PAVEMENT DESIGN & PERFORMANCE STUDY
PHASE B: DEFLECTION STUDY

Interim Report No. 6

Subgrade Moisture & Temperature Variations Under Road Pavements in Virginia

by

N. K. Vaswani
Principal Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

In this investigation the changes in the subgrade moisture content under five road pavements ranging in age from new to about ten years old were determined and evaluated. The moisture content was determined by means of a nuclear moisture depth probe.

This investigation has shown that: (1) the higher compaction and dry density of the subgrade soil, the lower is the moisture content; (2) the subgrade moisture content increases sharply from the beginning to the end of construction and then the rate of increase shows; (3) there is a sharp increase in moisture content — due to precipitation — within a year or two from the date of the construction of the subgrade, after which the rate of increase in moisture decreases; and (4) after about ten years there is very little increase, in the subgrade moisture content.

SUBGRADE MOISTURE AND TEMPERATURE VARIATION UNDER ROAD PAVEMENTS IN VIRGINIA

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PURPOSE AND SCOPE

The strength of a pavement 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.

In this investigation it was proposed to study the variation in moisture in five projects varying in age from new to about ten years old and spread over Virginia. In the new projects, the moisture content was to be measured during the construction period.

METHODS ADOPTED FOR 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.

For measuring subgrade moisture content two methods were tried, one by electric resistance and the other by nuclear depth probe, and the nuclear method was finally adopted. The correlation techniques used in the preparation of calibration charts for nuclear moisture depth probes and the recommended method for the final determination of moisture content are described in Interim Report No. 5.*

The subgrade temperatures were measured by means of thermisters.

The precipitation, temperature, and moisture content data so collected are described in the following paragraphs.

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* N. K. Vaswani, "Nuclear Measurement of Subgrade Moisture — Interim Report No. 5," November 1973. VHRC 73-R17.

Measurement of Precipitation

From 1970 and 1971 records, rainfall data for the 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 are applicable to site 1; and those for Fredericksburg are applicable to site 8.

Data on snow for 1970 showed no ground cover up to the end of November. In December 1970, the maximum depth of snow on the ground was a trace in Charlottesville and Fredericksburg and none at Culpeper. In January 1971, the maximum depth of snow on the ground was six inches in Fredericksburg, and ten inches in Charlottesville and Culpeper. In February 1971, the maximum depth of snow on the ground was one inch at Fredericksburg and Charlottesville, with no record available for Culpeper. In March 1971, the maximum depth of snow on the ground was seven inches at Fredericksburg, nine inches at Charlottesville, with no record available for Culpeper. The climatological data show that in these places snow was on the ground for about five days in December 1970, 31 days in January 1971, four days in February 1971, and five days in March 1971.

Underground and Subgrade Moisture and Temperature Measurements

The moisture content below uncovered ground and under roadway shoulders and pavements was determined with the nuclear depth probe. These measurements were usually made at 1, 2, and 3 ft. below the uncovered ground or below the bottom of the shoulder or the pavement. The moisture content determinations below uncovered ground were taken for locations 1 through 9 in Table 1. Graphs of the moisture contents from May 1, 1970, to May 1, 1971, for the nine sites are given in Figures 2, 3 and 4.

Moisture contents below the pavement or shoulder were recorded for five of the locations, 13 through 17, shown in Table I. On each of these five locations, two sites were chosen; One in a cut, and the other in a fill. The measurements on these locations were made over a period of 18 to 24 months. Graphs of the subgrade moisture contents for these four sites are given later in this report.

Temperatures and temperature gradients under the pavement or shoulders in the subgrade or below uncovered ground were determined by means of thermisters embedded at 0, 1, 2, and 3 ft. intervals. Sometimes the subground or subgrade temperatures were measured by lowering the thermisters in the access tube for the nuclear probe. In measuring the temperature in the access tube at various depths, the thermisters were kept at the specified depths for 48 hours. The air in the access tube was sealed by a rubber stopper with the lead wires from the thermisters coming out from the stopper. It was found that the temperatures recorded by the thermisters embedded in soil were almost identical with the temperatures recorded by the thermisters installed in the aluminum tube.

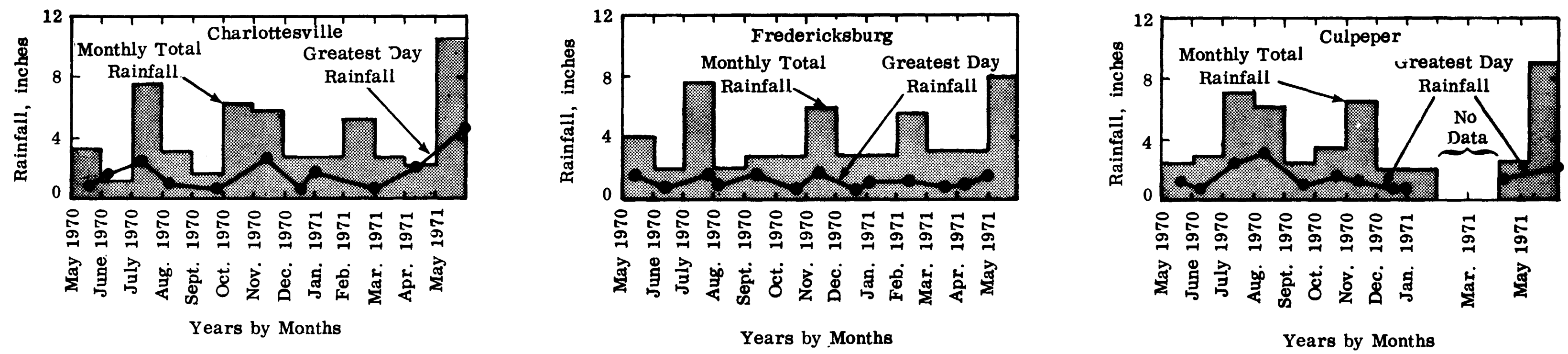
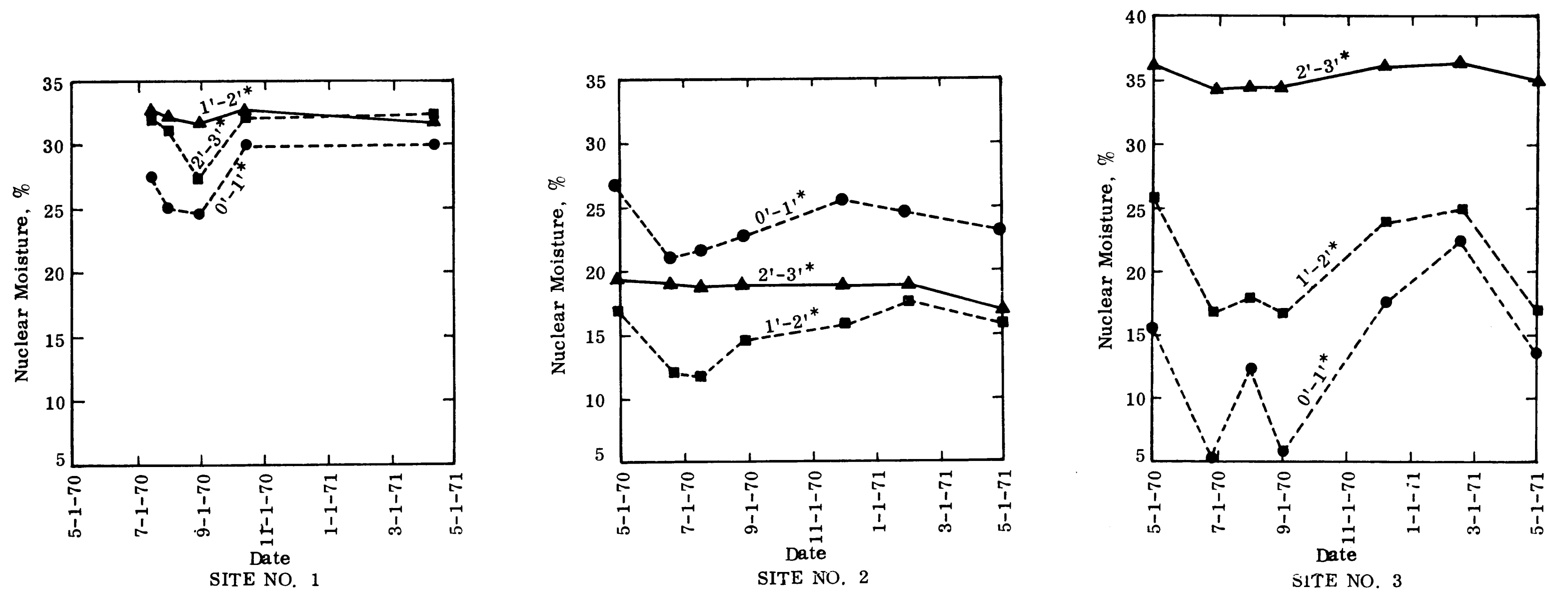


Figure 1. Precipitation data for Charlottesville, Fredericksburg and Culpeper.

TABLE I

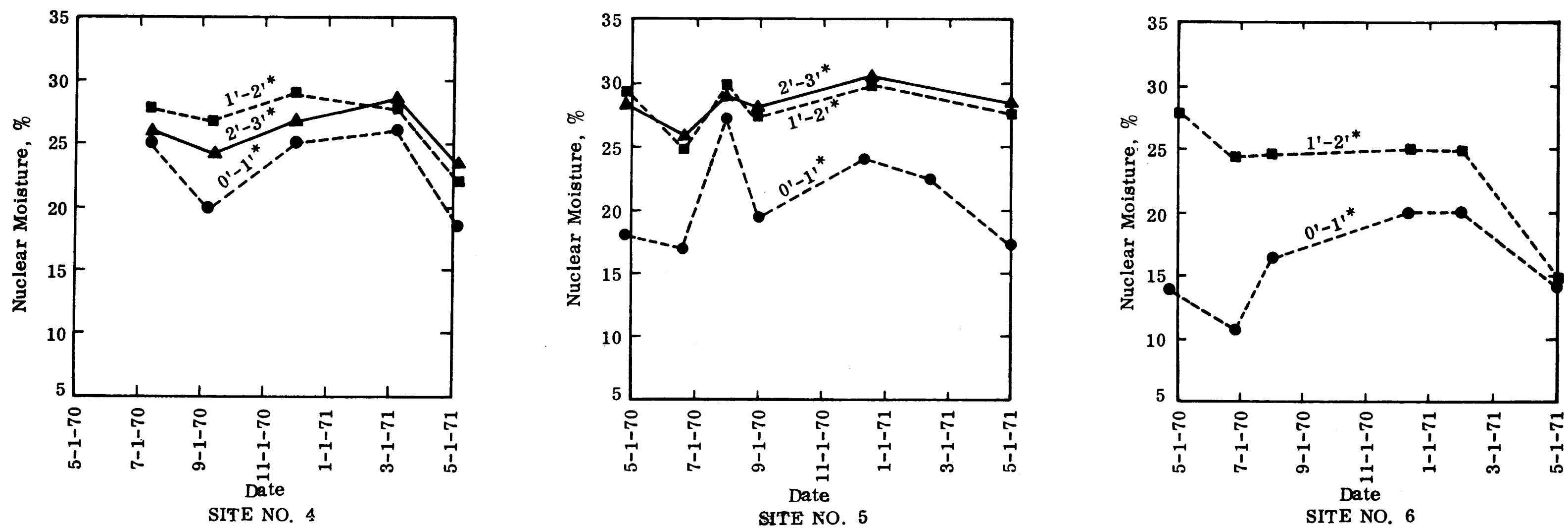
PHYSICAL AND CHEMICAL ANALYSES AND ATTERBURG LIMITS OF SOIL

Soil or Location Number	Location	Physical Condition	Physical Analysis: Sieve Analysis - Passing 10	20	40	60	80	100	200	Silt	Clay	Atterburg Lts. L.L.	P.L.	Chemical Analysis: SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	TiO_2	MgO	Na_2O	Loss 1000°C
1	Culpeper	Uncovered Gr.	100	98.2	96.7	95.3	94.3	93.6	90.9	40	45	53	38	38.7	--	19.7	0.2	--	--	--	--	10.5
2	Batesville	" "	100	91.7	85.4	--	73.1	67.9	54.8	25	31	0	0	--	--	--	--	--	--	--	--	--
3	Zion Cross Rds.	" "	100	97.1	93.1	87.7	85.7	83.7	76.9	31	41	41	28	64.7	15.9	7.7	1.0	0.1	1.5	0.2	1.3	6.5
4	Skibo Lodge, Ch'ville	" "	100	96.8	95.2	90.0	86.5	82.9	73.0	34	37	54	36	--	--	--	--	--	--	--	--	--
5	Airport - Albemarle	" "	100	96.0	87.6	77.2	71.0	66.3	52.0	29	24	41	35	--	--	--	--	--	--	--	--	--
6	Rt. 631	" "	100	95.8	85.1	77.5	70.3	70.0	61.8	29	33	46	30	59.7	19.6	8.0	2.3	0.1	16.5	0.4	0.4	6.8
7	Engr. Building	" "	100	98.2	96.2	92.4	89.2	86.6	78.8	20	57	58	36	--	--	--	--	--	--	--	--	--
8	Fredericksburg	" "	100	85.2	62.3	61.5	23.2	21.4	00.0	0	0	-	-	79.6	--	2.6	0.5	--	--	--	--	4.2
9	Gordonsville	" "	100	96.0	93.0	89.4	86.6	84.5	77.4	26	41	52	32	58.1	--	11.1	1.4	--	--	--	--	7.7
10	Rt. 708	" "	100	94.8	85.9	--	66.5	60.5	48.2	-	-	-	-	59.7	22.2	6.6	0.8	1.0	1.5	0.3	1.2	7.3
11	Brightwood	" "	--	--	--	--	--	--	--	-	-	-	-	61.3	21.2	12.1	5.2	0.4	0.9	0.2	0.8	5.5
12	Red Hill	" "	--	--	--	--	--	--	--	-	-	-	-	56.7	18.3	10.2	1.5	0.7	2.8	2.9	0.8	6.3
13	31, Williamsburg (Fill)	Pavement	100	97.2	90.9	79.6	71.5	69.9	54.7	23	29	-	-	--	--	--	--	--	--	--	--	--
	(Cut)	"	100	89.0	57.1	57.1	5.6	5.6	0.0	-	-	-	-	--	--	--	--	--	--	--	--	--
14	29 Ch'ville Bypass	Pvt. & Shoulder	100	93.9	88.2	83.4	80.1	78.0	69.8	27	41	53	34	--	--	--	--	--	--	--	--	--
15	Sprouses Corner 15	" "	--	--	--	--	--	--	--	-	-	-	-	--	--	--	--	--	--	--	--	--
16	Madison Bypass (Fill)	" "	100	91.2	83.8	72.8	70.3	66.4	54.1	25	16	31	26	--	--	--	--	--	--	--	--	--
	(Cut)	" "	100	87.0	79.6	73.6	68.2	63.6	42.9	23	13	29	23	--	--	--	--	--	--	--	--	--
17	Massey Corner, (Fill)	" "	100	85.8	73.9	--	60.9	58.2	50.7	-	-	-	-	--	--	--	--	--	--	--	--	--
	Rt. 0211 (Cut)	" "	100	90.0	80.0	--	66.5	63.3	54.3	-	-	-	-	--	--	--	--	--	--	--	--	--
18	Rt. 29, Monroe (Fill)	" "	100	97.3	93.1	85.5	79.5	75.5	63.7	25	37	47	28	--	--	--	--	--	--	--	--	--
	(Cut)	" "	100	94.4	89.5	83.4	77.8	73.6	54.4	36	9	38	33	--	--	--	--	--	--	--	--	--



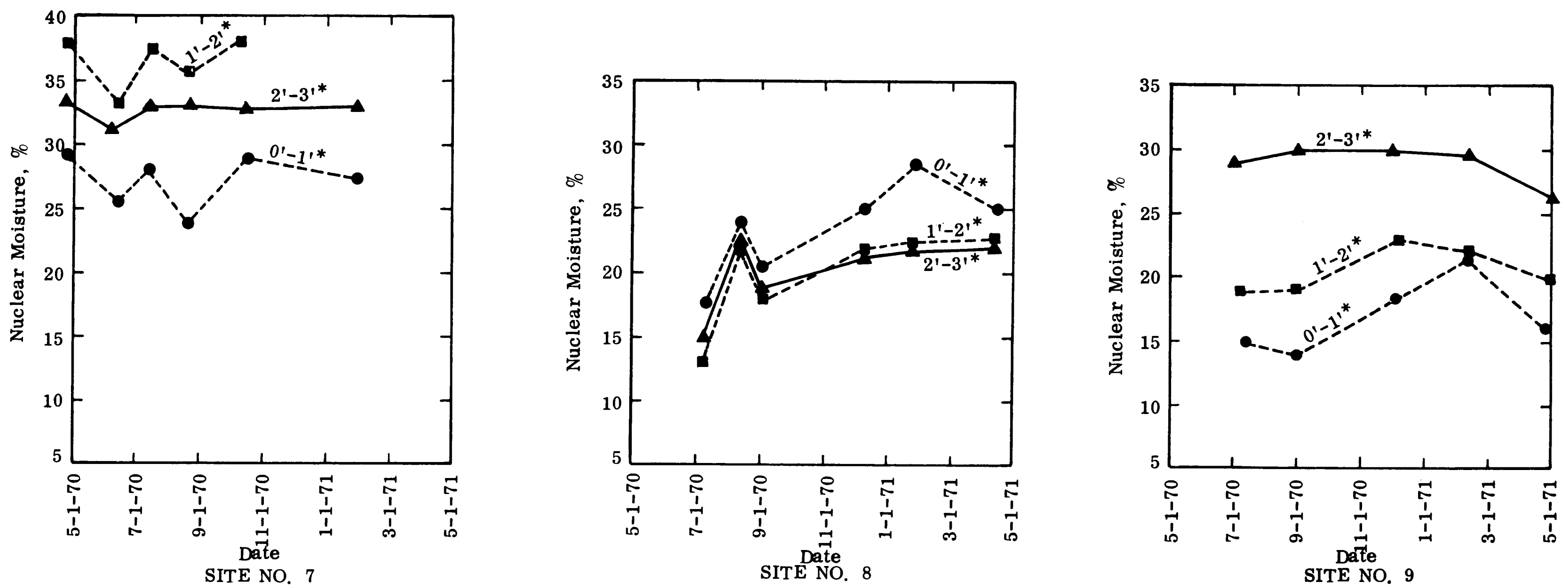
* Denotes depth below ground level.

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



*Denotes depth below ground level.

Figure 3. Moisture content below ground level at sites 4, 5 and 6.



*Denotes depth below ground level.

Figure 4. Moisture content below ground level for sites 7, 8 and 9.

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Subgrade temperatures were continuously recorded for two satellite pavements and occasionally recorded for other projects. On each of these projects two sites were chosen, one under the pavement in a cut and the other under the pavement in a fill. In addition, temperatures were recorded below the shoulder subgrades and also below the natural ground at various locations some miles distant from the satellite projects. Two graphs of temperature versus time, one for site 15 (from March 1969 to November 1969) and the other for site 14 (from January 1969 to November 1971), for both the fills and cuts, are shown in Figures 5 and 6 respectively.

Evaluation of Subgrade Temperature

The following conclusions were drawn from the evaluation of the subgrade temperatures.

1. The minimum subgrade temperature is higher than the average temperature of the five previous days, as shown in Figures 5 and 6. For a few days in January, the average of the five previous days' temperatures is slightly below the freezing point. During these few days, subgrade temperatures below the pavements and the shoulders of project no. 14 were taken. It was found that the subgrade temperature below the pavement was slightly above the freezing temperature while the subgrade immediately below the shoulder was frozen. The shoulder consisted of about a six-inch depth of stone aggregate which was porous and covered with snow at the time of this recording.

2. As is evident from Figures 5 and 6, the changes in the subgrade soil temperature follow changes in the air temperature. Thus, during spring and summer the temperatures in the upper part of the subgrade are higher than those in the lower parts. This trend changes during autumn and winter. Figure 7 shows the temperature gradient recorded during the summer and the winter. This figure also shows the air temperature at the time of testing, the average of five previous days' air temperatures, and the subgrade temperatures for two 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.

3. Figures 5 and 6 show that the subgrade temperatures in fills are lower than those in cuts. The variation is from $2^{o}F$ to $10^{o}F$, depending upon the air temperatures; the higher the air temperature, the higher the variation.

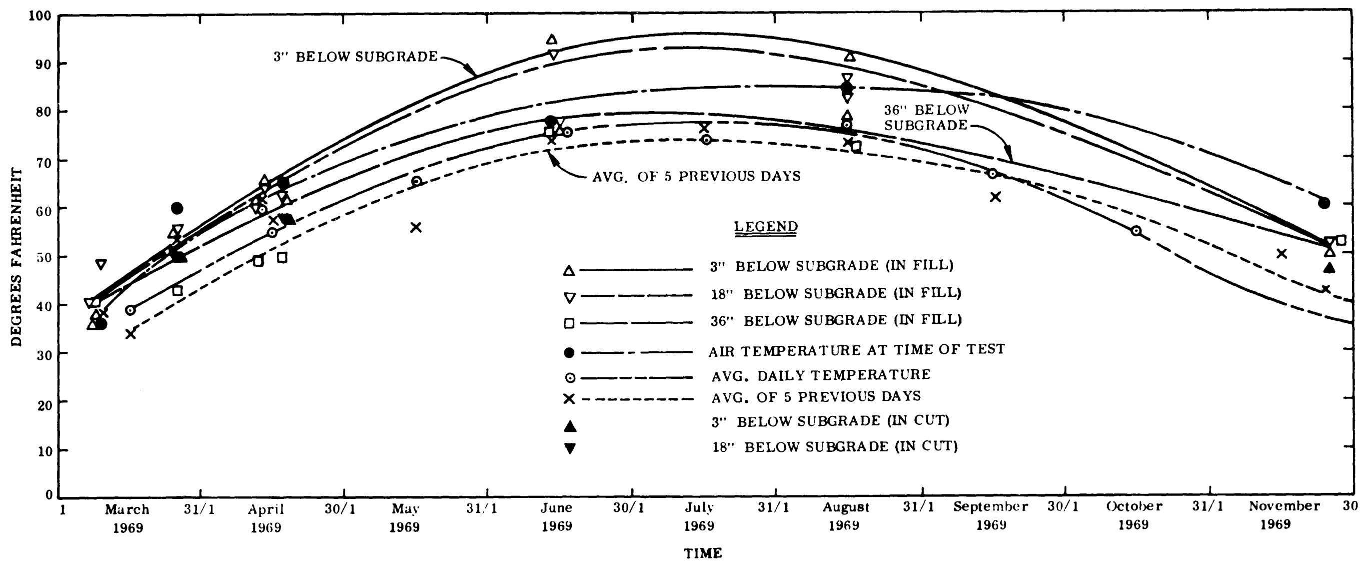


Figure 5. Air and subgrade temperatures at location 15. (March 1969 to November 1969)

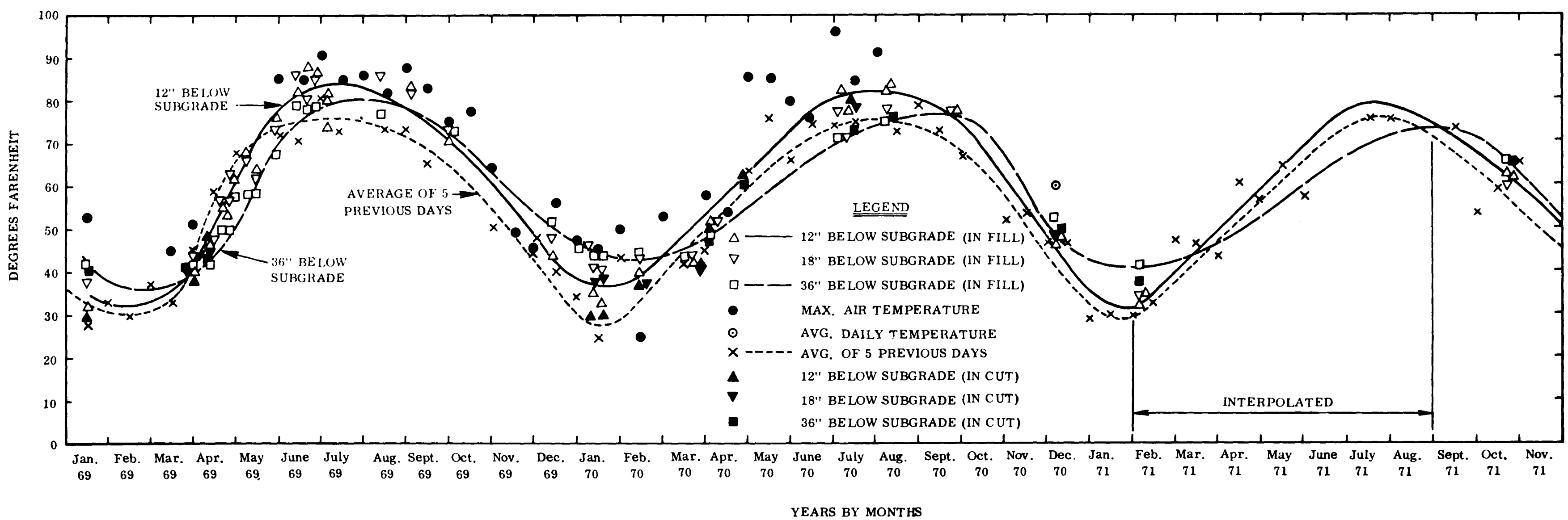


Figure 6. Air and subgrade temperatures at location 14. (January 1969 to November 1971)

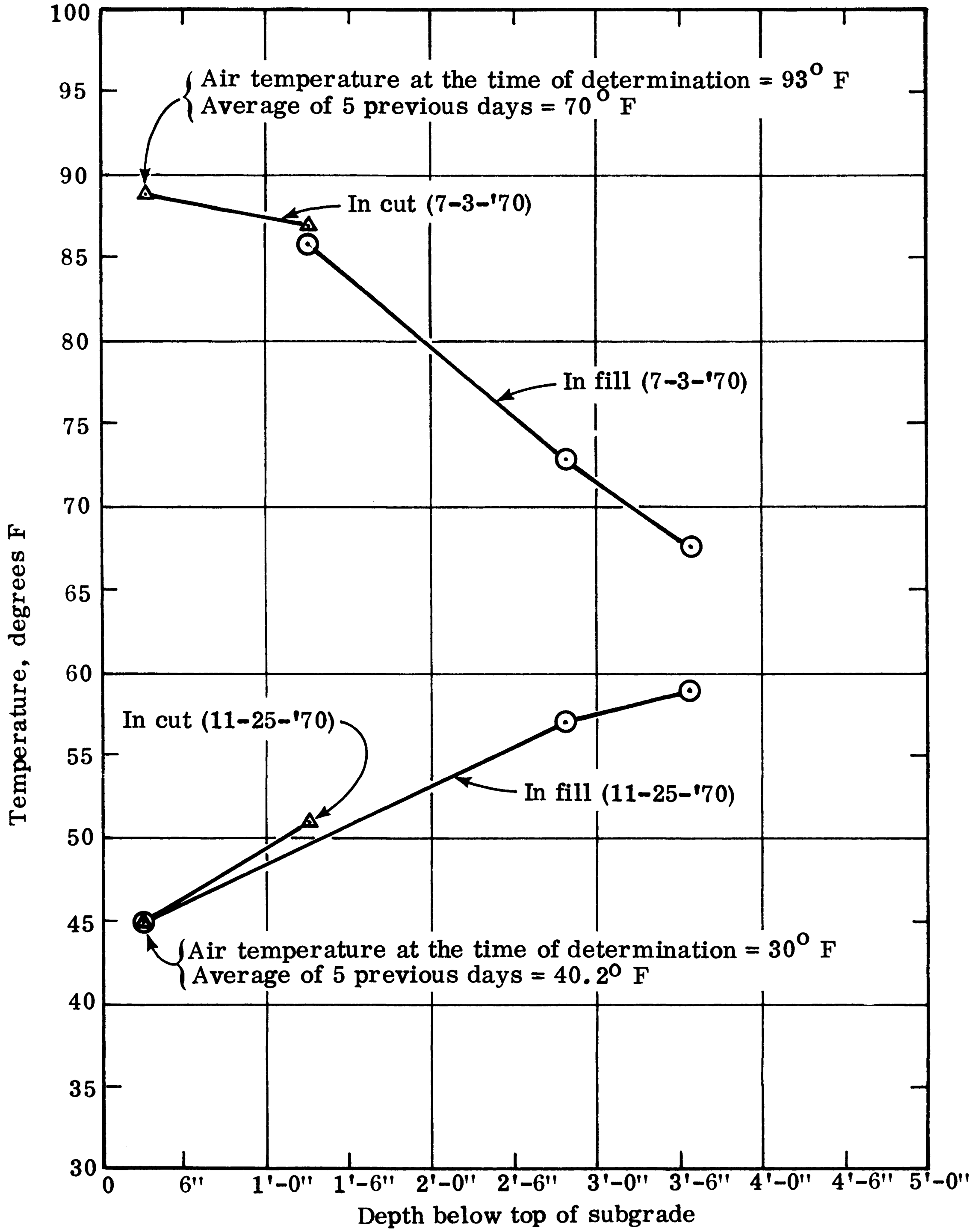


Figure 7. Typical summer and winter day temperatures at location 17.

EFFECT OF PRECIPITATION AND TEMPERATURE GRADIENT ON THE MOISTURE CONTENT BELOW GROUND WITHOUT PAVEMENT OR OTHER COVER MATERIAL

The moisture contents for nine sites without cover are shown in Figures 2, 3, and 4. Figure 1 shows the precipitation data for these sites as discussed previously. There is a high precipitation in July and November 1970 and May 1971. Sites 2 through 8 show that the underground moisture content increases in July and then, in most cases, continues to be high through January 1971, after which it tends to reduce. This trend occurred in spite of the low precipitation in September and December and, in two cases, during October and August.

As mentioned before, there was no snow on the ground till the end of November and a trace of snow during 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, which resulted in thermal gradients with lower temperatures near the top of the ground and high temperatures further down. The reduction of the temperature near the top of the ground from August through the end of January is evident from the data presented in Figures 5 and 6.

It is therefore evident that the factors contributing to high moisture contents for uncovered ground are the precipitation and the low temperatures during autumn and winter. November through March may therefore be considered as a period of high moisture contents for uncovered ground.

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

Data from five satellite projects are presented and analyzed below.

1. Project Location No. 14 — The subgrade on this project was completed in April 1969 and the pavement in December 1969. The precipitation and temperatures for this project are shown in Figure 1 and 6 respectively.

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, as shown in Table I, has 41% clay and 27% silt.

Figure 8 shows the subgrade moisture at three levels for four sites in the shoulder or pavement in a cut and a fill. The moisture data were taken from April 1969 till one year after completion of the pavement.

This figure shows that 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%, i. e., from 7% to 10% to 25% to 30%. After construction, the rate of increase in the moisture content was so low as to be almost unnoticeable.

Figure 8 shows that in the cut area during the construction the moisture content rose by about 3 to 5%, i. e., from 7% to 10% to 8% to 15%. After construction, the rate of increase--as in the fill area--was so low as to be almost unnoticeable.

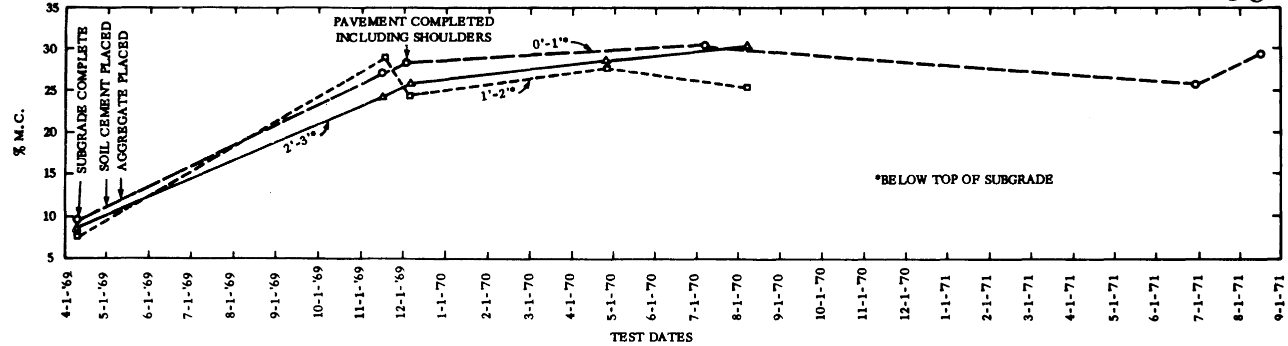
The high rate of increase of the moisture content during construction may be the direct effect of precipitation which entered the subgrade treatment, subbase, base, and shoulder much more easily during construction when it was more exposed and porous than after construction.

The higher increase in the moisture content in the fill area as compared to the cut area could be caused by a lower density and higher moisture holding power of the soil in the fill area than the rocky ground in the cut area. Also subgrade soil is better compacted on rocky foundations and hence is more dense as compared to the same soil compacted on weaker foundations.

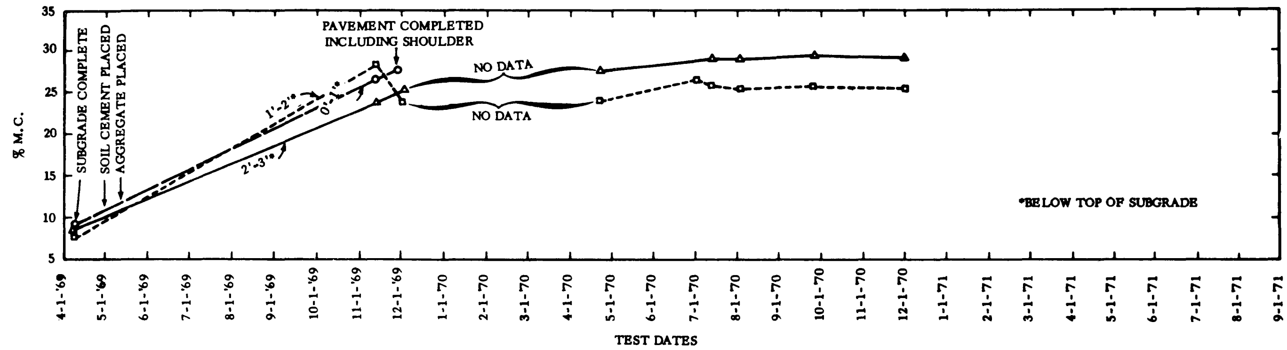
Also the temperature gradients in autumn and winter tend to raise the subgrade moisture towards the top from the lower levels. In the case of rocky foundations like the one in the cut, there is very little moisture in the foundation and hence the rise of moisture is proportionately less.

Figures 8 (a), (b) and (d) show that in the cut as well as in the fill, during construction the moisture content at 0 to 2 ft. was higher than at 2 ft. to 3 ft. by about 5%. This trend reversed itself--in all three cases--immediately after construction was over. The reason for this change could be threefold: 1) The reduced effect of increasing the moisture from the top due to precipitation immediately after the construction, 2) the temperature gradient of autumn and winter reversed itself, making the moisture move from the upper layer to the lower layers of the subgrades, and 3) both the cut and fill areas are in a topography which draws the water away from the roadway rather than towards it.

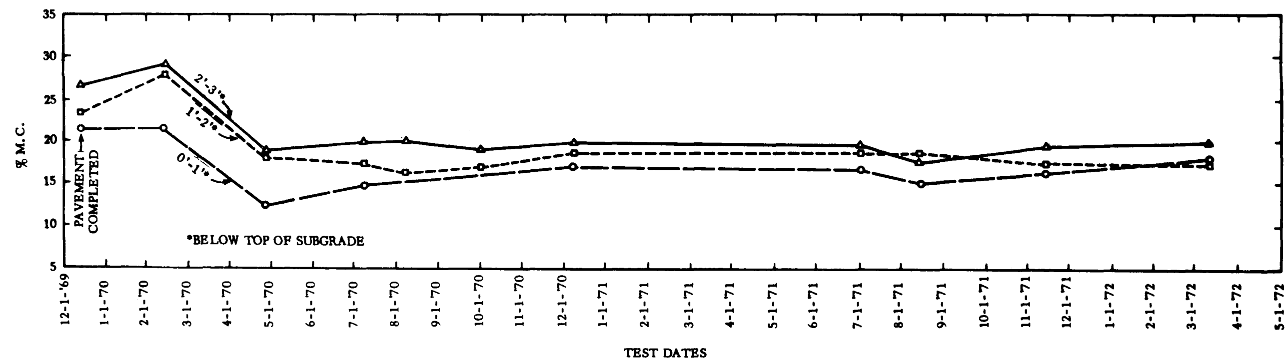
From the above discussion it could be concluded that: 1) The subgrade soil accumulated and held the moisture during the time of construction mostly due to precipitation and low density of the subgrade material, depending upon the amount of compaction and soil gradation. The moisture accumulation was as high as about 20 percent in the fill.



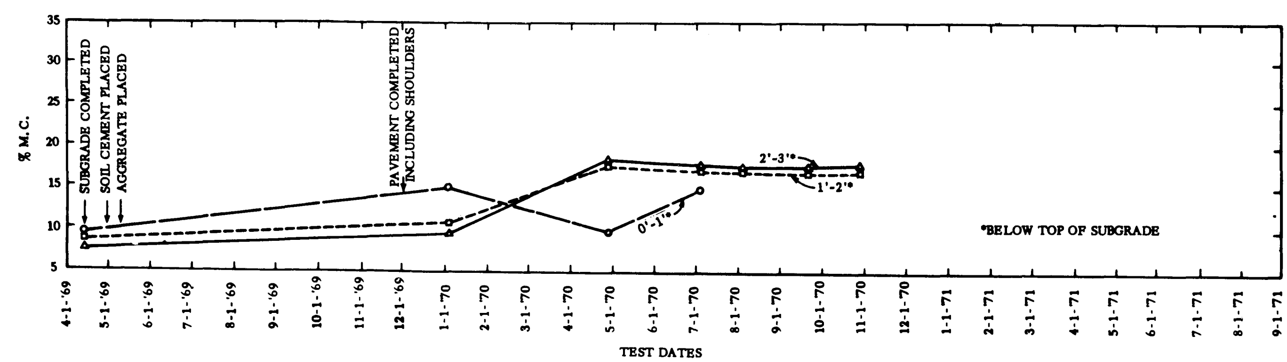
(a) Under pavement in fill area.



(b) Under shoulder in fill area.



(c) Under pavement in cut area.



(d) Under shoulder in cut area.

Figure 8. Seasonal variation in subgrade moisture at location 14.

2) The temperature gradient did affect the amount of subgrade moisture. The variation in moisture content due to the temperature gradient--though depending upon the total moisture content--could not have been greater than 5%.

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 is such that it tends to drain the moisture away from the roadway.

2. Project Location No. 16. — The pavement on this project was completed in September 1970. The project is located between Culpeper and Charlottesville. The precipitation records for it are shown in Figure I. The pavement structure is almost the same as that of the project on location 14 and hence for the purpose of this evaluation the air and subgrade temperatures could be considered the same as for the project on location 14.

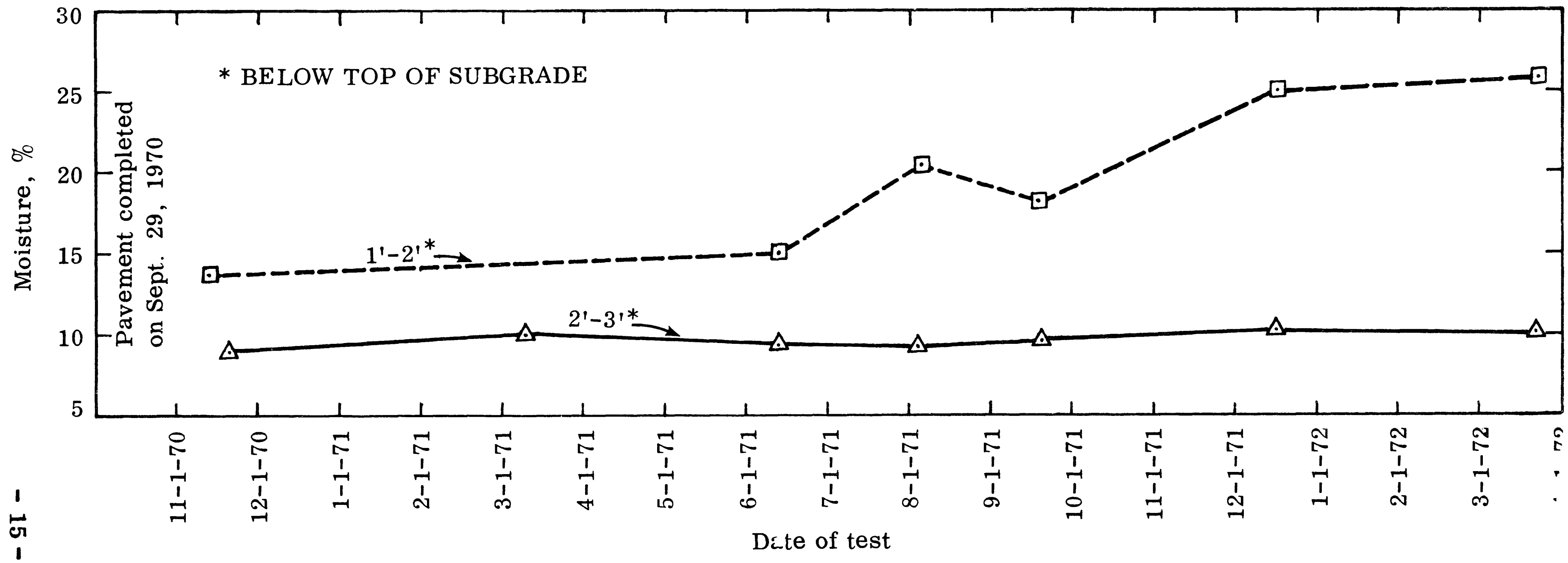
The project is located in fill and cut areas. The fills and cuts are not as deep as in the project at location no.14 described above. Like the project at location 14, the cut in this project has a rocky foundation except for a leveling fill for the subgrade. The adjacent ground in the cut has a tendency to drain towards 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, as shown in Table I, has 16% clay and 25% silt.

Figure 9 shows the subgrade moisture at two levels for two sites, one under the pavement in the fill and the other under the pavement in the cut. The subgrade moisture data were taken from November 1970 through April 1972, i. e., for a continuous period of about 18 months.

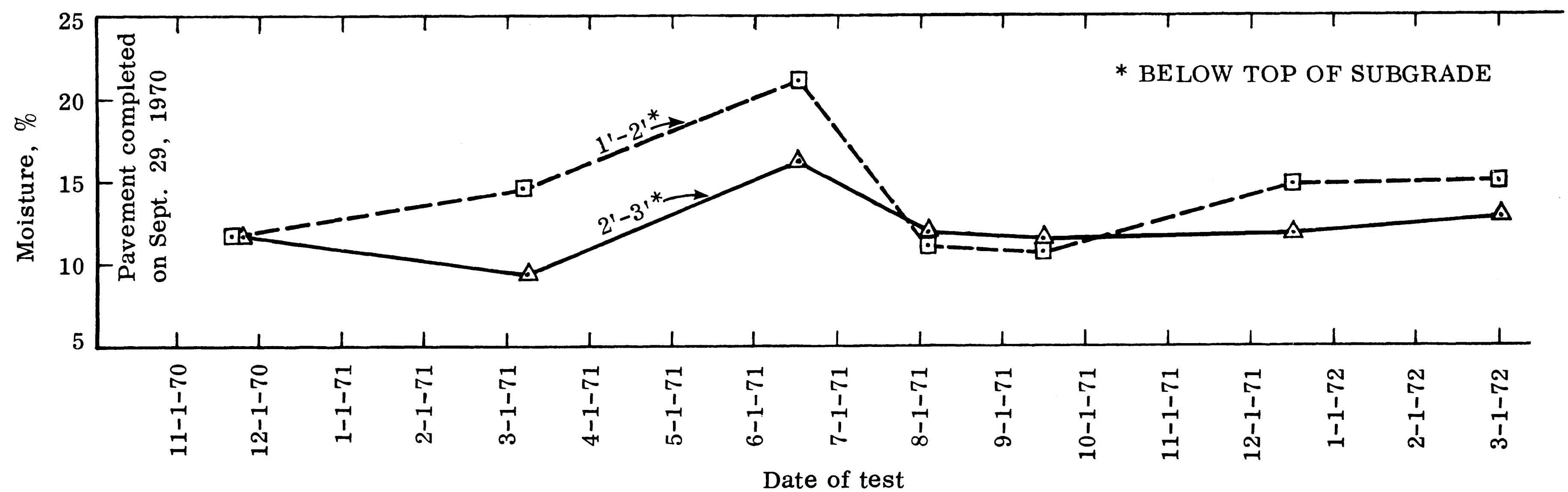
The subgrade moisture content after completion of the project was 10% to 15% in the fill and about 12% in the cut.

Figure 9 shows that the subgrade moisture in the fill continued to increase from 10% to 15% to 26% in the 17-month period after construction. It seems that the subgrade had a capability to absorb water and hold it in the same manner as was observed on the project at location 14. This capacity to absorb precipitation stopped on the project at location 14 when the moisture content reached between 25% and 30%. Since the moisture in project 14 also reached 26%, it is possible that the rate of increase in the moisture content would now reduce.

Figure 9 shows that the subgrade moisture in the cut increased to about 15% to 20% as compared to 8% to 15% on location 14, and then reduced in the summer of 1971.



(a) Under pavement in fill area.



(b) Under pavement in cut area.

Figure 9. Seasonal variation in subgrade moisture at location 16.

From the above it could be concluded that:
1) In new construction, the subgrade moisture rapidly increases due to precipitation till it reaches a certain level, depending upon the density, compaction, and gradation of the soil. 2) After this semi-saturated 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. Project Location No. 13 — This project is located in the coastal zone and in cut and fill areas with curb and gutter. 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% silt and 29% clay. The fill is over a creek.

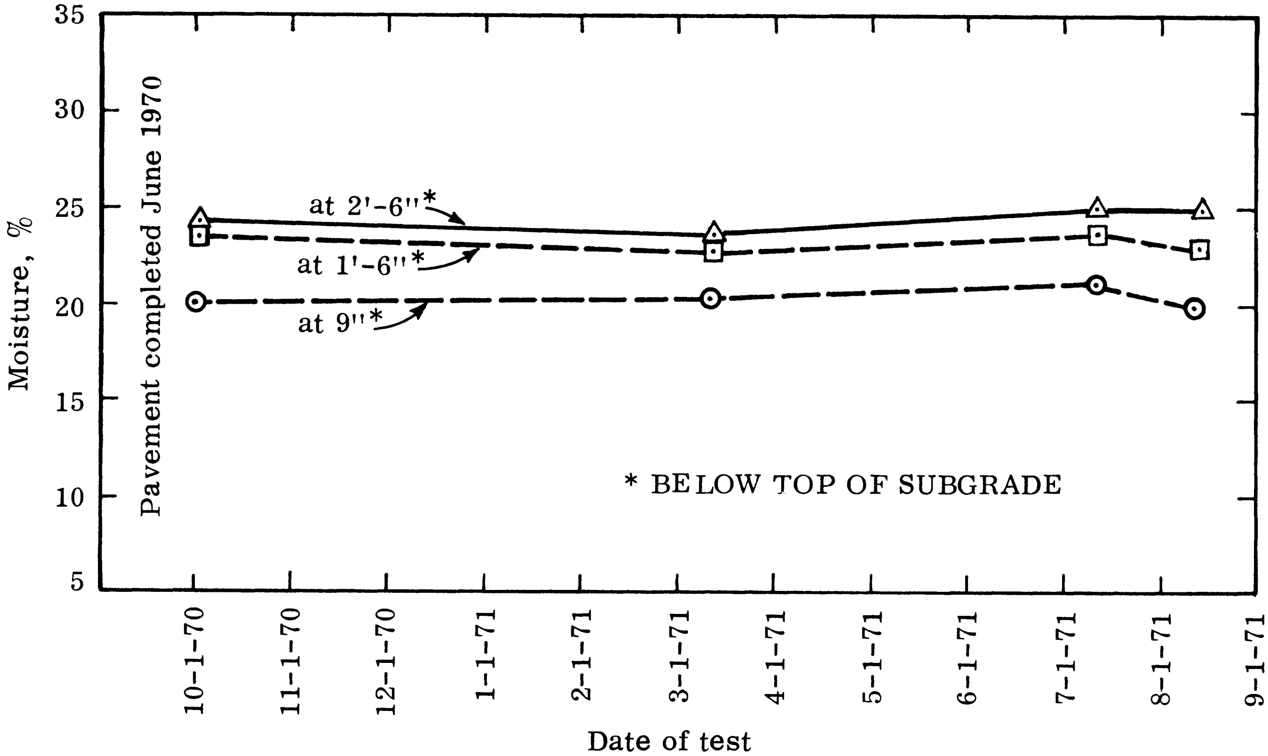
The pavement was completed in June 1970 and consists of 10.5 inches of full depth asphaltic concrete. After completion of the road, measurements of subgrade moisture were started in October 1970. The data for the subgrade moisture below the pavement in the cut and fill areas are shown in Figure 10.

In the fill area the subgrade moisture during the 12-month period remained almost constant and was in the range of 20% to 25%, with lower percentages of moisture near the pavement than at a distance from it. This is the same pattern as was observed for the project at location no. 14, with drainage away from the pavement. In this case curb and gutters also prevent drainage towards the pavement subgrade.

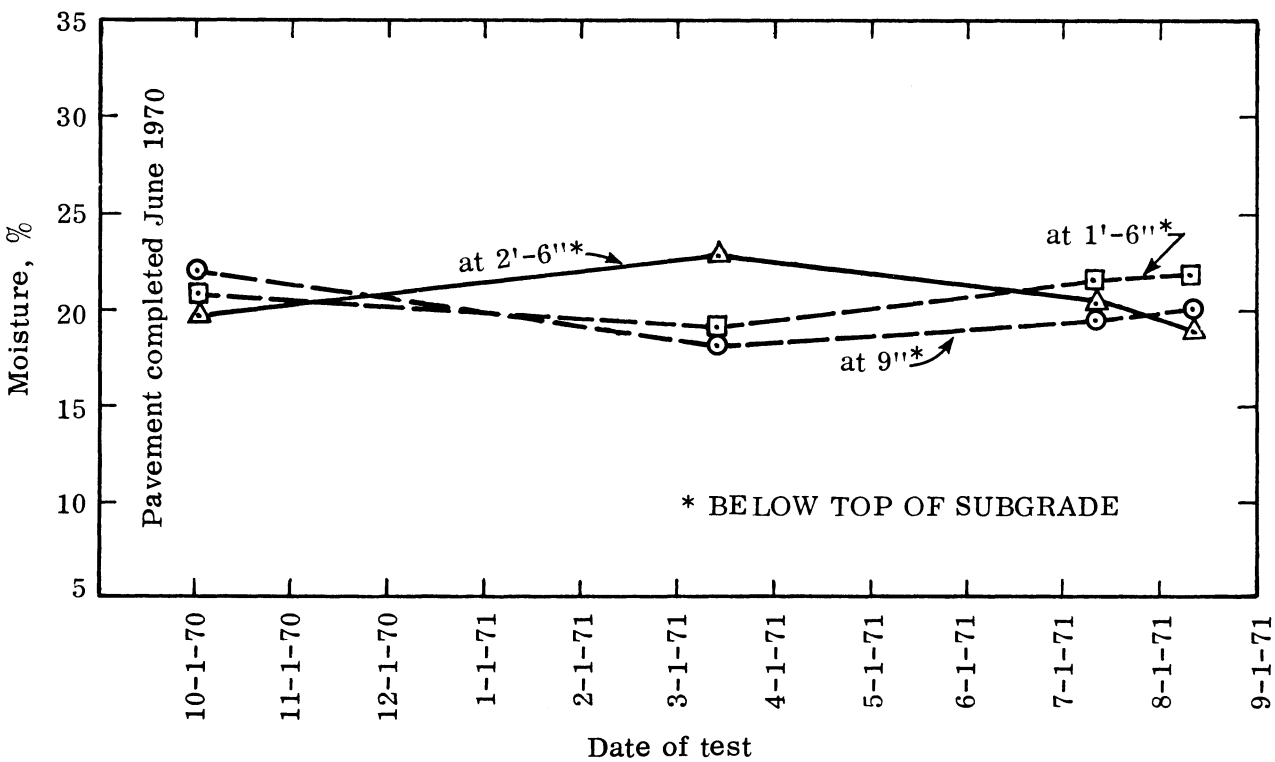
4. Project Location No. 15 — This project is about 12 years old and is located in fill and cut areas. The fill is over a deep depression and hence the subgrade moisture has a tendency to drain away from the subgrade unless held by other forces. The cut is over a rocky foundation except for a leveling fill for the subgrade. The side drains of the cut usually collect a lot of water, which indicates that the ground water is draining towards the cut.

Figure 11 shows the moisture content below the subgrade at three levels in the fill area under the pavement and shoulder and in a cut area under the pavement only.

Figure 11 shows that the moisture content under the pavement in the cut as well as in the fill remains almost constant. In the cut area the moisture varies from 25% to 34% as compared to 30% to 44% in the fill area. This tendency of lower moisture contents in the cut than in the fill was observed in the three projects discussed above, in spite of the fact that the ground drains towards the cut. The only possible reason is the higher density of the subgrade soils on the rocky foundation in the cut.

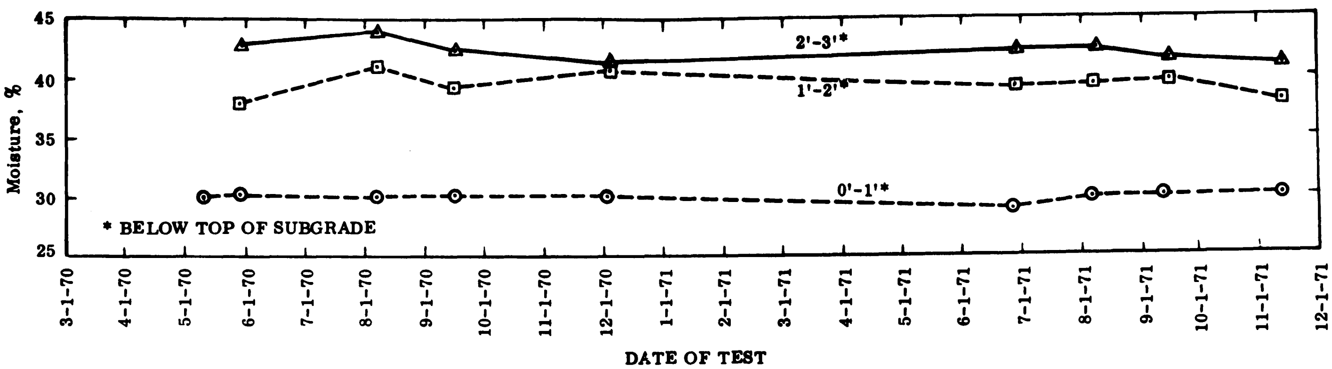


(a) Under pavement in fill area.

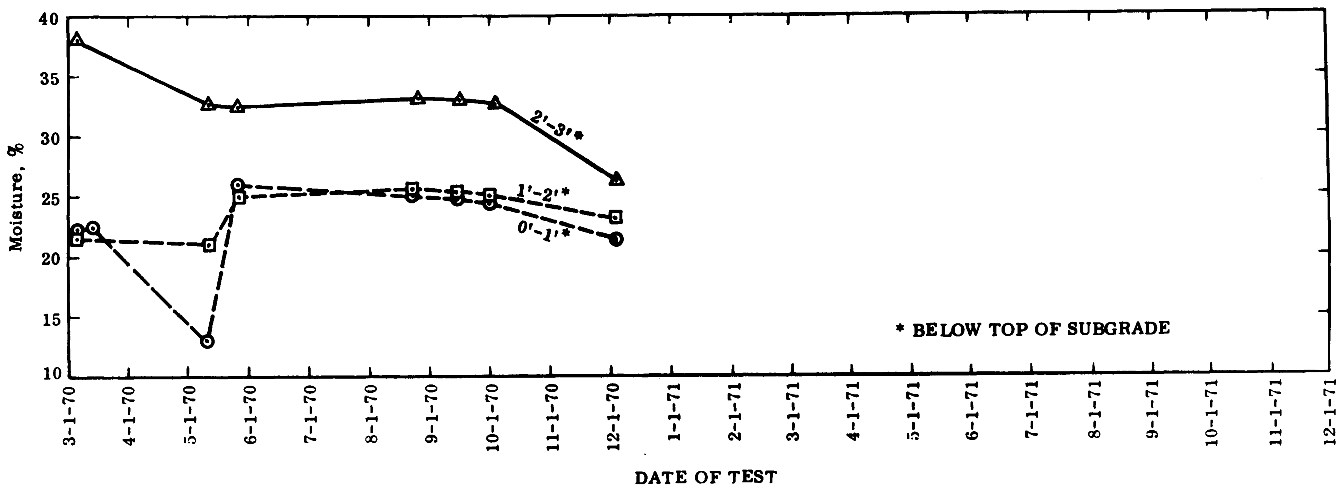


(b) Under pavement in cut area.

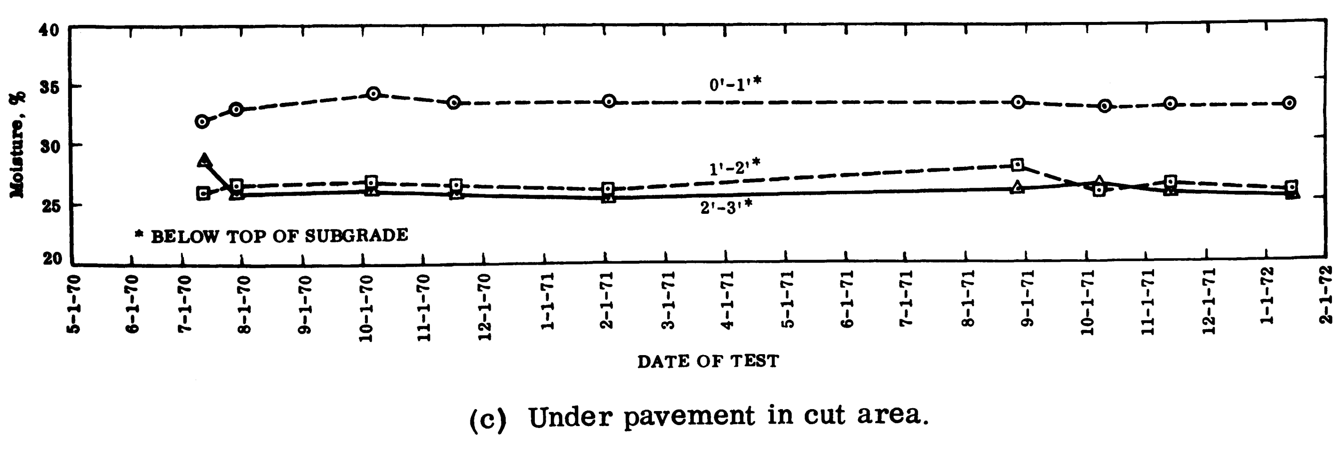
Figure 10. Seasonal variation in subgrade moisture at location 13 (under 10.5" A.C.).



(a) Under pavement in fill area.



(b) Under shoulder in fill area.



(c) Under pavement in cut area.

Figure 11. Seasonal variation in subgrade moisture at location 15.

As stated above the subgrade soil moisture content in this cut and fill is much higher as compared to the other projects discussed. This fact probably tends to prove that after the soil rapidly increases in moisture due to precipitation, the rate of increase in moisture decreases, but continues slowly during the life of the pavement and changes with the temperature gradient till it reaches a level where 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 is sloping 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 towards the pavement, the moisture content is highest near the bottom of the pavement and decreases in the lower layers of the subgrade.

As shown in Figure 11, in the fill area under the shoulder the moisture content seems to have been affected by the climatic conditions. The shoulder cover in this area consists of gravel less than four inches thick. In the three previous cases, the gravel thickness varied from six to nine inches. Since the moisture was draining away, the moisture content was lower in the top layer than in the bottom layer.

5. Project Location No. 17 — The four projects discussed have shown that the moisture content of the subgrade soil in the fill is much less than that of the soil in the cut. This was in spite of the few cases where the ground drainage was towards the cut area as compared to the ground draining away from the fill area. This clearly showed that in the cut area, due to better compaction and hence more density, and also probably because of the rocky foundation, the subgrade moisture was less than in the fill.

To confirm that the moisture content was more related to the density of soil than to the rocky cut, the moisture versus density relationship was drawn for this project. This relationship is shown in Figure 13 (a). This figure shows that the density of the subgrade soil in the fill varies from about 104 to about 115 pcf, while in the cut it varies from about 118 to about 142 pcf. For the same depth, the density in the cut shoulder is less than that in the cut pavement.

The same trend is noted for soils with no cover as shown in Figure 13 (b).

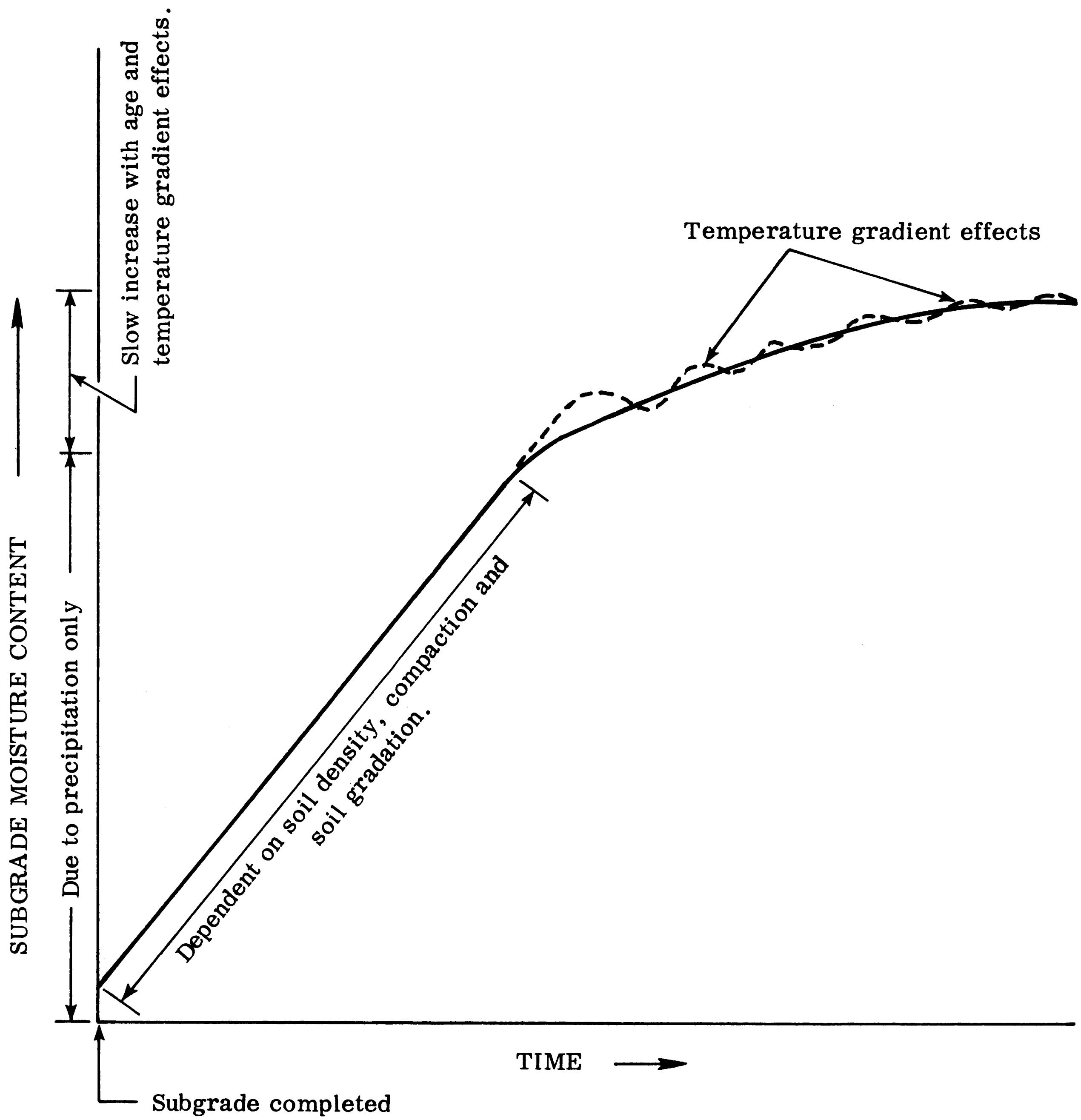
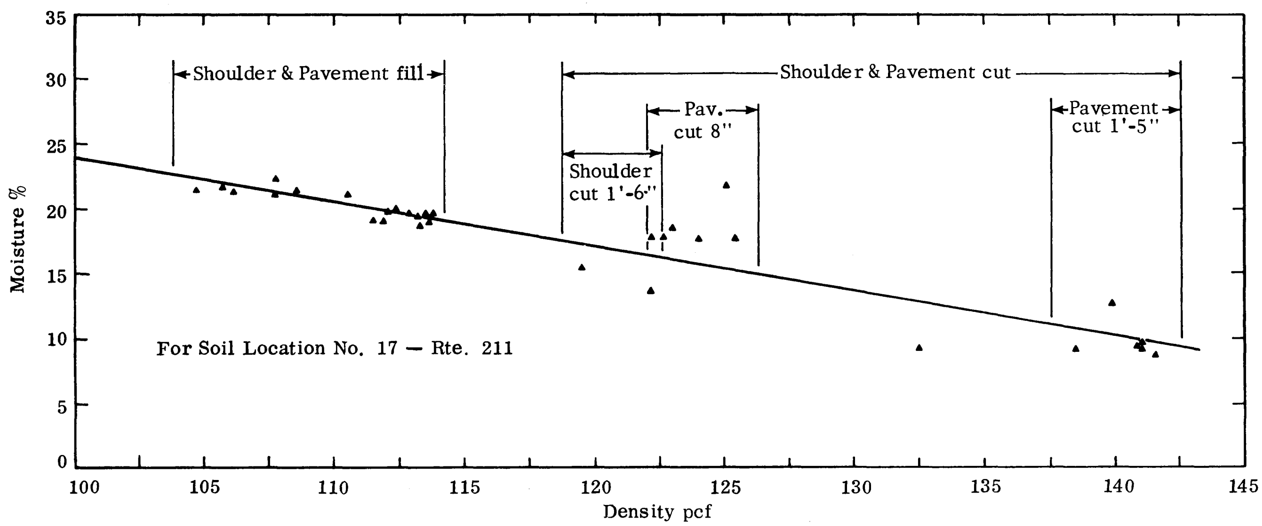
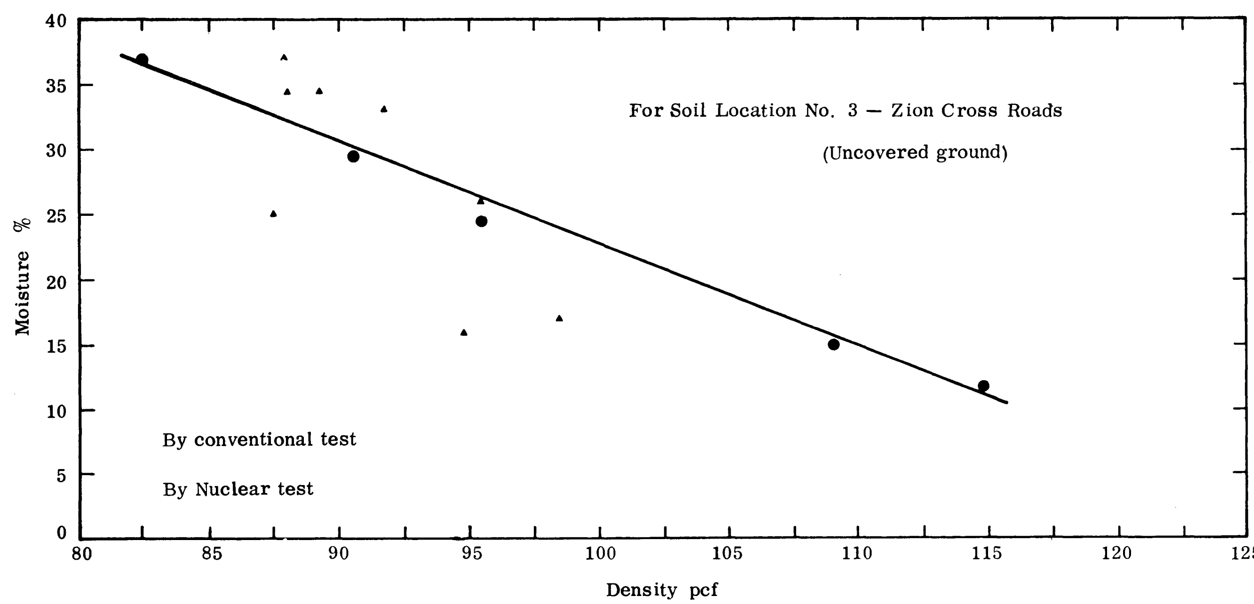


Figure 12. Subgrade moisture variation with time.



(a) Moisture content vs. density at location 17 for cut and fill area.



(b) Moisture content vs. density by conventional test and by nuclear test in lab.

Figure 13. Soil density vs. moisture content.

CONCLUSIONS

Based on this investigation the follwing conclusions are made.

1. The higher the compaction and dry density of the subgrade soil, the lower is the subgrade moisture content.

2. The subgrade moisture continues to increase from the date the subgrade is constructed. There is a sharp increase due to precipitation for a year or two from the date the subgrade is constructed. The rate of increase is dependent upon the gradation, compaction, and dry density of the subgrade soil. After this period the rate of increase in moisture content decreases. This slow increase is due to precipitation, temperature gradients, and subsoil water level. After about ten years there is practically no change, or very little change, in subgrade moisture with no effects of temperature gradients.

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

4. The subsoil moisture content in uncovered ground and subgrades of pavement shoulders is very much affected by climatic conditions such as rain, snow, and temperature. The variation is maximum in uncovered ground, less in shoulders covered by a four-inch layer of aggregate and much less in shoulders having 6 to 9 inch layers of aggregate.

   The subgrades under the shoulders covered with 6 to 9 inch layers of aggregate were found to be frozen--probably due to the collection of snow over them--while the subgrades of pavements were not frozen.