CASE STUDIES OF VARIATIONS IN SUBGRADE MOISTURE AND TEMPERATURE UNDER ROAD PAVEMENTS IN VIRGINIA

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Changes in moisture under uncovered ground and in the subgrades of pavements were evaluated. The pavements ranged from new to about 10 years old. Moisture content was determined by a nuclear probe to determine moisture depth. The findings were as follows: (a) the higher the compaction and dry density of the subgrade soil were, the lower the moisture content would be; (b) subgrade moisture content increased sharply from the beginning to the end of construction; (c) for 1 or 2 years from the date of the subgrade construction, moisture content increased because of precipitation and after this time the rate of increase in moisture decreased; and (d) after about 10 years, there was little increase in the subgrade moisture content.

•PAVEMENT strength is greatly influenced by the moisture content of the subgrade. It is, therefore, essential to determine the changes in subgrade moisture and the factors contributing to these changes.

A comparison was made between the results of temperature and moisture measurements taken under uncovered ground and in subgrades under pavements. On new projects, moisture content was also measured during construction. In grounds covered with pavements, the effect of age of the cover was determined. The pavement projects, therefore, varied from new to about 12 years.

DATA COLLECTION

Precipitation and air-temperature data near the test sites were obtained from the monthly bulletin for Virginia supplied by the U.S. Department of Commerce. A nuclear method for measuring subgrade moisture contents was adopted. The subgrade temperatures were measured by thermistors. Data collected for precipitation, temperature, and moisture content are described in the following.

Measurement of Precipitation

Rainfall data from 1970 and 1971 for test sites at Charlottesville, Culpeper, and Fredericksburg were plotted and are shown in Figure 1. Precipitation data for Charlottesville are applicable to sites 2, 3, 4, 5, 6, 7, and 9; those for Culpeper to site 1; and those for Fredericksburg to site 8.

Data about snow on the ground for 1970 and 1971 show traces in December (for maximum of 5 days), 6 to 10 in. (15 to 25 cm) in January (for maximum of 31 days), about 1 in. (2.5 cm) in February (for maximum of 4 days), and 7 to 9 in. (18 to 23 cm) in March (for maximum of 9 days).

Publication of this paper sponsored by Committee on Subsurface Soil-Structure Interaction.

Measurements for Underground and Subgrade Moisture and Temperature

The moisture content below uncovered ground and under roadway shoulders and pavements was determined with a nuclear depth probe. These measurements were usually made at 1, 2, and 3 ft (0.3, 0.6, and 0.9 m) below the uncovered ground or below the bottom of the shoulder or the pavement.

The determinations of moisture content below uncovered ground were taken for locations 1 through 9 as given in Table 1. Table 1 also gives the physical analysis of the soil. Moisture contents from May 1, 1970, to May 1, 1971, for these nine locations are graphically shown in Figures 2, 3, and 4.

Moisture contents below the pavement or shoulder were recorded for locations 13 through 17 as given in Table 1. On each of these five locations, four sites were chosen: under the shoulder of a cut, under the pavement of a cut, under the shoulder of a fill, and under the pavement of a fill. The measurements on these locations were made over a period of 18 to 24 months. Subgrade moisture contents for these five locations are given later.

Temperatures and temperature gradients under the pavement or shoulders in the subgrade or below uncovered ground were determined by means of thermistors embedded at 0-, 1-, 2-, and 3-ft (0.3-, 0.6-, and 0.9-m) intervals.

Air and subgrade temperatures were continuously recorded for two satellite pavements and occasionally were recorded for other projects. Temperature versus time for location 15 (from March 1969 to November 1969) and for location 14 (from January 1969 to November 1971), for both the fills and cuts, are shown graphically in Figures 5 and 6 respectively.

EVALUATION OF SUBGRADE TEMPERATURE

The following conclusions were drawn from the evaluation of the subgrade temperatures. The minimum subgrade temperature was higher than the average temperature of the 5 previous days, as shown in Figures 5 and 6. For a few days in January, the average of the 5 previous days' temperature was slightly below the freezing point. During these few days, subgrade temperatures below the pavements and the shoulders of project 14 were taken. The subgrade temperature below the pavement was slightly above the freezing temperature, but the subgrade immediately below the shoulder was frozen. Frozen subgrades under the shoulders may occur because (a) snow is pushed from the pavement and collected on the shoulders, and (b) the untreated aggregate is 6 in. (15 cm) deep, is porous, and has higher thermal conductivity than does asphalt concrete.

Changes in the subgrade soil temperature followed changes in the air temperature (Figs. 5 and 6). Thus, during spring and summer, the temperatures in the upper part of the subgrade were higher than those in the lower part; this trend changed during autumn and winter. Figure 7 shows the temperature gradient recorded during summer and winter, the air temperature at the time of testing, the average of 5 previous days' air temperatures, and the subgrade temperatures for 2 days in summer and winter.

Because of the temperature gradient in the subgrade soil, there would be a moisture flow in the subgrade; for example, the moisture would move from the lower part to the upper part of the subgrade in autumn and winter and reverse its movement during spring and summer.

Figures 5 and 6 show that the subgrade temperatures in fills were lower than those in cuts. The variation was from 2 to 10 F (1 to 18 C) depending on the air temperatures: The higher the air temperature was, the higher the variation was.

Figure 1. Precipitation data.

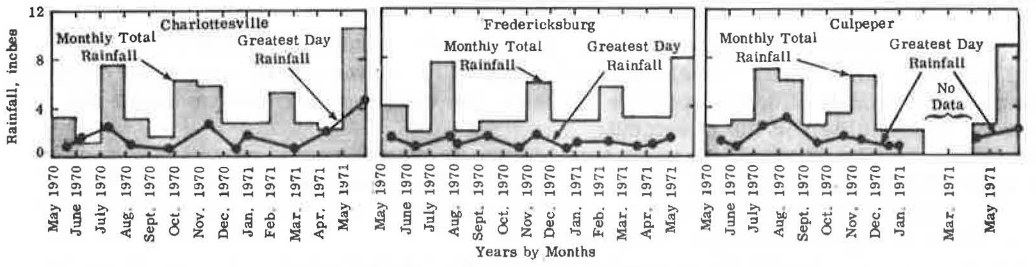


Table 1. Analysis of soil.

Location Number	Physical Condition	Aggregate Gradation (percent passing sieve size) No. 10	No. 20	No. 40	No. 60	No. 80	No. 100	No. 200	Silt (percent)	Clay (percent)	Atterberg Limits (percent) Liquid Limit	Plastic Limit
1	Uncovered ground	100	98.2	96.7	95.3	94.3	93.6	90.9	40	45	53	38
2	Uncovered ground	100	91.7	85.4	–	73.1	67.9	54.8	25	31	0	0
3	Uncovered ground	100	97.1	93.1	87.7	85.7	83.7	76.9	31	41	41	28
4	Uncovered ground	100	96.8	95.2	90.0	86.5	82.9	73.0	34	37	54	36
5	Uncovered ground	100	96.0	87.6	77.2	71.0	66.3	52.0	29	24	41	35
6	Uncovered ground	100	95.8	85.1	77.5	70.3	70.0	61.8	29	33	46	30
7	Uncovered ground	100	98.2	96.2	92.4	89.2	86.6	78.8	20	57	58	36
8	Uncovered ground	100	85.2	62.3	61.5	23.2	21.4	00.0	0	0	–	–
9	Uncovered ground	100	96.0	93.0	89.4	86.6	84.5	77.4	26	41	52	32
13	Pavement, fill	100	97.2	90.9	79.6	71.5	69.9	54.7	23	29	–	–
	Pavement, cut	100	89.0	57.1	57.1	5.6	5.6	0.0	–	–	–	–
14	Pavement and shoulder	100	93.9	88.2	83.4	80.1	78.0	69.8	27	41	53	34
15	Pavement and shoulder	–	–	–	–	–	–	–	–	–	–	–
16	Pavement and shoulder, fill	100	91.2	83.8	72.8	70.3	66.4	54.1	25	16	31	26
	Pavement and shoulder, cut	100	87.0	79.6	73.6	68.2	63.6	42.9	23	13	29	23
17	Pavement and shoulder, fill	100	85.8	73.9	–	60.9	58.2	50.7	–	–	–	–
	Pavement and shoulder, cut	100	90.0	80.0	–	66.5	63.3	54.3	–	–	–	–

Figure 2. Moisture content below ground level at locations 1, 2, and 3.

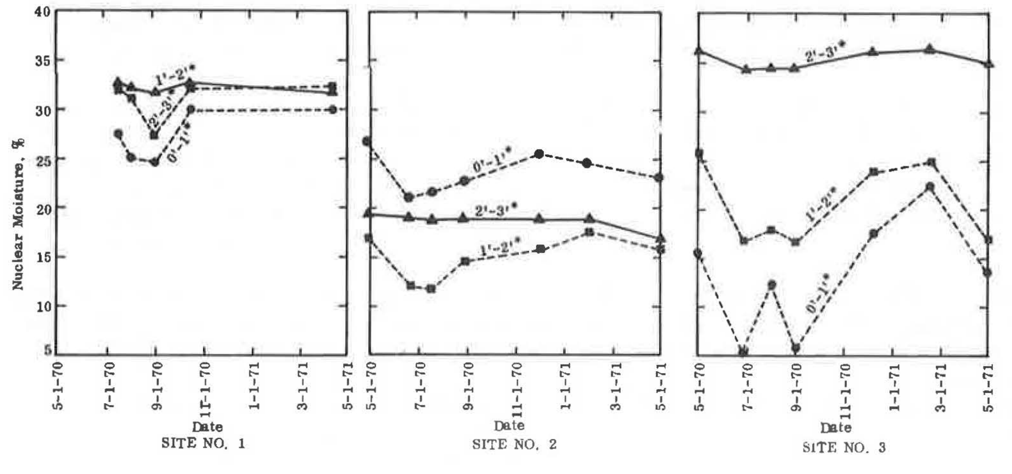


Figure 3. Moisture content below ground level at locations 4, 5, and 6 (*denotes depth below ground level).

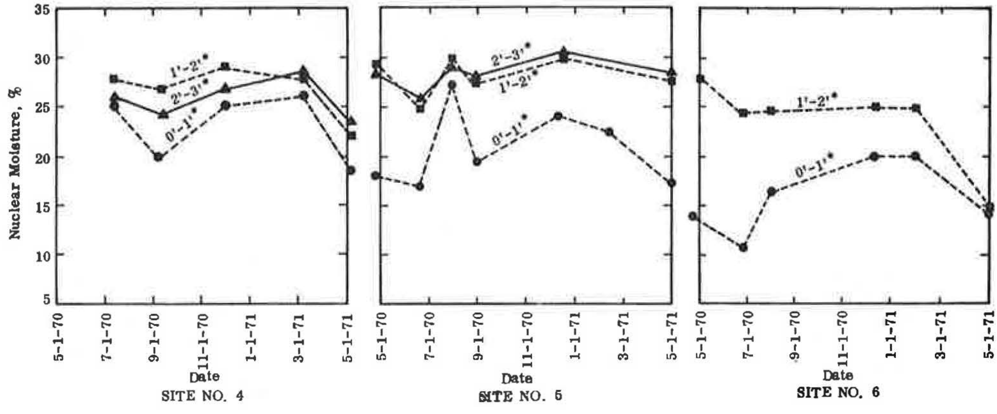


Figure 4. Moisture content below ground level for locations 7, 8, and 9 (*denotes depth below ground level).

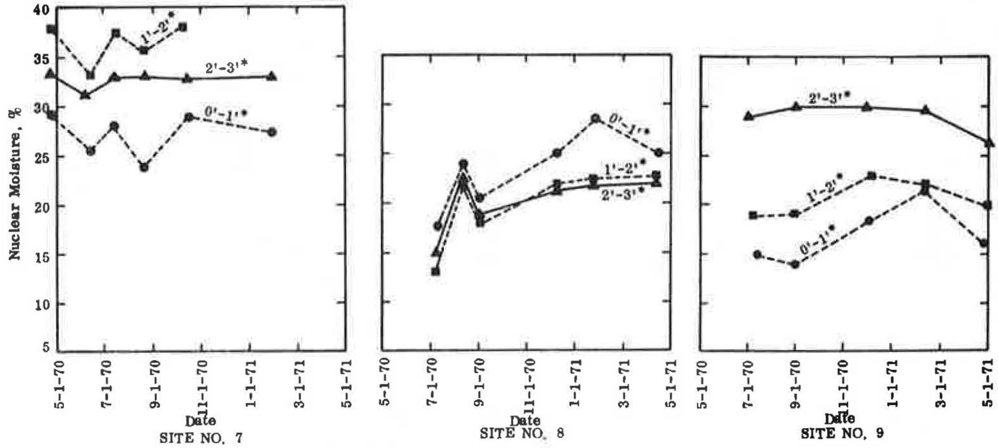


Figure 5. Air and subgrade temperatures at location 15.

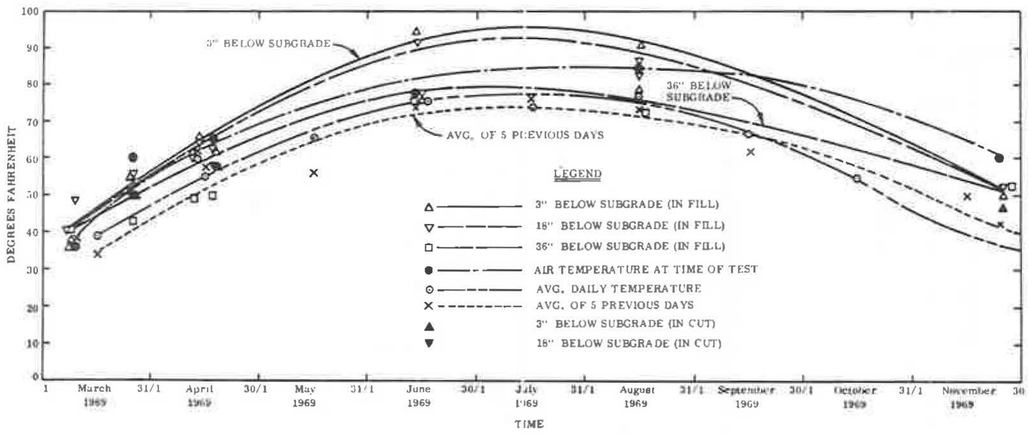


Figure 6. Air and subgrade temperatures at location 14.

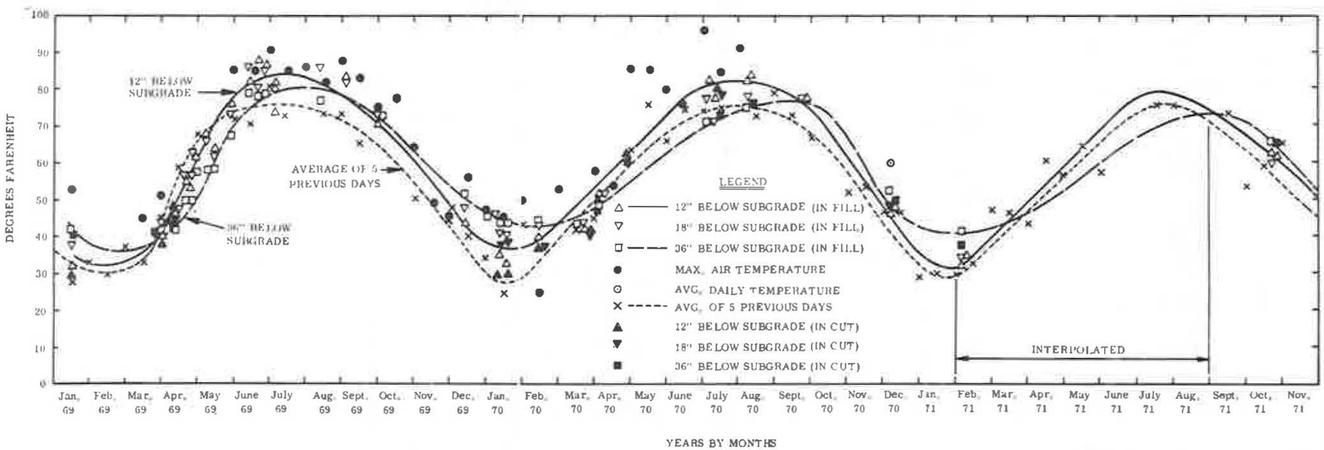
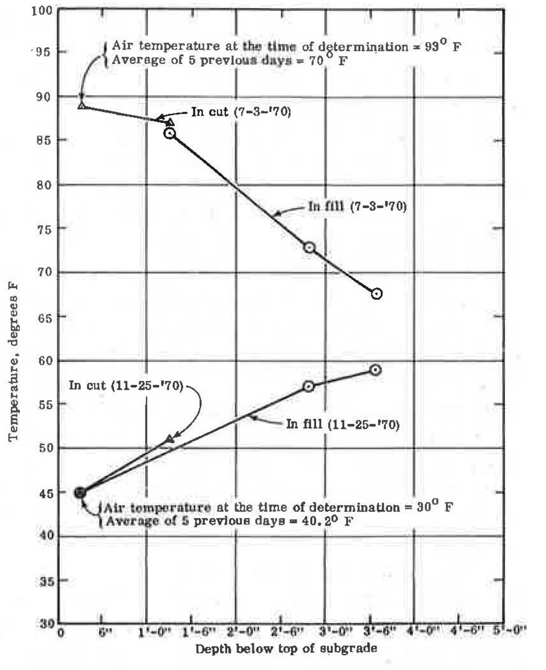


Figure 7. Typical summer and winter day temperatures at location 17.



EFFECTS OF PRECIPITATION AND TEMPERATURE GRADIENT ON UNDERGROUND MOISTURE CONTENT WITHOUT COVER MATERIAL

The moisture contents for nine sites without cover are shown in Figures 2, 3, and 4. There was a high precipitation in July and November 1970 and May 1971 (Fig. 1). Sites 2 through 8 show that the underground moisture content increased in July and then, in most cases, continued to be high through January 1971, after which it decreased. This trend occurred in spite of the low precipitation in September and December and, in two cases, during October and August.

Because no snow was on the ground until the end of November and a trace of snow appeared in December, the only possible reason for the high subsoil moisture contents, even during the low precipitation periods, would be the decrease in air temperature from August 1970 through January 1971. This resulted in thermal gradients with lower temperatures near the top of the ground and high temperatures farther down. The reduction of the temperature near the top of the ground from August through the end of January is evident from the data in Figures 5 and 6.

Evidently, the factors contributing to high moisture contents for uncovered ground are precipitation and low temperatures during autumn and winter. November through March may, therefore, be a period of high moisture contents for uncovered ground.

EFFECTS OF PRECIPITATION, TEMPERATURE GRADIENT, AND TOPOGRAPHY ON SUBGRADE MOISTURE CONTENTS

Data from five locations are discussed to illustrate the effects of precipitation, temperature gradient, and topography on subgrade moisture contents.

Project Location 14

The subgrade on the project at location 14 was completed in April 1969, and the pavement in December 1969. The precipitation and temperatures for this project are shown in Figures 1 and 6.

The project is located in fill and cut areas. The fill is over a deep creek; hence, the subgrade moisture has a tendency to drain away unless held by other forces. The cut has a rocky foundation except for a leveling fill for the subgrade. The ground in the cut slopes away from the road area and provides subsoil drainage away from the pavement. The subgrade soil contains 41 percent clay and 27 percent silt (Table 1).

Figure 8 shows the subgrade moisture at three levels for four sites under the shoulder or pavement in a cut or a fill. The moisture data were taken from April 1969 until 1 year after completion of the pavement. In the fill area during the construction, i.e., the time of completion of the subgrade, the pavement, and the shoulder, the range of the moisture contents rose by about 20 percent, from 7 to 10 percent in April at the time of subgrade completion to 25 to 30 percent in December at the time of pavement completion. After construction, the rate of increase in the moisture content was so low that it was almost unnoticeable.

Figure 8 also shows that, in the cut area during construction, the moisture content rose by about 3 to 5 percent, from 7 to 10 percent in April at the time of subgrade completion to 8 to 15 percent in December at the time of pavement completion. After construction, the rate of increase, as in the fill area, was so low that it was almost unnoticeable.

The high rate of increase in the moisture content during construction may have been the direct effect of precipitation that entered the subgrade treatment, subbase, base, and shoulder much more easily during construction (when the subgrade was more exposed and porous) than after construction.

The higher increase in the moisture content in the fill area may have been caused by the lower density and higher moisture holding power of the soil in the fill area than in the rocky ground in the cut area. Also subgrade soil is better compacted on rocky foundations and, therefore, is more dense than the same soil compacted on weaker foundations.

Temperature gradients in autumn and winter tend to raise the subgrade moisture toward the top from the lower levels. In the case of rocky foundations like the one in the cut, there is little moisture in the foundation, and, therefore, the rise of moisture is proportionately less.

Figures 8a, b, and d show that in the cut as well as in the fill during construction the moisture content at 0 to 2 ft (0.3 to 0.6 m) was higher than at 2 to 3 ft (0.6 to 0.9 m) by about 5 percent. This trend reversed itself in all three cases immediately after construction was over. The reason for this change may have been (a) the reduced effect of increasing moisture from the top because of precipitation immediately after the construction, (b) the temperature gradient of autumn and winter reversed itself, which made the moisture move from the upper to the lower layers of the subgrades, and (c) both the cut and fill areas are in a topography that draws the water away from the roadway rather than toward it.

The following conclusions can be made from the previous discussions:

1. The subgrade soil accumulated and held the moisture during the time of construction mostly because of precipitation and low density of the subgrade material; this also depended on the amount of compaction and soil gradation. The moisture accumulation was as high as about 20 percent in the fill.

2. The temperature gradient did affect the amount of subgrade moisture. The variation in moisture content due to the temperature gradient (although this depended on total moisture content) could not have been greater than 5 percent.

3. The moisture content in the upper layer of the subgrade could be less than that in the lower part of the subgrade if the topography were such that it drained the moisture away from the roadway.

Figure 8. Seasonal variation in subgrade moisture at location 14: (a) under pavement in fill, (b) under shoulder in fill, (c) under pavement in cut, and (d) under shoulder in cut.

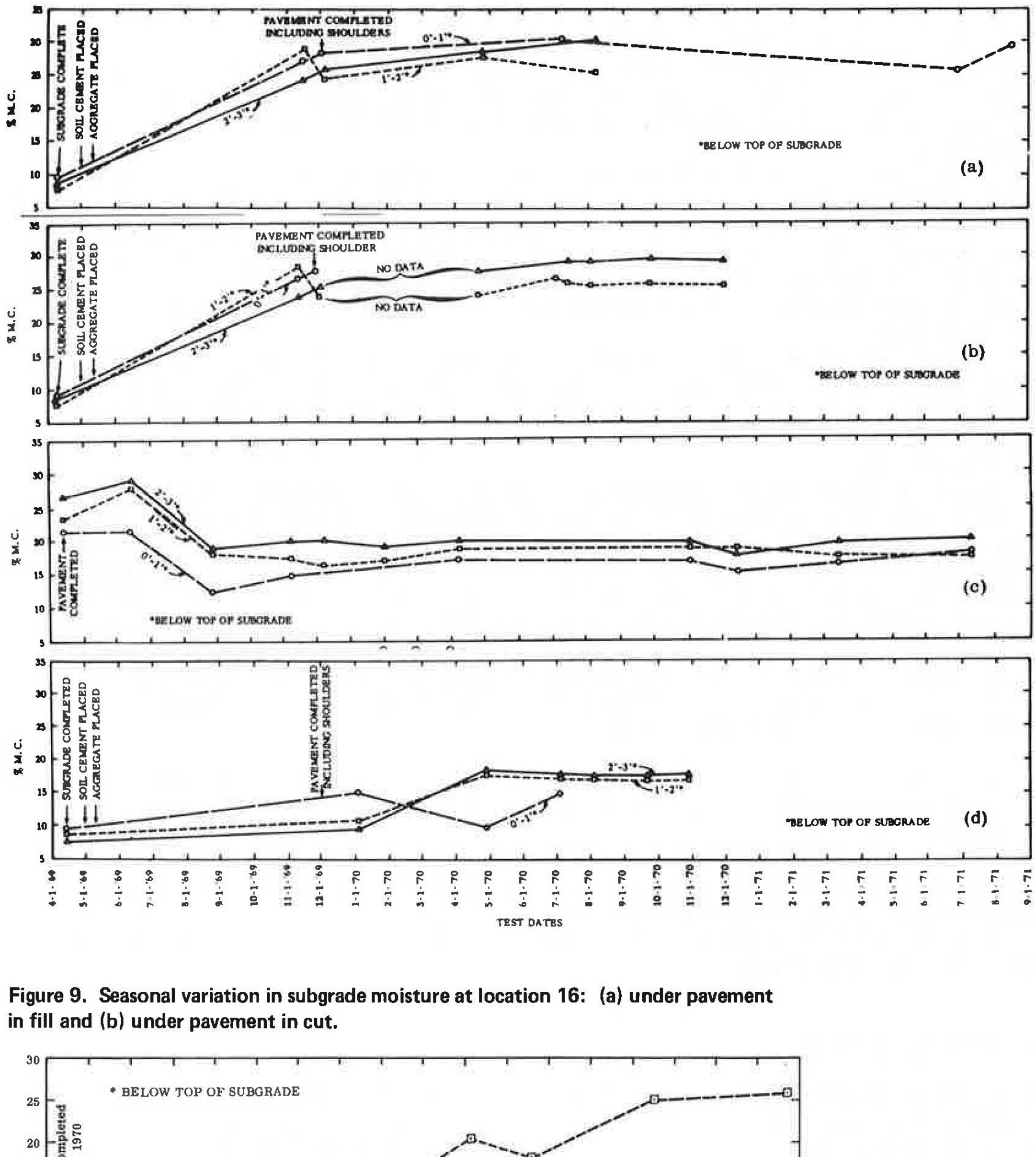
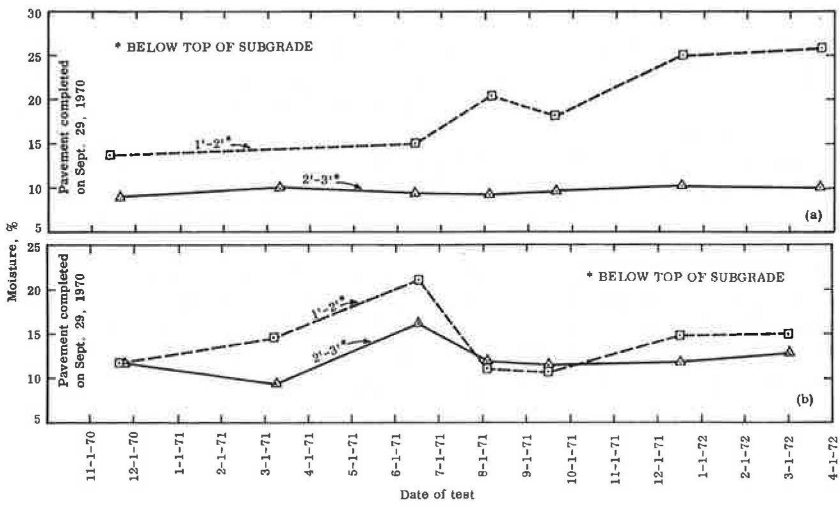


Figure 9. Seasonal variation in subgrade moisture at location 16: (a) under pavement in fill and (b) under pavement in cut.



Project Location 16

Pavement on the project at location 16 was completed in September 1970. The project is located between Culpeper and Charlottesville. The precipitation records for it are shown in Figure 1. Because the pavement structure is almost the same as that at location 14, for this evaluation, the air and subgrade temperatures were also considered the same.

The project is located in fill and cut areas. The fills and cuts are not so deep as those at location 14. Similarly, the cut has a rocky foundation except for a leveling fill for the subgrade. The adjacent ground in the cut has a tendency to drain toward the cut, as is evident from the occasional collection of water in the side drains. The fill is over a small creek, and the moisture in the fill subgrade has a tendency to drain away from the pavement. The subgrade soil contains 16 percent clay and 25 percent silt (Table 1).

Figure 9 shows the subgrade moisture under the pavement in the fill and under the pavement in the cut. The subgrade moisture data were taken from November 1970 to April 1972, i.e., for a continuous period of about 18 months. The subgrade moisture content after completion of the project was 10 to 15 percent in the fill and about 12 percent in the cut.

Figure 9 shows that the subgrade moisture in the fill continued to increase from 10 to 15 percent in November 1970, i.e., immediately after completion of the pavement, to 26 percent in the 17-month period after construction. The subgrade seemed to absorb water and hold it in the same way as at location 14. This capacity to absorb precipitation stopped on the project at location 14 when the moisture content reached between 25 and 30 percent. Because the moisture at location 14 also reached 26 percent, it is possible that the rate of increase in the moisture content would now decrease.

Subgrade moisture in the cut increased to about 15 to 20 percent as compared to 8 to 15 percent at location 14 and then decreased in the summer of 1971 (Fig. 9). Therefore, the following observations can be made:

1. In new construction, the subgrade moisture rapidly increased because of precipitation until it reached a certain level. This depends on the density, compaction, and gradation of the soil.
2. After this semisaturated level due to precipitation is reached, the rate of increase in moisture content slows down, and the variations in moisture levels due to temperature gradients become noticeable.
3. After about 10 years, there is almost no change in subgrade moisture and no effect of temperature gradient.

Project Location 13

Location 13 is in the coastal zone and in cut and fill areas with curbs and gutters. The general topography slopes away from the pavement. The subgrade soil in the cut area is sandy with no clay or silt. In the fill area, the subgrade contains 23 percent silt and 29 percent clay. The fill is over a creek.

The pavement was completed in June 1970 and consists of 10.5 in. (27 cm) of full-depth asphalt concrete. After completion of the road, measurements of subgrade moisture were started in October 1970. Data for the subgrade moisture below the pavement in the cut and fill areas are shown in Figure 10.

In the fill area, the subgrade moisture during the 12-month period remained almost constant and ranged from 20 to 25 percent. There were lower percentages of moisture near the pavement than farther from it. This is the same pattern, in which water drained away from the pavement, as was observed for location 14. In this case, curb and gutters also prevented drainage toward the pavement subgrade.

Figure 10. Seasonal variation in subgrade moisture at location 13: (a) under pavement in fill and (b) under pavement in cut.

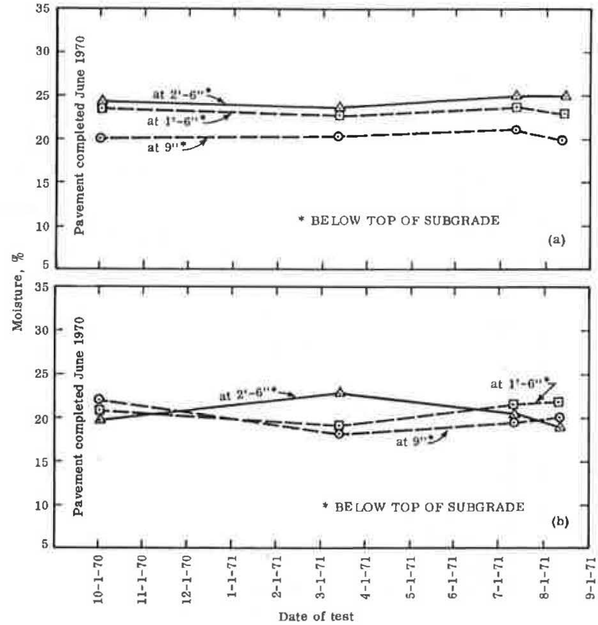


Figure 11. Seasonal variation in subgrade moisture at location 15: (a) under pavement in fill, (b) under shoulder in fill, and (c) under pavement in cut.

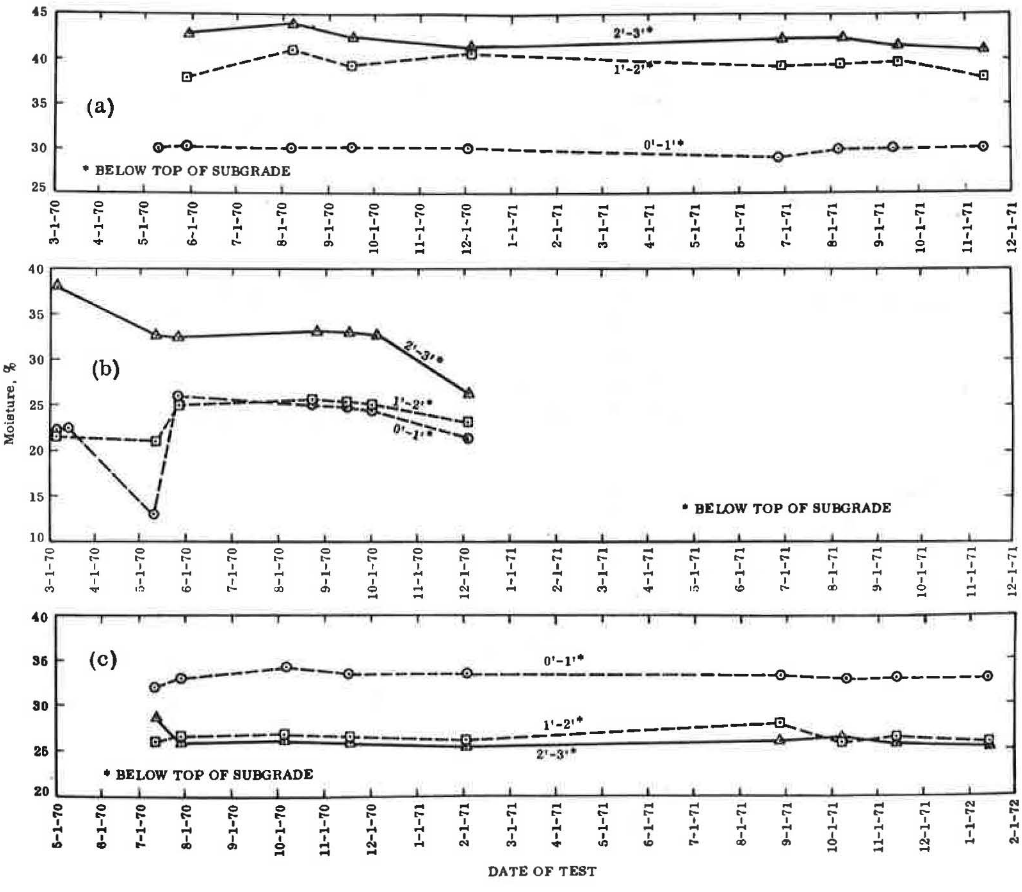


Figure 12. Subgrade moisture variation with time.

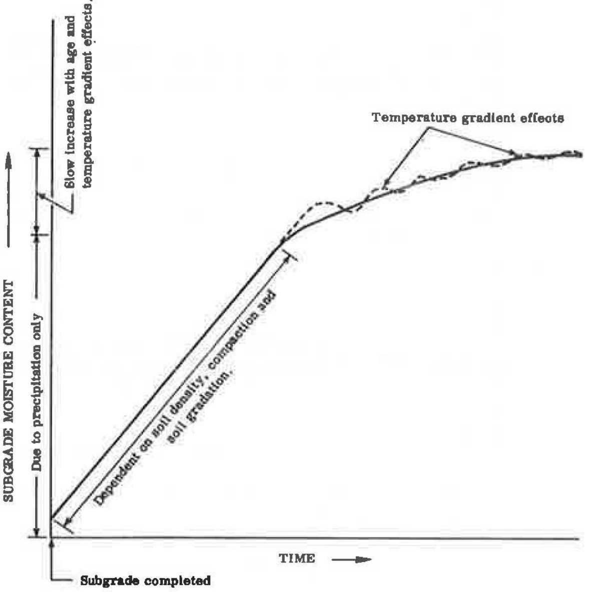
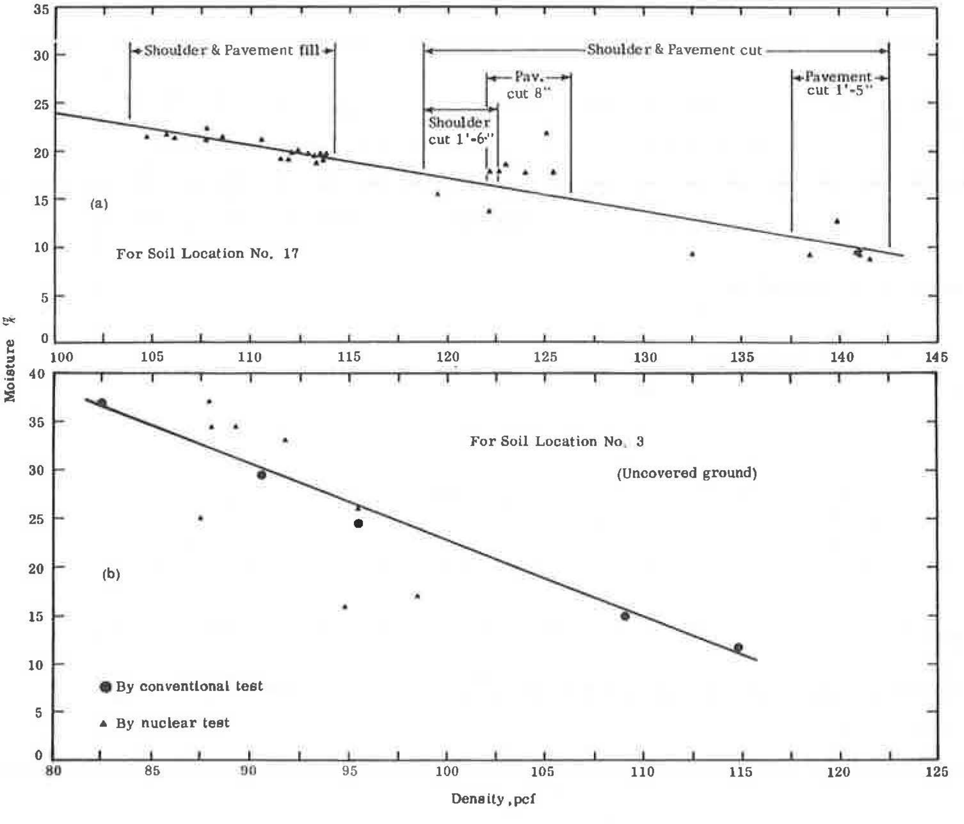


Figure 13. Soil density versus moisture content: (a) for cut and fill at location 17 and (b) by conventional and nuclear tests in laboratory.



Project Location 15

The project at location 15 is about 12 years old and is located in fill and cut areas. The fill is over a deep depression and, therefore, the subgrade moisture tends to drain away from the subgrade unless it is held by other forces. The cut is over a rocky foundation except for a leveling fill for the subgrade. The side drains of the cut usually collect a lot of water, which indicates that the groundwater is draining toward the cut.

Figure 11 shows the moisture content below the subgrade at three levels: under the pavement and shoulder in the fill area and under the pavement only in a cut area. It shows that the moisture content under the pavement, in the cut, and in the fill remained almost constant. In the cut area, the moisture varied from 25 to 34 percent as compared to 30 to 44 percent in the fill area. This tendency toward lower moisture contents in the cut was observed in projects at locations 14, 16, and 13, although the ground drains toward the cut. The only possible reason for this tendency is the higher density of the subgrade soils on the rocky foundation in the cut.

As stated previously, the subgrade soil moisture content in this cut and fill is much higher than those of the other projects dissussed. This probably proves that after the soil rapidly increases in moisture because of precipitation, the rate of increase in moisture decreases but continues slowly during the life of the pavement and changes with the temperature gradient until it reaches a level at which the temperature gradient loses much of its effect; i.e., the subgrade moisture content follows the pattern shown in Figure 12.

Figure 11 shows that in the fill area, where the drainage slopes away from the pavement, the moisture content near the bottom of the pavement is lower than in the layers underlying it, and, if the drainage slopes toward the pavement, the moisture content is highest near the bottom of the pavement and decreases in the lower layers of the subgrade.

In the fill area under the shoulder (and in uncovered ground), the moisture content seems to have been affected by the climatic conditions (Fig. 11). The shoulder cover in this area consists of gravel less than 4 in. (10 cm) thick. In the three previous cases, the gravel thickness varied from 6 to 9 in. (15 to 23 cm). Because the moisture was draining away, the moisture content was lower in the top layer than in the bottom layer.

Project Location 17

In the four projects discussed, the moisture content of the subgrade soil in the fill was much less than that of the soil in the cut. This was in spite of the few cases in which the ground drainage was toward the cut area rather than away from the fill area. This clearly showed that, in the cut area, because of better compaction, more density, and probably the rocky foundation, the subgrade moisture was less than in the fill.

The moisture versus density relationship was drawn for the project at location 17 so that we could confirm that moisture content was more related to the density of soil than to the rocky cut. This relationship is shown in Figure 13a, which shows that the density of the subgrade soil in the fill varied from about 104 to about 115 pcf (1666 to 1842 kg/m^3), but in the cut it varied from about 118 to 142 pcf (1890 to 2275 kg/m^3). For the same depth, the density in the cut shoulder was less than that in the cut pavement. The same trend was noted for soils with no cover as shown in Figure 13b.

CONCLUSIONS

Based on this investigation, the following conclusions were made:

1. As expected, the higher the compaction and dry density of the subgrade soil were, the lower the subgrade moisture content was.
2. In new construction, the subgrade moisture rapidly increased because of precipitation until it reached a certain level depending upon the density, compaction, and gradation of the soil. After this semisaturated level due to precipitation was reached,

the rate of increase in moisture content slowed down, and the variations in moisture level due to temperature gradients became noticeable. After about 10 years, there was practically no change in subgrade moisture and temperature gradient had no effect.

3. When the drainage was away from the pavement, the moisture content in the top layer of the subgrade was usually lower than that in the lower layers, and, if the drainage was toward the pavement, the moisture content in the top layer was usually higher than that in the underlying layers.

4. The subsoil moisture content in uncovered ground and subgrades of pavement shoulders was greatly affected by climatic conditions such as rain, snow, and temperature. The variation was maximum in uncovered ground, less in shoulders covered by a 4-in. (10-cm) layer of aggregate, and much less in shoulders having 6- to 9-in. (15- to 23-cm) layers of aggregate. The subgrades under the shoulders covered with 6- to 9-in. (15- to 23-cm) layers of aggregate were frozen. This was probably due to (a) the collection of snow over them or (b) the higher thermal conductivity of the porous, untreated aggregate as compared to that of asphalt concrete.