STUDY ON THE FEASIBILITY OF CORRELATING PERCOLATION TIME WITH LABORATORY PERMEABILITY

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STUDY ON THE FEASIBILITY OF CORRELATING PERCOLATION TIME WITH LABORATORY PERMEABILITY

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ABSTRACT

A study was carried out in the field and in the laboratory to attempt to correlate the field percolation time ("t" time) and the laboratory permeability data. Field percolation tests were conducted at 16 sites in different Ontario soils and laboratory tests were performed on soil samples obtained at the same test sites.

The field percolation time was correlated with the laboratory permeability, which was the primary objective of the investigation. In addition, the correlation of percolation time and the grain size distribution and the plasticity data of soils was considered. An approximate correlation was suggested for sandy soils between the percolation time, permeability and grain size distribution. However, poor correlation was found for clayey soils between the percolation time and the laboratory soil data. Explanations were offered for the apparent poor correlation.

Project Staff

The following staff members assisted in carrying out the field percolation tests and soil testing in the laboratory.

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1. INTRODUCTION

Field percolation tests have been used for almost fifty years to evaluate the Infiltration capacity of soil for septic tank effluent. The general procedure of the test is as follows: a hole is dug or bored in the soil to the depth of the proposed trench bottom and water is poured into the hole for a period of several hours to wet the surrounding soil. After the soaking period, the water level in the hole is adjusted to a specified depth and the time required for the water level in the hole to drop one inch is measured. This time is generally referred to as the percolation time (perc. time or "t" time, frequently expressed as minutes per inch or simply as minutes), which is used to estimate the ability of soil to adsorb septic tank effluent.

The percolation test is relatively simple, but it is time consuming and troublesome when water is not readily available nearby and its procedure restricts it to be performed under moderate climatic conditions. Furthermore, its reliability as an indicator of soil suitability for on-site sewage disposal has been questioned. Therefore, a project was initiated in the summer of 1973 to study the possibility of using laboratory soil data to estimate the percolation time of Mario soils. Such indicators might be used independently or in conjunction with the percolation test.

The main advantages of using laboratory test results for the prediction of "t" time are:

1. The laboratory tests can be done at any time of the year after the soil samples are obtained in the field, and

2. The laboratory tests can be done with relatively simple apparatus and require shorter time to perform than the field percolation tests.

In order to investigate alternatives to the percolation tests, field percolation tests were done in the summer seasons of 1973 and 1974 at a number of sites underlain by different soil conditions. Soils samples were taken from the bottom of or adjacent to the percolation holes. Subsequently, the following laboratory tests were done on soil samples:

(i) permeability test,
(ii) grain size distribution by sieve analysis or hydrometer test, and
(iii) plasticity index (liquid limit test or plastic limit test).

In conjunction with the experimental program, a literature study was undertaken to collect data pertaining to percolation tests, permeability tests and the physical characteristics of different soils.

2. REVIEW OF THE PERCOLATION TEST

The percolation test was initially devised by Henry Ryon in the late 1920's (Federick, 1948) as a tool for sizing tile fields (drain field or leaching bed) and cesspools. Ryon's test involved digging a hole one foot square and 18 inches deep, or to the depth of the proposed trenches. The soil around the holes was soaked with water, then the hole was filled with six inches of water and the time it took the water level to drop one inch was measured. This time was considered the "t" time of the soil. In order to correlate the "t" time with the performance of the tile field system, Ryon determined the sewage loading rate of the installation. He also noted the prevailing conditions of the soil and system in addition to performing the percolation test. He classified the systems which he studied into three groups:

i. apparently loaded to capacity,
ii. overflowed at time, and
iii. overflowing at time of inspection.

The percolation rate and loading rate were plotted on a graph and an envelope was drawn on the assumption that above the curve the loading would be too much and below the curve the loading would be safe. Figure 1(a) contain Ryon's proposed relationship of tile field loading rates to "t" time (percolation rate). This curve represents the design criterion and has been in general acceptance for interpreting the percolation rate in terms of tile field design in septic tank installation.

Ryon also studied cesspool loading rates and related them to percolation rates. The proposed relationship is shy in Figure 1(b).

In the late 1940's, the Environmental Health Center of the U.S. Public Health Service performed a comprehensive study to investigate the reliability of Ryon's percolation test. To do so field studies of 45 tile fields were carried out in much the same manner as were Ryon's studies. The loading rates and history of each system were determined and recorded.

In 1948, Kiker published a procedure for conducting the percolation test and presented a formula for computing the allowable sewage loading rate, G, which is related to the value of "t" time

$$G = 29 / (t + 6.24)$$

where t is the percolation time in minutes per inch, and G is the rate of sewage application in U.S. gallons per day per square foot of bottom trench area.

Ludwig and Ludwig (1949) and Ludwig *et al* (1950) proposed a modification for measuring the changes in the percolation rate with time, and a mathematical analysis of the measurements. They also proposed that the allowable sewage effluent absorption rate is approximately equal to 5% of the clear water rate.

In 1952, Federick proposed a modification of Ryon's test and formulations for calculating the allowable sewage loading rate, Q, in U.S. gal. per sq. ft. per day, as a function of the "t" time. For tile fields, $Q = 5/\sqrt{t}$ and for leaching cesspools, $Q = 7/\sqrt{t}$.

To date, the percolation test has been adopted by many government agencies in Canada and the U.S.A. Through the years, the test has undergone various minor modifications. The procedure most widely used and frequently referred to is the Standard Percolation Test Procedure recommended by the U.S. Public Health Service (USPHS Test) (U.S. Public Health Service, 1957). In this procedure the preparation and soaking of the test holes are standardized. In order to reduce the cost and labour of doing the tests, it is recommended that smaller auger holes (4 to 12 inches (10-30 cm) in diameter) be used instead of 1 foot square holes as originally employed by Ryon. All these modifications are designed to ensure a successful measurement and to give a more reproducible result in the same soil.

3. TESTING PROGRAM

A number of sites were selected for this project on the basis of several criteria:

i. fairly uniform soil condition at the testing area,
ii. availability of water,
iii. easy access to the site, and
iv. a variety of soil types.

At the outset of the project, tests were mainly done in sandy soils, and later silty and clayey soils were tested.

3.1 Procedure for Percolation Testing

At one site, usually three closely spaced holes were used for the tests so that a more representative percolation time of the soil could be obtained. The depth of a hole was about 2 ft. (60 cm) and the diameter was 4 inches (10 cm). The hole was initially filled with water to the depth of about 12 inches (30 cm) above the bottom of the hole and the soil adjacent to the hole was soaked, usually for a period of 24 hours. Following the soaking period, the water level in the hole was adjusted to approximately 6 inches (15 cm) above the bottom of the hole. The required time for the water level to fall one inch (2.5 cm) was measured repeatedly until fairly consistent time readings were obtained. The average of the last 2 or 3 readings was considered as the percolation time ("t" time).

In doing the percolation test in sand, a wire mesh was placed in the hole to support the side walls of the hole.

3.2 Equipment for Percolation Testing

Figures 2(a) and 2(b) show the equipment used for field testing. The parts are listed as follows:

(A) Drums - to contain water which was used during the soaking period and during the percolation testing.

(B) Yard Stick - to measure the movement of the float ("E" in Figure 2(b)

(C) Timer - to measure time with an accuracy of 1 second.

(D) Soil Scraper - to clean up the loose soil at the bottom of the percolation hole.

3.3 Laboratory Testing

At each percolation test site, soil samples were obtained for testing in the laboratory. Several tests were performed:

i. Permeability test

ii. Sieve analysis for sandy soils,

iii. Hydrometer test for clayey soils,

iv. Atterberg limit tests (plastic limit and liquid limit tests).

The last three tests were performed on disturbed soil samples and permeability tests were performed either on disturbed (compacted) or "undisturbed" samples. The procedure for conducting the permeability test is briefly described as follows:

i. Permeability of Sand

Basically, two laboratory methods were used to determine the permeability coefficient of sandy soils.

1) The constant head method and

2) The falling head method.

The constant head method usually is recommended for coarse and gravelly sand when the flow of water is fast and the value of permeability is in the order of 10^{-1} to 10^{-2} m/sec. The falling head method is generally used for silty fine sand and for soils with slight cohesion.

In both methods, a disturbed soil sample was uniformly compacted in several equal layers in a permeameter to a density approximately equal to the *in situ* soil density. Then air was removed from the soil sample and the soil was saturated by de-aired water. When the flow of water became steady the following measurements were taken and recorded: time, initial and final water head (in the falling head method), the discharge of water percolating through the sample (in the constant head method), the temperature of water, the weight of the compacted soil, its volume, area and height. From these measurements the value of the permeability and the dry density of the compacted soil could be: calculated.

ii Permeability of Clayey Soil

A triaxial permeameter (Chan & Kenney, 1973) was used to measure the permeability coefficient of an "undisturbed" sample which was obtained with a Shelby tube (thin-walled steel tube) 2 inches (5 cm) in diameter. The soil sample was extruded from the tube and cut to length, usually three inches (7.5 cm) long. The soil sample was set up in the triaxial cell and a small pressure, about 3 to 5 p.s.i. (0.2 to 0.35 kg/cm2was used to consolidate the sample. Before the permeability measurement, water was allowed to enter the soil sample to bring the soil closer to saturation. During the test, a back-pressure of 15 p.s.i. (1 kg/cm^2) was used to dissolve some of the air bubbles in the soil. The hydraulic gradient used in the test was approximately equal to 5. The "constant head" method was employed for the permeability measurement.

4. TEST RESULTS

The experimental data obtained in this project and test results collected by other investigators are presented in tabulated and graphical forms.

In this project, percolation tests were performed at a total of 16 sites underlain by different soils ranging from very pervious sand to relatively impervious clay. The results of "t" time measurements, permeability, grain size and plasticity data are summarized in Table 1.

In the past several years, many field percolation tests were performed by the staff of the Southwestern Region of the Ministry of the Environment at sites near London, Ontario. The prevailing soil in the area is glacial till, which is relatively impervious. In addition to the field testing, soil samples were obtained for grain-size analysis and the determination of the plasticity indices. The test results are summarized in Table 2.

As part of the project, an extensive search of percolation test data in literature was done. The results from different sources are tabulated in Tables 3 to 9.

The data summarized in the tables are presented in several graphs. Figure 3 is a plot of percolation time vs. permeability coefficient. In Figure 4, the percolation time is plotted on the U.S. Dept. of Agriculture (U.S.D.A.) soil textural classification chart. On the same figure, the results obtained by Derr *et al* (1969) are also plotted.

Figure 5 contains a simplified relationship between soil types and grain size, which was proposed by Bernhart (1973). The percentage of silt and clay particles (<0.074 mm) in a soil is plotted against its percolation time in Figure 6. In Figure 7, the plasticity index, Which is the difference between liquid limit and plastic limit is plotted against percolation time.

5. DISCUSSION

5.1 Factors Affecting "t" Time

Figure 8 shows a typical section of a percolation hole. The groundwater table is located a few feet below the bottom of the hole and therefore the soil around and beneath the hole is unsaturated. Field measurements by Hill (1966) showed that the soil surrounding a 10 in. -diameter (25 cm) hole was indeed not saturated after the soaking procedure. Surface AD is the free water level of the water column in the hole; the envelope ABCD denotes an arbitrary boundary in the soil system. The rate of seepage of water from the hole into the unsaturated soil system is affected by:

1. the unsaturated permeability coefficient of the soil system and
2. the boundary conditions of the flow system, e.g. the height of the water column in the hole and the soil moisture tension (suction) on the boundary, such as ABCD in Figure 8.

The three-dimensional flow of water is caused by gravitational forces and the suctional forces in the unsaturated soil.

Because the value of permeability for different soils varies significantly, (10^{-1} to 10^{-9} cm/sec. see Table 10) and while boundary conditions in the soil system do not change excessively, it is quite obvious that the permeability factor would be the more important parameter.

5.1.1 Unsaturated Permeability

The unsaturated permeability is a complicated soil parameter. Unlike the saturated permeability, the unsaturated permeability depends on the soil moisture tension (suction). Figure 9 shows an example of the permeability (hydraulic conductivity) as a function of soil moisture tension. For sand, the hydraulic conductivity decreases drastically with increasing soil moisture tension and at certain values of soil moisture tension, the hydraulic conductivity of sand can be smaller than that of clay.

The conductivity of clay also decreases with an increase of soil moisture tension; however, the rate of decrease becomes smaller at higher values of moisture tension.

In a percolation test, even after the soaking period, the soil is unsaturated (Hill, 1966) because the seepage of water from the test hole under a small hydraulic head cannot completely remove the Air from the voids in the soil mass. The soil immediately adjacent to the test hole would be closer to saturation and therefore the soil moisture tension is lower. Farther away from the hole, the soil is drier and the soil moisture tension is generally higher. Because the unsaturated permeability is influenced by the soil moisture tension and because the soil moisture tension is not equal at various points around the percolation hole, a uniform system can have unequal values of permeability at different points.

The previous discussion applies to a uniform soil system. In the case of a stratified soil (i.e. soil with layers of different material) or a heterogeneous soil deposit, the situation will be much more complicated. The permeability of each soil layer is governed by a certain permeability - soil moisture tension relationship. In a percolation test, the water flow pattern is three-dimensional and will be very complicated in a heterogeneous soil system. The permeability of a soil at a specific point will influence the amount of soil water movement, and the amount of soil water in turn will influence the unsaturated permeability. Therefore, in a heterogeneous soil system, it is indicated that the permeability of the soil varies more significantly in comparison with a uniform soil.

The soil in which a percolation test is performed is near the ground surface. It is obvious that the amount of soil moisture contained in the soil changes with the weather condition. Therefore, the unsaturated permeability of a soil will vary in different seasons of the year. The soaking of the soil before the percolation measurement will increase the amount of moisture in a dry soil and reduce the difference in the moisture content between an initially dry soil and wet soil. However, the soaking of the soil around the hole will not likely produce in successive tests an identical moisture regime (or soil moisture tension) in soils which were initially quite dry or wet. Because of the difference in permeability, it has been found that in the same soil, the percolation rates obtained can vary by a factor of two or three.

5.1.2 Differences in Boundary Conditions

The rate of flow of water from the hole is affected by the moisture suction of the unsaturated soil adjacent to the hole. The suctional gradient existing in the soil at the time of testing is affected by: (a) the weather condition during testing time, (b) the time spent in soaking the soil, (c) the soil characteristics (for more permeable soil, the soil suction is probably reduced more effectively by a given period of soaking time).

5.1.3 Differences in Testing Conditions

When a percolation hole is prepared, the soil around the perimeter and the bottom of the hole is disturbed. If care is not exercised in preparing the hole, the soil will be smeared and greatly disturbed, which decreases the permeability of the soil.

During the soaking period, some fine soil particles are washed down from the side walls to the bottom of the hole, which will impede the flow of water through the bottom. For soils which are quite dry initially, the soaking water causes slaking of the soil and consequently a large quantity of fine-grained soil particles will be deposited at the bottom of the hole. The loose material needs to be removed very carefully so that the blocking of the flow of water during the percolation test is minimized.

As discussed in subsection 5.1.1, the length of the soaking time can affect the moisture content of the soil, and hence the unsaturated permeability and the suctional gradients in the soil.

The method used to measure the "t" time can also affect the test result. Generally, two methods have been used:

i. the average time per inch for the water level to drop a few inches in the hole is considered as the "t" time and

ii. the water level in the hole is kept at a fairly constant level (e.g. 6 inches above the bottom of the hole), and the time which takes the water level to drop 1 inch is considered as the "t" time.

5.2 Factors Affecting Laboratory Permeability Measurement

To perform laboratory permeability tests it is necessary to take samples in the field. For clayey soils, a 2 in. (5 cm)- diameter Shelby tube (thin-walled steel tube with a sharp cutting edge) is usually used to obtain an "undisturbed" sample. Because the soil to be sampled is near the ground surface and is generally dessicated, it is often very difficult to obtain a good sample. More than frequently, a drop hammer is used to force the tube into the soil. This sampling technique can have several damaging effects to the soil sample:

i. large disturbance to the structure of the soil adjacent to the inner surface of the tube.
ii. closing up of the fissures, cracks and root holes which may exist in the soil *in si*tu and which are significant to the flow of water, and
iii. slight increase in the density of the soil sample.

These factors can cause a significant decrease in the permeability of the soil.

In the laboratory, the clayey soil sample is consolidated slightly before the permeability measurement. After the consolidation process, the fissures, cracks, small root holes in the soil sample are closed up more and the volume of voids in the soil structure is slightly decreased. Consequently, the permeability of the soil sample is further reduced.

In laboratory test, the water flows in one direction through the soil sample. In a sample with different soil layers, (e.g. stratified soil), the water permeates across the layers and the flaw is controlled by the less permeable layers. In a percolation test, the water flow pattern is three-dimensional, and the lateral flow can be very important. If the soil is layered, the seepage in the lateral direction can be greatly increased by the presence of the more permeable thin layers which are not significant in the laboratory one-dimensional flow condition. Therefore, the average field permeability of a stratified soil can be grossly underestimated in the laboratory.

5.3 Discussion of Test Results

From the previous discussions, it can be seen that the "t" time of a soil is mainly affected by the unsaturated permeability. Therefore, it would seem feasible and reasonable to relate approximately the "t" time of a soil to its permeability whose value is equivalent to the combined values of permeability of the soil at different points adjacent to the test hole. Such a relationship is given in a U.S. Department of the Interior publication (1963). According to the equation a "t" time of 60 minutes corresponds to a permeability value of 3.2×10^{-5} cm/sec(See Fig. 10 for detailed calculations); a "t" time of 5 minutes corresponds to a value of permeability equal to 4×10^{-4} cm/sec. It should be emphasized that this "t" time and permeability relationship is derived on the basis of a number of simplifying assumptions with regard to the flow regime and boundary conditions.

Theoretically, if the relationship of the unsaturated permeability and the soil moisture tension can be determined experimentally and the equivalent permeability equal to the combined values of the permeability coefficients at various points adjacent to the test hole can be computed, it would then be possible to compute the "t" time of the soil for specific boundary conditions from the equivalent permeability. In practice, it is very difficult and time consuming to measure the unsaturated permeability and is practically impossible to calculate the equivalent permeability around the hole. Therefore, from a practical view point, the saturated permeability appears to be a reasonable alternative for estimating the "t" time of a soil.

Figure 3 is a graphic summary of "t" time versus permeability.

Firstly, the discussion will be for soils with values of permeability greater than 10^{-5} cm/sec. These soils are mainly sandy and silty soils and generally are cohesionless. However, some clayey (cohesive) soils, because of their soil structure, may have permeability values belonging to this category. It can be seen that there is a significant amount of scattering of the points. This is not unexpected because the "t" time of the soil is affected by many factors (refer to Section 5.1), some of which are rather difficult to control.

However, despite a number of factors which can influence the "t" time and permeability measurements, on the basis of the experimental data, an <u>empirical</u> relationship between the permeability and the "t" time of soils can be suggested for the design of tile fields in sandy and silty soils with permeability values greater than 10^{-5} cm/sec. (See Table 11).

For non-cohesive sandy and silty soils with permeability values between 10^{-5} and 10^{-6} cm/sec, it appears that the corresponding "t" time is approximately 60 minutes. However, it should be emphasized that this correlation is based on very limited data and therefore it should be used with caution and judgement together with other soil test data.

The suggested values of "t" time corresponding to the permeability should be considered as envelopes for practical design purposes. Although the correlation is a crude one, it would be useful and adequate for estimating the required tile field area, because Ryon's correlation between the allowable sewage loading rate and "t" time is also a very approximate one.

It can be seen that the suggested empirical relationship between the "t" time and the permeability is quite different from the theoretical "t" time and permeability relationship as given by the U.S. Bureau of Reclamation equation. The difference can be attributed to:

i. assumptions made in the theory are not all valid,
ii. complications occurred in field testings, e.g. smearing of the surface of the hole and the sedimentation of the soil particles at the bottom of the hole, are not taken into account in the derivation of the equation and
iii. the saturated permeability is used in the empirical correlation, but actually the seepage of water from the hole into the surrounding soil is affected by the unsaturated permeability.

For soils with permeability values smaller than 10^{-5} cm/sec, it would be very difficult to correlate the "t" tine of the soil to its permeability because of significant scattering in the experimental points and because the data collected to date is limited.

The significant scattering of the experimental points can be attributed, to a very large extent, to the limitations of the laboratory technique which was used to measure the laboratory permeability of clayey soil samples. At some test sites, (e.g. Clairville and Whitby), the structure of the soil in situ was favourable for the percolation of water; however, the beneficial features were probably not present or were eliminated in the small soil samples. Consequently, the measured laboratory permeability became very small (10^{-7} to 10^{-8} cm/sec).

The data contained in the U.S.D.A. triangular chart (Figure 4) will be useful for non-cohesive sandy and silty soils, but will be of limited use for clayey soils. However, the data do point out that for clayey soils, the probability of having a "t" time above 60 minutes is high.

The "t" time suggested by Derr *et al* (1969) for clayey soils (e.g. clay, silty clay) appear to be on the low side. However, it should be remembered that their data were obtained by testing soils in Pennsylvania State and the reported "t" time were results of statistical evaluation. Therefore, the Pennsylvania results should be used with extreme caution for Ontario soils.

Figure 6 is a plot of the percentage of silt and clay content of a soil vs "t" time. For practical purposes a design envelope is suggested.

For clayey soils, it can be seen that a 90% silt and clay content can mean a "t" time ranging from a few minutes to a few hundred minutes. No design envelope is suggested for soils with larger than 40% silt and clay content.

Referring to Figure 7, the plasticity index of soils varies with a very wide range of "t" time. For example, a value of plasticity index equal to 10 can indicate a "t" time of a few minutes to a few hundred minutes. Therefore, it would be difficult to estimate the "t" time for the soil solely on the basis of the plasticity of the soil.

6. SUMMARY AND CONCLUSIONS

The percolation time ("t" time) in a field percolation test is affected by several factors:

i. the soil characteristics, the most important one being the unsaturated permeability.
ii. the soil moisture tension or suction in the soil adjacent to the test hole, and
iii. the conditions during testing.

On the basis of experimental data, a design envelope (or guideline) can be proposed for the estimate of "t" time from the permeability of non-cohesive or slightly cohesive sandy and silty soils (see Table 11). However, it is not possible at this time to recommend an approximate "t" time and permeability relationship for clayey (cohesive and structured) soils. The main reason appears to be that the soil structure of the laboratory permeability test sample is significantly different from the *in situ*, undisturbed soil structure.

In the field test, the presence of fissures, cracks, rootlet, worm holes, thin pervious soil layers, etc., can greatly reduce the "t" time of a soil. In the laboratory test, these beneficial features are either destroyed during sampling and testing or they are simply not present in the small soil sample. Therefore, the laboratory test results will always indicate a more impervious condition than that existing in the field. If the laboratory data show that the soil is relatively pervious, it means that the soil should have a good infiltrative capacity for water. However, if the laboratory results indicate that the soil is relatively impervious, it does not necessarily mean that the soil is impervious in the field.

The use of the percentage silt and clay content in a soil as an indicator for "t" time is feasible for sandy and silty soils and not practical for clayey soils because such soils with a large percentage of silt and clay content might have a small value of "t" time.

For sandy soils, it is possible to estimate approximately their "t" time on the basis of the grain-size distribution curve which can be determined in the laboratory.

For clayey soils, it is difficult to correlate the "t" time with data on permeability, grain size distribution and plasticity. However, these soil test results should be useful, at least in a qualitative sense, to a technician (or health inspector) because the results would indicate the probability of the soil being a "problem" soil for the installation of tile fields. For example, if the soil has a small value of permeability, a large percent of silt and clay content and a high value of plasticity, then it is quite likely that the soil would also have a large value of "t" time. In addition to the use of the laboratory data, it is advisable to study carefully the *in situ* soil structure and the density of the soil in a trench or an exposed soil surface. If the soil is not disturbed and has fissures, cracks, rootlet and worm holes and small channels, and the soil does not appear very dense, the clayey soil would probably have a "t" time less than 60 minutes. However, if the soil is dense and massive in structure, it is quite likely that the material would have a "t" time exceeding 60 minutes.

To date, it is still a difficult problem to assess the suitability of clayey (structured) soils for the absorption of septic -tank effluent. In the absence of a better field or laboratory indicator, the value of "t" time of clayey soils would be a useful parameter for design. However, if it is not feasible to perform the field percolation test in such soils, an evaluation of the suitability of clayey soils on the basis of soil properties, soil maps and local knowledge of the performance of existing tile fields in similar soils would be a good alternative (U.S.D.A., 1961, Morris *et al*, 1962, Seglin, 1965, Huddleton and Olson, 1967).

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TABLE 1. Percolation & Laboratory Test Results Obtained In This Project.

Site	"t" Time (min/in)	Permeability (cm/sec) (compacted sample)	Soil Characteristics						Soil Type
			Sand %	Silt %	Clay %	L.L.%	P.L. %	P.I.%	
Woodbine Beach	0.4		99	1					
(Metro Toronto)	0.3	1.2×10^{-2}	97	3					
	0.2		98	2					sand
	0.2		97	3					
Fairly Lake Area	3.7	2.3×10^{-2}	85	15					
(near Huntsville),	1.0	1.9×10^{-2}	96	4					sand
Site 1									
Fairly Lake	3.0	1.3×10^{-2}	85	15					
Area, Site 2	5.0	7.3×10^{-4}	88	12					sand
Fairly Lake	1.0	1.4×10^{-2}	94	6					
Area, Site 3	1.0	3.2×10^{-2}	93	7					sand
Port Credit	3.4	2.3×10^{-3}	71	23	6				silty
	3.7	3.4×10^{-3}	69	25	6				fine sand
Severn River and	4.3		14	70	16				CL-ML
Hwy. 11 Intersection	16.5		12	73	15				
Komoka	45.0	7.3×10^{-6}	65	28	7				silty sand
	40.0	4.0×10^{-6}							
Poplar Hill	9.0	4.2×10^{-6}	52	38	10				silty sand
Orillia	14.5		62.1	25.3	12.6				
	39.0		61.5	28.9	9.6				
	23.0		62.4	26.9	10.7	1			ML

TABLE 1.Cont'd

Site	"t" Time (min/in)	Permeability (cm/sec) (Shelby Tube Sample)	Soil Characteristics						Soil Type
			Sand %	Silt %	Clay %	L.L.%	P.L.%	P.I.%	
Rowntree's Mill Park	1.8	2.5 x10^{-5}	22	64	14	30.2	19.3	10.9	CL
(Metro Toronto)	5.7								
	4.7								
	1.7		28	59	13	26.2	19.2	7.0	CL-ML
Clairville Conservation	1.3	2.1 x 10^{-7}	32	50	18	28.5	18.7	9.8	CL
Area, (Metro Toronto)	1.2								
	1.2								
	1.2		12	63	25	36.1	22.8	13.3	CI
Heart Lake Area	175.0	1.3 x 10^{-7}	23	51	26	35.0	20.7	14.3	CL
(near Brampton)	192.0								
	153.0								
Whitby	13.5	1.6 x 10^{-8}	6	52	42	51.0	22.8	28.2	CH
	20.5	1.7 x 10^{-7}	4	68	28	38.4	17.8	20.6	CI
			6	45	49	47.8	20.0	27.8	CI
Rexdale	5.0	1 x 10^{-7}	11	35	54	35.1	17.8	17.3	CI
	158.0	(Estimated)	10	35	55	39.2	19.0	20.2	CI
	95.0		15	41	44	35.4	18.6	16.8	CI
	99.0		10	37	53				
Markham	127.0	1 x 10^{-7}	48	36	16	29.3	16.8	12.5	CL
	94.0	(Estimated)							
Don Mills	4560	1 x 10^{-8}							
		(Estimated)	40	43	17	25.4	15.0	10.4	CL

TABLE 1. Cont'd

Remarks

1. The soils are classified according to the Unified Soil Classification System.
   CL = clay of low plasticity (lean clay).
   ML = sandy silt.
   CI = clay of intermediate plasticity.
   CH = clay of high plasticity (Fat clay).

2. L.L. = Liquid Limit. P.L. = Plastic Limit. P.I. = Plasticity Index.

3. The first eight sites were underlain by non-plastic (non-cohesive) soils.

TABLE 2. Percolation Test Results And Characteristics of Soils in Southwestern Region of MOE.

Site	"t" Time (min/in)	Soil Characteristics						Soil Type
		Sand %	Silt %	Clay%	L.L.	P.L.%	P.I. %	
Snider	120	16	56	28	28.6	15.0	13.6	CL
	160	11	48	41	42.5	18.8	23.6	CI
	128	12	54	34	40.8	18.1	22.7	CI
	160	17	59	24	24.1	13.9	10.2	CL
Conklin	120	25	51	24	29.1	14.0	15.1	CL
	160	20	53	27				CL
	400	10	57	33				CL
Durcharme	360	21	48	31	30.5	14.8	15.7	CL
	120	22	54	25	25.5	13.7	11.8	CL
	280	17	51	32	29.5	14.6	14.9	CL
Maypark	100	6	68	26	31.3	16.6	14.8	CL
	140	22	53	25	30.5	16.7	12.8	CL
Kuelk	60	14	62	24	27.3	15.5	11.8	CL
	36	10	64	26	27.3	13.7	13.6	CL
Montieth	18	28	51	21	23.0	13.6	9.4	CL
	148	21	57	22	24.7	14.4	10.3	CL
	80	23	56	21	31.5	17.2	14.3	CL
	60	25	49	26	25.0	13.4	11.1	CL
Martin May	120	9	78	13	21.2	17.3	3.9	ML
	80	13	48	39	39.3	16.4	22.9	CL

TABLE 2. Cont'd

Site	"t" Time	Soil Characteristics						Soil Type
	(min/in)	Sand %	Silt %	Clay %	L.L.%	P.L.%	P.I.%	
Kinsmen	480	4	71	25	22.0	15.3	6.7	CL-ML
	120	15	52	33	28.2	15.1	13.1	CL
Roy	36	25	60	15	21.0	16.2	14.8	ML-CL
	48	5	68	27	34.7	17.2	17.5	CL
Dzisk	60	8	48	44	41.2	16.5	24.7	CL
Wynne	56	12	67	21	22.6	13.5	9.1	CL
	56	20	52	28	28.0	13.7	14.3	CL
	12	7	53	40	49.9	17.8	32.1	CI
wild	360	41	32	27	31.8	14.9	16.9	CL
	120	17	47	36	37.2	15.0	22.2	CL
Langlois	80	19	55	26	36.1	16.6	19.5	CI
	88	21	57	23	29.2	16.1	13.1	CL
Heterington	400				33.1	16.7	16.4	CL

<u>Remarks</u>

1. The size of percolation hole was 8" (20 cm) in diameter.
2. The original percolation time ("t" time) was obtained for the drop of the water level from 12" (30 cm) to 11" measured from the bottom of the hole. In order to be consistent with percolation time from other sources, the percolation time for the water level drop from 6" to 5" was estimated [t (6" to 5") = t (12" to 11") x a factor of 2] and reported in this table. The experience in doing percolation tests in Ontario indicates that this factor is about 2.

TABLE 3: Test Results From Bouma (1970).

Site a Soil	"t" Time (min/in)	Permeability (cm/sec) (Double Tube Method)	Grain Size Distribution		
			Sand%	Silt%	Clay%
Charmany Silt Loam * AP (Silt Loam) 20 cm	11.3	1.2×10^{-4}	4.0	81.0	15.0
B_2 (Silty Clay loam) 60 cm	19.9	6.0×10^{-4}	1.6	65.9	32.5
B_3 (Silty Clay Loam) 120 cm	34.5	3.0×10^{-4}	2.0	67.9	30.1
Mandt Silt Loam AP (Silt Loam) 20 cm	6.0	1.2×10^{-4}	11.9	68.1	20.0
B_2 (Silty Clay Loam) 50 cm	21.0	2.9×10^{-4}	1.8	68.2	30.0
B_3 (Silty Clay Loam) 80 cm	31.8	8.1×10^{-5}	2.2	67.8	30.0
Ormo Clay, Cultivated AP (Clay) 20 cm	99.0	5.8×10^{-5}	2.6	26.3	71.1
B_2 (Silty Clay) 50 cm	50.8	7.0×10^{-5}	6.6	53.4	40.0
B_3 (Silty Clay Loam) 80 cm	37.7	5.8×10^{-5}	1.9	61.9	36.2
Arena Loamy Sand B_3 (Fine Sand) 80 cm	7.2	4.9×10^{-3}	94.6	2.9	2.5
Plattville I Silt Loam, Cultivated. B_3 (Silty Clay Loam) 80 cm	38.5	2.3×10^{-4}	2.4	66.4	31.2
Plattville II Silt Loam, Virgin B_3 (Silty Clay Loam) 80 cm	6.5	8.7×10^{-4}	2.5	67.5	30.0

Remarks:

1. Size of hole = 10" (25 cm)
2. 2" gravel at the bottom of the hole.
3. 14" water head above the bottom (12" water head above the gravel) for soaking.
4. 8" water head above the bottom (6" water head above the gravel) for percolation time measurements.
5. Agricultural soil classification system used by Bouma.

TABLE 4. Test Results From Bouma (1971).

Site and Soil	"t" Time (min/in)	Permeability (cm/sec) Double Tube Method
Batavia Silt Loam B_2 (60 cm)	22.8	6.9×10^{-4}
B_3 (120 cm)	56.2	2.6×10^{-4}
Plano Silt Loam B_2 (50 cm)	18.3	3.2×10^{-4}
B_3 (80 cm)	24.4	1.3×10^{-4}
Tama Silt Loam B_2t (Virgin Site) (80 cm)	8.7	1.1×10^{-3}
B_3 (Cultivated)(80 cm)	25.4	3.1×10^{-4}
Saybrook Silt Loam IIC (Stony Sandy Loam Tilt)	3.0	9.3×10^{-4}
Plainfield Loamy Sand C (120 cm in sand)	2.3	3.5×10^{-3}

Remarks:

1. Size of hole = 6 in (15 cm).
2. 2" gravel at the bottom of test hole.
3. Water head was measured from the top of gravel.

TABLE 5. Test Results From Bouma (1972).

Site and Soil	"t." Time (min/in)	Permeability (cm/sec) Double tube method	Grain Size Distribution		
			Sand %	Silt %	Clay %
Kelly Lake Tustin Fine Sandy Loam IIB_2 (Sandy Clay Loam) 46-76 cm.	200.0	1.2×10^{-5}	47	27	26
Ashland Hibbing Silty Clay Loam B_3 (Clay) 65-120 cm.	1400.0	2.3×10^{-6}	25	28.5	46.5
Dardis Vilas Loamy Sand C (Coarse Sand) 90 cm+	< 1.0	6.9×10^{-3}	99	1	0
Marshfield Withee Silt Loam IIB_3 (Clay Loam) 63-120 cm.	1400.0	2.3×10^{-6}	37.5	33	29.5

Remarks

1. Size of Hole = 4"-6".
2. 2" gravel at the bottom of the hole.
3. Depth of water was measured from top of gravel.

TABLE 6. Test Results From Mokma (1966).

Site and Soil	"t" Time (min/in)	Permeability Core Sample (cm/sec)	Grain Size Distribution		
			Sand%	Silt%	Clay%
St. Clair Loam C2 (Silty Clay)	182.0*	1.4×10^{-5}	16.7	39.9	43.4
Miami Sandy Loam B22t (Sandy Clay Loam)	48.3*	1.2×10^{-4}	51.0	26.5	22.5
Hillsdale Sandy Loam B22t (Sandy Loam)	41.7*	1.7×10^{-4}	67.7	15.7	16.6
Oshtemo Loamy Sand B22 (Gravelly Sandy Loam)	2.6*	7.3×10^{-3}	81.8	5.8	12.4
Graycalm Loam Sand A2 (Sand)	1.4*	1.2×10^{-2}	96.8	2.4	0.8

Remarks:

1. Size of hole = 7".
2. 2" Gravel at the bottom of the hole.
3. Water head was measured from top of gravel.
4. Percolation time was measured when the water level was 4 to 8 inches above the gravel.

* The average percolation time measured in the period from April to August.

TABLE 7. Test Results From Healy & Laak (1973).

"t" Time (min/in)	Permeability (cm/sec) core sample
2.2	1.3×10^{-4}
7.1	1.3×10^{-4}
6.4	2.6×10^{-4}
5.1	3.9×10^{-4}
10.4	2.1×10^{-4}
1.3	6.6×10^{-4}
2.4	7.2×10^{-4}
2.7	8.8×10^{-4}
2.9	7.8×10^{-4}
3.5	6.8×10^{-4}
3.5	9.1×10^{-4}
1.6	1.3×10^{-3}
5.1	1.2×10^{-3}
1.4	2.1×10^{-3}
1.6	2.4×10^{-3}
2.0	2.6×10^{-3}
1.5	3.0×10^{-3}
2.1	4.0×10^{-3}
3.9	4.0×10^{-3}
14.2	5.7×10^{-4}
11.6	2.1×10^{-3}
16.0	1.8×10^{-3}
11.8	3.5×10^{-3}
3.6	1.4×10^{-2}
0.9	3.3×10^{-2}

Remarks:

1. Size of Hole = 6" - 8"
2. Depth of Hole = 2' - 3'
3. The percolation time was measured after second filling of the hole to a depth of 12", by observing the rate of water level falling between 8 and 4 inches.

TABLE 8. Test Results From Hill (1966).

Site & Soil	"t" Time (min/in)	Permeability (cm/sec) Core Sample
Merrimac sandy loam		
at 18"	4.5	6.1 x 10^{-3}
at 36"	2.4	1.2 x 10^{-2}
Cheshire fine sandy loam		
at 18"	7.4	1.5 x 10^{-3}
Wethershield silt loam		
at 18"	60.0	4.2 x 10^{4}

Remarks:

1. Size of hole = 10".
2. $10^{1}/_{2}$ inches gravel at the bottom of the hole during presoaking.
3. $4^{1}/_{2}$ inches gravel at the bottom of the hole during percolating time measurement.
4. Percolation time was measured by the water drop from 6 to 5 inches.
5. Water head was measured from the bottom of test hole.

TABLE 9. Mean Percolation Time For Field Designated Permeability Classes.

Permeability Class	Permeability Range (cm/sec)	"t" Time (min/in)
Very slow	Less than 0.35×10^{-4}	304.8
Slow	0.35×10^{-4} to 1.4×10^{-4}	152.4
Moderately slow	1.4×10^{-4} to 5.7×10^{-4}	54.4
Moderate	5.7×10^{-4} to 17.6×10^{-4}	11.5
Moderately rapid	17.6×10^{-4} to 35.2×10^{-4}	5.6
Rapid	35.2×10^{-4} to 70.4×10^{-4}	2.9
Very rapid	Over 70.4×10^{-4}	2.5

Remarks:

1. Permeability class is based on U.S. Dept. of Agriculture Classification.
2. Data are from Derr *et al* (1969).
3. The percolation testing method used was similar to the procedure outlined by the U.S. Public Health Service (1967).

TABLE 10. Approximate Permeability Of Different Soils.

Typical	Value of K cm/sec*	Relative Permeability
Coarse gravel	over 1 x 10^{-1}	Very permeable
Sand, fine sand	1 x 10^{-1} - 1 x 10^{-3}	Medium permeability
Silty sand, dirty sand	1 x 10^{-3} - 1 x 10^{-5}	Low permeability
Silt	1 x 10^{-5} - 1 x 10^{-7}	Very low permeability
Clay	less than 1 x 10^{-7}	Practically impervious

* (To convert to feet per minute, multiply above values by 2; to convert to feet per day, multiply above by 3 x 10^{3}).

TABLE 11. Proposed Relationship Between Lab Permeability And "t" Time.

Lab Permeability (cm/sec)	"t" Time (min/in)
10^{-2} or larger	5
10^{-2} to 10^{-3}	20
10^{-3} to 10^{-4}	40
10^{-4} to 10^{-5}	50

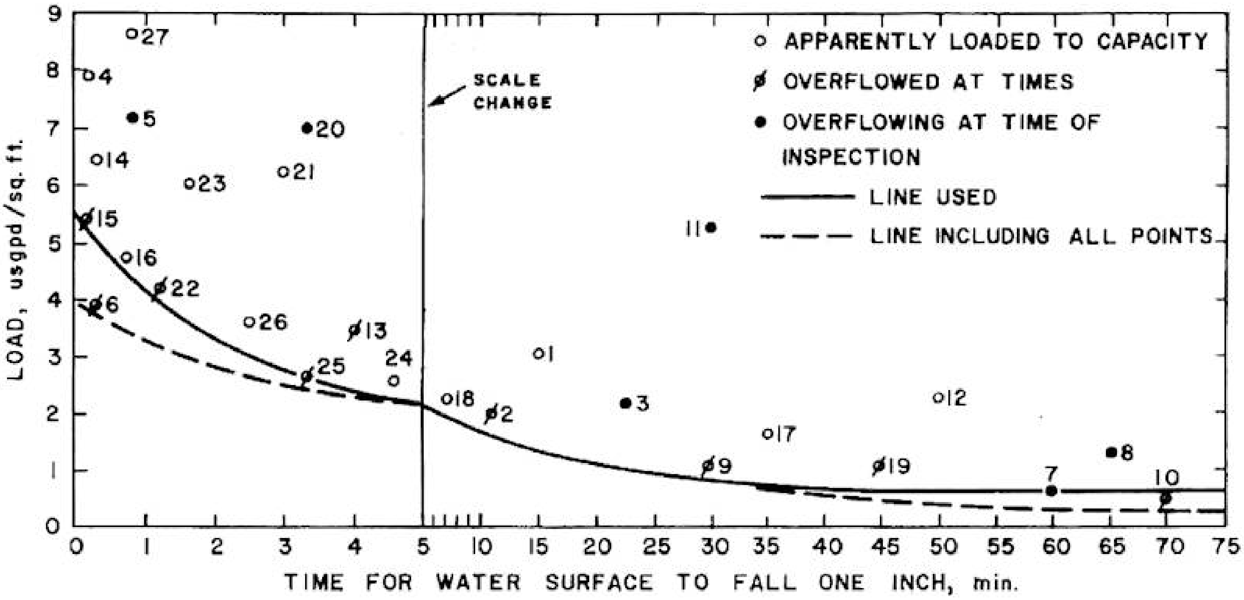


FIGURE 1(a): Relationship Of Tile Field Loading Rates To Percolation Test Rates. (After McGauhey And Krone, 1967).

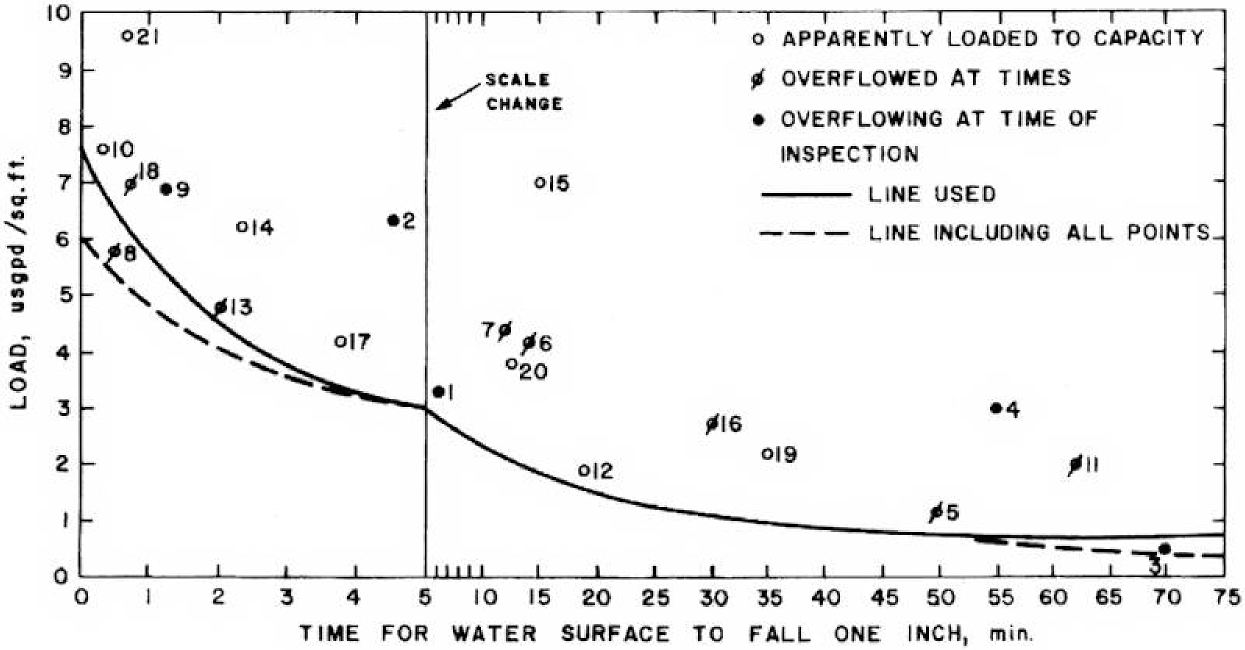


FIGURE 1(b): Relationship Of Cesspool Loading Rates To Percolation Test Rates. (After McGauhey And Krone, 1967)

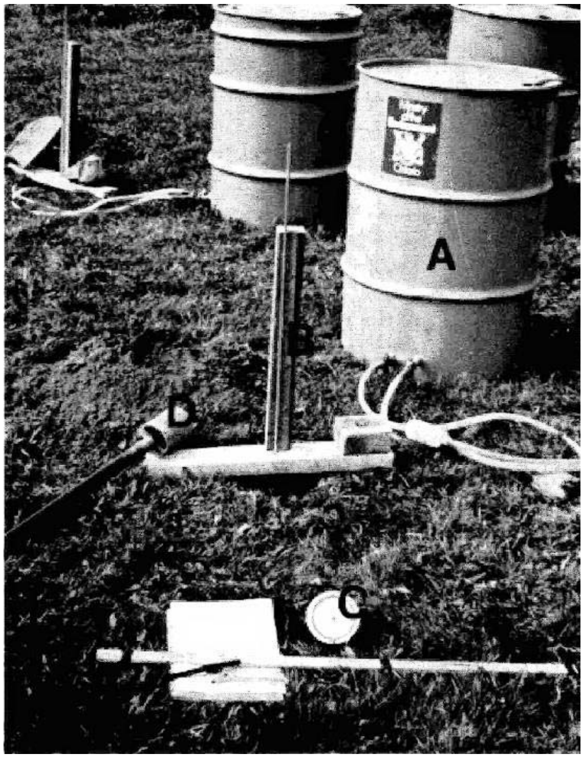


FIGURE 2(a): Equipment For Percolation Testing.

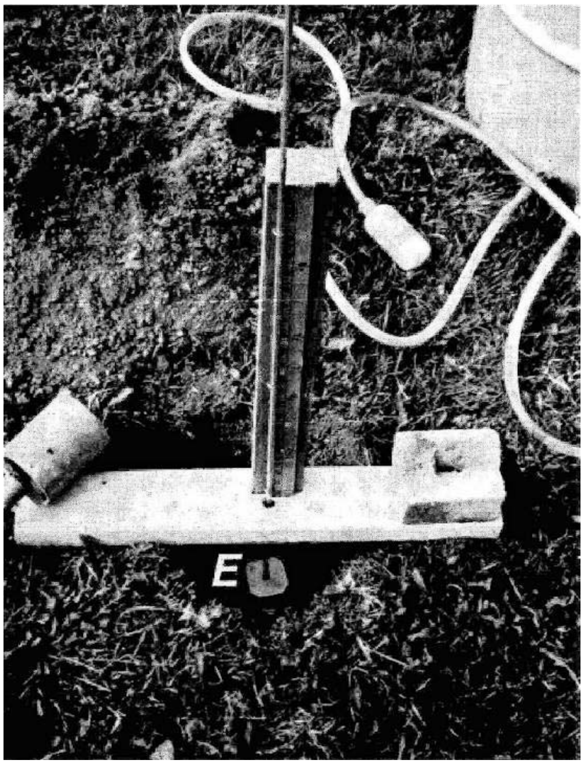


FIGURE 2(b): A Close View Of The Float.

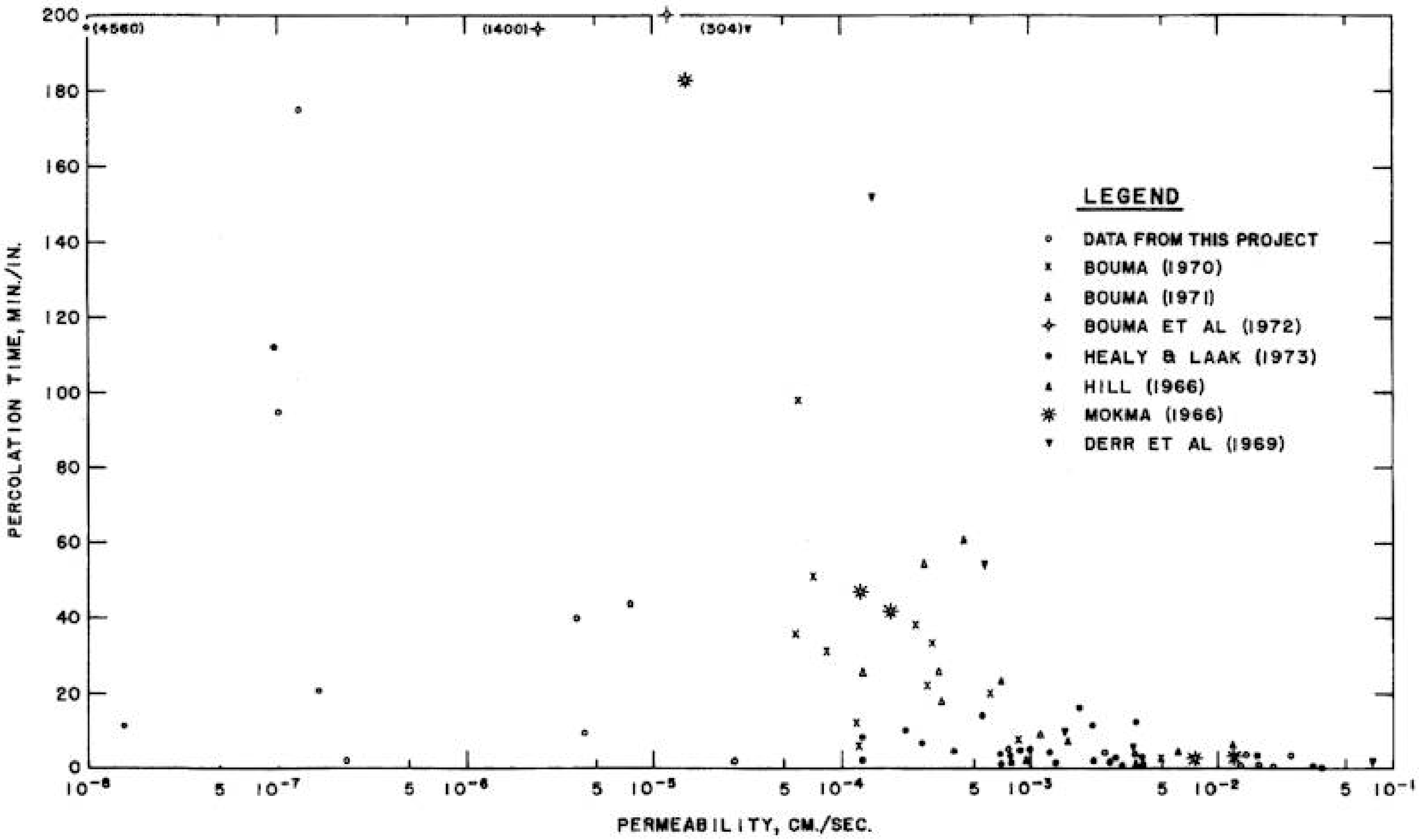


FIGURE 3: Percolation Time Vs Permeability.

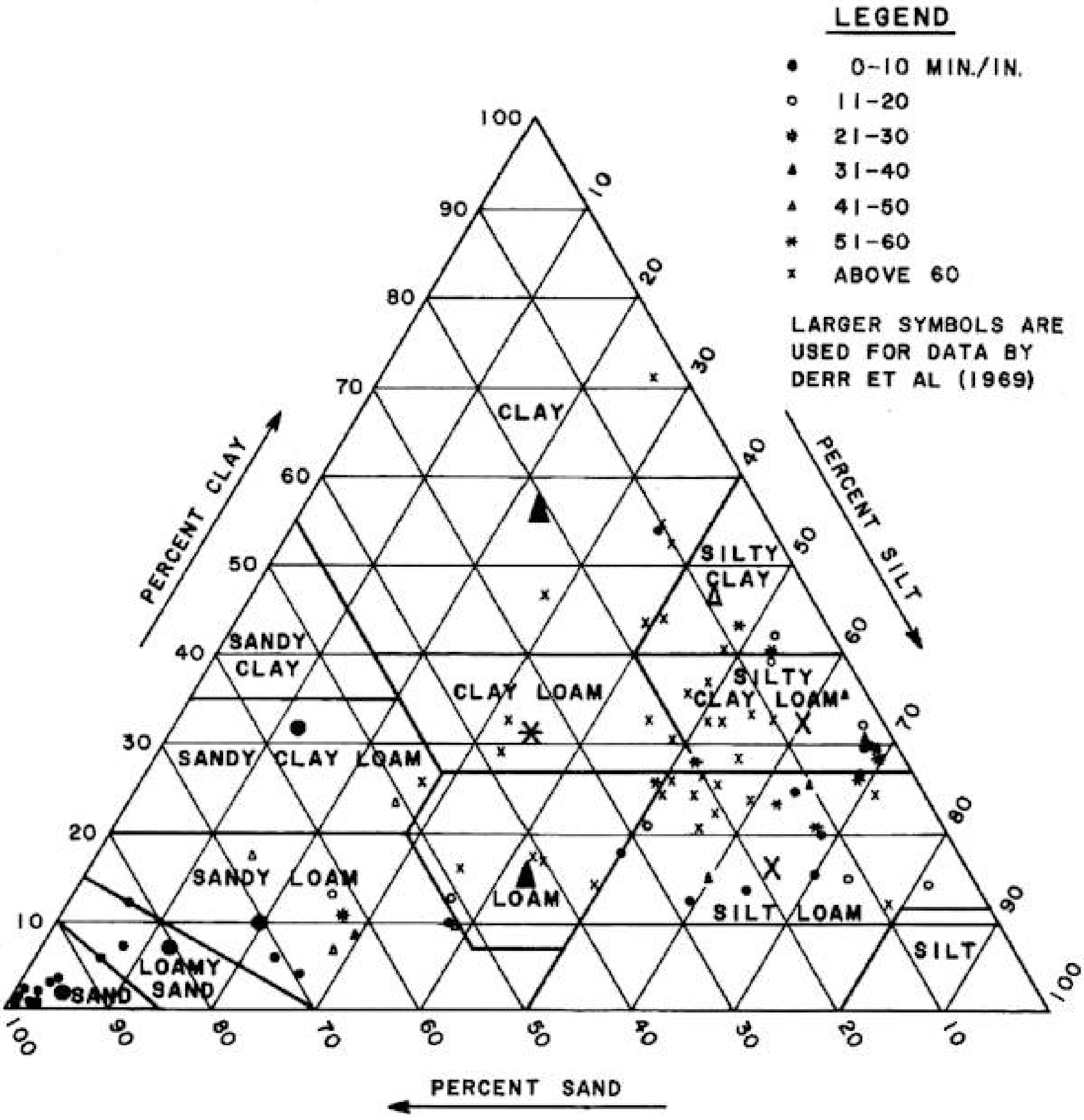


FIGURE 4: Percolation Time Vs Soil Texture.

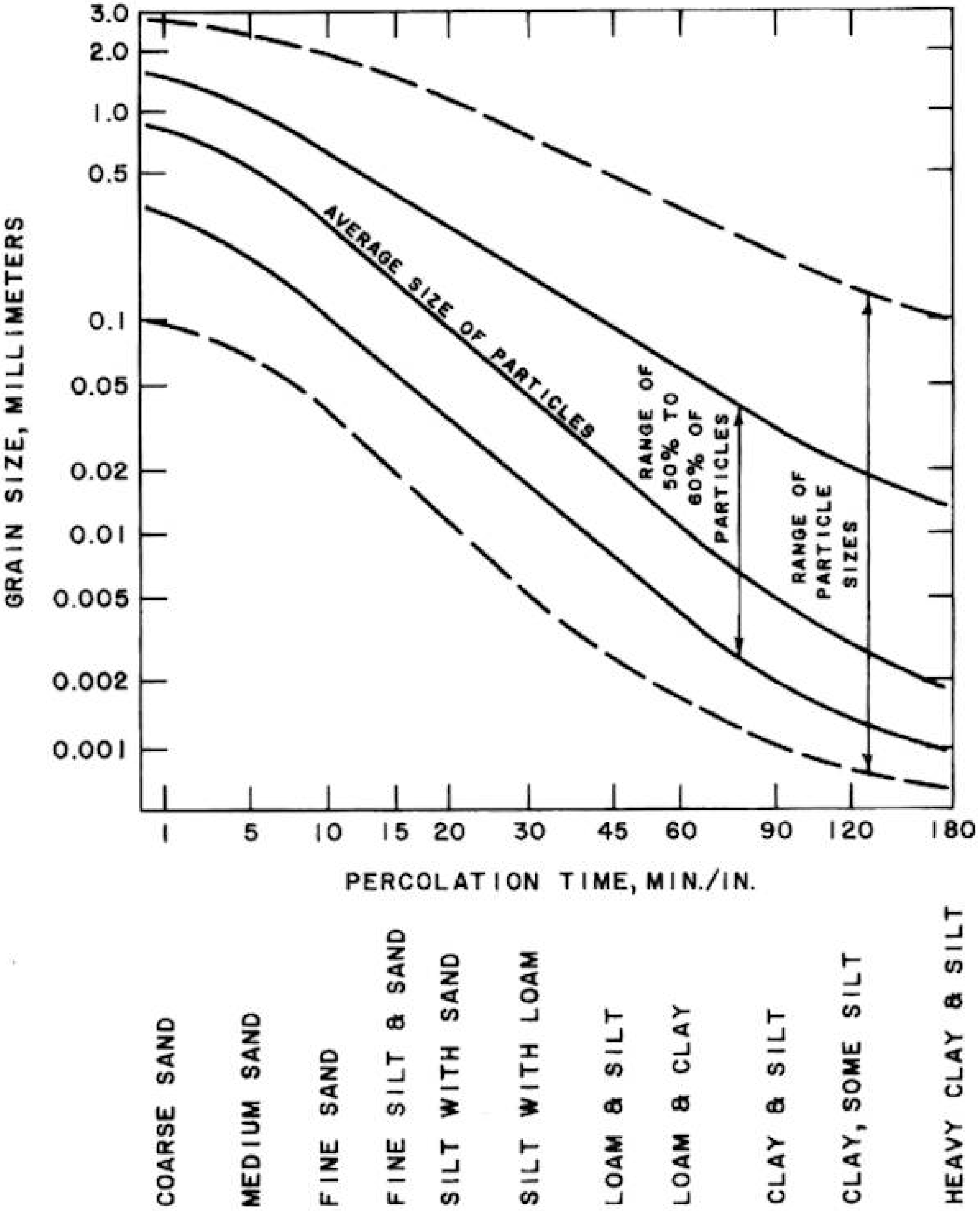


FIGURE 5: Simplified Relationship Between Soil Types And Grain Size (After Bernhart, 1973).

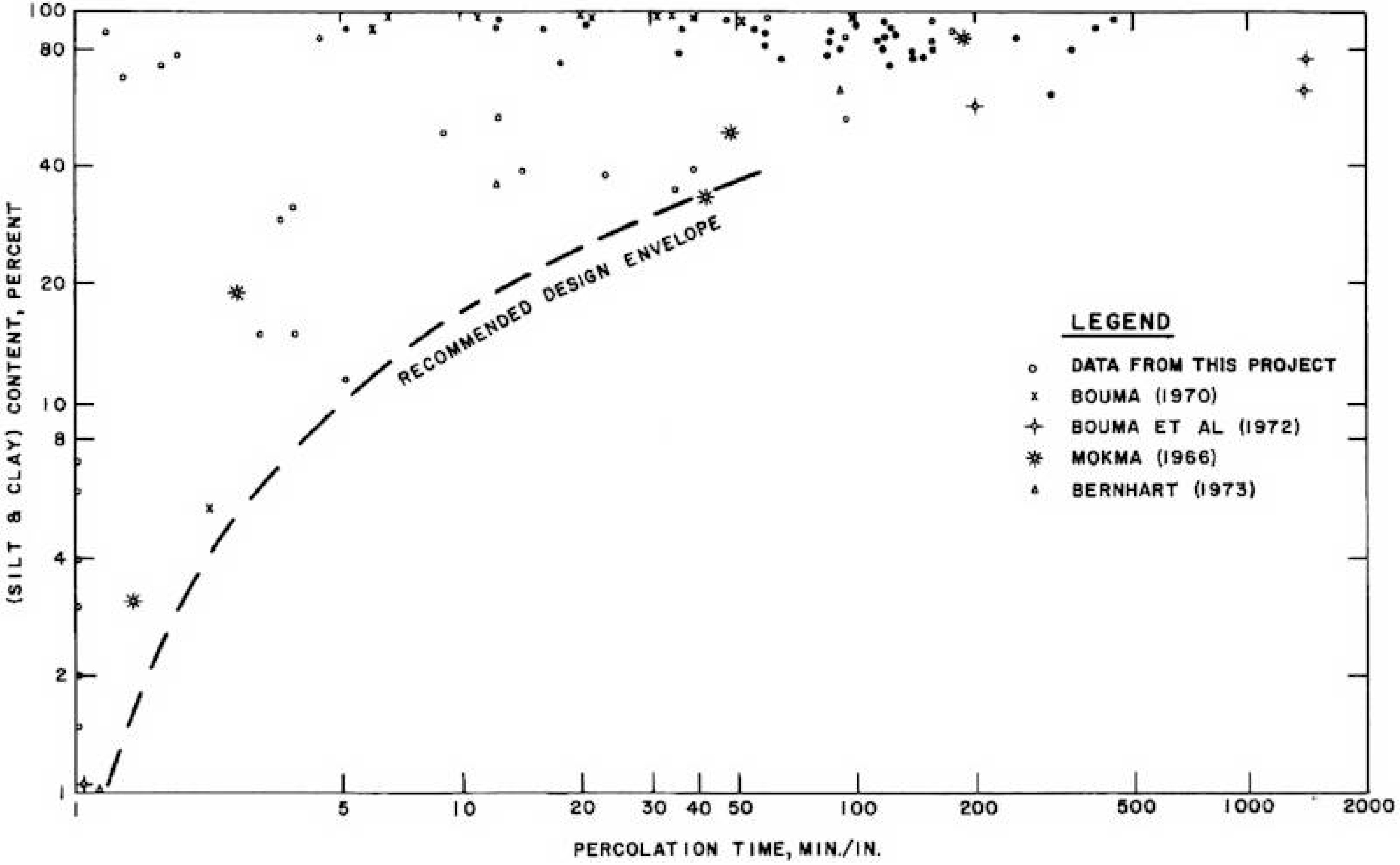


FIGURE 6: Percolation Time vs Percent Of Silt & Clay.

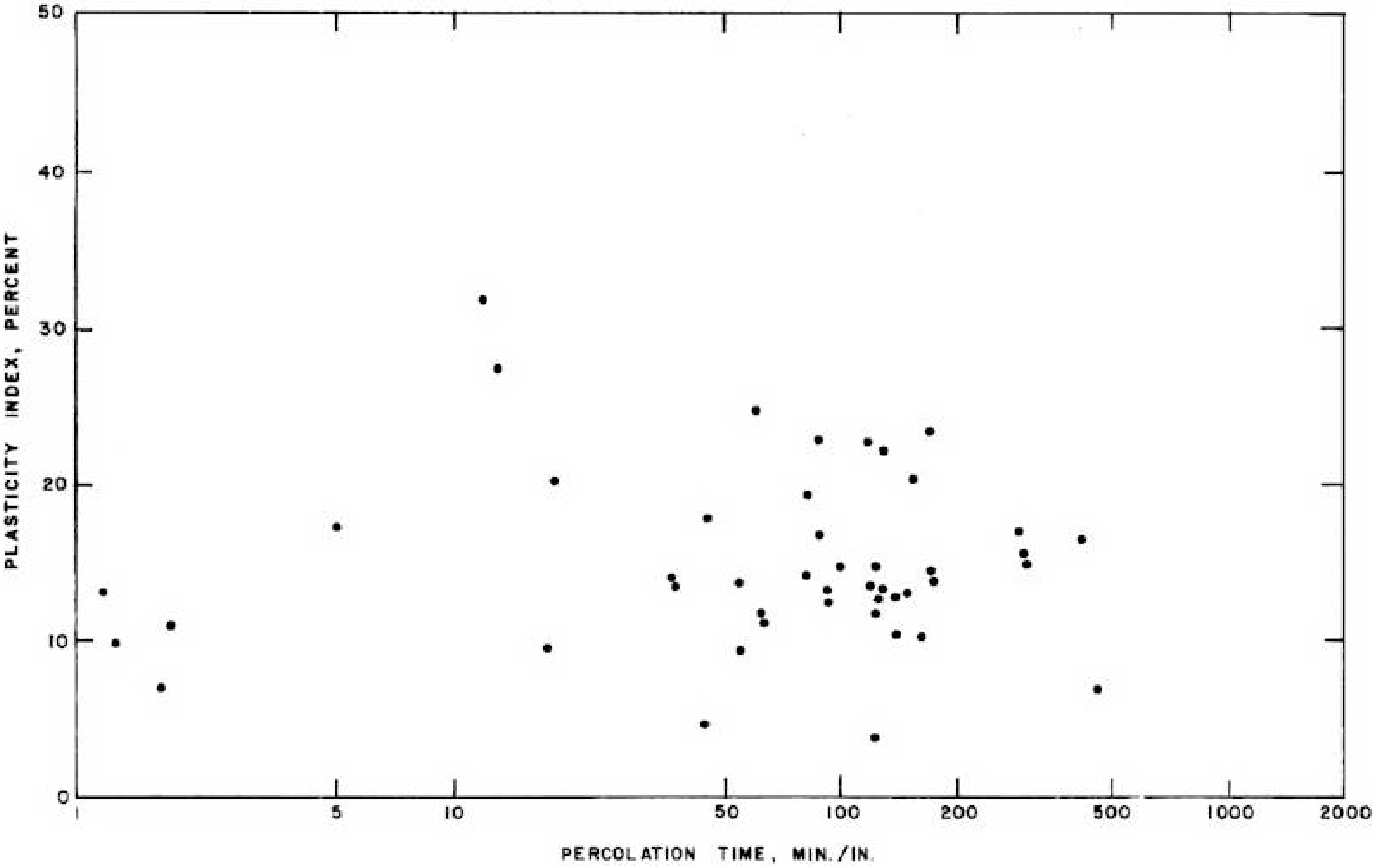


FIGURE 7: Percolation Time vs Soil Plasticity.

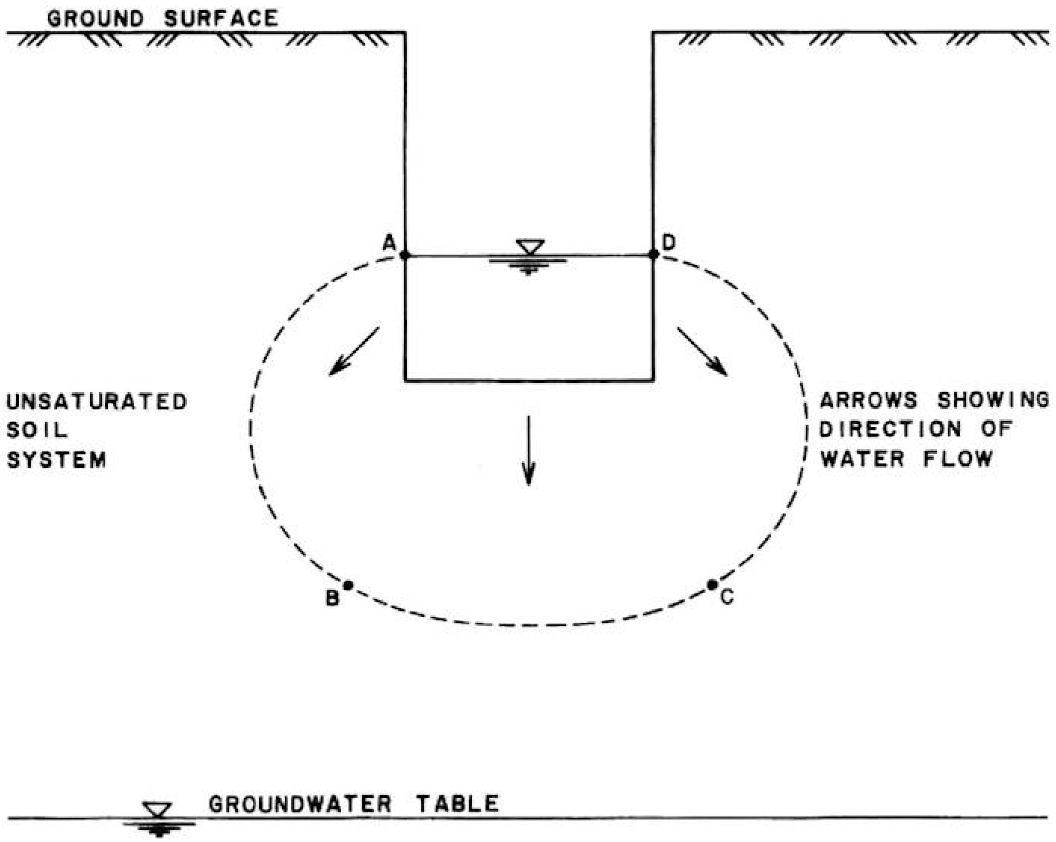


FIGURE 8: Cross-Section of Percolation Hole.

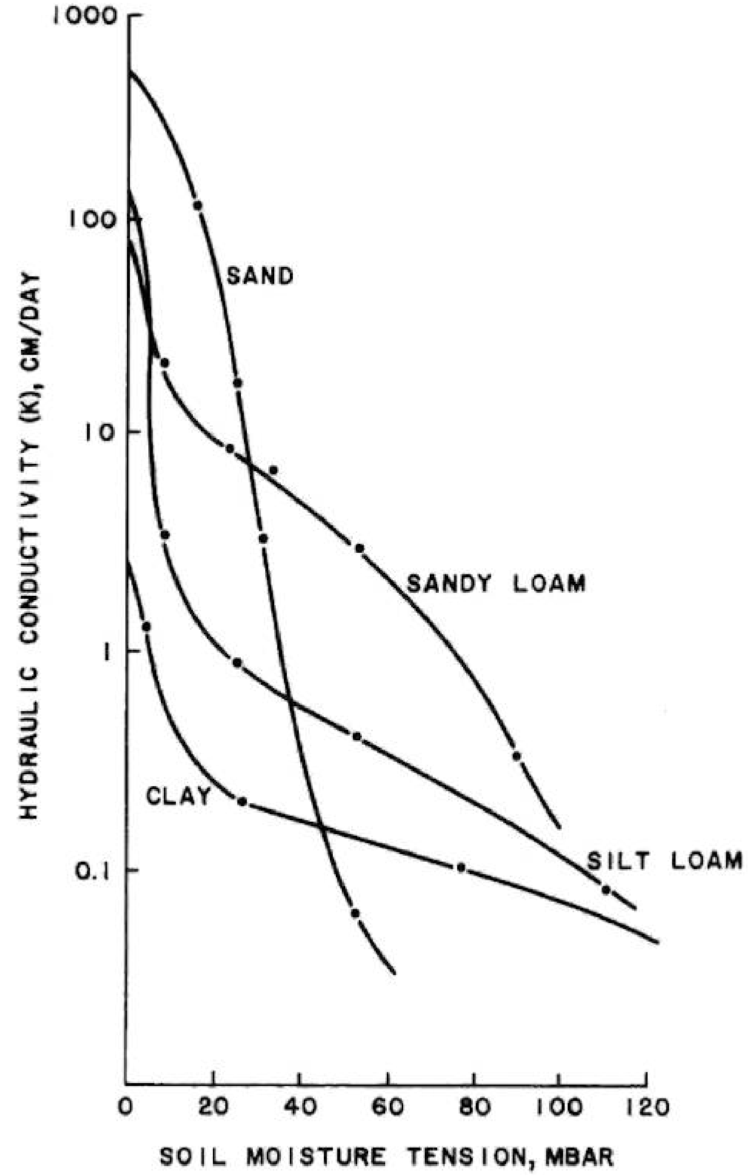
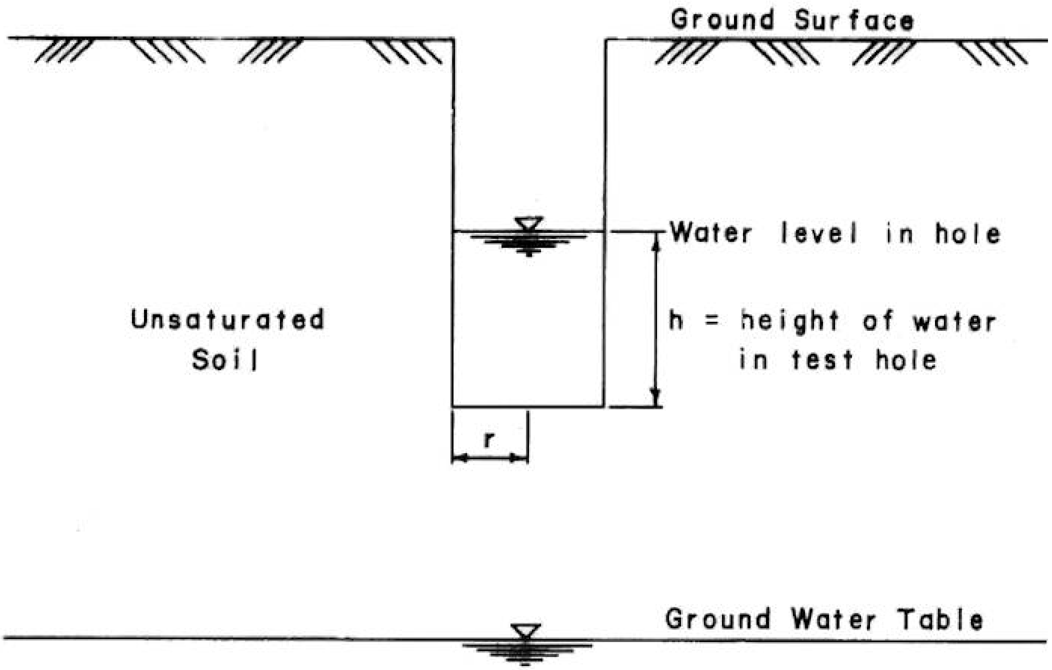


FIGURE 9: Hydraulic Conductivity (Permeability) as a Function of Soil Moisture Tension (After Bouma *et al* 1972).



$$k_{20} = 525{,}600 \, \frac{[\sinh^{-1}(h/r) - 1]\, Q/2\pi}{h^2} \, (\mu_t / \mu_{20})$$

where: k_{20} = coefficient of permeability, ft. per year,
h = height of water in the hole, ft.
r = radius of hole, ft.
Q = discharge rate of water from hole for steady state condition, cu. ft/min.
μ_t = viscosity of water at temperature t
μ_{20} = viscosity of water at 20°C

For a 4 inch-diameter hole, $r = 1/6$ ft, $h = 6$ in $= 0.5$ ft.
$t = 10$ min. for I in drop of water level in the 4-in hole.
$Q = \pi \, (1/6)^2 \times 1/12$ cu. ft./10 min.
$t =$ 10 min., $k_{20} = 1.93 \times 10^{-4}$ cm/sec.
$t =$ 60 min., $k_{20} = 3.2 \times 10^{-5}$ cm/sec.

FIGURE 10: Calculations of k From "t" Time Using U.S. Bureau Of Reclamation Equation.