Field Studies on Subgrade Moisture Conditions

JOHN W. GUINNEE, Senior Engineer, Materials Division
Missouri State Highway Department

Introductory Remarks by the Chairman

> Mach in "Die Mechanik in ihrer Entwicklung" stated: "All our principles of mechanics, as we have shown in detail, are experienced knowledge concerning the relative position and motion of bodies. They could not be, and were not, admitted in the areas in which they are now recognized as valid, without previous testing. No one is warranted in extending these principles beyond the boundaries of experience."
>
> Bodies are usually defined as things that possess mass and extension in space or form. Forces and energies are associated with the mass properties and for many theoretical purposes the extension in space or form is of only secondary importance. This has led to a widespread practice of neglecting form properties and often reducing a body to the absolute minimum, that is, a point in space that is acted upon by forces. For real systems, form is as important as mass and forces interact not only with mass but with forms and are themselves influenced by the latters' geometrical features. For biological systems, this has been demonstrated in a beautiful and exemplary manner by D'Arcy Wentworth Thompson in his classic "On Growth and Form."
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> Sometimes, in the analysis of soil moisture conditions, we become so much involved in the consideration of the forces that we forget about the geometrical features of the system in which we are interested. It is gratifying, therefore, that Mr. Guinnee in his field studies on subgrade moisture conditions presents evidence not only on the influence of climatic forces and factors, but also on that of geometrical features of the pavement base-subgrade system.

● **THIS PAPER** is in the nature of a summary of various investigational studies undertaken to obtain information concerning (a) the subgrade moisture content, its change with time and environment, (b) the source of post construction subgrade moisture, (c) the means by which this subgrade moisture travels or accumulates, and (d) the potentials which cause such flow. This paper will also serve as a temporary closure to these projects due to the demands of the expanded interstate program on the personnel involved. This information is deemed necessary to a more complete understanding of subgrade moisture conditions from which a more rational and economical design method might be evolved.

Since these listed purposes are so inclusive it must be understood that they are basically behind each project, even though that project may not have been pursued to completion. The information thus gained serves as a basis for the over-all considerations which will be covered. The progress reports from which this paper has been taken are of considerable volume so that only a few illustrations of each project and some typical project data will be included. The discussion of the results of all projects will be covered in a later portion of the paper.

The various construction projects which have been studied all contain the following basic design features unless otherwise noted. The pavement is of P.C.C. construction 8 in. thick by 24 ft wide with a parabolic crown of 1 ½ in. at the center. "Dummy" asphaltic filler contraction joints are spaced at 20 ft and the pavement is laid on a 4-in. by 26-ft compacted stone base. The 10-ft shoulders are sloped 6 ¼ in. and the standard ditches are 2 ft below the edge of the shoulder.

SEASONAL MOISTURE VARIATIONS

A project study was initiated in 1950 to try to determine the variations in the subgrade moisture due to seasonal changes as well as the extent of long-time moisture accumulation under concrete pavements. As an adjunct, the original moisture data would provide a reference datum for future performance investigations.

The Construction Division requires that pavement thickness cores be taken from newly constructed slabs so that actual thickness measurements can be made to verify wet concrete stick measurements. Since the pavements were thus ported through normal operating procedure it seemed as though these ports might afford an ideal entrance

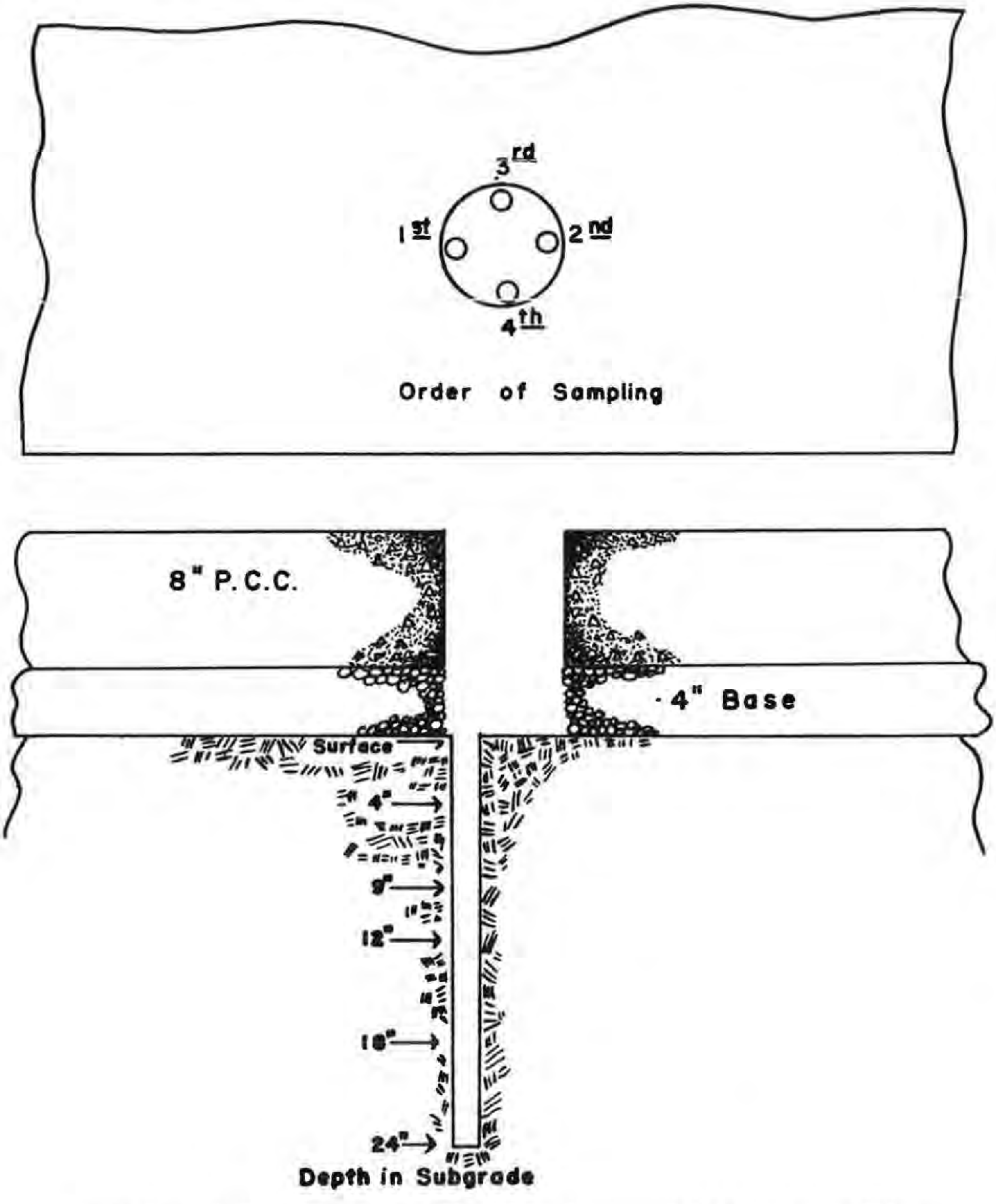


Figure 1. Details of manual sampling through pavement thickness core holes.

for manual subgrade moisture sampling. With the above purpose in mind, arrangements were made for a soils crew to accompany the core drill to sample the subgrade as soon as the cores were removed. All of the locations where the cores were required were sampled to obtain the original subgrade moisture content. The details and the order of sampling are shown in Figure 1. Every attempt was made to return the soil. base, and pavement to its natural condition after each sampling. Similar soil was tamped firmly into the auger hole, the base was replaced and compacted and the core hole was filled with a well-rodded, rich concrete mixture.

Thereafter according to plan, one-fifth of the locations were resampled after three months. These same locations were sampled twice more at three-month intervals until four successive samples had been taken. The second one-fifth of the locations were then sampled for three successive three-month intervals. It was hoped that this successive three-month sampling system would give the seasonal variations as well as the moisture history for four years. On projects where it was deemed of sufficient importance new core holes were drilled adjacent to the original series so that a continuing sampling system could be carried on. The projects selected for resampling were chosen so as to give a representation of different soils. Some new projects were sampled for the original moistures only, thus providing the datum as set forth in the purpose (that is, for possible future investigations of performance).

Under this plan, projects were sampled on a "take what comes" basis providing

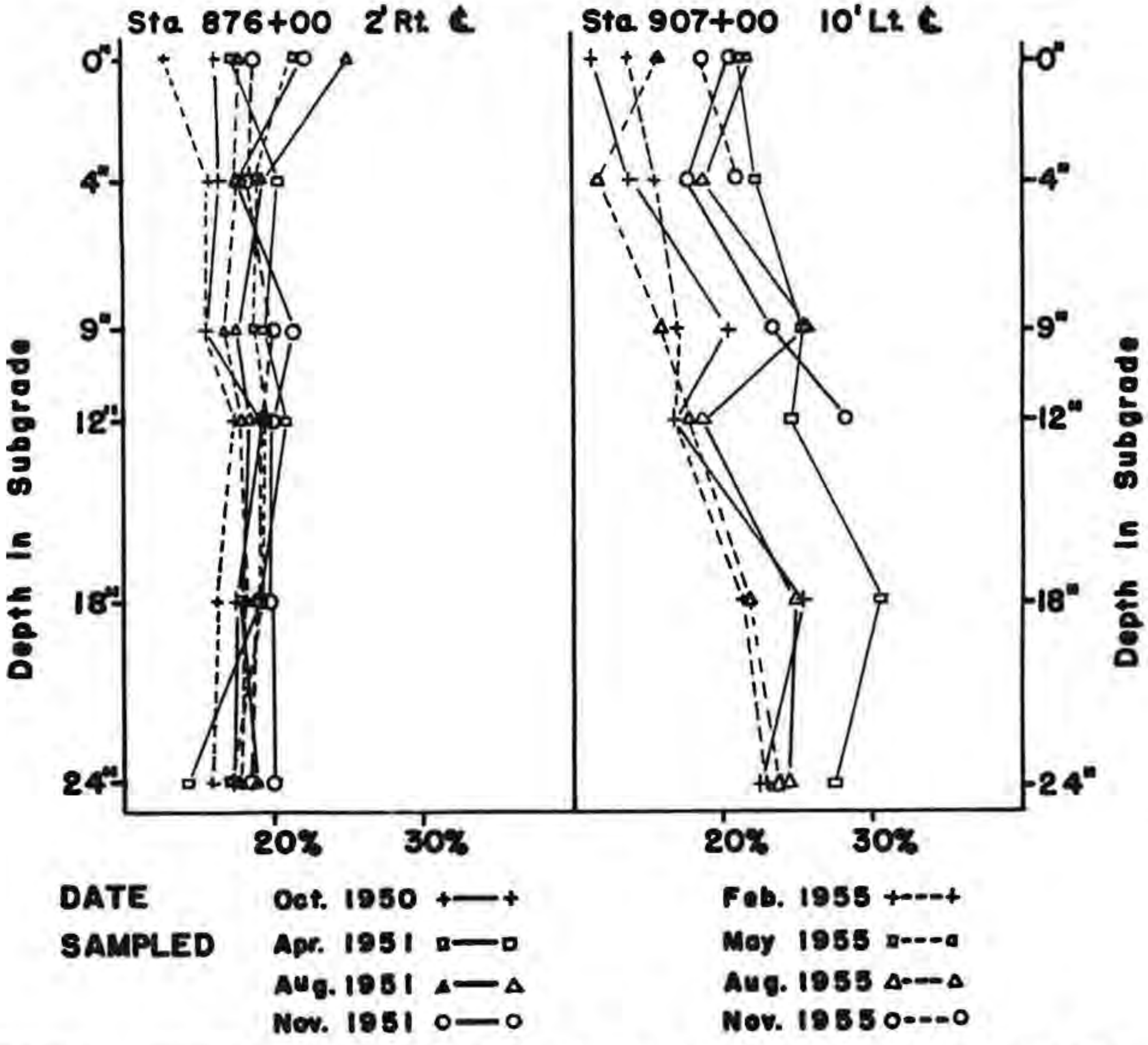


Figure 2. Individual moistures at successive sampling dates for two locations near Columbia, Route US 40.

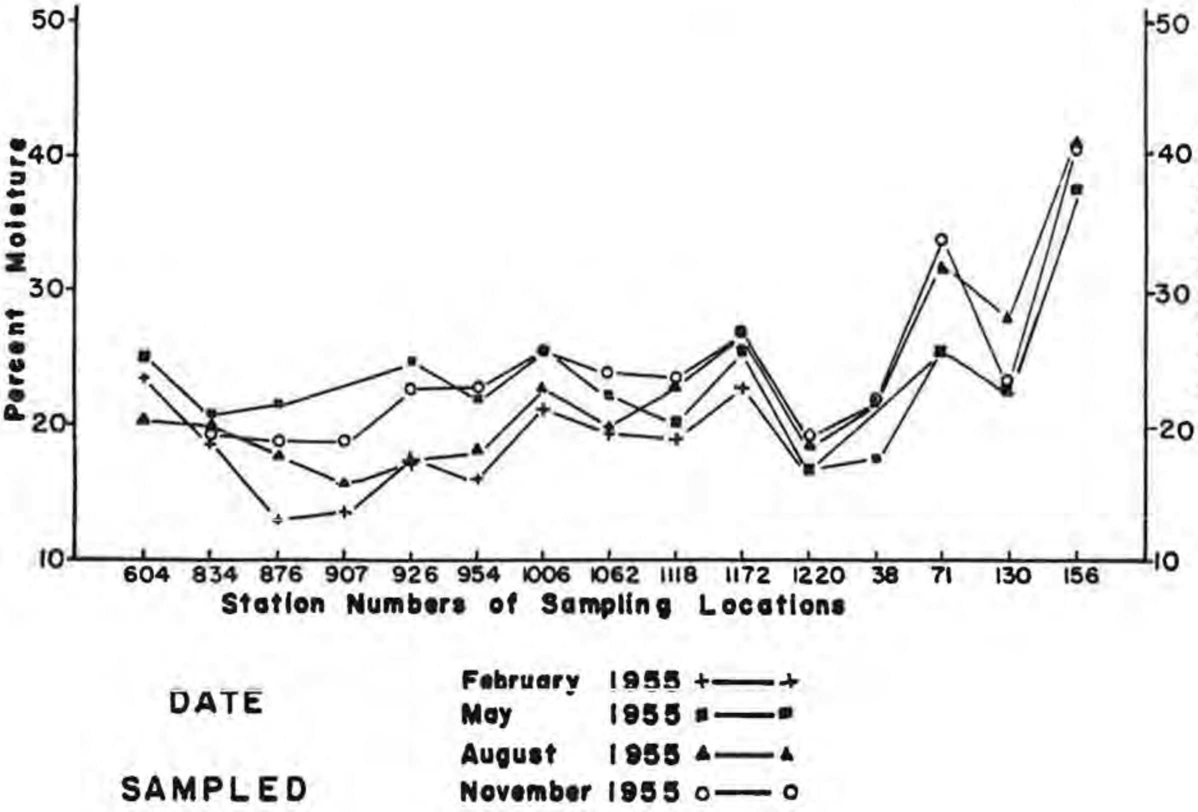


Figure 3. Subgrade surface moistures at successive samplings for the entire project near Columbia, Route US 40.

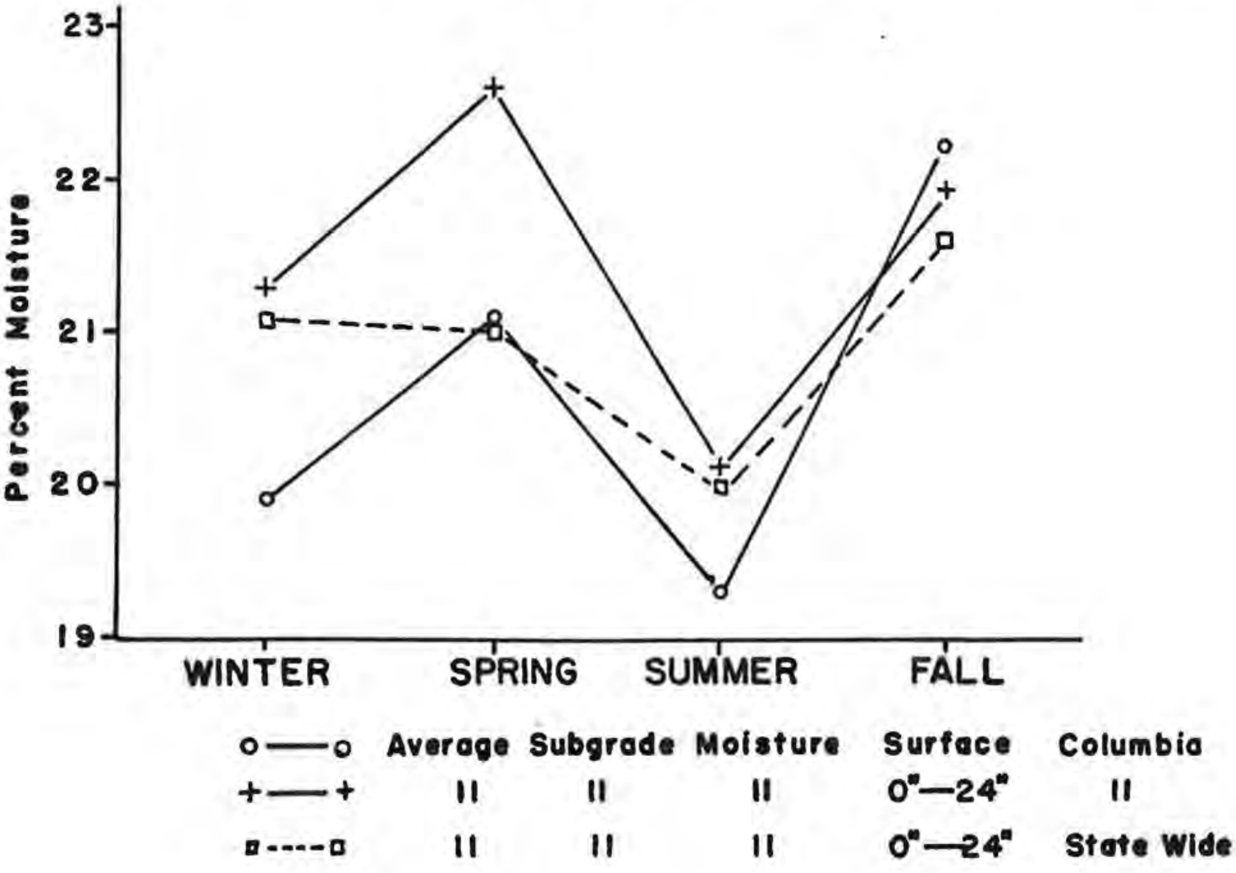


Figure 4. Seasonal average of the subgrade moisture.

they were of sufficient length and were composed of new subgrade construction. This system thereby provided an automatic randomizing effect on the sampling locations since the core hole sites were selected by the resident engineer with regard to construction only. A minimum of eight cores per mile were required whether any thin pavement was suspected or not.

Figure 2 shows the individual moistures obtained at eight successive sampling dates for two locations near Columbia, Route US 40. The variation in moisture is typical of the various locations of this project. It should be noted that, although four years had passed, the moisture levels in 1955 were no greater than in 1951 and perhaps even somewhat lower in these two illustrations.

Figure 3 shows the variation in the moisture of the subgrade surface along the entire project for successive sampling dates. This longitudinal variation is typical of the several projects studied showing the wide spread of moisture contents which occur along the project even though the difference in characteristics of the soil may be slight (that is, Sta. 1062 P.I. 22.6 Group A-7-6(16) and Sta. 156 P.I. 30.6 Group A-7-6(19)). On other projects where the variation in soil group ranges from A-4(4) to A-7-6(19), the spread of moisture content is correspondingly greater, but when appraised with reference to these characteristics the variations appeared to be reasonable.

Seasonal variations obtained from the averages of seven years of sampling are shown in Figure 4. The small spread in average moisture (less than 4 percent) is probably related to the geographical location of Missouri; not far enough north to year after year be affected by moisture potentials of extreme colds of relatively long duration, nor far enough south to be affected by the relatively high rainfall and temperatures of the southeast or by the low rainfall and high temperatures of the southwest. The actual value of these averages is of little importance since they represent a range of soil classifications. The general trend, however, should be representative of existing statewide conditions.

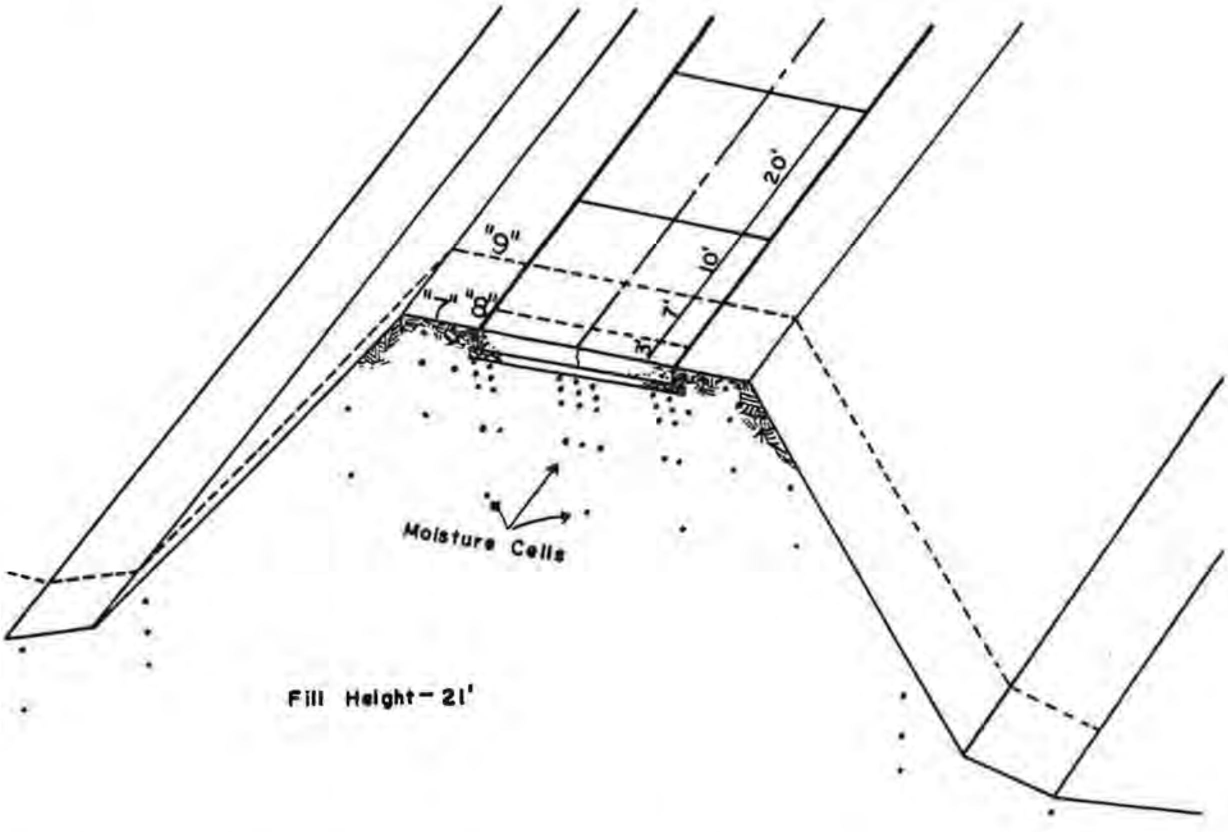


Figure 5. Lines "7," "8," and "9" showing moisture cell installations at 4-in., 9-in., 18-in., 36-in. and 72-in. depths in the subgrade.

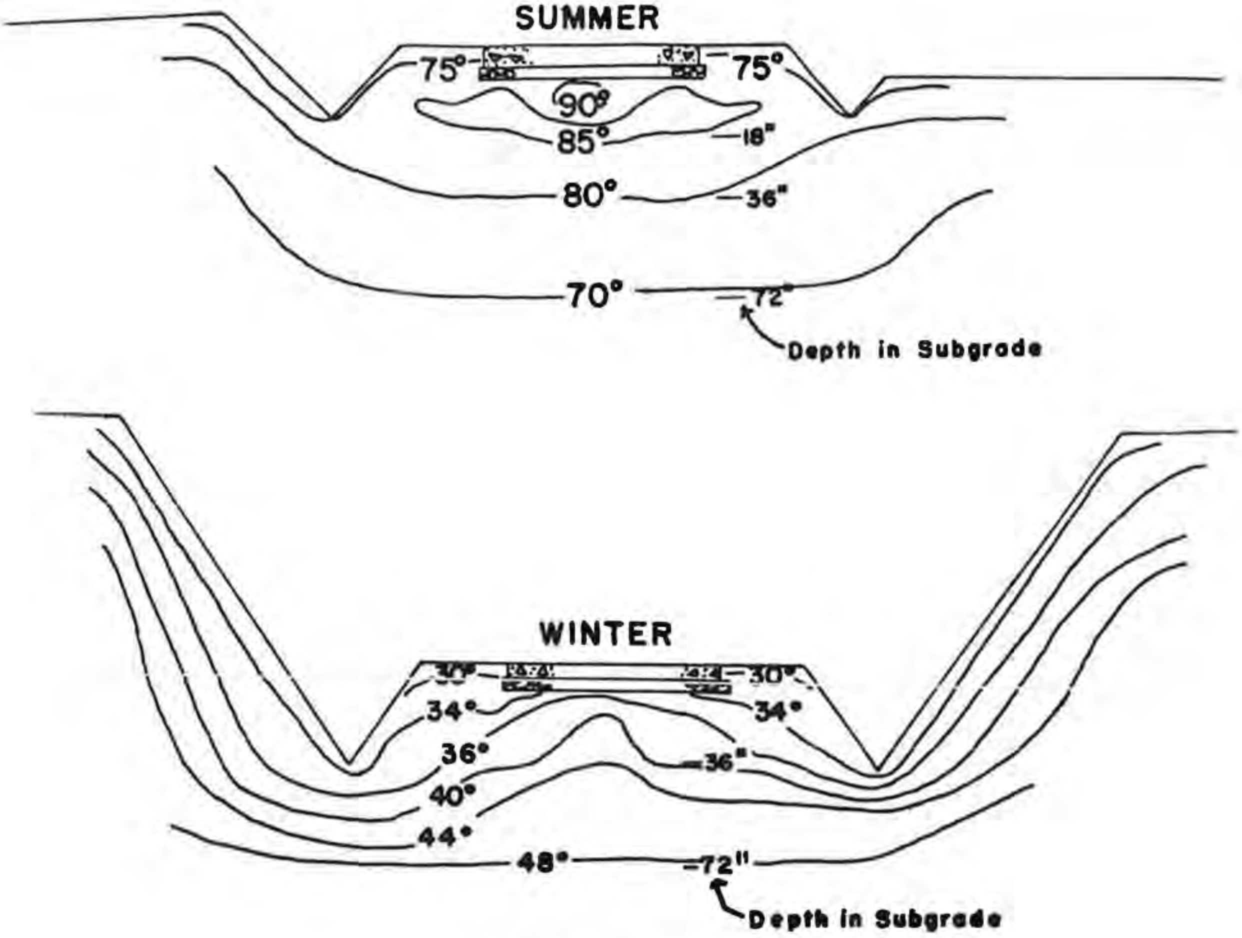


Figure 6. Typical isotherms.

MOISTURE ENTRANCE

An investigation was undertaken to try to determine the main source of supply for subgrade moisture and at the same time to select if possible the moisture cell locations which would be most generally representative of the average moisture level in the subgrade. Approximately 50 plaster moisture cells were installed in each of nine locations similar to those shown in Figure 5, with Lines 1, 2, and 3 placed in side-hill cut, 4, 5, and 6 in a 12-ft cut and 7, 8, and 9 in a 21-ft fill, with Lines 1 and 9 only 1,000 ft apart. The leads from the moisture cells and temperature coils were gathered into two terminal boxes for each set of three lines, one box on each side of the pavement.

Figure 6 shows typical isotherms during the summer and the winter. These isotherms were used in making temperature corrections to the resistance readings of the moisture cells. It was interesting to observe the sheltering effect of the backslopes of the cut section in contrast to the exposure of the fill section.

Typical moisture distribution levels as obtained by the moisture cells are shown in Figures 7, 8 and 9. These moisture levels were discontinuous because of the heterogeneous nature of the soil and because, as must be constantly kept in mind, the interpretation of moisture contents from resistance readings must go through temperature correction and calibration charts both of which may introduce errors into this interpretation. This project has been discontinued because the plaster cells had reached their maximum dependable life, having been in the earth for over five years.

CONTROLLED MOISTURE ENTRANCE

In 1951 this study was set up to obtain additional information concerning the ways by which moisture enters the subgrade subsequent to the base and pavement construction.

It was designed so as to limit or control certain of the ways by which moisture might enter the system. To make the study as complete as possible and yet to keep out many extraneous influences, it was constructed in eight comparable 100-ft sections, each

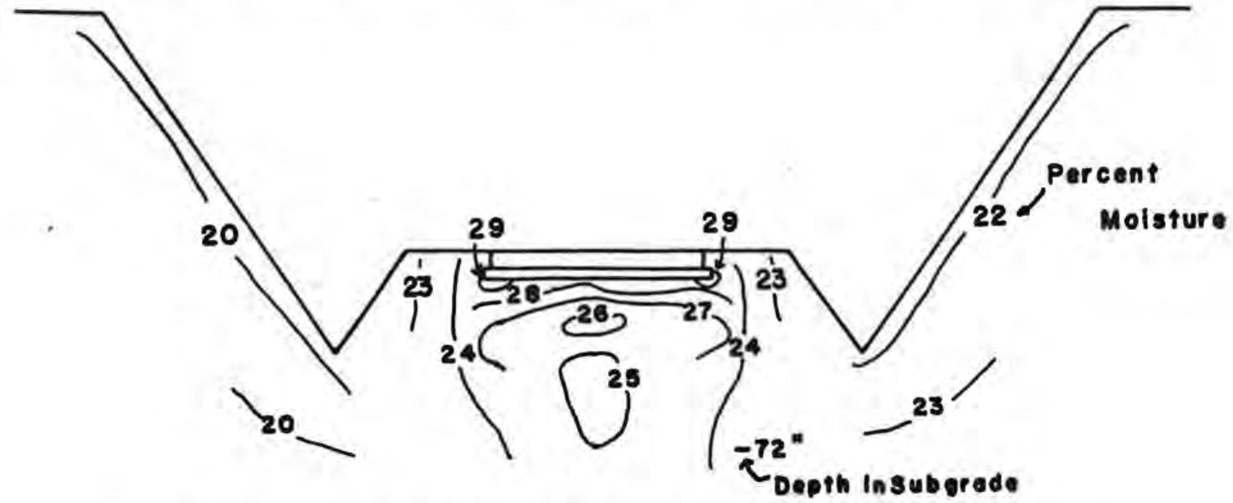


Figure 7. Typical moisture distribution levels on a winter day.

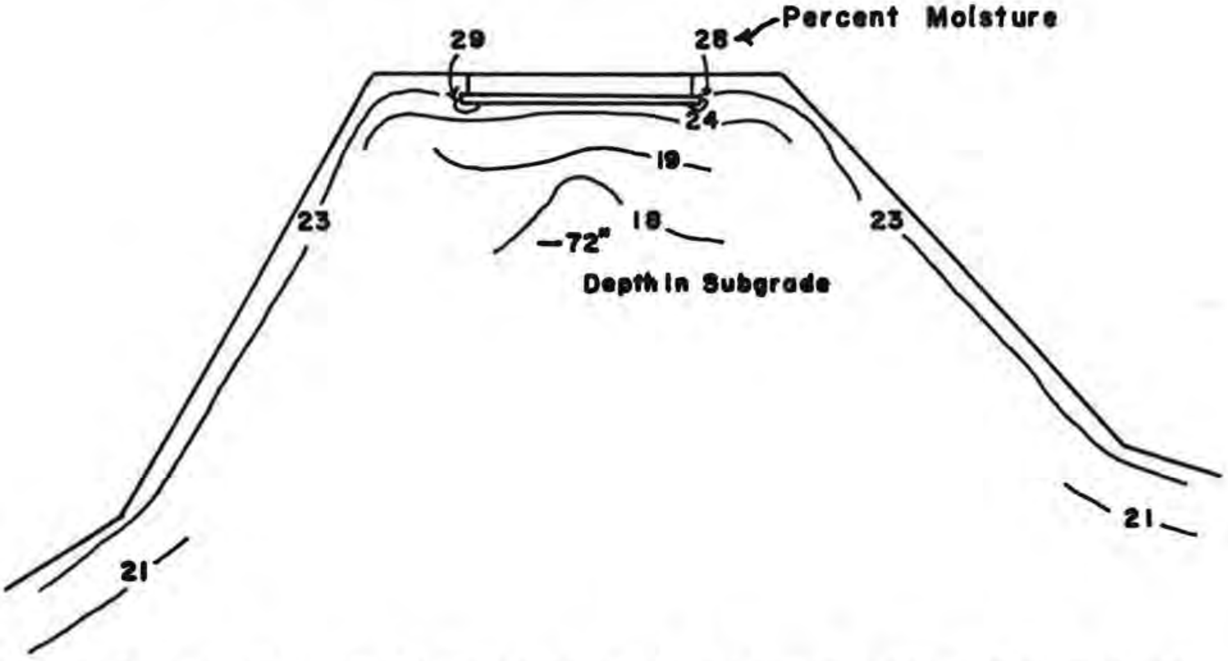


Figure 8. Typical moisture distribution levels on a summer day after a light shower.

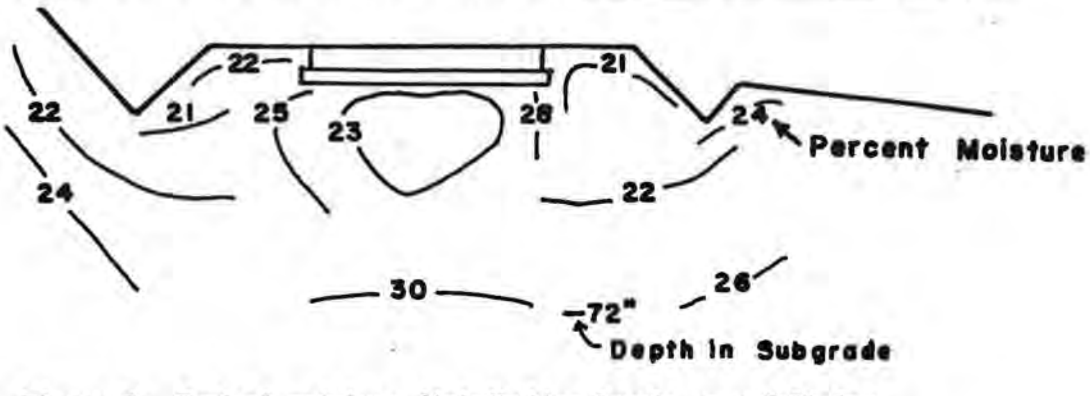
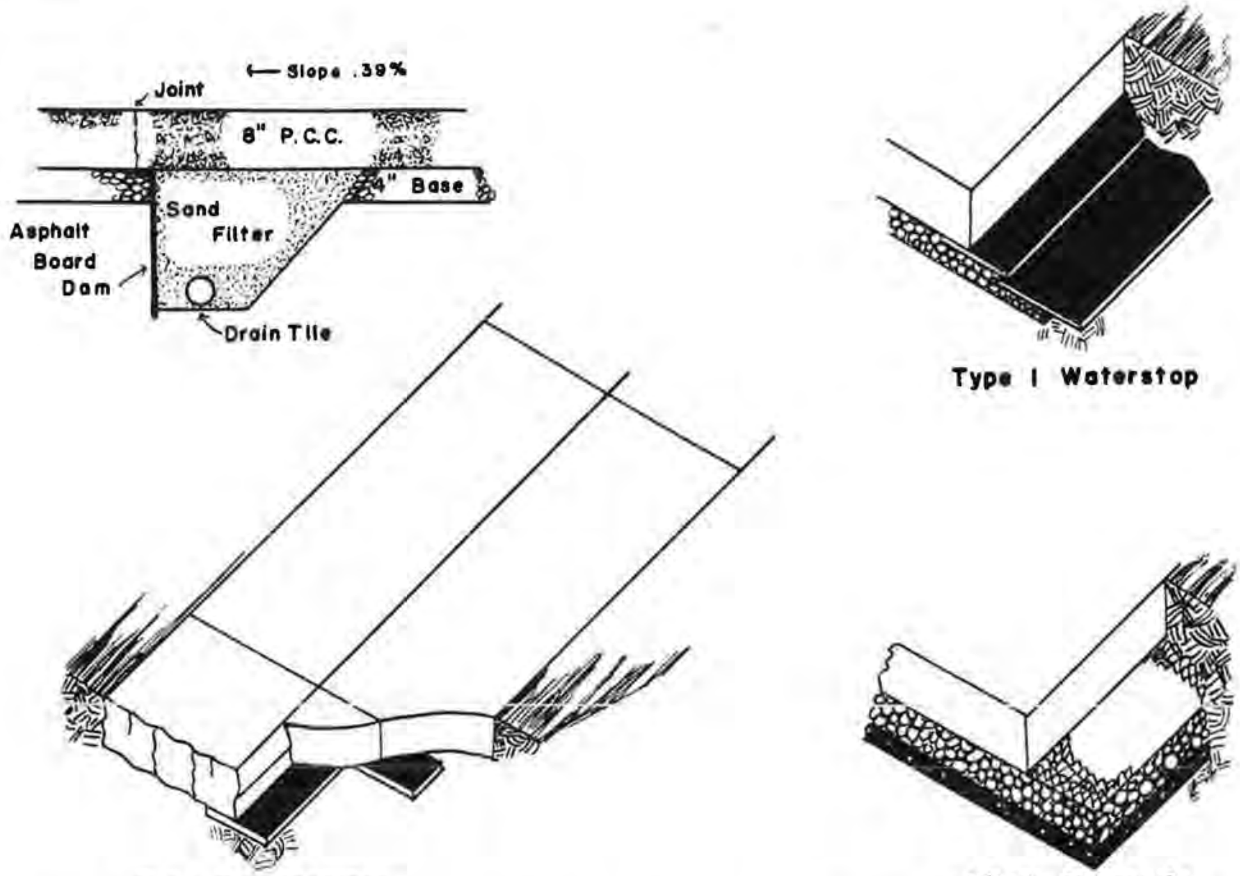


Figure 9. Typical moisture distribution levels on a fall day.



Type I Waterstop

Type 2 Waterstop

Oiled Subgrade

Figure 10. Details of methods of moisture entrance control and of drain construction.

with five contraction joints at 20-ft centers, all on a slight fill and with all the non-experimental design features to be identical with standard practice. As shown in Figures 10 and 11, attempts were made to prohibit the surface moisture from entering the system through the interior joints (Type 2), past the edges or through the joints (Type 1 and 2) or from the base at any point (oiled subgrade). These membranes, designated in Figure 10 as "waterstop," were sealed to the bottom of the slab by the use of an asphaltic emulsion applied just prior to the placement of the wet concrete. The three sections together with a blank section were duplicated on a 4-in. by 26-ft rolled stone base and directly on the subgrade.

Twelve moisture cells were installed in identical groups in the center 20-ft slab of each section to try to check on the extent of moisture entrance at the center joint, transverse joint, or edges.

Supplementally, special underdrains and dams of the design shown in Figure 10 were installed at the downgrade end of each 100-ft section for two reasons. (1) To try to evaluate any differences in the amount of surface water which drained over the subgrade (or through the pavement-base-subgrade system in some manner). (2) To try to stop any excess water from one section intruding upon the next adjacent section. These underdrains were connected to catchments in which provisions were made to measure the drainage.

A graph showing the total accumulated drainage from each of the 100-ft sections is presented in Figure 12. The fact that the base sections drained more water might indicate that they kept more water from entering the system but the average moisture of each section as indicated by the moisture cells showed that the sections on base were wetter than those with no base except for the untreated sections. It is interesting to note that the section with the oiled earth subgrade under the base, even though consistently draining the most water, maintained a lower subgrade moisture level than the other three base sections.

The section with oiled earth subgrade and no base had the lowest subgrade moisture level of all eight sections, consistently 10 percent below the rest.

A comparison of the average seasonal moisture and drainage for the Section 6 which was consistently the wettest, and Section 4, which was consistently the driest, is shown in Figure 13. This comparison shows that even though the drainage per inch of rainfall was at its lowest in the spring, the average moisture level was at its peak for both the wettest and driest sections.

TABLE 1

DROUTH DATA

Year	Total Rainfall in.	Deviation from Average
1952	29.34	-9.45
1953	23.98	-14.81
1954	32.34	-6.45
1955	28.23	-10.56

PAVEMENT CONSTRUCTED ON A VERY DRY SUBGRADE

This study was started in 1953 when it was noted that pavement was being constructed on very dry subgrade, the dryness of which extended in depth. Table 1 shows the extent of the drouth which was affecting Missouri at that time.

In this study subgrade moisture samples were obtained to depths of 24 in. in a transverse line at 3-ft intervals starting at the designated north edge of the slab and extending to the south edge (9 locations with 6 samples each). These original moisture samples were taken from 13 locations about evenly divided between fill, cut, and transition section. After the base was laid a few spot checks were made and the subgrade surface moisture was found to have risen to almost that of the previous underlying soil moisture levels, but still approximately 6 to 10 percent below the plastic limit. On the completion of the paving and shouldering, bench marks were set well back in the backslope and imbedded to 20 ft to attempt to keep disturbance of the bench marks to a

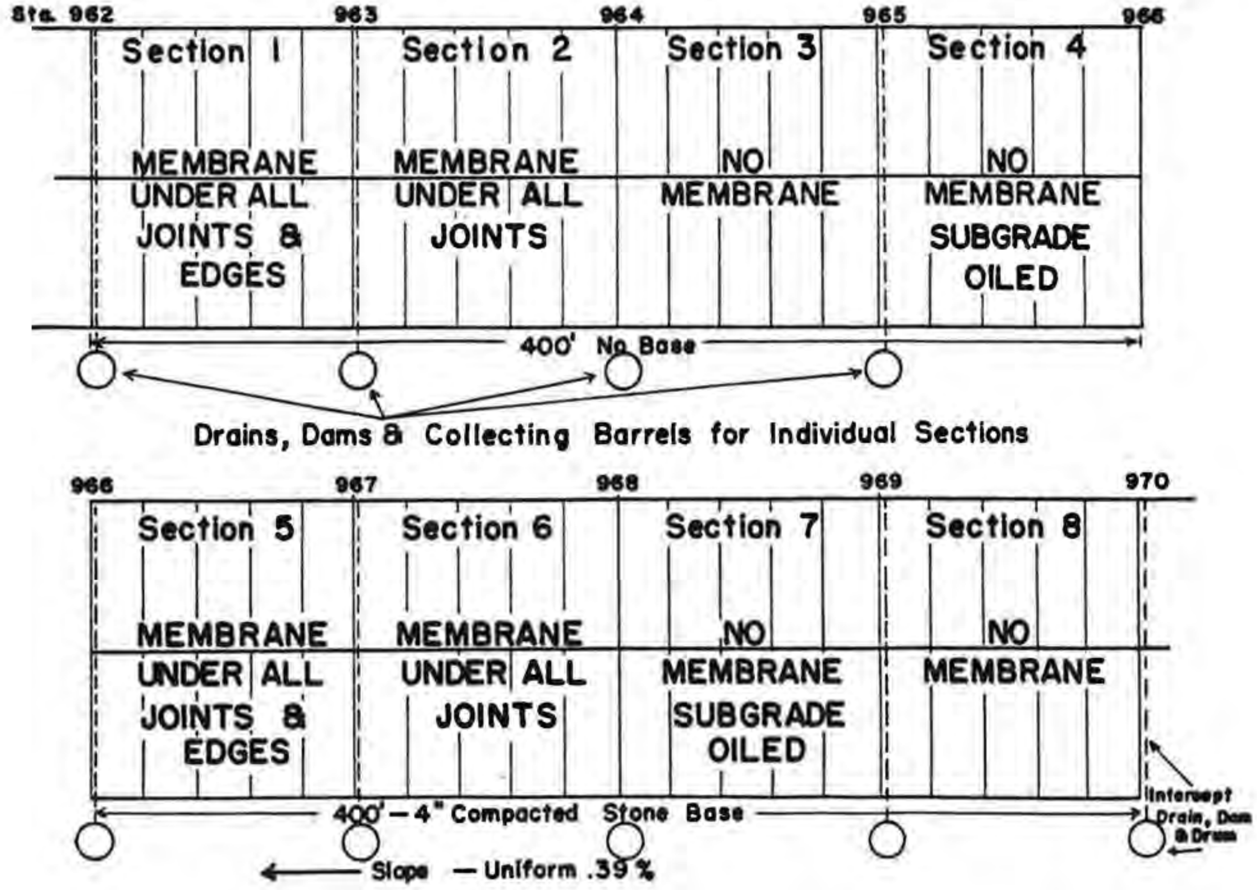


Figure 11. Controlled moisture entrance variations.

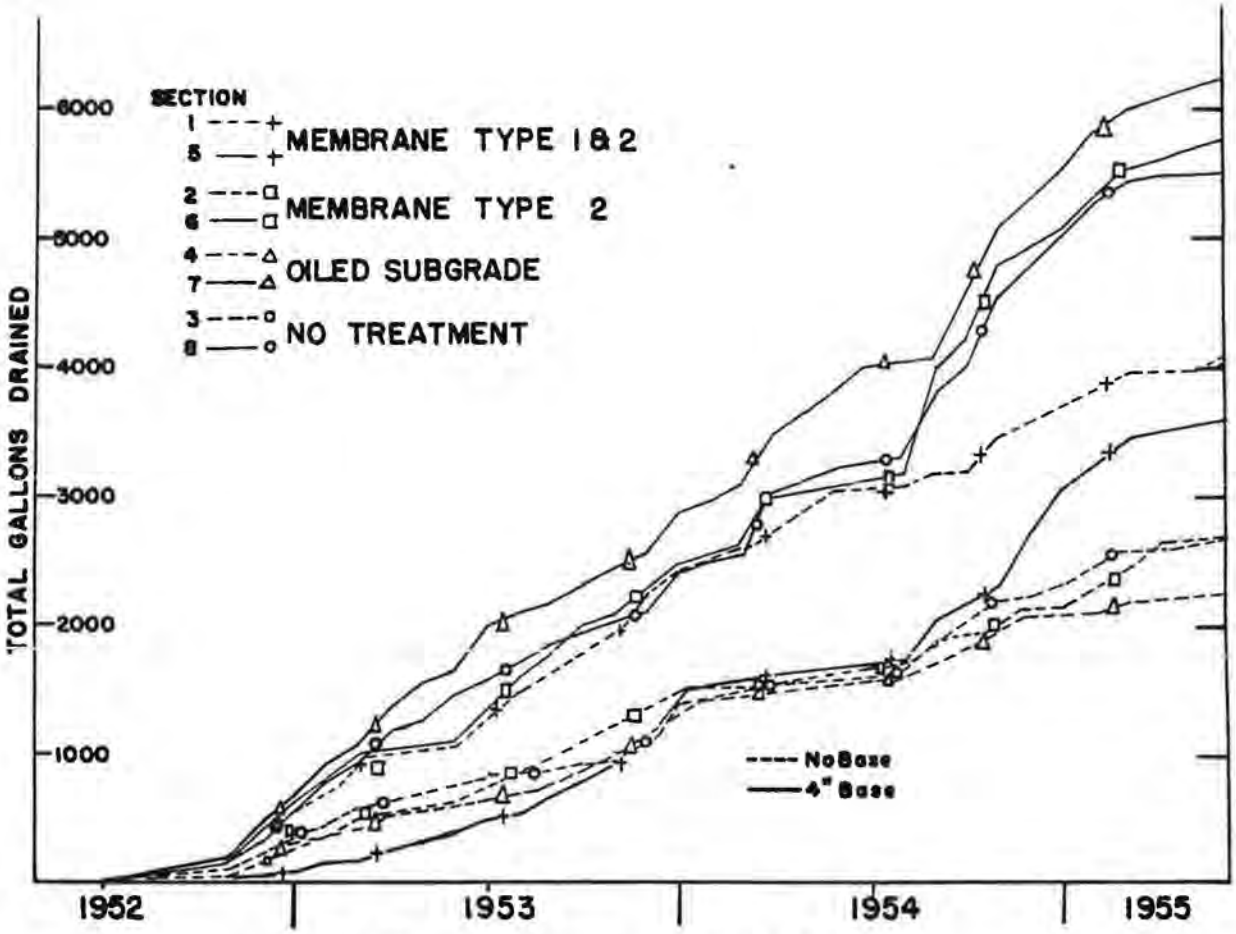


Figure 12. Comparisons of cumulative drainage.

minimum. At the same time permanent marks were placed at six locations across the slab and directly over one of the previously sampled transverse lines. Elevation readings were obtained at these points to provide the original datum. The marks were placed at 4 in. from each edge of the slab, 4 in. on each side of the centerline and at the quarter points of the slab (that is, 6 ft from each edge).

Thereafter tri-monthly subgrade moisture samples were taken through one core hole at each of the locations where the elevations were being checked. The elevations were checked once a month with every third month coinciding with the moisture sampling time. Figure 14 shows the vertical movement, at a typical fill location, of the six points on the slab surface as corresponding to the moisture contents of the tri-monthly subgrade sampling.

As an adjunct to the other companion studies the subgrade moisture data thus obtained were averaged to show the seasonal variation depicted in Figure 15.

DISCUSSION

In a general sense, the foregoing data present a picture of subgrade moisture conditions in Missouri. It must be borne in mind that the majority of these tests and studies were under way during the nearly five years of drouth which plagued Missouri farmers. While it was not evident except in minor cases that this drouth affected the newly constructed concrete pavements, it did cause damage to many flexible pavements and to the asphaltic widening of older concrete slabs. The damage was mainly in the nature of subsidence due to desiccation, especially that caused by the hair roots of vegetation which is not a reversible process.

The data depicted in Figures 7, 8 and 9 show that the main source of surface moisture entrance into the subgrade system is past the edges of the pavement. The bulbs of high moisture content were apparent more often under the edges of the slab than at any other place and these bulbs also proved to have the widest range of moisture, relative to the rest of the subgrade, at the times of high moisture levels. These spots also evidenced the greatest spread of moisture levels for that portion of the roadbed directly below the pavement. It can then be assumed that the same means of wetting the subgrade soil (that is, past the edges of the slab) is also a means of drying the subgrade under a reversal of conditions.

Information which applies to this discussion but which was obtained from a study outside of this particular group is shown in Figures 16 and 17. It is presented at this time to substantiate the following statements. A more or less continuous channel was discovered next to the vertical edge of the slab. At the time of this study, the crack between the slab and the shoulder soil appeared to be very slight but on excavation the channel with a cross-section as much as 2 in. by 3 in. was found at the lower corner of the slab edge. This opening or channel also extended for some distance under the slab as spaces of ¼ in. to ½ in. were visually apparent. Observations were made on all other studies which entailed the opening of the concrete so that the base could be visually inspected. From these observations it was concluded that water flow in the pavement-base-subgrade surface system was no different than in any other system, following the path of least resistance whether it be over, under, around or through the base materials.

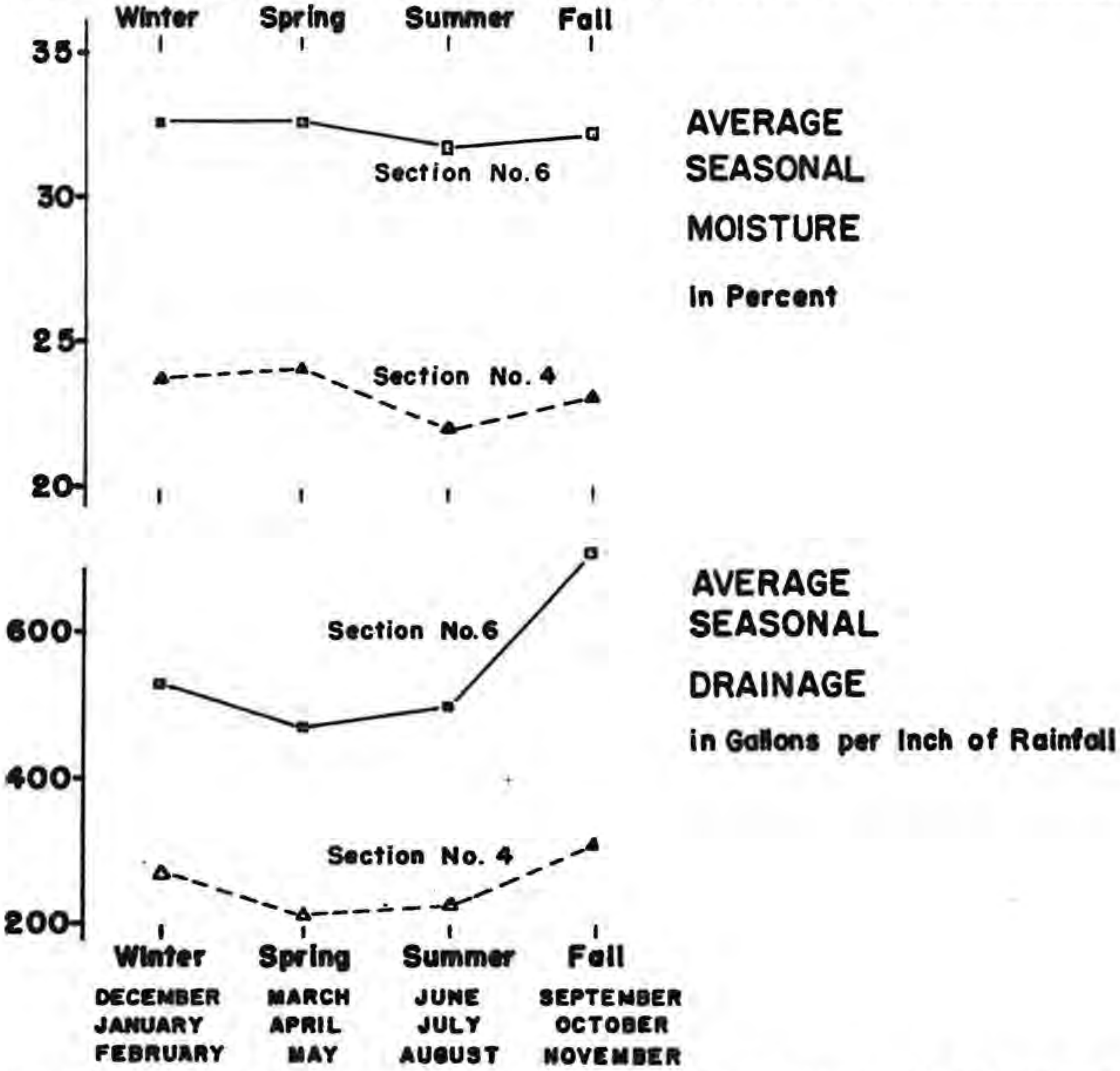


Figure 13. Comparison of average seasonal moistures and average seasonal drainage for two sections.

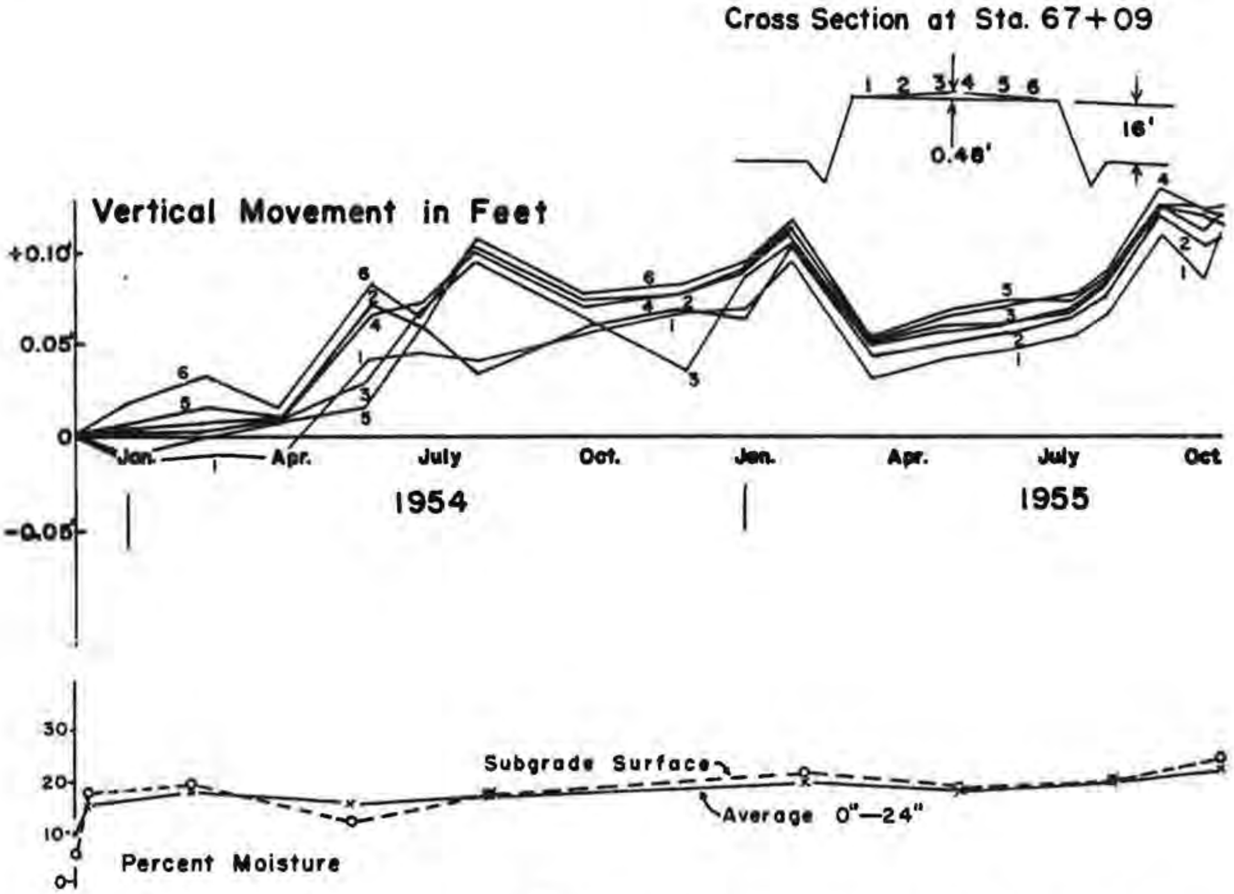


Figure 14. Vertical movement of surface of slab constructed on dry subgrade.

This means of entrance was discounted as a major factor in the appraisal of the ultimate average moisture level of the subgrade system by the data obtained from the "Controlled Moisture Entrance" study. This study showed quite plainly that there were no major differences in the average moisture levels of the sections where the moisture entrance past the edge or through the joints was controlled and the section with no control. The efficacious effect of the oiled earth subgrade was more apparent in the section with no base than the section with base. Since the only preparation was by surface planing and spraying with oil, it is quite possible that the process of placing the base might have somewhat damaged the oiled surface. At any rate the oiled earth subgrade under the base did provide a delaying effect upon the rise in the average subgrade moisture, also a stabilizing effect in that the fluctuation of the moisture level was decreased.

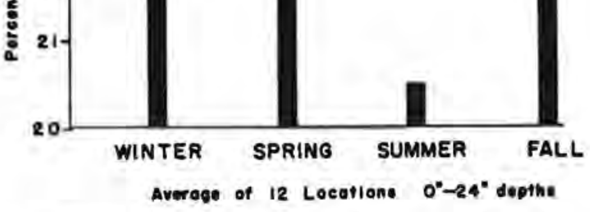


Figure 15. Average subgrade moisture.

All of these studies have shown that the moisture level of the subgrade rises rather rapidly after construction where no sufficient preventive treatment is provided. A previously reported study (1) substantiates this indication. In many cases the climb of the averages to close to the plastic limit had occurred in three months or less. Lancaster (2) has shown that in his study of flexible construction it took nearly seven years for the average moisture content of those points 8 ft from the edge, to rise to the three-month level of those points 2 ft from the edge.

The seasonal variations in average subgrade moistures were not very great but a more indicative measure of the possible changes of subgrade moisture might be found in the examination of the changes at any particular location. For example, data obtained in the "Seasonal Moisture Variation" study showed that at one location the subgrade surface moisture content varied approximately 25 percent in three months. The fact that there is no great variation in the averages over the seven years of sampling is an indication that prediction of ultimate average moisture levels need not regard seasonal effects. This statement is made with the reservation that it applies only to concrete pavements on base course material in Missouri.

A subgrade in which the average density, indicated by compaction reports, is 100 pcf would have a saturation moisture content of 24.7 percent. Therefore, if a moisture content of 38 percent was found in the top 12 in., the density would have changed to 82.4 pcf, again assuming saturation. This change in density would indicate a vertical expansion of 2 ½ in. Yet in this case the measured change in the elevation of the slab surface at the adjacent check point was only 1 in. From this it can only be assumed that the resultant expansion was horizontal as well as vertical even though considerations of resistance would seem to indicate otherwise. Although this study indicates considerable vertical movement throughout the project, there was little evidence of critical pavement distress. The most recent measurements of faulting at the transverse joints on this project have been showing a decrease in the total inches per mile of faulting from 47 in. to 40 in. Whether or not this is a true trend remains to be seen.

Calculated theoretical moisture distributions based on the approach of Croney (3), indicate that some differences in basic assumptions must exist (that is, impermeable and infinite cover) to account for the lack of correlation. Nevertheless it is felt that based upon whatever assumption is made, the best time to cover the subgrade would

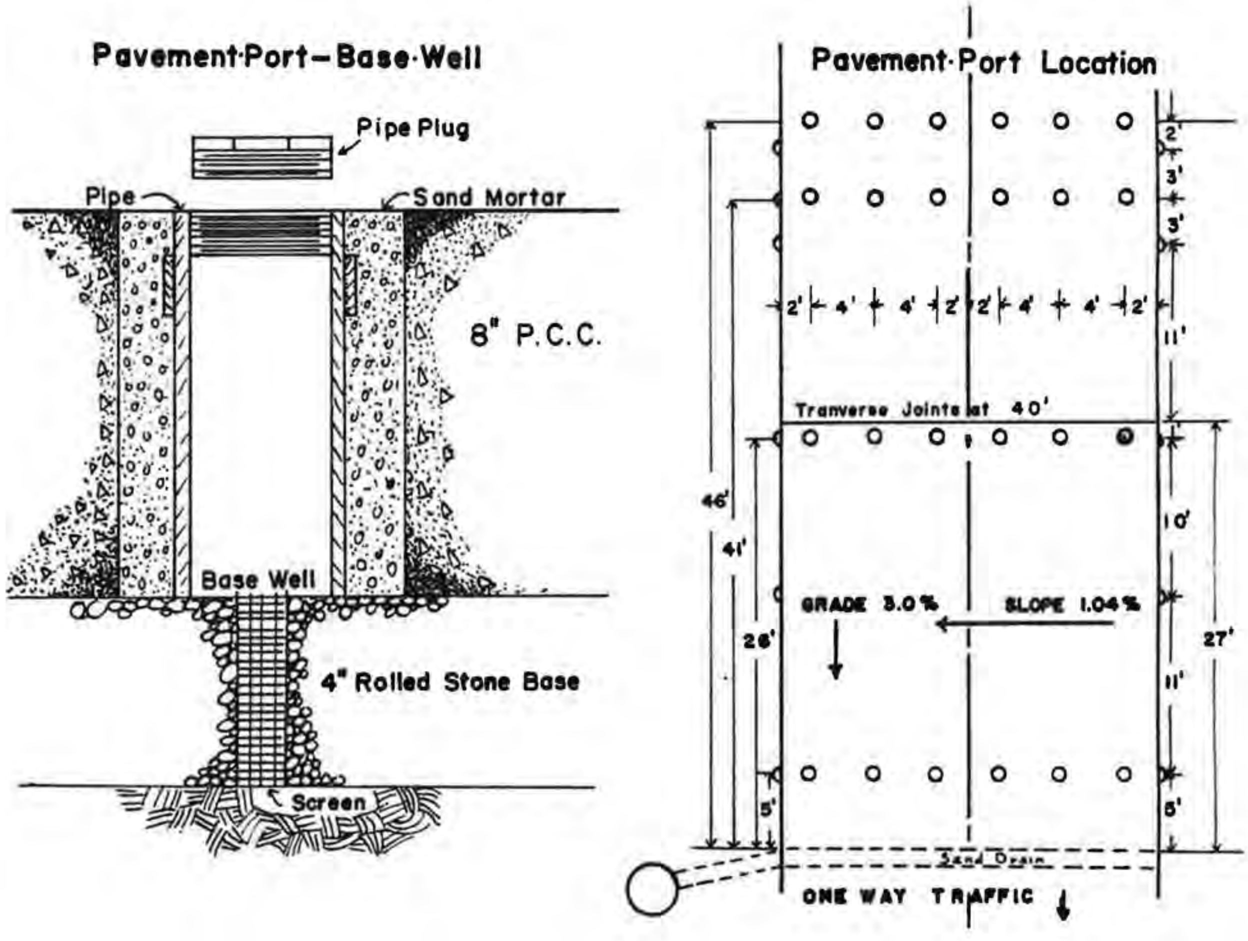


Figure 16. Details of base moisture flow study.

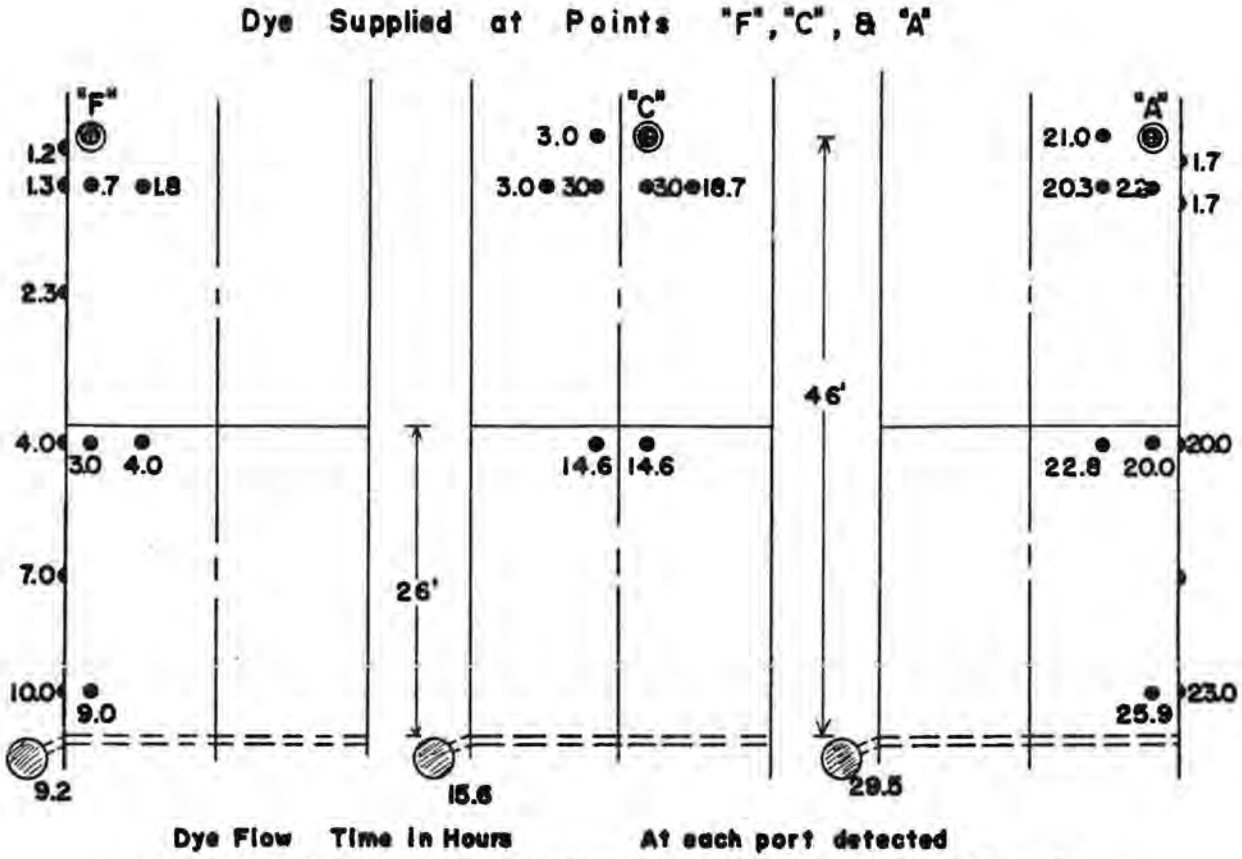


Figure 17. Dye flow times in hours from different points of supply.

be when the moisture distribution curve is at or above the optimum moisture for compaction and yet remains below the theoretical curve as defined above. It would then seem that if the cover could be made to more closely follow the basic theoretical assumptions, the likelihood of the subgrade remaining in a stable moisture condition would be enhanced. If such could be obtained then the engineering design of such roadway foundations could be more economically based on valid supporting values, which could be determined in the laboratory.

CONCLUSION

Since some of these studies may be reopened in the future it would not be proper to list any conclusions now, but instead some indicated questions are presented.

1. What avail (as far as subgrade moisture is concerned) is the sealing of center and transverse joints, if the edges are not (or cannot be) sealed?
2. Is there an advantage in making a base course less permeable so that the subgrade surface would possibly show less variation in moisture content even though its average may be higher than that under a permeable base?
3. Continuous membrane seems to produce a more uniform, although possibly a higher subgrade moisture content. Will the added cost be justified on the basis of long term results?

ACKNOWLEDGMENTS

The author wishes to express appreciation for the guidance and encouragement given by F. V. Reagel, Engineer of Materials, and Dr. H. F. Winterkorn, Princeton University. Also to Charles E. Thomas for his cooperation in obtaining the progress reports upon which this paper has been based.

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