DEPARTMENT OF SOILS, GEOLOGY AND FOUNDATIONS

Movement of Moisture Through Soils

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● THE FLOW OF MOISTURE through soil is being studied at Cornell University. This portion of the study was conducted continuously from October 1954, through April 1956, in the Ithaca area. Observation of moisture conditions in subgrades of flexible pavements were made before and after the installation of subdrainage. The study is being sponsored by the Armco Steel Corporation through the fellowship program of Cornell University.

The Moisture Measuring Equipment

The instrument used for measuring soil moisture conditions was the Neutron Soil Moisture Meter developed at Cornell University (*1, 2, 3,* and *4*).

Soil moisture conditions being measured with the meter in a typical installation are shown in Figure 1. A permanent stainless steel access tube ($1\frac{1}{8}$ in. OD) was installed in the subgrade. The probe is inserted in the access tube to the

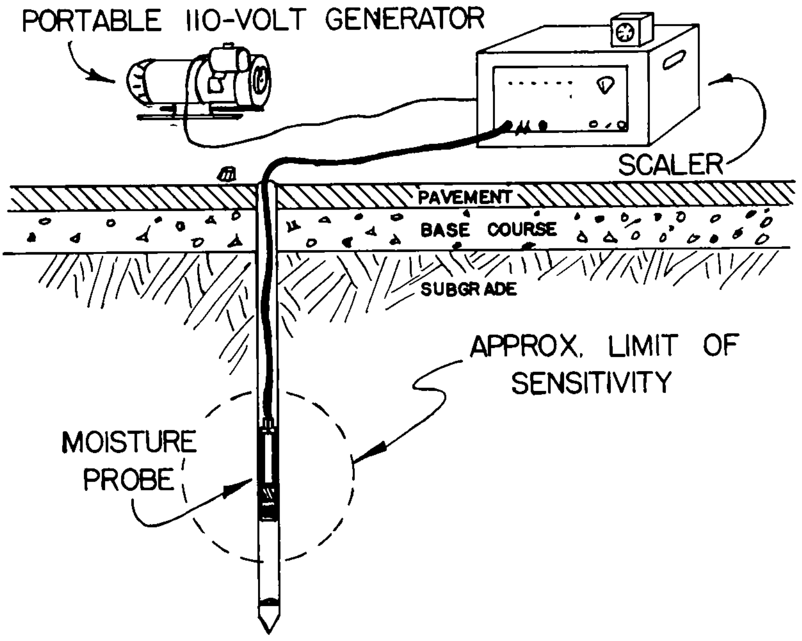

Figure 1. Typical arrangement for measuring moisture in soil with the Neutron Soil Moisture Meter.

desired depth. The probe contains a source of neutrons and a slow neutron detector. Fast neutrons from the probe penetrate the soil in a scattering fashion. If these neutrons collide with a heavy nucleus, such as hydrogen (in water), their velocity is considerably reduced. However, some return to the probe where they are detected by the slow neutron detector and are recorded on the scaler. More moisture in the vicinity of the probe results in a higher count rate recorded on the scaler. Each reading in the soil is converted by means of a calibration curve to moisture density. Since dry density is not known in many cases, moisture in pounds per cubic foot is the term used.

The calibration curve was obtained by conducting moisture meter readings in the field and then obtaining representative samples for moisture and density tests (a few tests were conducted in the laboratory to find points in the dry range of the curve). Each reading in soil was divided by a reading in a bucket of paraffin to obtain a ratio which was plotted against moisture density. This method avoids the constant recalibration required when the neutron source is changed or becomes weaker.

Accuracy of the instrument was found to be sufficient for the type of investigation undertaken. Three minute readings in soil produced moisture density readings accurate within 2 lb per cu ft. The bulb of soil affected by the probe was approximately 1 cu ft. Only slightly higher readings occurred when readings were taken near materials high in organic matter (asphalt, roots, etc.).

General Program of the Investigation

Pavement failure sites needing subdrainage were first investigated by means of auger borings and laboratory tests to determine subsurface conditions and possible subdrain layouts. If subdrainage could be installed at a site in question, stainless steel access tubes were installed so that moisture conditions both before and after subdrain installation could be observed at bi-weekly periods.

The access tubes were placed to provide a fairly complete picture of subgrade moisture conditions. More than 50 access tubes were installed during this investigation. Several problems connected with installation and providing true readings had to be overcome.

A complete photographic record was kept of each site. Ground water table readings were also taken whenever possible by the most convenient means.

Full-Scale Highway Subdrain Test Sites

Site 1. Figure 2 is a cross-section of the side-hill location. Water was trapped

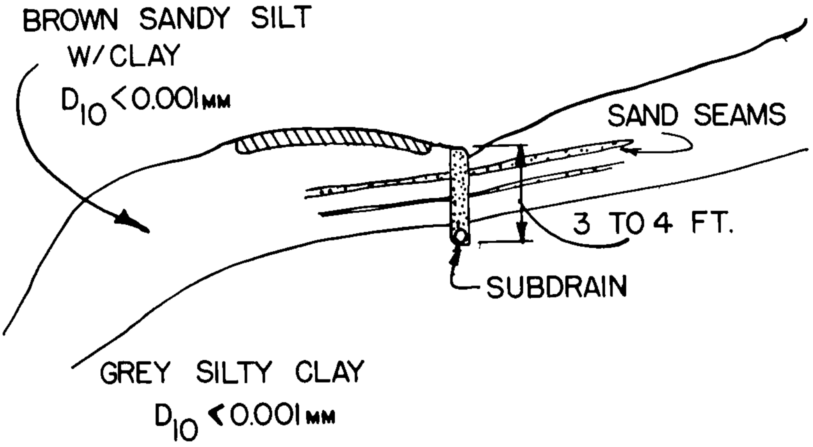

Figure 2. Cross-section at subdrain Site 1 showing the single longitudinal subdrain.

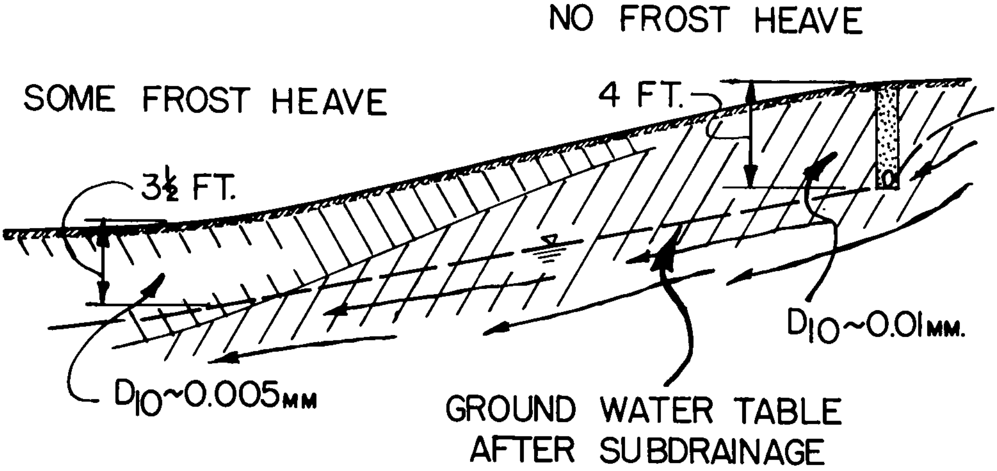

Figure 3. Centerline section at subdrain Site 2 showing the transverse cut-off subdrain and resulting ground water table. Frost heave conditions during the following winter are also shown.

on the lower, less pervious, silty clay layer causing subgrade failures in the upper sandy silt with clay deposit. Moisture conditions in the subgrade did not change after the installation of a longitudinal cut-off type subdrain. The only lowered moisture densities were immediately below the pavement in the dry summer months. This effect extended to a depth of approximately 1 ft. During the period, the free water table varied from the surface to a depth of 13 ft, yet no significant changes in moisture density of the subgrade were noticed. The effective grain sizes of both main soil types were below 0.001 mm.

After the installation of the subdrain, 3 to 4 ft deep, frost heaving was reduced to a total of ½ in. for the winter months as compared to several inches before the installation.

Site 2. There were two soil types involved in this side-hill seepage case (Figure 3). The soil near the subdrain was slightly coarser than that farther down the hill. The water table subsided to the depth shown in about two weeks during a spring thaw. Reduced moisture densities were noticed near the subdrain, yet none were noticed in the finer soil. No frost heaving occurred at the subdrain where the water table was at a 4-ft depth,

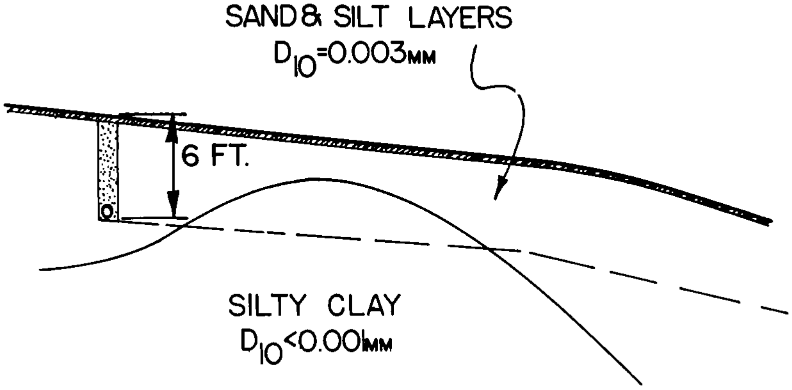

Figure 4. Centerline section at subdrain Site 3 showing the depth of the system of subdrains which completely cut off water from entering the subgrade from any side.

but approximately 2 in. were noticed where the depth to the free water table was 3½ ft.

Site 3. Figure 4 shows a section through the highway centerline. A clay deposit formed a dam producing a high water table in the upper deposit of sand, silt and gravel layers. The approximate average effective grain size of the upper deposit was 0.003 mm. After the installation of a subdrain system which surrounded the subgrade by a trench approximately 5 to 6 ft deep, the moisture density of the upper soil was decidedly reduced. However, the lower silty clay deposit, with an effective grain size well below 0.001 mm, showed no change in moisture conditions as the result of the installation of subdrainage (even though the free water table was lowered several feet below the upper portions of this deposit). During the winter which followed subdrainage installation, no measurable frost heave occurred.

Figure 5 compares conditions before and after subdrainage, as well as the moisture conditions which were predicted on the basis of empirical rules, based on grain size distribution (*5*). The actual and predicted conditions compare well.

Site 4. This roadway extends directly up and down hill. Water tended to seep "out of the pavement" and in some areas caused failures. The subgrade consisted of sand and gravel with silt in a stratified deposit. This was superimposed on a deposit of sand and silt with clay. The effective grain sizes of the upper layers varied from 0.01 to 0.1 mm while that for the lower less pervious deposit was less than 0.001 mm. A longitudinal type subdrain was installed and an attempt was made to measure "drawdown" effects.

Only the upper few feet of soil imme-

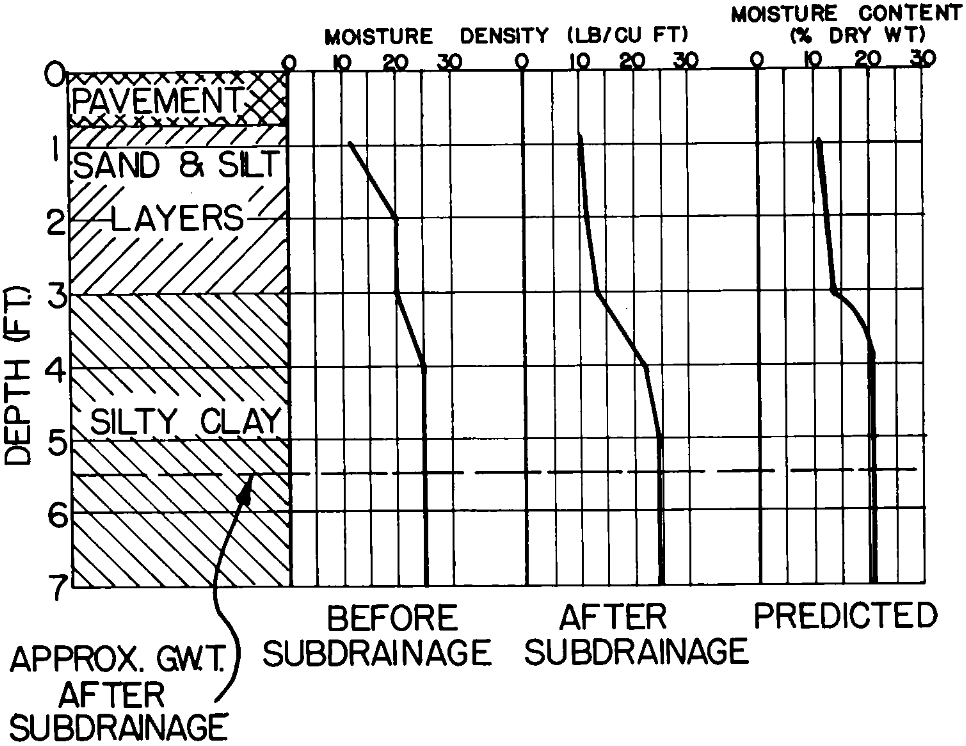

Figure 5. Site 3 moisture conditions before and after the installation of subdrainage compared to the predicted conditions based upon a water table lowered to 5 1/2-ft depth.

diately beside the subdrain showed a reduction in moisture density, and the remainder did not change as a result of this subdrain installation. The water table was not changed except in the immediate area beside the subdrain. No observations were made during a freezing season after the subdrain installation.

Drainability of Soils by Subdrainage

There is not available a great deal of information on the effectiveness of subdrainage, and as a result, many subdrains are installed on a "hoping they will work" basis. It would be desirable to have available some rough rule as a preliminary guide. Because fine grained soils seem to be the most difficult to drain and since most reference books on the subject refer to drainability versus grain size, an attempt to link observed conditions with the effective grain sizes of soils was made.

No attempt was made to measure the rate of drainage of the soils, because close observations on all water entering and leaving the soil mass would be required. Soils were considered drainable if they reduced significantly in moisture density and remained in this condition through the wet seasons of the year.

Figure 6 is a set of curves presented by Meizner (*6*). Curve E is the result of field checks on drains in the north central part of the United States. Curves L and Z were obtained by Lebdeff and Zunker from laboratory tests. Field observations at the full scale subdrain sites, in this study, lie between the curves E and L. No attempt was made to plot a curve of these observations because only a general range could be plotted (the moisture density was found to vary with height above a free water table — usually decreased with height).

Field observations support the belief that properly installed cut-off type subdrains will effectively reduce the moisture contents only in soils where the ef-

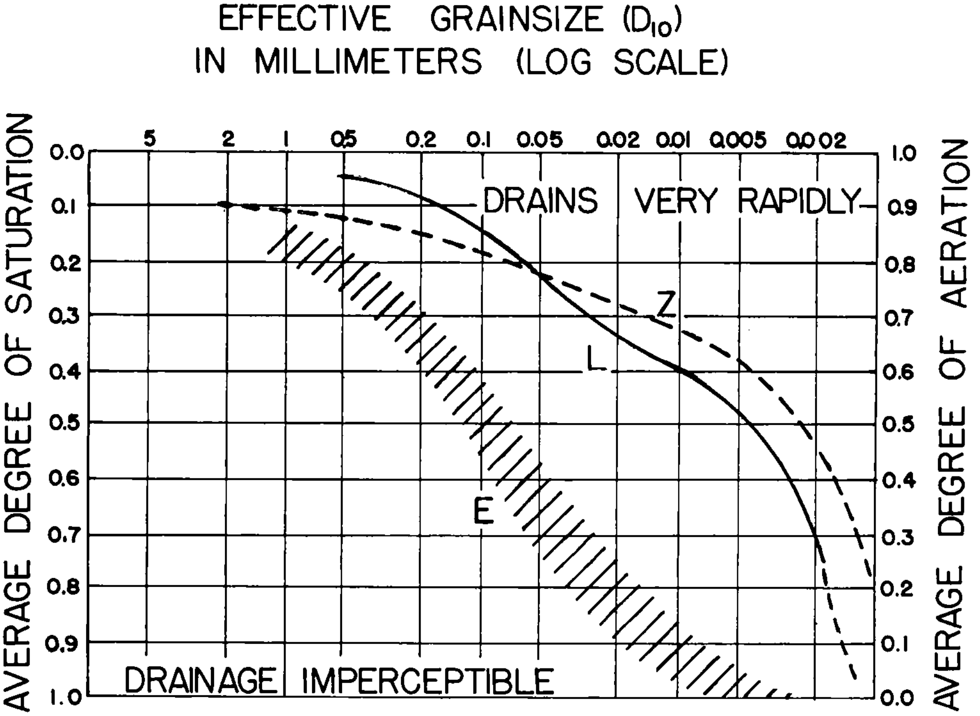

Figure 6. The drainability of soil related to grain size (after Meizner).

fective grain size (D_{10}) is greater than 0.002 mm. This effect extends for distances down hill from cut-off type subdrains similar to conditions shown in the literature. However, for the single drawdown case observed, no such drained conditions occurred even though the effective grain size was well above 0.002 mm. The slight stratifications at the site were sufficient to lower the vertical permeability to a small fraction of that in the horizontal direction. Therefore, a drawdown effect should not be depended upon unless the installation of cut-off type subdrains is impossible.

The choice of the limiting effective grain size at 0.002 mm is substantiated by approximate rules available in the literature. However, many (town and county highway superintendents in particular) do not recognize the significance of this information as it applies to deciding whether or not the installation of subdrainage will aid a given situation. The use of a single value of effective grain size as a rough limit of soil drainability might provide an approximate answer to this question.

In some local highway departments it is not possible to determine effective grain size for several reasons. Therefore, a simple test to determine soil drainability is needed. Many forms of inplace permeability tests are in use, but these are too complicated for use by the average maintenance foreman. An auger hole permeability test was attempted at each subdrain site (Figure 7). The time indicated is that required for the water level in the bottom foot of a 4-in. auger hole to drop 1 in. (first wetting water poured in bottom of hole above the free water table). Figure 7 is approximate only, but a simple test of this nature might aid in determining whether or not to install subdrains.

Frost Heave Reduction Due to Subdrainage

At each site the frost heave was measured in an approximate manner. This was done by constant observation of the tops of the access tubes with respect to the pavement surface. It was found that 0.002 mm is not the lower limit of effective grain size for a soil in order for subdrains to reduce the height of frost heave. In each case where cut-off type subdrains were installed at 4-ft depth or

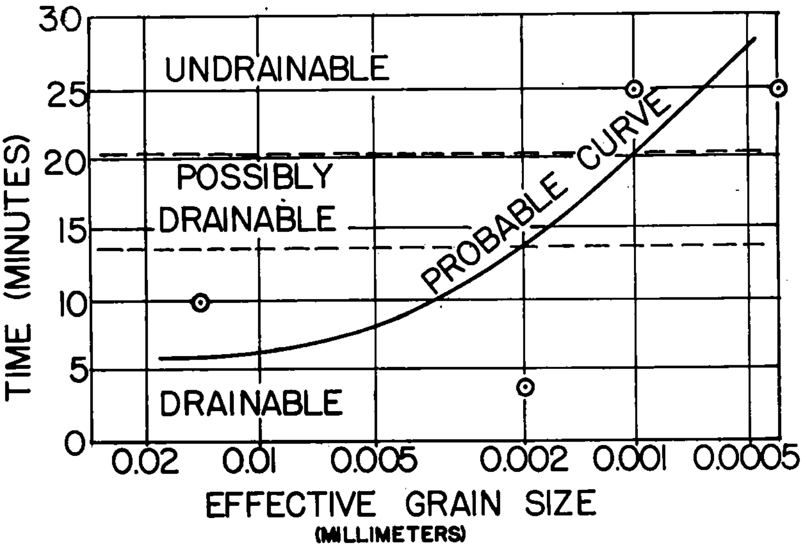

Figure 7. Results of a percolation test at each subdrain site related to drainability. The test measured the time for water in the bottom foot of a 4-in. auger hole to drop 1 in.

greater, frost heave did not occur even in soils which did not reduce in moisture density after the installation of subdrains. Frost heaving had been significant at every site before subdrains were installed. However, in the fine grained soils the tensions produced 4 ft above the level of the cut-off type subdrains were sufficient to reduce significantly the movement of water to frost lenses.

CONCLUSIONS

The various site conditions were not ideal for study of one problem at a time and only a few sites could be investigated, but it was possible to draw some approximate conclusions regarding highway subdrainage practices, as follows:

1. Cut-off type subdrains should be used whenever possible at areas requiring a lowered ground water table.
2. Reduced moisture contents in soils should not be expected where the effective grain sizes are less than 0.002 mm.
3. Frost heaving in frost susceptible soils (including those with D_{10} less than 0.002 mm) will be reduced considerably by installing subdrains more than 4 ft deep.

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