Control of Moisture and Volume Changes in Clay Subgrades by Subdrainage

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Observations of the vertical heave at the edge of a runway pavement and moisture variations in the clay subgrade as affected by the subdrainage system are presented. The paper also reports on a model study of the effect of two different filter materials on the drying of the clay subgrade near the subdrainage under different surfacing conditions.

It was found that the subdrainage system has a definite beneficial effect on the moisture distributions in the clay. By removing free water which penetrates cracks, it helps in maintaining a low range of moisture variations between summer and winter and thus inhibits large movement at the edge of the pavement.

The selection of the filter material should be governed mainly by moisture variation considerations. It is desirable to use a fine permeable material for the subdrainage system because such a material would tend to serve as a moisture reservoir for the clay during the drying period and act as a capillary cut-off against drying out of the clay underneath the pavement.

•SHOULDERS OF ROADS and runways built on expansive clay subgrades in Israel are usually left unsurfaced. As a result they are highly susceptible to climatic changes. They heave vertically and move laterally on wetting, and crack on drying. Thus, moisture tends to penetrate laterally under the edge of the pavement, causing volume changes in the clay subgrade and differential movement accompanied by cracking within the pavement itself. Because of low groundwater table, drainage facilities usually consist only of open ditches to remove surface runoff. Many engineers consider subsurface drainage unnecessary for fat clays.

In recent years, however, clay shoulders construction, particularly of runways, has incorporated properly designed subsurface systems to drain the base course. The drainage system is usually composed of an open-joint drain surrounded by fine crushed stones, as a filter material, buried at a shallow depth. In many cases, a narrow strip of the shoulders overlying and adjacent to the subdrainage system was covered with a cheap surfacing to protect the edge of the pavement.

Engineers who have worked with highways and runways have found that even for clay subgrades in semiarid climates the removal of subsurface water is often an important problem. The clay, despite being impervious when intact, develops vertical and horizontal cracking during the dry season, which makes it very pervious at the beginning of the winter rains. Movement observations of a pavement with covered shoulders indicated that the availability of a subdrainage system affects the moisture regime in the clay subgrade under both the pavement and the shoulders.

In the case of unsurfaced shoulders, drying of the clay plays a significant role in the moisture regime at the vicinity of the pavement edge. A relatively deep subdrainage system may help reduce moisture variations if fine sand is used as a filter material.

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At the start of the dry season the capillary water held in the sand helps to maintain the adjacent clay in a moist state. When capillary water is no longer available, the dry fine sand acts as a cutoff to further drying of the clay subgrade under the pavement.

This paper deals with observations of movements and moisture variations in clay subgrades of runways as affected by the subdrainage system. It also discusses a model study (1) of the effect of two different filter materials on the drying of the clay subgrade under different surfacing conditions.

FIELD MOVEMENT OBSERVATIONS

Extensive field observations (2) of the behavior of a runway built on an expansive clay subgrade have been carried out since completion of the construction during the summer of 1956. The runway pavement was of the flexible type, with asphalt seal-coated granular shoulders extending 3.0 m on each side. No groundwater was encountered in borings of up to 15 m deep.

Surface water drainage was provided by sloping the shoulders on either side of the runway toward open ditches located at 45 m from the edge of the pavement. Base course and shoulder seepage subdrainage was also provided at both sides of the pavement, with the exception of 100 m on one side of the runway. The subdrainage system (Fig. 1) consisted of open-joint pipe laid in the bottom of an excavated trench located at the edge of the covered shoulders and backfilled with a filter of fine crushed stone to the level of the base course. The omission of the subdrainage system on one side

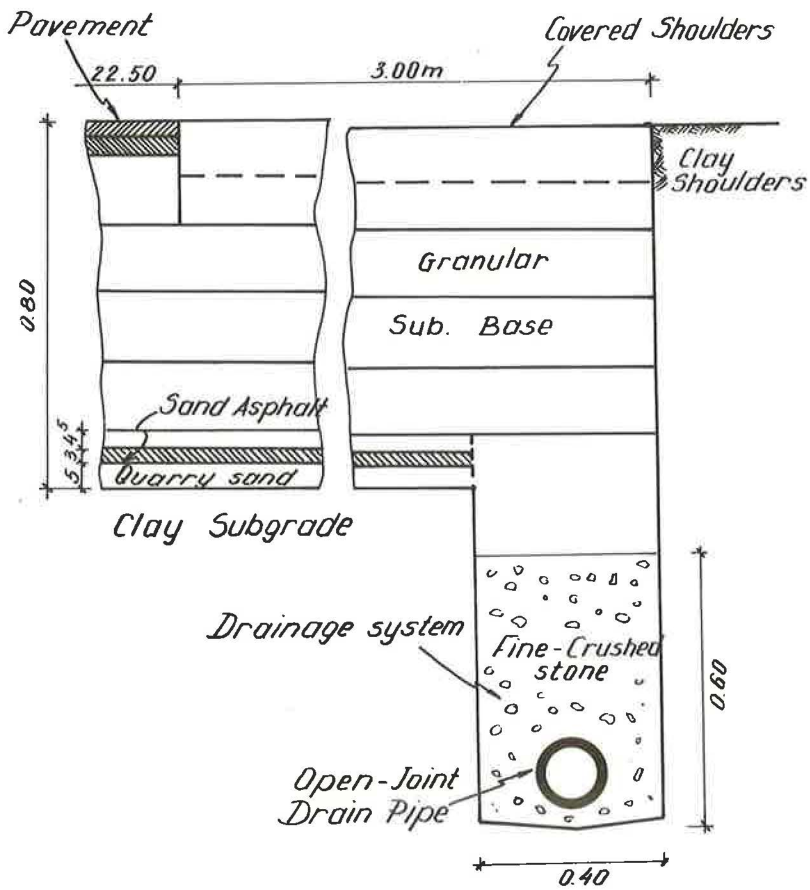


Figure 1. Section through pavement, shoulder and subdrainage system.

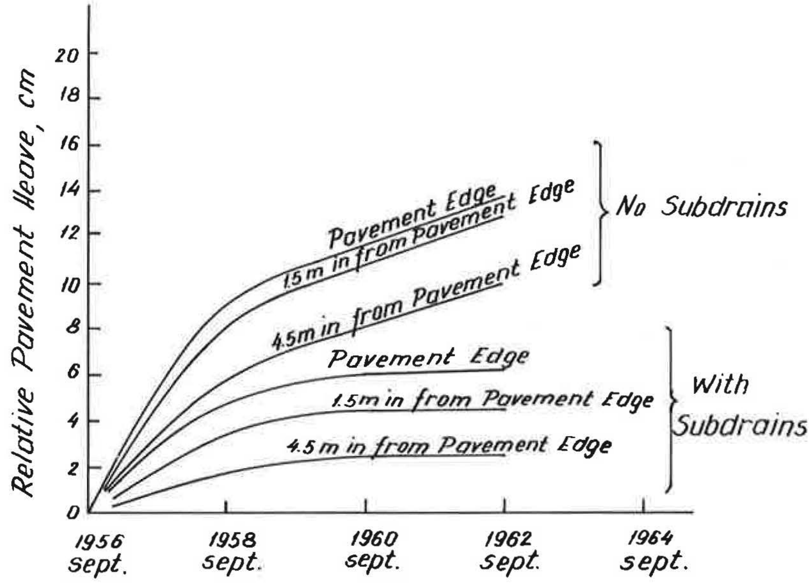


Figure 2. Movement of edge of pavement with and without subdrainage system.

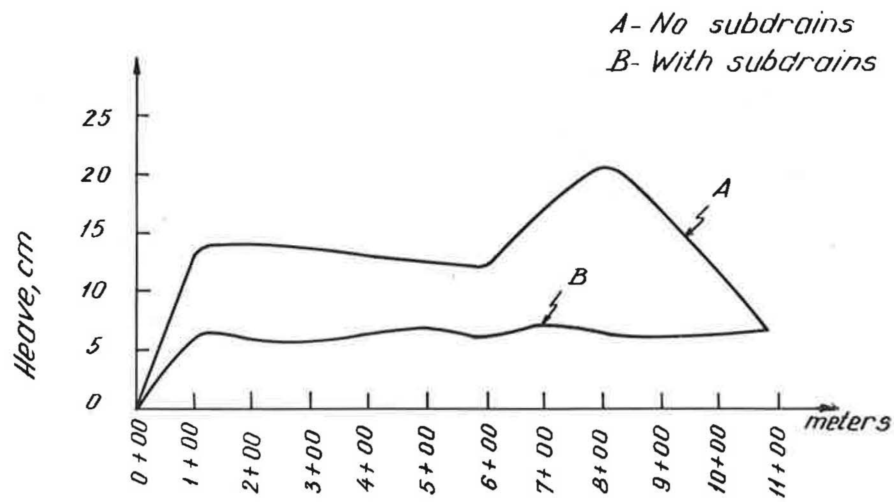


Figure 3. Longitudinal section of pavement showing heave of pavement edges.

of the pavement along the 100-m stretch provided a valuable opportunity for comparison of the effect of the system on movements of the pavement edges.

Level surveys of the vertical movements of the pavement with respect to a bench mark 11 m deep were made at the end of the summer for several years. The bench mark was protected by a pipe sleeve to isolate it from the upper soil movements. There was a general heave of the pavement. The results of the observations presented in Figures 2 and 3, however, are confined to the pavement center and therefore do not include the overall heave of the covered area. Figure 2 shows the accumulation of heave with time (1956-1962) at the sides of the pavement both with and without the subdrains, based on the averaging of 10 sections. A difference in heave of about 8 cm between the 2 sides of the pavement is shown. The side of the pavement with the subdrains, in addition to heaving less, showed less distortion of cross-section than the

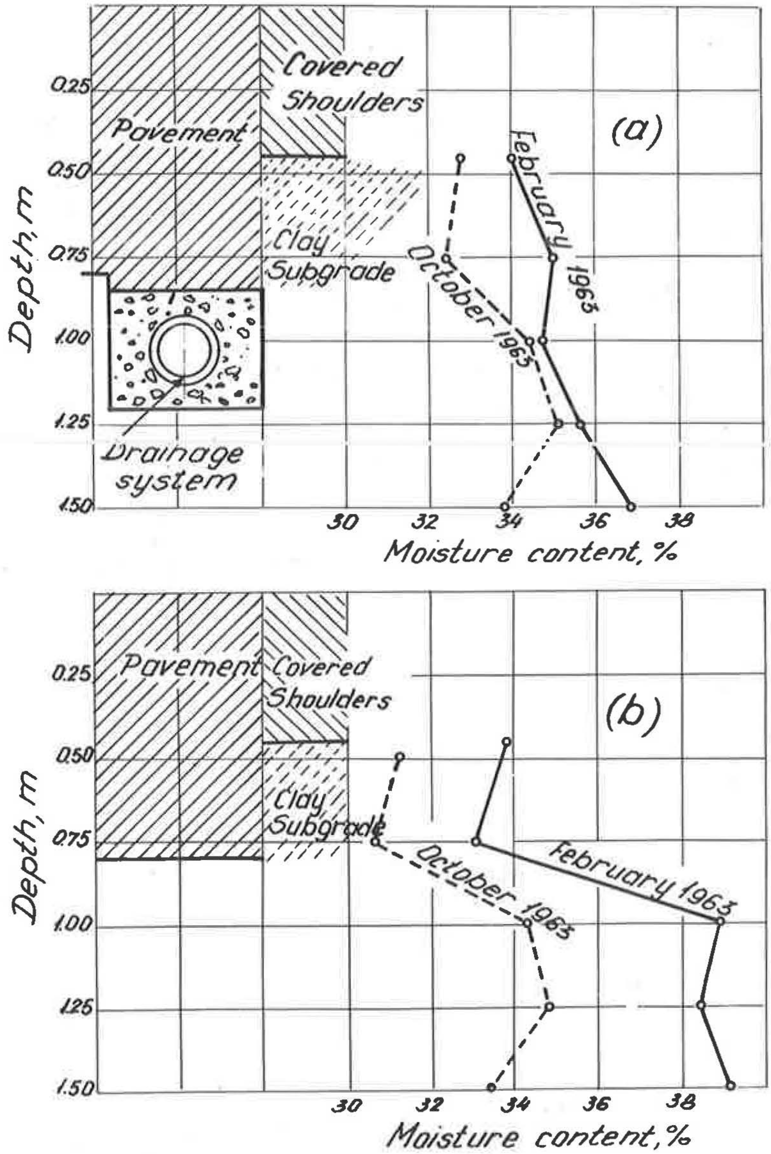


Figure 4. Moisture variations in clay shoulders of runway: (a) adjacent to drainage system, (b) without drainage facilities.

side without the subdrains. Whereas the side of the pavement with subdrains achieved a stable condition 4 yr after construction, the side without subdrains was still heaving 6 yr after construction.

Figure 3 shows the heave of the pavement edges on both sides of the 100-m stretch of the runway in longitudinal direction. The benefit of the subdrains may be easily observed from this figure. The intersection points between lines A and B represent heave at cross-sections at the beginning and the end of the 100-m stretch of runway which had subdrains on both sides.

FIELD OBSERVATIONS OF MOISTURE PROFILES

Moisture distributions at the end of the wet and dry seasons, underneath covered-clay shoulders of a taxiway located at the same site where the vertical heave was measured, are shown in Figure 4. Figure 4a shows the distributions adjacent to the shoulder with a subdrainage system, and Figure 4b shows the distributions for the shoulder without the system. The range of moisture variation between summer and winter in the clay adjacent to the drainage system amounts to a maximum of 2.5 percent, whereas the same range for the other shoulder amounts to as much as 6 percent. These differences are significant by themselves, as they determine the amount of heave, but they served mainly for comparison with the moisture variations measured in the laboratory models.

These figures show that moisture conditions in the clay without the drainage, as compared with the other shoulder, were wetter at the end of the winter, whereas conditions at the end of the summer were essentially the same. The drainage system apparently helped to remove free water which penetrated the surface cracks in the shoulder and kept the moisture distribution within a close range of the summer profile. On the other hand, where no subdrainage facility was provided the water which penetrated the cracks caused a larger increase in the moisture range through saturation of the clay subgrade.

No measurements of the amount of water drained were made during these observations, but there was visual evidence of significant flow through the outlets, particularly during the initial period of the wet season.

PURPOSE AND SCOPE OF MODEL STUDY

The specific purpose of the study was to determine the effect of various filter materials on the moisture distribution in the clay, particularly for exposed shoulders under drying conditions.

The study included models of moisture variations in a clay layer over-lying various filter materials, i.e., simulations of the clay in the vicinity of the drainage system. The following combinations were selected: (a) exposed clay on top of a fine dune sand; (b) exposed clay on top of a coarse crushed stone; and (c) covered clay on top of the filter materials as in a and b. The cover used consisted of 1-cm thick sand-asphalt layer.

The filter materials selected for this study represent a range of materials which, from a filter-criteria viewpoint, are considered adequate both to prevent migration of fines into the drainage system and to remove seepage quickly.

DESCRIPTION OF SOILS STUDIED

The clay represents typical expansive clays in Israel. It is highly plastic (liquid limit (L. L.) = 65-80, plasticity index (P. I.) = 40-55, shrinkage limit (S. L.) = 8.5-11) and exhibits severe swelling properties. The dominant clay mineral is smectite (montmorillonite). The clay was sampled from the airfield in which the various measurements were made.

The dune sand is a fine, uniformly graded sand, with a 50 percent size of 0.15 mm and a maximum size of 0.5 to 0.8 mm. The saturated permeability of the sand is about 10^{-2} cm/sec. The coarse crushed stone originates from a limestone. It has a uniform gradation with a maximum size of 30 mm and 50 percent size of 15 mm.

DESCRIPTION OF MODEL STUDY

Instrumentation and Techniques

The laboratory models were made of 6-in. diameter Perspex cylinders in which a clay layer 18-cm thick was compacted on top of a layer of filter material. A load simulating the overburden pressure on the clay in the field was exerted on the model by a spring setup (Fig. 5). Through holes bored in the Perspex column, tensiometers made of a slender ceramic cylinder and connected to a mercury manometer were in-

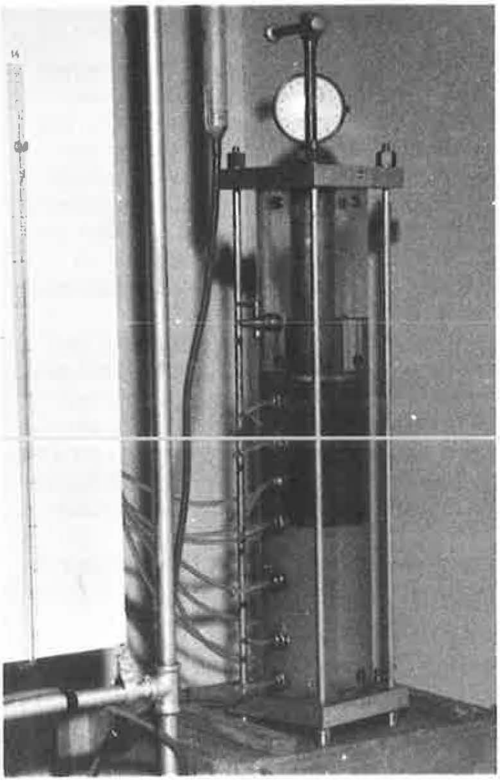


Figure 5. Model of clay layer overlaying sand layer, showing connections to tensiometers and spring setup for load application.

serted into the clay, as well as into the filter material, at various levels including the level of the interface between the two materials. The clay layer was saturated under a head of water and then allowed to swell under the imposed load. Later, any free water in the filter material and on top of the clay was allowed to drain. The clay was then permitted to dry by being exposed to the atmosphere through holes in the plate transmitting the spring load and in the Perspex cylinder. During both cycles of wetting and drying, suction and movement were recorded. The measurements were carried out in a constant temperature room, with a temperature as high as 30 C to accelerate the drying process. The measurements were continued over the period of time required for attaining stable conditions.

The suction measured in the models was converted later into moisture contents by using a moisture-suction curve determined by another apparatus under the same placement and loading conditions (3).

The clay was compacted into the cylinder by a static pressure to a density of 1.40 gm/cu cm at a moisture content of 24 percent. These placement conditions correspond to about 95 percent of the optimum conditions obtained by Modified AASHO compaction. The pressure applied on the layered system in the models was 0.15 kg/sq cm, simulating an overburden of 1 m, corresponding to the depth of the drainage system.

Experimental Results

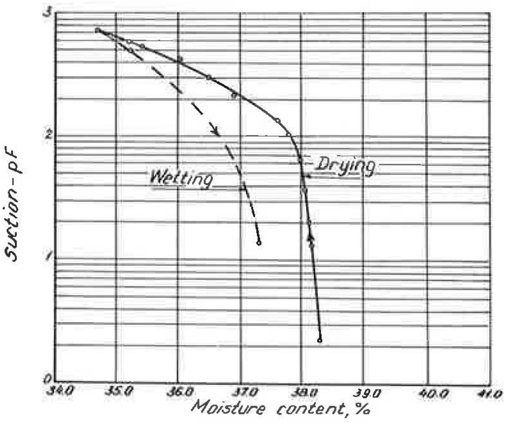
Moisture-Suction Relationship of Clay. —The moisture-suction function of the clay during a cycle of drying and wetting is shown in Figure 6. The curve was obtained after saturation of the sample under the same pressure as applied in the models, i. e., 0.15 kg/sq cm.

The apparatus used for suction determination (3) allowed for measurement of suction up to ¾ atmos. However, the range of moisture corresponding to suction up to ¾ atmos. (Fig. 6) is approximately the same as the range of moistures observed in the field (Fig. 4), i.e., 34 to 39 percent, particularly at the depth adjacent to the drainage system.

Suction and Moisture Variations in the Models.

Exposed Clay. —Figure 7 shows the distribution of pressure head with depth in the clay and filter materials during the wetting process achieved by the application of a relatively low head on top of the clay. Figure 7a shows the pressure head distribution for the clay-sand model and 7b for the clay-gravel model. The negative pore pressures (suctions) recorded at the interfaces between the clay and the granular materials are typical for unsaturated flow taking place in clay under low head (4); the suction at the sand interface amounted to about 30 cm of water, whereas the same value for the gravel was about 9 cm of water.

Figures 8a and 9a show the distributions of suction with depth in models measured at different times during the drying process. The clay was allowed to saturate from



Note: Initial dry density of clay = 1.4 g/cm³
Initial moisture after saturation = 38.5 %

Figure 6. Moisture-suction relationship for clay.

the bottom by application of a relatively high head before drying. The moisture content distributions with depth at the same times, as interpreted from Figure 6, are shown in Figure 8b. The suctions and therefore the moisture changes developed in the clay in contact with the sand were far smaller than in the clay in contact with the crushed stone, after the same period of drying.

Covered Clay. —Figures 10 and 11 show the suction and moisture distributions during the drying process for the models of the covered clay. The moisture content at the interface between the clay and sand has remained virtually unchanged with time. In addition, the variation in moisture through the depth of the clay profile was rather small and amounted to a maximum of 2 percent close to the surface, after 60 days. However, con-

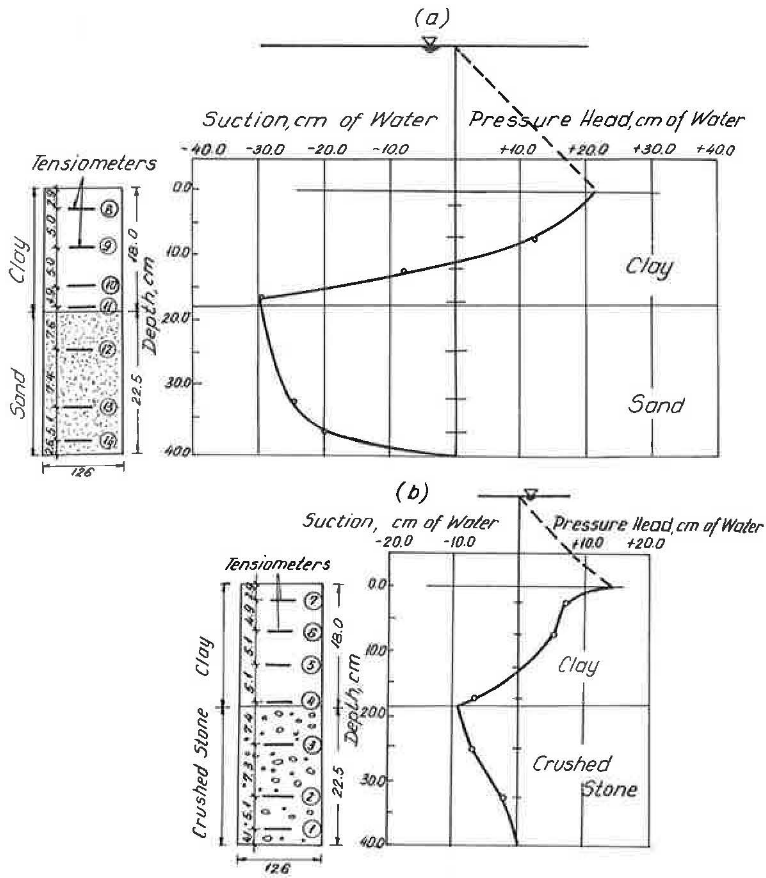


Figure 7. Distribution of pressure-head in uncovered clay models: (a) clay overlying sand, (b) clay overlying crushed stone.

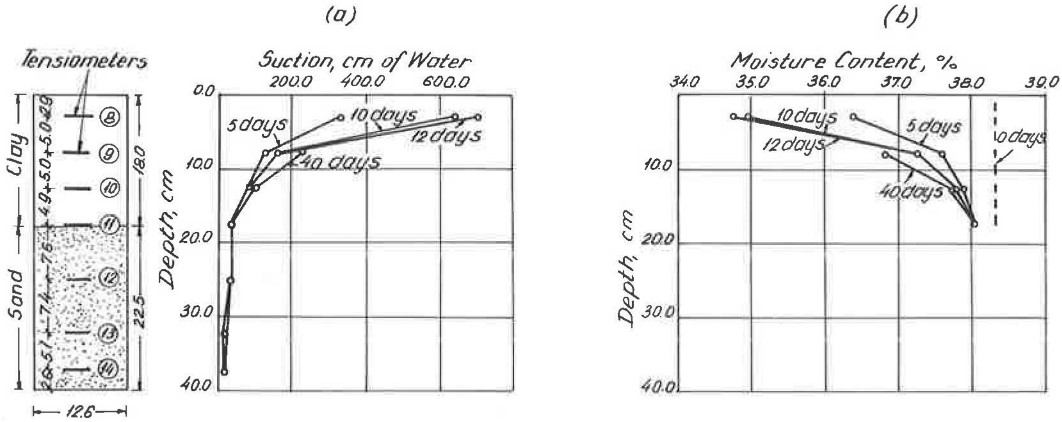


Figure 8. Distribution of suction and moisture with depth on drying of uncovered clay overlying sand.

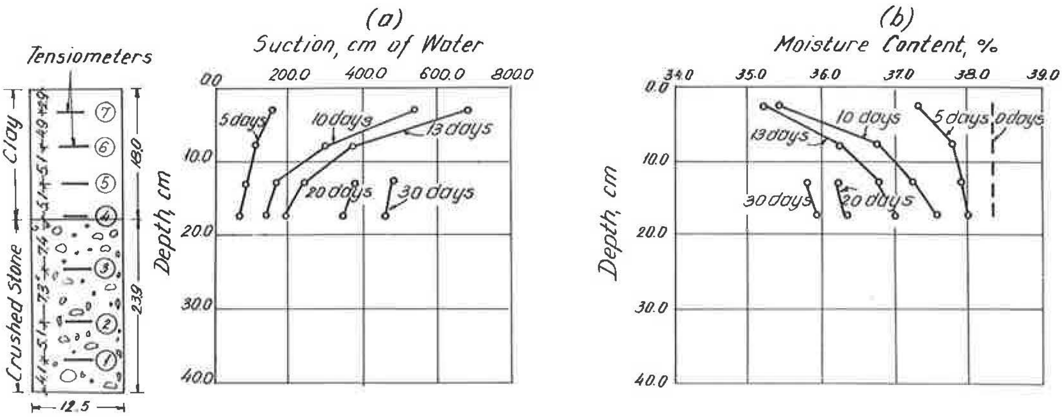


Figure 9. Distribution of suction and moisture with depth on drying of clay overlying crushed stone.

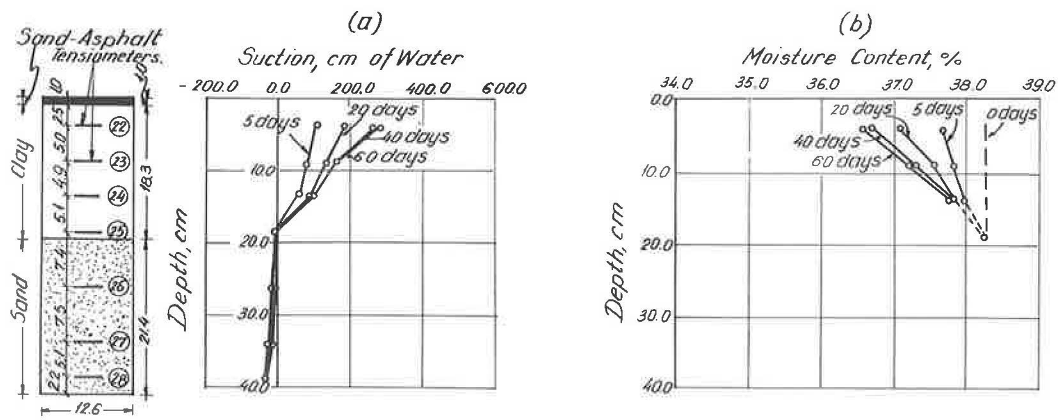


Figure 10. Distribution of suction and moisture with depth on drying of covered clay overlying sand.

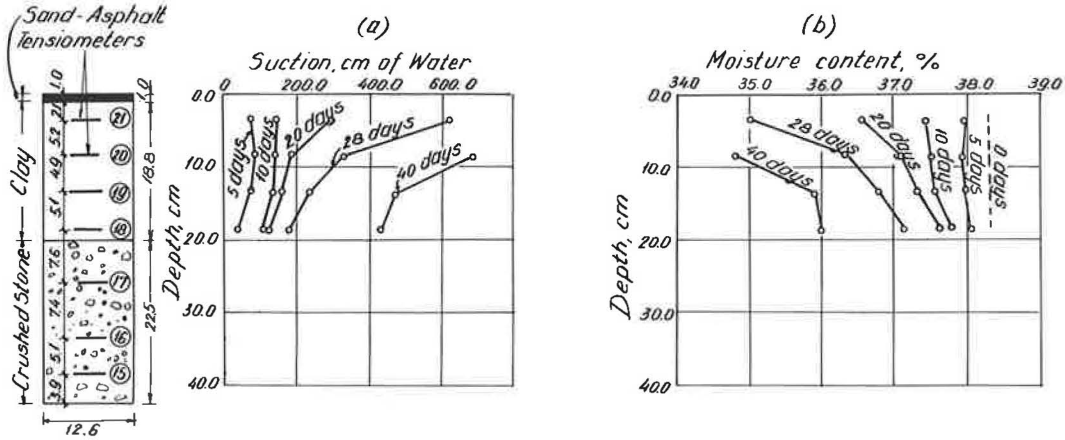


Figure 11. Distribution of suction and moisture with depth on drying of covered clay overlying crushed stone.

siderable suction was recorded at the interface between the clay and the crushed stone, in spite of the cover. Moisture changes throughout the profile in the model were also noticeable and amounted to more than 5 percent after 40 days.

DISCUSSION

The application of the experimental results from laboratory models is limited from various viewpoints: (a) the thickness of the clay layer in the models was severalfold smaller than the actual thickness of the clay in the field; (b) the clay in the models was remolded and compacted as compared with the natural structure of the clay in the field; (c) usually the clay in the field is located adjacent to the drainage system as compared to the clay overlying the system in the models; (d) moisture in nature moves laterally and vertically, whereas in the models the movement was confined to the vertical direction only; (e) the initial moisture of the clay before the drying process was assumed uniform and corresponds to saturation moisture, as compared to nonuniform distribution in the field; and (f) suction in the field, particularly at the surface, is much higher than was measureable in the models.

Nevertheless, the experimental results may be analyzed mainly from two viewpoints: (a) the significance of the drainage system during the drying state, and (b) the effect of the composition of the filter material on maintaining a stable moisture regime in the clay.

The incorporation of a subdrainage system in highway and runway clay shoulders and selection of the filter material composition are usually determined solely by hydraulic and piping considerations. In semiarid countries, however, where the groundwater table is usually low and the only source of seepage water in the pavement and shoulders originates from percolation, the head of water acting on the subdrainage system is rather low and its duration short. Under such low heads, unsaturated flow takes place (4) resulting in negative pore pressure (suction) at the interface between the clay and the filter materials (Fig. 7). These negative pressures in the pore water increase the effective stress in the clay (5) and decrease the danger of washing out of clay particles or aggregates into the drainage system. From this viewpoint, it would have been possible to select a relatively coarse filter material for the subdrainage system.

The models showed, however, that the composition of the filter material should not be ignored in design because it may play a significant role in establishing a more stable moisture regime in the clay surrounding the drainage system during the drying cycle. Figure 12 shows the moisture changes at the interface between the clay and filter materials under the various cover conditions as a function of drying time. Virtually no moisture changes occurred at the interface between the sand and the covered clay, and

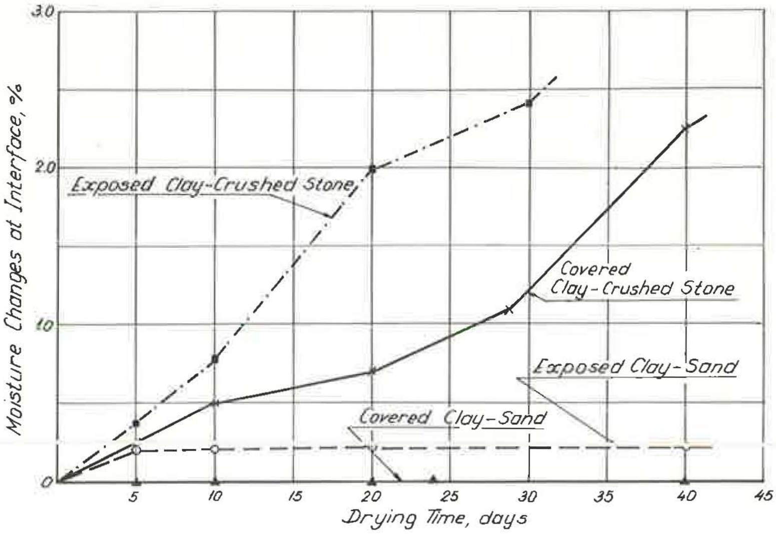


Figure 12. Moisture variations at interface of clay and filter materials under various cover conditions on drying.

very small changes occurred between the same materials under no cover. This means, actually, that the moisture held in the sand tends to serve as a source of moisture for the clay, reducing drying at the vicinity of the subdrainage system. Therefore, under similar conditions in the field, it is desirable that the material selected for the filter be composed of fine sand, to minimize moisture changes on drying.

An approximate calculation of gradients and flux shows that the difference in behavior between the clay overlaying the sand and the crushed stone was due to the removal of water from the sand by the clay. This behavior is responsible for the constant moisture kept within the interface between the sand and clay. Approximately 6 percent of the moisture available in the sand could be withdrawn by the clay while drying. Should drying continue, the sand would tend to act as an effective barrier against drying out of the clay subgrade immediately underneath the pavement edge. For these measures to be effective, however, the trench of the subdrainage system should extend to the depth of seasonal moisture variation and be backfilled with water-holding material, such as fine sand.

CONCLUSIONS

In spite of the limitations involved in the laboratory model study presented in this paper, the following conclusions may be deduced on the effect of the subdrainage system on the moisture regime in clay shoulders:

1. The subdrainage system has a definite positive effect on the moisture distributions in the clay subgrade. By removing free water which penetrates cracks, the system helps to maintain a low range of moisture variations between summer and winter and thus inhibits large movements at the edge of the pavement.

2. In semiarid countries the selection of the filter material for the drainage system should be governed mainly by criteria of moisture variations in the clay adjacent to the system and not by piping considerations.

3. Under the foregoing conditions, it is desirable to use a fine permeable material for the subdrainage system, since this material would tend to serve both as a moisture reservoir for the clay during the drying period and a barrier against drying out of the clay underneath the pavement.

ACKNOWLEDGMENTS

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REFERENCES

1. Globinsky, Z. Model Study of Suction, Moisture and Movement Variations in Clay Shoulders of Runways, Technion, Israel Inst. of Tech., M. Sc. thesis, Haifa, Israel, 1964.
2. Wiseman, G. A Study of Expansive Clay Subgrades Under Airfield Pavements. Israel Inst. of Tech., Dr. Sci. thesis, Haifa, 1959.
3. Kassiff, G. and Globinsky, Z. Apparatus for Measurement of Suction Under External Load. Highway Research Record 111, pp. 24-30, 1966.
4. Kisch, M. The Theory of Seepage from Clay Blanketed Resevoirs. Géotechnique, Vol. 9, 1959.
5. Croney, D., Coleman, J. D., and Black, W. P. M. Movement and Distribution of Water in Soil Relation to Highway Design and Performance. Highway Research Board Spec. Rept. 40, pp. 226-252, 1958.