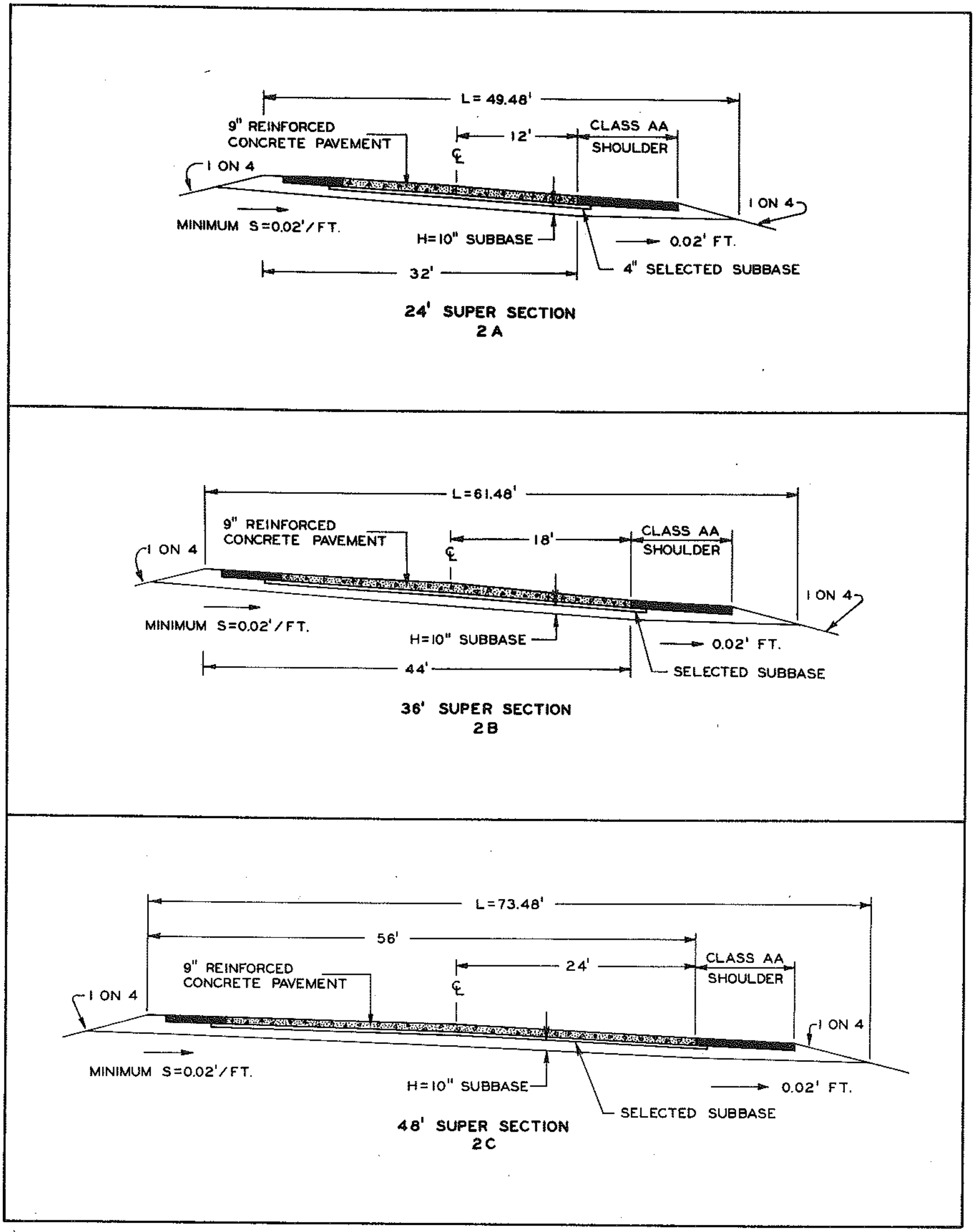


Figure 3. Typical cross-sections for rigid pavements.

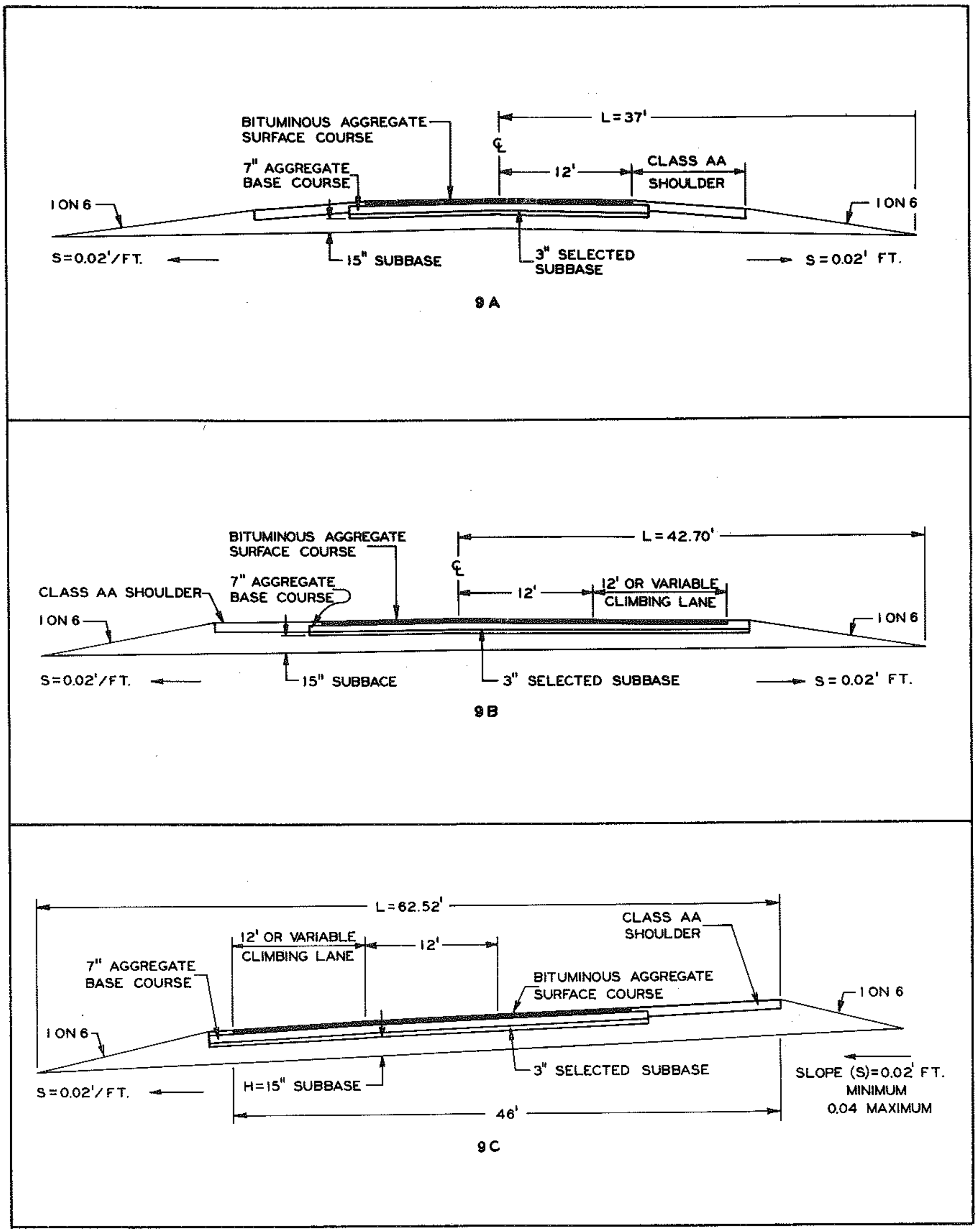


Figure 4. Typical cross-sections for flexible pavements.

TABLE 1
SUBBASE DRAINAGE REQUIREMENT
FOR STANDARD PAVEMENT CROSS-
SECTIONS, WHEN TIME FOR 50% DRAINAGE, t_{50} = 10 DAYS

Cross-Section I. D.	Length of Drainage Path, L, ft	Subbase Thickness, H, ft	Subgrade Slope, S, ft/ft	Cross-Section Drainability Requirement (k/n_e)
1A	29.9	0.83	0.02	31.3
1B	36.2	0.83	0.02	42.0
1C	42.4	0.83	0.02	53.5
2A	49.5	0.83	0.02 min.	67.3
2A	49.5	0.83	0.06* max.	32.2
2B	61.5	0.83	0.02 min.	91.8
2B	61.5	0.83	0.06* max.	41.8
2C	73.5	0.83	0.02 min.	117.4
2C	73.5	0.83	0.06* max.	51.5
9A	37.0	1.25	0.02	34.4
9B	42.7	1.25	0.02	43.4
9C	62.5	1.25	0.02 min.	78.1
9C	62.5	1.25	0.04* max.	52.1

* Slope assumed for entire length of subbase-subgrade interface.

TABLE 2
SAMPLE IDENTIFICATION AND GRADATION

Sample No.	Source	Description	Gradation - Percent Passing Sieve No. Shown							
			200	100	50	30	8	4	3/8-in.	3/4-in.
1	Flume Waste	Green Oak Plant, crushed flume waste	5.9	9.0	19.3	34.0	69.0	87.2	99.7	100
2	Flume Waste	Green Oak Plant, from de-sander (rounded)	1.2	2.3	11.9	40.9	84.7	96.8	99.6	100
3	Lab. Mix	Proposed supplemental spec. crushed aggregate	10.0	35.0	42.0	61.0	90.0	100	---	---
4	Lab. Mix	Proposed supplemental spec. rounded aggregate	10.0	35.0	42.0	61.0	90.0	100	---	---
5	Lab. Mix	Granular Material Class II, crushed aggregate	7.0	30.0	37.0	57.0	89.0	100	---	---
6	Lab. Mix	Granular Material Class II, rounded aggregate	7.0	30.0	37.0	57.0	89.0	100	---	---
7	Lab. Mix	Granular Material Class II, rounded - 2% clay	7.0	30.0	37.0	57.0	89.0	100	---	---
8	Bank Run	North of State Rd, Ingham Co.	8.8	29.4	77.8	97.6	100	---	---	---
9	Bank Run	NE 1/4 of NE 1/4 Sec. 13 Geech Rd Shiawassee Co.	2.9	5.5	25.0	52.2	77.7	86.1	93.9	100
10	Bank Run	SE 1/4 Sec. 9 Vernon Twp. M-78 Sta. 1444 - Shiawassee Co.	4.6	7.8	28.8	71.9	89.6	94.3	97.7	100
11	Bank Run	N 1/2 of NE 1/4 Sec. 12 York Twp. Washtenaw Co., Willis Rd (top layer)	2.3	4.4	32.9	77.2	93.3	95.9	98.6	100
12	Bank Run	Same location as 11 (bottom layer)	27.4	62.8	89.5	98.0	99.5	99.8	100	---
13	Bank Run	Holloway Pit Near Hass Rd Oakland Co. (dense graded)	6.5	9.3	20.5	39.4	70.6	80.3	88.0	100
14	Other	Dense Graded 22A rounded aggregate (100% - 1in.)	7.0	9.5	12.5	24.0	32.5	45.0	61.0	87.0
15	Other	Beach Sand M-57 near Marion Springs Rd	0.7	5.8	69.1	99.5	100	---	---	---

TABLE 3
DRAINABILITY PROPERTIES OF SUBBASE MATERIALS OF TABLE 2

Sample No. [1]	Percent Sat. When 100% Grav. Drain.	Effective Porosity, n_e	Coef. Perm. ft/day, k	Mtl. Drainage Characteristic (k/n_e)
1	76.1	0.05	1.74	34.8
2	66.6	0.10	30.99	309.9
3	82.6	0.05	0.30	6.0
4	78.0	0.05	0.11	2.2
5	78.3	0.06	0.64	10.7
6	75.8	0.06	0.42	7.0
7	76.5	0.06	0.08	1.3
8	83.3	0.06	2.06	34.4
9	68.6	0.09	0.42	4.7
10	74.0	0.08	0.08	1.0
11	75.3	0.08	7.46	93.3
12	79.7	0.07	0.58	8.3
13	80.5	0.04	0.04	1.0
14	65.0	0.04	0.08	2.0
15	93.5	0.02	10.57	528.5
[2]	----	0.06 [3]	0.283	4.7

[1] See Table 2.
[2] Casagrande's Arbitrary division between good and poor permeability.
[3] Assumed value based on average of samples 1 through 15.

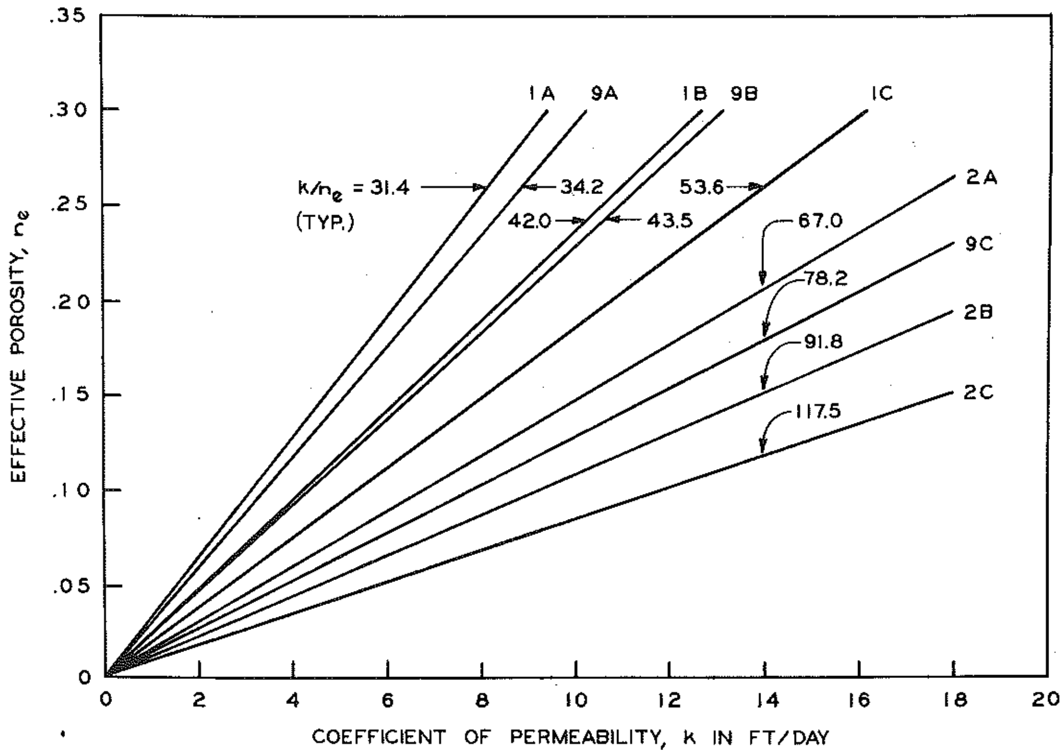


Figure 5. Slope (k/n_e) requirements of standard typical cross-sections (subgrade slope = 0.02 ft/ft).

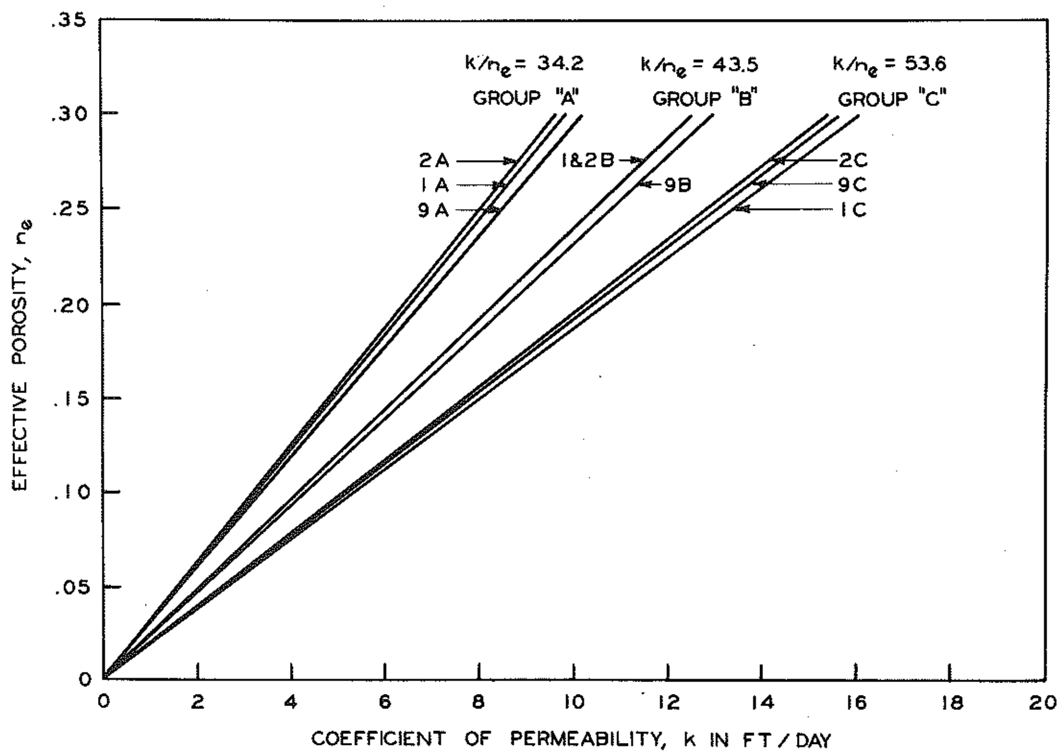


Figure 6. Slope (k/n_e) requirements of standard typical cross-sections (subgrade slope = max. specified by std. cross-sections).

The suitability of Class II and supplemental Class II grading limits for providing adequately drainable materials can be determined by comparing the $\frac{k}{n_e}$ ratio requirements of each cross-section with the practical minimum $\frac{k}{n_e}$ ratio provided by the grading limits, as represented by material Nos. 4 and 6. If the $\frac{k}{n_e}$ ratios of Sample Nos. 4 or 6 are equal to or larger than required by the cross-section, it would indicate the present subbase grading limit provides materials which normally will meet or exceed Casagrande's requirement of 10 days or less drainage time. However, if these materials do not meet this requirement, the implication is that the grading limits should be adjusted so that the bulk of material accepted for subbase use is more drainable than that presently used. Drainability guidelines for subbase materials can be based directly on the $\frac{k}{n_e}$ ratio requirements of the individual cross-section.

Drainability $\frac{k}{n_e}$ Requirements of Standard Michigan Cross-Sections

Table 1 summarizes the $\frac{k}{n_e}$ ratios, which dictate the permeability and effective porosity requirements of acceptable subbase materials. For each of the standard cross-sections shown in Figures 2, 3, and 4, these data are shown in graphical form in Figures 5 and 6. Figure 5 shows that when the subgrade slope is the minimum specified by the standard cross-section, 0.02 ft/ft, the $\frac{k}{n_e}$ ratios vary widely for most of the cross-sections represented. Thus, nearly every cross-section has a different subbase material requirement. However, Figure 6 shows that when the entire subgrade slope is the maximum specified by the standard cross-section, the $\frac{k}{n_e}$ ratios fall into three narrow groups. These groups, which are labeled A, B, and C, represent those cross-sections with the same suffix. For example, cross-sections 1A, 2A, and 9A are all in group A. From Figure 6, the $\frac{k}{n_e}$ requirements of groups A, B, and C are 34.2, 43.5, and 53.6, respectively. These requirements can be used to determine the acceptability of any potential subbase material if the subgrade slope is the maximum permitted by present cross-sections.

Comparison of $\frac{k}{n_e}$ Provided by Typical Subbase Materials with That Required by Standard Michigan Cross-Sections

The practical lower $\frac{k}{n_e}$ ratio limits of Class II and supplemental Class II materials are 7.0 and 2.2, respectively (Table 2). These values, com-

TABLE 4

TIME (DAYS) REQUIRED FOR 50% DRAINAGE WHEN SUBBASE MATERIALS HAVE MINIMUM DRAINABILITY PROPERTIES PERMITTED BY INDICATED SPECIFICATION

Std. Cross-Section I. D.	Max. Time (Days) for 50% Drainage[1]		
	Class II Mtls. $(k/n_e) = 6.9$	Supp. Class II Mtls. $(k/n_e) = 2.2$	Mtls. Who's k = 0.283 $(k/n_e) = 4.7$[2]
1A	45	142	67
1A	61	191	89
1C	78	243	114
2A	97	306	143
2A	47	146	68
2B	133	417	195
2B	61	190	89
2C	170	533	250
2C	75	234	110
9A	50	156	73
9B	63	197	92
9C	113	355	166
9C	76	237	111

[1] These values represent a practical max. drainage time. Some Mtls. meeting Class II, Supp. Class II, or Mtls. with k = 0.283 may exceed the max. drainage time indicated.

[2] Effective porosity, n_e, assumed to equal 0.06.

pared to the $\frac{k}{n_e}$ ratio required by the standard cross-sections having maximum subgrade slopes (Fig. 6) indicate that Class II and supplemental Class II specifications will accept materials which drain too slowly to meet Casagrande's drainage requirement. On the basis of Eq. (5), the maximum times required to drain subbases built of material whose $\frac{k}{n_e}$ ratio is at the lower limit accepted by Class II specifications, are 50, 63, and 78 days, respectively, for the cross-section groups A, B, and C as indicated in Figure 6. Although conclusions in this report are based on Casagrande's 10 day drainage recommendation, the slower drainage time indicated for Class II materials may be acceptable if it results in subbase performance equivalent to that expected of the entire pavement. In the future, it may be possible to conduct field studies to indicate maximum permissible drainage time. In the meantime, however, it is clear that Class II grading requirements are such that they can include materials whose drainability is considerably less than that recommended by Casagrande.

The Casagrande drainage design method and his 10 day 50 percent drainage requirement have been recommended by the Highway Research Board for the drainage design of subbase layers (4).

The arbitrary dividing line between good and poor permeability, 0.283 ft/day, is frequently suggested as a lower permeability limit for subbase materials (5). As indicated in Table 3, the $\frac{k}{n_e}$ ratio, of a material whose permeability if 0.283 ft/day, assuming $n_e = 0.06$, is 4.7 which is less than that for the practical lower limit of Class II materials (6.9). If the arbitrary permeability limit of 0.283 ft/day were used as the lower allowable limit, Table 4 shows that the maximum drainage times for cross-section groups A, B, and C would be about 73, 93, and 114 days, respectively, depending on the actual effective porosity value of the material. On the basis of these data it is concluded that the arbitrary permeability value of 0.283 ft/day is too low to be used as a lower permeability limit for subbase materials.

From Figure 6, the $\frac{k}{n_e}$ ratios required by cross-section groups A, B, and C are 34.2, 43.5 and 53.6, respectively. If the $\frac{k}{n_e}$ ratio of 53.6 were required as a lower limit for all subbase material the maximum drainage time for cross-section groups A, B, and C would be 6.4, 8.1 and 10 days, respectively. Such a limit would allow for possible future widening of the pavement up to four lanes wide, without exceeding the 10 day drainage limit. If a $\frac{k}{n_e}$ ratio of 34.2 were required, the drainage time for cross-section groups A, B, and C would be 10, 12.7 and 15.7 days, respectively. Although the drainage time could, in this case, exceed the 10 day limit, the difference in drainage time between groups A and C should be too small to have a significant effect on pavement performance. However, it is contrary to good engineering practice to have the lowest drainage factor of safety for the most expensive pavements (group C) and the highest factor of safety for the least expensive pavements (group A). Therefore, it is suggested that a $\frac{k}{n_e}$ ratio of 53.6, which enables 10 days or less drainage of any pavement group, be used as a lower limit for determining the acceptability of subbase materials.

Although it has been assumed in this report that no deviation from standard cross-sections would occur, it should be noted that where granular materials of $\frac{k}{n_e}$ ratios greater than 53.6 are not economically available it is possible to alter the cross-section so that its $\frac{k}{n_e}$ requirement is compatible with the $\frac{k}{n_e}$ ratio of locally available materials. For example, if cross-section (1C) Figure 2, were modified to a 22-in. thick subbase layer at the center line of the pavement and the subgrade slope were increased to 0.04 ft/ft, its $\frac{k}{n_e}$ ratio requirement (computed on the basis of Eq. (6)) would be reduced from 53.6 to 25.5. Or, if edge drains were placed 21 ft either side of the centerline of the cross-section (1C\ it would reduce the $\frac{k}{n_e}$ ratio from 53.6 to 13.1.

Discussion

The Corps of Engineers have pointed out that it is theoretically possible for a subbase material to meet Casagrande's drainage criteria and still remain nearly 100 percent saturated. This is possible when the effective porosity, n_e, approaches zero. This characteristic is illustrated in Figure 6, where the relationship between k and n_e for any material has its origin at $k = 0$, and $n_e = 0$. Thus, any permeable material would be accepted by Casagrande's design method if its effective porosity, n_e, were zero. For this reason, it is necessary to supplement Casagrande's drainage design method by limiting the capillary water content of a subbase material. As indicated in reports by Mullis (6) and MDSH Research Report No. R-671 (7) there is some justification for requiring all base and subbase materials to be less than 90 percent saturated before they are subjected to freezing. On this basis, it should be required that all subbase materials be less than 90 percent saturated when 50 percent gravity drained. This requirement is based solely on the frost susceptibility of the material. The relationship between percent saturation and stability of granular material under repetitive load has not yet been established. Seed, et al (8) reported the effect that saturating a dry base course material has on the resilient deformation characteristics of the entire pavement section indicating that when water first was added to the base, no change in resilient deformation was observed. As the base approached complete saturation, however, the resilient deformation increased quickly, the increase being in excess of 60 percent of that in the dry state. These data indicate that the presence of water in the base had little effect on its stability until a critical percent saturation was reached, at which level its stability was suddenly reduced. Additional research is required to establish a maximum level of saturation for which no significant reduction in stability may be expected.

Casagrande's drainage design method can be utilized in several ways, ranging from replacing gradation requirements with $\frac{k}{n_e}$ requirements, to simply using it to check materials suspected of inadequate drainability. Because $\frac{k}{n_e}$ determinations may be too time consuming for normal construction operations, Casagrande's method is possibly more suited to some intermediary role, a few of which are suggested in the following paragraphs.

The data presented in this report show that Class II grading requirements provide materials whose maximum drainage time is 30 to 50 days, if Class II materials which are dense graded or which contain clay are excluded. The normal or average sand subbase material will drain faster and should in most cases meet or exceed the 10 day drainage requirement. For example, tests conducted on sand subbase samples collected from M 59 east of Pontiac indicate the material to have a uniform $\frac{k}{n_e}$ ratio and that from 2 to 6 days will be required for 50 percent drainage. These data are summarized in Table 5. On the other hand, densely graded subbase materials, such as Sample No. 13, Table 2, meet Class II grading requirements, but even when used in a two-lane bituminous concrete pavement (9A cross-section) would require over 300 days for drainage. Thus, although Class II grading limits are usually effective in providing adequately drainable sand subbase materials, those Class II materials which are densely graded or contain clay usually are not sufficiently drainable for Michigan's standard pavement cross-sections. Therefore, Casagrande's method could be used to conduct research aimed at modifying Class II grading requirements to preclude the possibility of accepting these materials.

TABLE 5
DRAINABILITY CHARACTERISTICS OF SAND SUBBASE FROM M-59 EAST OF PONTIAC

Station	Dry Density, lb/cu ft	Percent Sat. 50% Drained	Effective Porosity, n_e	Coef. Perm., k, ft/day	(k/n_e)	Time for 50% Drainage (t_{50}), days
369 + 00	107.3	73.8	0.10	5.5	55	6
379 + 00	107.5	71.1	0.10	5.5	55	6
389 + 00	106.2	71.4	0.11	7.5	68	5
399 + 00	106.4	77.8	0.08	8.6	107	3
408 + 00	106.0	71.6	0.11	5.9	54	6
419 + 00	106.3	75.4	0.09	8.4	93	3
429 + 00	107.0	77.5	0.08	8.7	109	3
439 + 00	105.8	77.8	0.08	12.3	154	2
449 + 00	106.4	76.2	0.09	12.4	138	2
459 + 00	106.8	75.0	0.09	6.6	73	4

The data shown in Table 4 indicate that supplemental Class II grading requirements may permit the use of materials whose maximum drainage time is excessive compared to that for Class II materials. Casagrande's method could be used to develop supplemental Class II grading requirements which would permit acceptance of materials of higher fines (-200 and -100 materials) by requiring other grading characteristics, such that the supplemental grading requirement would have the same $\frac{k}{n_e}$ ratio characteristics as that provided by Class II requirements.

Record test samples could be tested to determine the $\frac{k}{n_e}$ ratio. Results of such tests could be used to determine if a subbase layer has the desired drainability and, at some later date, to develop a correlation between drainage time and pavement performance.

In areas where it is advantageous to utilize a material source which does not meet grading requirements, such as stamp sand, a $\frac{k}{n_e}$ ratio requirement could be used to establish the acceptability of the material.

Conclusions

1. Casagrande's drainability design method appears to be a practical method of determining the acceptability of granular materials which do not meet Class II grading requirements, but only if supplemented with a minimum gravity drainable water content requirement.

2. The drainability requirement of all standard typical pavement cross-sections, when the maximum subgrade slope is specified, can be set at a $\frac{k}{n_e}$ ratio of 53.6. The requirement could be more accurately tied to the cross-section group if $\frac{k}{n_e}$ ratios of 34.2, 43.5, and 53.6 were, respectively, required of cross-section groups A, B, and C.

3. Class II and, particularly, supplemental Class II grading specifications may accept materials which, when placed to standard typical cross-section requirements, drain much too slowly to meet Casagrande's drainage requirement. Modification of these grading requirements is suggested.

4. In those areas where subbase materials having adequate $\frac{k}{n_e}$ ratio properties are too scarce or expensive, it may be possible to utilize locally available materials by modification of pavement cross-section such that the $\frac{k}{n_e}$ requirement of the cross-section is equivalent to that of the available materials.

5. The arbitrary permeability value of 0.283 ft/day, commonly used as the borderline between good and poor permeability for subbase materials, is not a satisfactory lower permeability limit for any group of pavement cross-sections.

6. The $\frac{k}{n_e}$ ratio requirement reported, applies only to subbases for which transient flow conditions are anticipated. When steady flow conditions are anticipated the drainability requirement must be selected on the basis of a steady flow criteria.

7. For the sake of uniformity of subbase material requirements, cross-sections 2A, 2B, 2C, and 9C should be modified to include only the following subgrade slopes: 0.06 ft/ft for cross-sections 2A, 2B, and 2C; and 0.04 ft/ft for cross-section 9C.

8. Field application of the method described is very easy since all that is necessary is to send representative samples to the Testing Laboratory where the $\frac{k}{n_e}$ ratio would be determined. If the $\frac{k}{n_e}$ ratios of the material are equal to or larger than the appropriate ratio indicated in conclusion 2, and if the material is less than 90 percent saturated when gravity drainage is complete, the material should be satisfactory.

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