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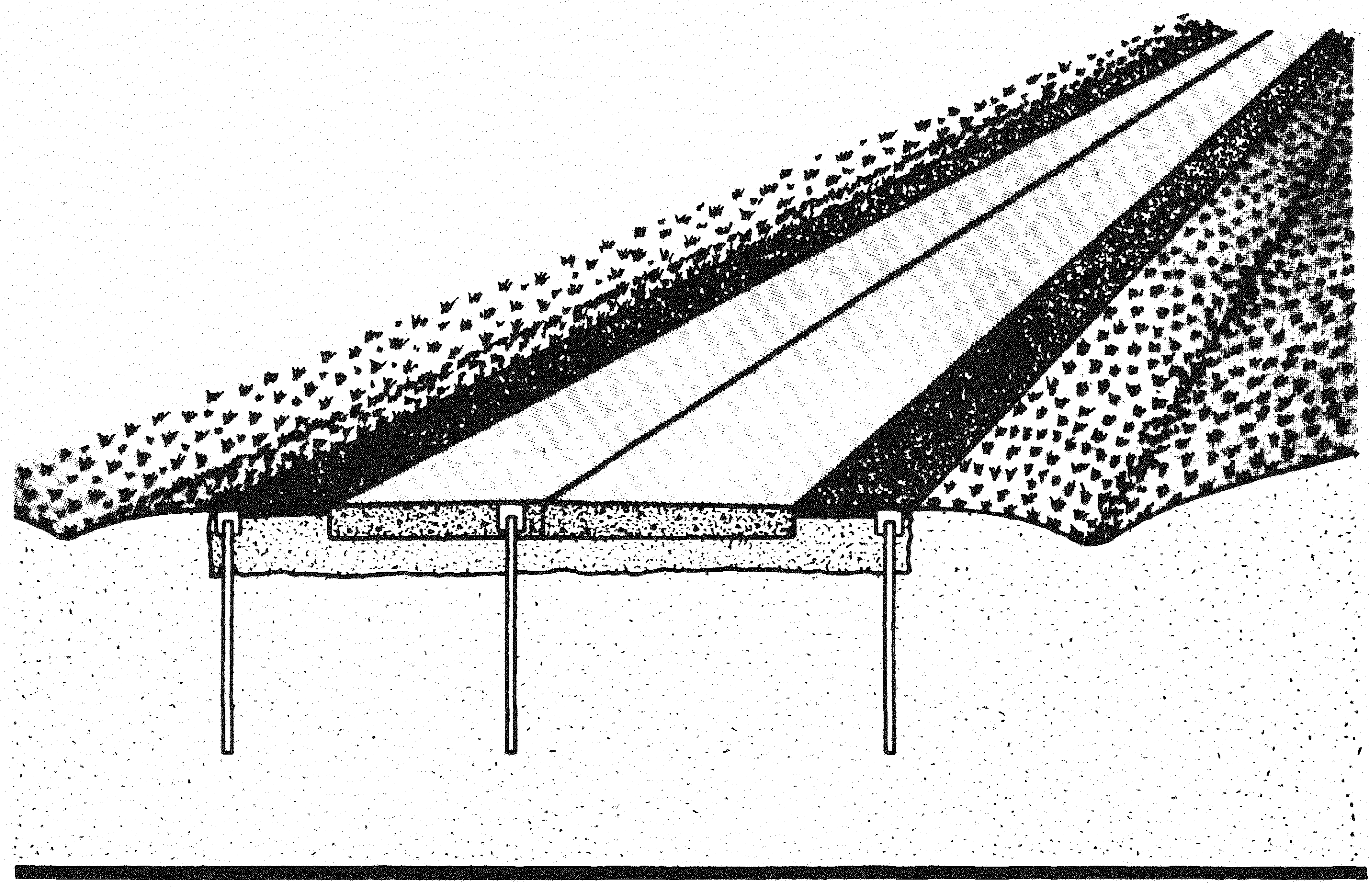

SUBGRADE MOISTURE VARIATIONS

INTERIM REPORT VI

EVALUATION OF COLLECTED DATA 1966-1967

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by

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and

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Project Director

Research Project 64-01-3
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by the

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Office of Engineering Research
Oklahoma State University
Stillwater, Oklahoma

May, 1968

PREFACE

A prime objective of this research study is to relate measured moisture changes under Oklahoma highway pavements to soil, climate, and pavement behavior. Only after relations between cause, extent, and effect are defined can procedures be developed for improving pavement performance.

Furthermore, the volume of data obtained by this study requires that both collected data and collection procedures be periodically evaluated, to provide insight for future work. It is in this light, and this light only, that the report should be considered. Evaluations and correlations contained herein have substantiated some theories of moisture migration and shown interesting quantitative trends. Research procedures have been verified and guidelines for detailed future study have been established. However, data collected from only 60 percent of current field test sites for a one year period is not sufficient to provide final qualitative answers to the subgrade moisture variations problem, though it is hoped such data will be developed before project termination in 1970. For example, the authors have carefully refrained from entering the rigid vs. flexible pavement controversy, though they reserve the right to do so in the future.

This report is the sixth of an interim nature to be submitted by the Subgrade Moisture Variations research project, Oklahoma Research Program Number 64-01-3. Future interim reports will update and hopefully reinforce the conclusions of this report.

Support for this study is provided by the State of Oklahoma, Department of Highways, in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, and by the U.S. Department of Health, Education, and Welfare, under the NDEA fellowship program. This support is gratefully acknowledged.

B.D.M.

T.A.H.

LIST OF REPORTS

Interim Report I: "Preliminary Planning," by T. Allan Haliburton, June, 1966, reviews current utilization of nuclear equipment and presents a tentative plan for project operations.

Interim Report II: "Access Tube Installation," by Wayne L. Heiliger and T. Allan Haliburton, January, 1967, describes procedures used to install access tubing for nuclear depth moisture-density equipment beneath highway pavements.

Interim Report III: "A Preliminary Standardization and Calibration Procedure for Nuclear Depth Moisture/Density Gages," by E. W. LeFevre and Phillip G. Manke, May, 1967, describes an interim calibration procedure for project use of nuclear depth moisture and density gages.

Interim Report IV: "Suggested Nuclear Depth Gage Calibration Procedures," by Raymond K. Moore and T. Allan Haliburton, January, 1968, describes final procedures used in calibrating project nuclear depth moisture and density gages.

Interim Report V: "Data Summary 1966-1967," by T. Allan Haliburton, April, 1968, presents all data collected at the first 30 field test sites during the period June, 1966 to August, 1967.

ABSTRACT

Data collected at field test sites 1-30 during the period June, 1966 - August, 1967 are evaluated, relating measured subgrade moisture changes to soil, climate, and pavement conditions. Relevant data were coded on IBM cards and sorted mechanically to obtain initial correlations. Engineering judgement was then applied to develop more detailed relationships. Cause, extent, and effect of subgrade moisture variations are discussed, as are general trends obtained from the collected data. Results obtained from previous subgrade moisture studies by other agencies are also presented.

Results of the evaluation substantiated some theories of moisture migration and showed interesting quantitative trends. Research procedures are verified and guidelines are established for future research activities.

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CHAPTER 1. INTRODUCTION

Subgrade moisture variations, with resulting changes in volume and strength of subgrade soils, help to cause many premature highway pavement failures. Thus, highway design life may often be lengthened by use of information about cause, extent, and effect of subgrade moisture variations.

Accordingly, the School of Civil Engineering at Oklahoma State University began, in June, 1964, a six-year HPR study to measure subgrade moisture variations, relate them to soil, climate, and highway pavement conditions, and suggest revised design procedures to improve pavement performance. Cooperating and sponsoring agencies are the Oklahoma Department of Highways and the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

After preliminary planning (Ref 1) nuclear depth moisture and density gages were selected to measure subgrade moisture conditions. Fifty research sites were installed throughout north central and northeastern Oklahoma. The sites were located on highways of various conditions, designs, and traffic volumes.

Statement of the Problem

Correlation of all data collected in field investigations must be conducted before any useful information is obtained for specific applications. Data collected from the initial thirty field test sites during the first year of measurement should be correlated in an attempt to relate moisture variations, subgrade soil types, climatic conditions, and pavement conditions. Data collection should be evaluated to suggest any revisions to current procedures.

Scope of this Investigation

The scope of this investigation is twofold: 1) to evaluate currently employed data collection procedures in an attempt to obtain more nearly accurate and representative data by most economical and/or efficient means, and 2) to attempt correlation of moisture variations, soil classifications, climatic conditions, and pavement performance, and to provide informative facts related to moisture variations beneath Oklahoma highways.

CHAPTER 2. THEORIES OF MOISTURE MIGRATION

Soil moisture migrates as a result of any force which upsets equilibrium in the soil-water system. Several different viewpoints exist in literature concerning forces which cause moisture to migrate. A few of the most widely discussed hypotheses are hydrostatic pressure, capillary pressure, disjoining pressure of aqueous films (often referred to as osmotic pressure), chemical potentials, and temperature gradients. Moisture may migrate through soil in the liquid phase, vapor phase, or a combination of the two, depending on forces causing pore water movement.

Moisture movement caused by hydrostatic pressure is usually considered to occur in saturated soils. Flow of this nature has been termed seepage and obeys the classical Darcy Law. However, research has shown that flow induced by hydrostatic pressure may occur in partially saturated soils, provided moisture present is sufficient to maintain a continuous capillary channel in the soil pores (Ref 2). Flow of this nature will also be governed by Darcy's Law. Migration of moisture under hydrostatic pressure will occur in the liquid phase from a higher to lower hydrostatic pressure.

Pores of a soil mass are analogous to small capillary tubes which wind through a medium. Water rises in a capillary tube as a result of surface tension of water. Forces causing capillary rise are inversely proportional to the radii of the capillary tubes. Pore size of soil has been related to the effective grain size D_e of that soil.

Although there is some controversy, the pore size is usually considered to be 1/5 D_e . Capillary force and thus height of capillary rise increases with decreasing grain size. For example, clays exhibit a much higher degree of capillary rise than do coarser grained silts. Although clay has a much greater height of capillary rise than silt, the time required for moisture to migrate an equal distance will be much greater in clay than in silt. Slow migration time in clays results from very small pores, which restrict the flow rate. As a result of the higher flow rate one finds that adverse capillary moisture conditions occur more quickly in silts than in clays.

Load or surcharge application on a soil mass will impose compressive stresses in the pore water, reducing tensile capillary stresses in the soil. Thus, load applications will reduce moisture migration from capillarity (Ref 3). Moisture migrations resulting from capillary forces may occur in either liquid or vapor phase, but usually occur as a combination of both. Cary (Ref 4) found that surface tension, and thus capillary force, increases as temperature decreases. Flow from warmer to cooler areas could be caused by such tension, but migration was found to occur in systems where no air-water interfaces existed. Moisture movement in these systems indicated forces other than tensile forces at work.

In clay soils such as those found in Oklahoma, moisture may migrate as a result of osmotic pressure. Osmotic pressures are caused by aqueous films within soil pores being disjoined by adsorbed water of clay particles. The adsorbed or double water layer, held by strong electrical forces, is much more viscous than free pore water. Free pore water may be cut off or bottled inside a void by the contact of double water layers of two clay particles. The less viscous pore water cannot flow freely past the viscous water plug. Osmotic pressures occur from the difference in ion concentration between the held pore water and the pore water in an adjacent void. Pore water held in this void will migrate in the vapor phase through the viscous double water layer barrier to the adjacent void in an attempt to equalize ion concentration. Although moisture migration occurs in the vapor phase, the vapor may condense once equilibrium between the adjacent voids is reached. Rate and quantity of migration of osmosis is very small; however, migration from osmosis may eventually cause substantial moisture variations in subgrade soils (Ref 5).

The presence of chemical or electromotive potentials causes activity of clays (Refs 6, 7). Chemical potentials are caused by differences in soil chemical composition. Activity of clay mineral ions is related by the base ion exchange potential of the particular soil. Moisture migrates across chemical potentials caused by differences in ion activity. Moisture will migrate from a clay mineral of low base ion exchange capacity such as kaolinite, to a clay mineral having a higher base ion exchange capacity such as montmorillonite. Chemical potentials may also occur between two clays of the same mineralogical composition, from the presence of different adsorbed ions. An example would be the potential between a sodium-montmorillonite clay and calcium-montmorillonite clay. Although the basic minerals are identical, moisture will migrate from the former clay to the latter, because of the potential difference between sodium and calcium ions.

Temperature gradients may also cause moisture to migrate. Vapor pressure, often called relative humidity when describing climatic conditions, is the pressure of vapor when in equilibrium with its liquid phase. Vapor pressures under uniform temperature conditions are not sufficient to cause moisture migration. Presence of a thermal gradient induces large differences in vapor pressures across the gradient. Temperature gradients in soil masses may occur from natural causes. Ground water exists at a relatively constant annual temperature, usually between 20° C and 40° C. Soil temperatures, especially near the surface, vary primarily with ambient temperatures. Changing climatic temperatures thus produce temperature gradients and high vapor pressure differentials in soil. The capacity of soil to absorb moisture decreases with increase in temperature, especially above 20° C (Ref 8). Increased temperature will increase vapor pressure, therefore moisture migrates from high to low temperature areas or high to low vapor pressures. Migration from temperature gradients has been found to occur most often at low water contents and in the vapor phase.

Soil moisture migration research conducted at the Road Research Laboratory in Great Britian helped to define moisture movement theories. Results of their studies indicate flow will occur from soils of low clay content to those of higher clay content. Differences in moisture content will cause flow from soils of high moisture content to soils of low water content, provided the soils are identical. Moisture migration was found to be greater in the vapor phase in soils of low moisture content, below the plastic limit, while flow in the liquid phase was greater at higher moisture contents, above the plastic limit. Migration in both liquid and vapor phase was found to decrease with increasing compactive effort (Ref 9).

Sources of free water must be present for moisture migration to occur in subgrades. Primary sources of moisture in subgrades are: 1) seepage of water into the subgrade from higher ground, 2) fluctuation of the water table, 3) percolation of water through the pavement surface, 4) migration of water from shoulder slopes or verges, 5) migration of water from water bearing layers below the subgrade, and 6) transfer of water vapor from any of the above sources. Figure 2.1 shows these sources in reference to a typical highway cross-section. Pavement sections may not be exposed to all of these sources at once, but any one may provide enough moisture to cause premature pavement failure. Oklahoma highways are susceptible to moisture migration from any one or combination of these sources.

Moisture migration theories were discussed herein to provide a basic understanding of modes by which moisture may move beneath highway subgrades. Protection of highway subgrades from these moisture variations remains a complex and baffling highway engineering problem.

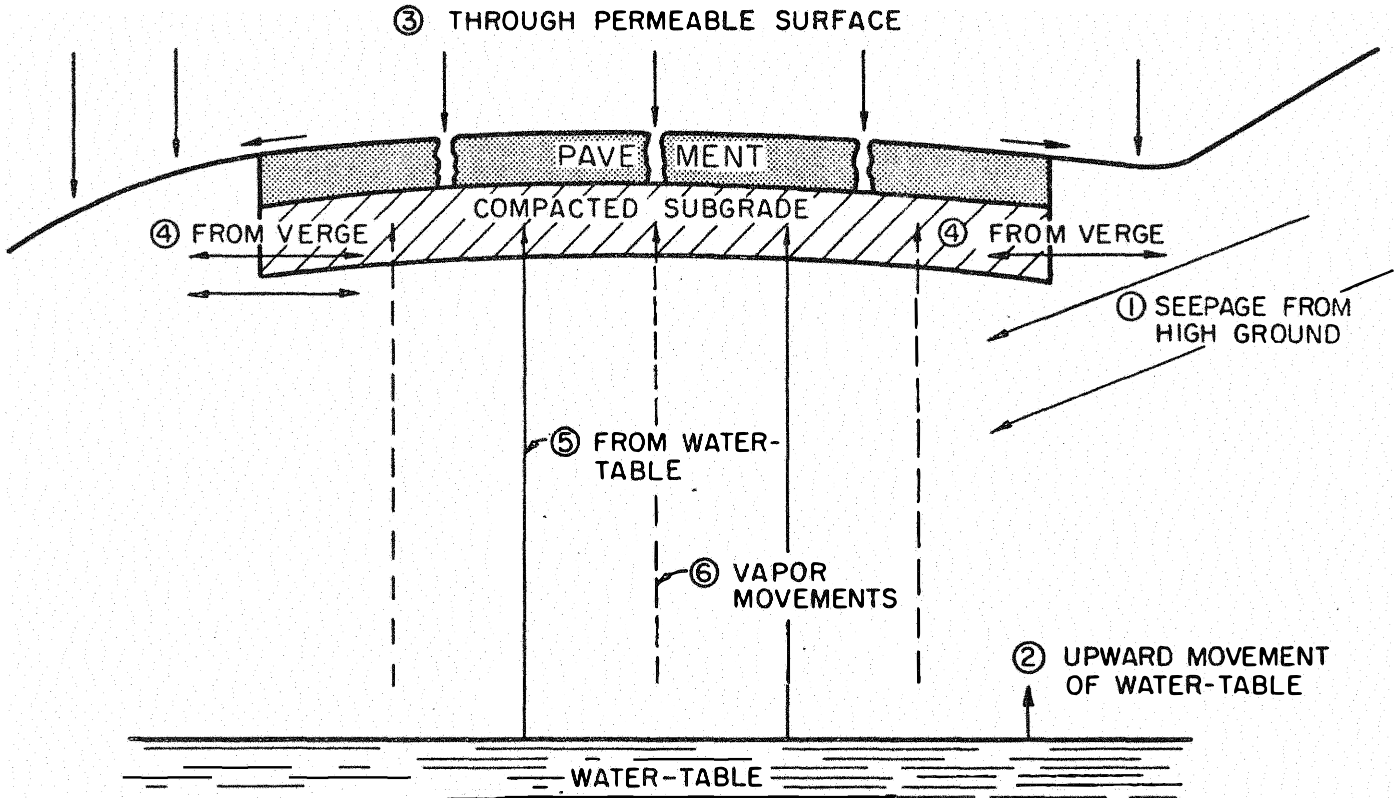


Figure 2.1 Sources of Free Water for Subgrade Moisture Migration (After Ref 9)

CHAPTER 3. REVIEW OF PREVIOUS SUBGRADE MOISTURE STUDIES

The post World War II era brought increased interest in subgrade moisture conditions. Highway engineers became aware that increased pavement thickness, improved compaction methods, and improved construction material control were not complete solutions to prevention of premature pavement failure.

Subgrade moisture conditions were investigated by the Missouri Highway Department, in a long-term study initiated in 1950 (Ref 10). The study was one of the first such projects initiated in the United States. New portland cement concrete slabs were chosen for five years of data collection and observation. Soil samples were taken concurrently with test coring of newly constructed pavements. Soil samples were taken to a depth of two feet into subgrades. Soil similar to that removed from subgrades was replaced to duplicate (as nearly as possible) original conditions. Base course material and pavement were also returned to near original conditions. Sites were sampled at three month intervals, each time reconstructing pavement sections to original conditions as nearly as possible. During the research period, Missouri experienced a long drought, thus dry climatic conditions affected results obtained in their subgrade moisture study.

Moisture variations were found to be very small during the investigation period. Maximum moisture occurrence was found at edges of pavement slabs and beneath shoulders. Joints between pavement and shoulder were found to be most vulnerable to moisture infiltration from surface runoff. Research evaluation indicated that pavement slabs placed over subgrades at periods when moisture distribution was above optimum compaction moisture produced the most stable subgrade moisture conditions.

Development of electrical resistance equipment enabled repeated measurement of in-situ moisture contents. Moisture measurement utilizing gypsum moisture blocks is probably the most common method currently employed. Gypsum blocks, connected in electrical circuits, are placed in soil subgrades. Resistance of the blocks to electrical current is correlated to soil moisture contents, thus changes in moisture content can be obtained from changes in resistance (Ref 11).

Large-scale subgrade moisture studies utilizing gypsum blocks were conducted throughout Australia by Aitcheson and Richards (Ref 12). Data were collected from installations beneath highway pavements over a three-year period.

Largest moisture variations were found to occur at shallow depths beneath pavement slabs while moisture conditions at depths of eight to ten feet were found to be relatively constant. Variations in moisture content were dependent on climatic conditions with maximum occurrences during winter months or following large rainfalls.

Shoulders and shoulder slopes or verges exhibited highest moisture variations during rainfall, indicating that runoff infiltration was greatest at the shoulders. Conversely, moisture conditions beneath the center of pavement slabs were not affected by rainfall to any great extent. Quick removal of runoff by good drainage conditions had great effects on seasonal moisture variation, thus highway cross-section geometrics may have as much effect on subgrade moisture conditions as any other single factor.

Russam and Dagg (Ref 13) conducted extensive investigations involving design of shoulder slopes and protective slope coverings. Kikuyu grass, gravel, and polyethylene membranes were used as shoulder slope coverings. Shoulder slopes were also varied in test sections.

Investigations indicated runoff infiltration to be greatest at sections having the more gentle or flatter shoulder slopes, independent of the type of protective covering used. Steep shoulder slopes removed rain water quickly, resulting in low infiltration.

Polyethylene membranes protected the subgrade against infiltration of small quantities of runoff, but could not withstand heavy rainfalls without rupture. Moisture conditions beneath pavements with shoulder slopes protected by polyethylene membranes were higher but remained more nearly constant than subgrades protected by other means.

Gravel protected slopes allowed maximum infiltration of runoff. Moisture conditions beneath gravel sealed slopes were maintained at near saturation conditions, resulting from reduced evapotranspiration losses on the gravel slopes.

Kikuyu grass, a very coarse forage grass with a very large root system, caused cracking and settlement of shoulders and pavement edges. Large quantities of water taken by the grass caused consolidation of subgrade soils.

Recently, research was conducted at Iowa State University comparing theoretical moisture accumulations to moisture changes actually measured beneath covered areas (Ref 14). A simulated pavement section was constructed of alternate layers of asphalt and roofing paper for field measurements. Theoretical quantities were computed from thermodynamic desorption curves.

Moisture variations resulting from temperature changes were found to be very small. Variations which were measured compared very closely with values computed from desorption curves.

Dry densities (i.e., soil void ratios) were found to affect equilibrium moisture content of the covered soils. Low densities occurred concurrently with high moisture content conditions and vice versa.

Lowering water table elevations in pavement subgrades has little effect on subgrade moisture variations. However, in most cases, use of subgrade drainage systems was found to prevent mud pumping and subgrade intrusion into subbase material (Ref 15). Subgrade drains have been successful to a certain extent in maintaining a constant moisture condition in pavement subgrades. Kassiff and Wiseman (Ref 16) found subdrains to serve two purposes in subgrades of highways in semi-arid areas. Drains removed excess free water from the subgrade during wet seasons, preventing large increases in moisture content. During dry seasons, drains acted as reservoirs, furnishing moisture to subgrade soils as needed. This type of system gave slightly higher but more nearly constant subgrade moisture contents.

Increased knowledge and research in nuclear physics resulted in evolution of nuclear equipment capable of measuring in-situ moisture content and density of soils. Nuclear equipment is advantageous in that repeatable, non-destructive, economical, and more nearly accurate results may be obtained by its use. Development of nuclear probes for soils and highway engineering use was begun around 1950 (Ref 17).

Moore (Ref 18), used nuclear depth equipment in studying short-term subgrade moisture conditions beneath a city street in College Station, Texas. Procedures involved instrumentation of the research site prior to construction of pavement slab, curb, and gutter. Access tubes were installed to depths of twenty feet, allowing moisture probes to be lowered into the subgrade. Thermocouples were also installed to measure temperature variations during the test period.

Data collected over a period of sixteen months indicated no appreciable moisture variations, resulting in no volume change of subgrade soils. Temperature variations were found to occur on an annual cycle at depths exceeding one foot in the subgrade. Temperatures beneath asphaltic concrete pavement were higher than those found at comparable depths in uncovered soil.

Research summarized in this chapter indicates that much remains to be learned about subgrade moisture variations and conditions. While many researchers agree on several quantitative relationships, little qualitative data are available. Contradictions also exist concerning many factors. It appears that any study to clarify subgrade moisture relationships must involve careful long-term, large-scale research. Data on all possible factors affecting subgrade moisture conditions must be collected, evaluated, and correlated. A preliminary approach to this problem is described in the following chapters.

CHAPTER 4. COLLECTION AND PRESENTATION OF DATA

Several methodology problems had to be solved before any subgrade moisture data could be collected. This chapter describes problems, procedures, and solutions associated with installation of research sites and collection of subgrade moisture data. Other factors influencing moisture variations are also discussed.

Nuclear Equipment

Nuclear moisture and density gages used for research were purchased from Troxler Electronic Laboratories, Inc., Raleigh, North Carolina. Equipment inventory consisted of:

1) 2-Model 200B transistorized scaler,
2) 2-Model 504 depth density probe with combination shield/standard, and
3) 2-Model 104 depth moisture probe with combination shield/standard.

Both moisture and density gages measured soil properties indirectly by the radiation backscatter phenomena. Detailed explanations of operating methodology are given by Moore (Ref 19).

Initial calibration curves for the depth gages were obtained from preliminary calibration procedures conducted at Oklahoma State University (Ref 20). Additional calibration research was conducted by Moore (Ref 19) in which soils commonly found in Oklahoma highway subgrades were used. Calibration involved compacting soil into 55-gallon barrels (soil standards) at known values of moisture content and density. Scaler responses were recorded from moisture and density gages when placed in the soil standards. Calibration curves were obtained by plotting nuclear count ratio versus known values of moisture content and density.

<u>Drilling Equipment</u>

Preparation of research sites for collection of data by nuclear depth equipment involved installation of two-inch OD seamless aluminum access tubes through highway pavements into subgrade soils. Chosen depth of access tubes was ten feet, and very straight, close tolerance holes were necessary to obtain minimum air gap around the access tubes after placement.

Much time was spent in designing and testing a mobile drilling unit capable of coring through highway pavements and augering into the subgrade. The final design was constructed by R. A. Young and Son, Inc., Oklahoma City, Oklahoma. The unit, mounted on a standard wide-bed one-half ton pickup truck, consisted of:

1) Minuteman Rotary Mobile drill,
2) Quincy air compressor, and
3) Hydraulic cylinder.

Diamond core barrels were employed in coring six-inch holes through highway pavements to gain access to underlying subgrade soils. Special auger sections were used to drill two-inch access tube holes once the cores were removed.

Field Test Site Selection

Fifty research sites are presently located in northeastern and north central Oklahoma. Thirty of these sites were installed during the summer of 1966 and 20 during the summer of 1967. Preliminary site selections were made in the office from an official Oklahoma state highway map.

Initial locations were selected on the basis of three major criteria:

1. on Primary Federal Aid highways,
2. within ten miles of climatological recording stations, and
3. within a reasonable driving radius of Oklahoma State University, Stillwater, Oklahoma.

Final selection of field research sites was made in the field. The general area of preliminary selection was visited to find an exact location possessing good sight distance in both directions, adequate pavement width and typical Oklahoma highway cross-section, with desired soil conditions. Adequate sight distance at each site was necessary for highway safety and continuous traffic flow since drilling operations during installation and later periodic data collection would involve partial blocking of the highway. Pavement widths were considered since less obstruction to traffic would exist on wider sections. Most Primary Federal Aid highways had sections of adequate width. The majority of test sites were located on grade sections or sections of slight cut or fill.

Test sites were subject to relocation by the drilling crew when difficulties were encountered during installation. Problems requiring site relocation will be discussed in the following section. Final test site locations are given in Appendix 1.

Site Installation and Initial Data Collection

Each research site installation consists of three ten-foot long access tubes, one on each shoulder and one at centerline of pavement as shown in Fig 4.1. At sites with open shoulders, shoulder access tubes were installed through the extreme edges of pavement as indicated in Fig 4.2. Drilling was initiated at each site at one of the shoulder holes. Both men on the installation crew worked to install the first hole. After completion of the shoulder hole, one man began drilling on the centerline hole while standards and initial nuclear data were being taken in the previously installed access tube.

In some locations, rock was encountered during drilling procedures. Research sites were relocated by the drilling crew if bed rock was encountered at depths less than four feet; however, holes penetrating subgrades deeper than four feet were not abandoned and relocated.

Two one-minute nuclear count readings were taken at one foot intervals progressing from the bottom of access tubes. An extension tube (which fit over the access tube) was used to hold the shield/standard above the hole while the probe was lowered into the tube for readings. Reading levels were adjusted for each individual tube so that the depth probes (each approximately 18 inches long) would be just beneath the pavement during the last reading. Adjustments for tube length were made in the first reading interval since the first reading was made with depth probes sitting on the bottom of the tube. Figure 4.3 indicates the three possible cases of tube length. In tubes of 10 foot or any even foot length the initial interval was six inches (Fig 4.3a). Tubes

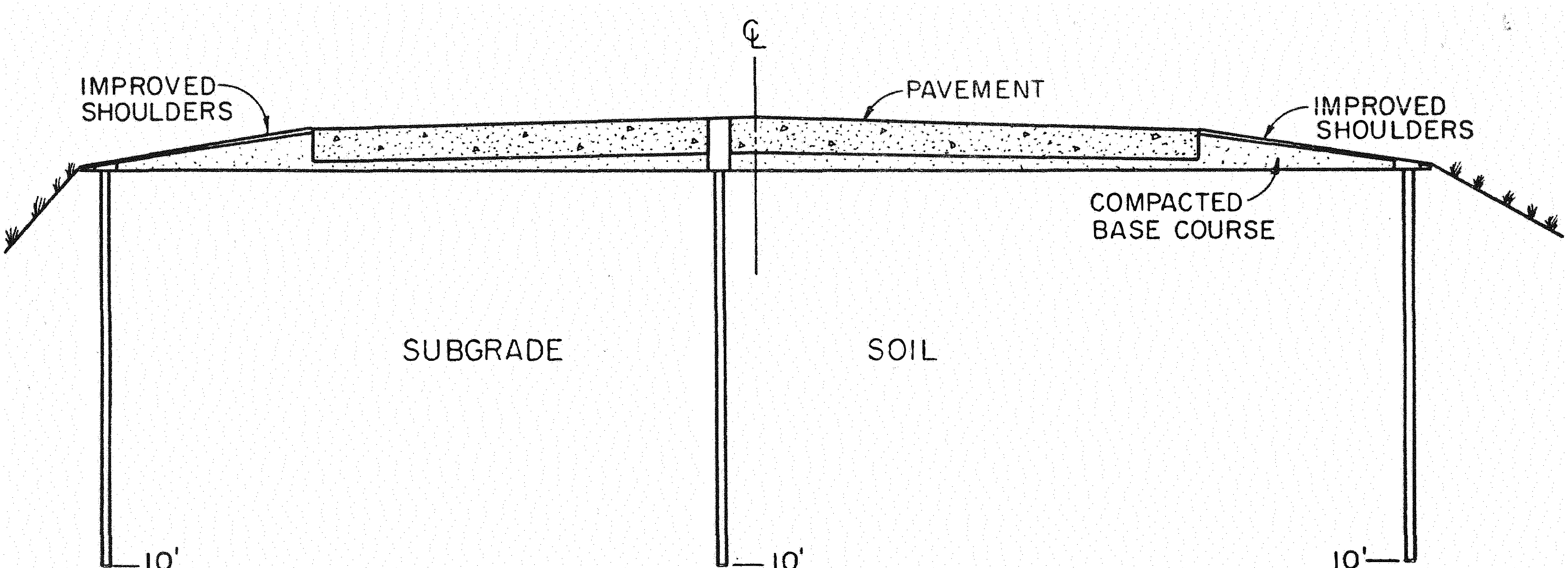


Figure 4.1 Site Installation on Pavements with Sealed Shoulders

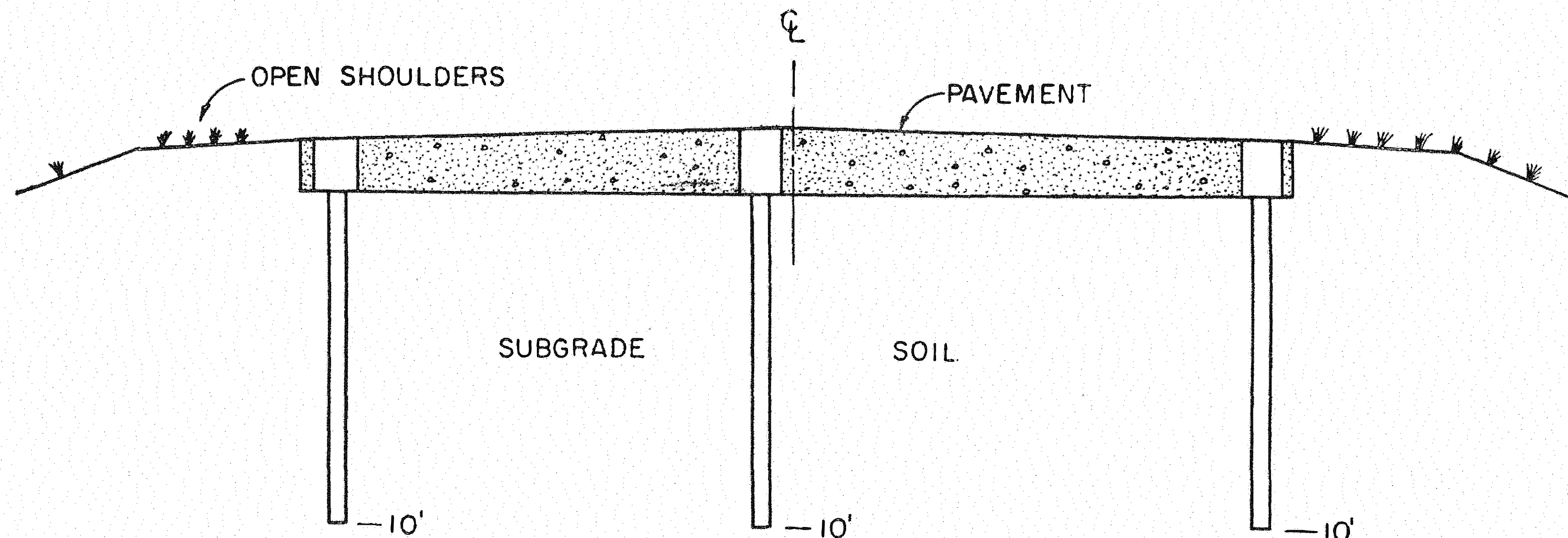


Figure 4.2 Site Installation on Pavements with Open Shoulders

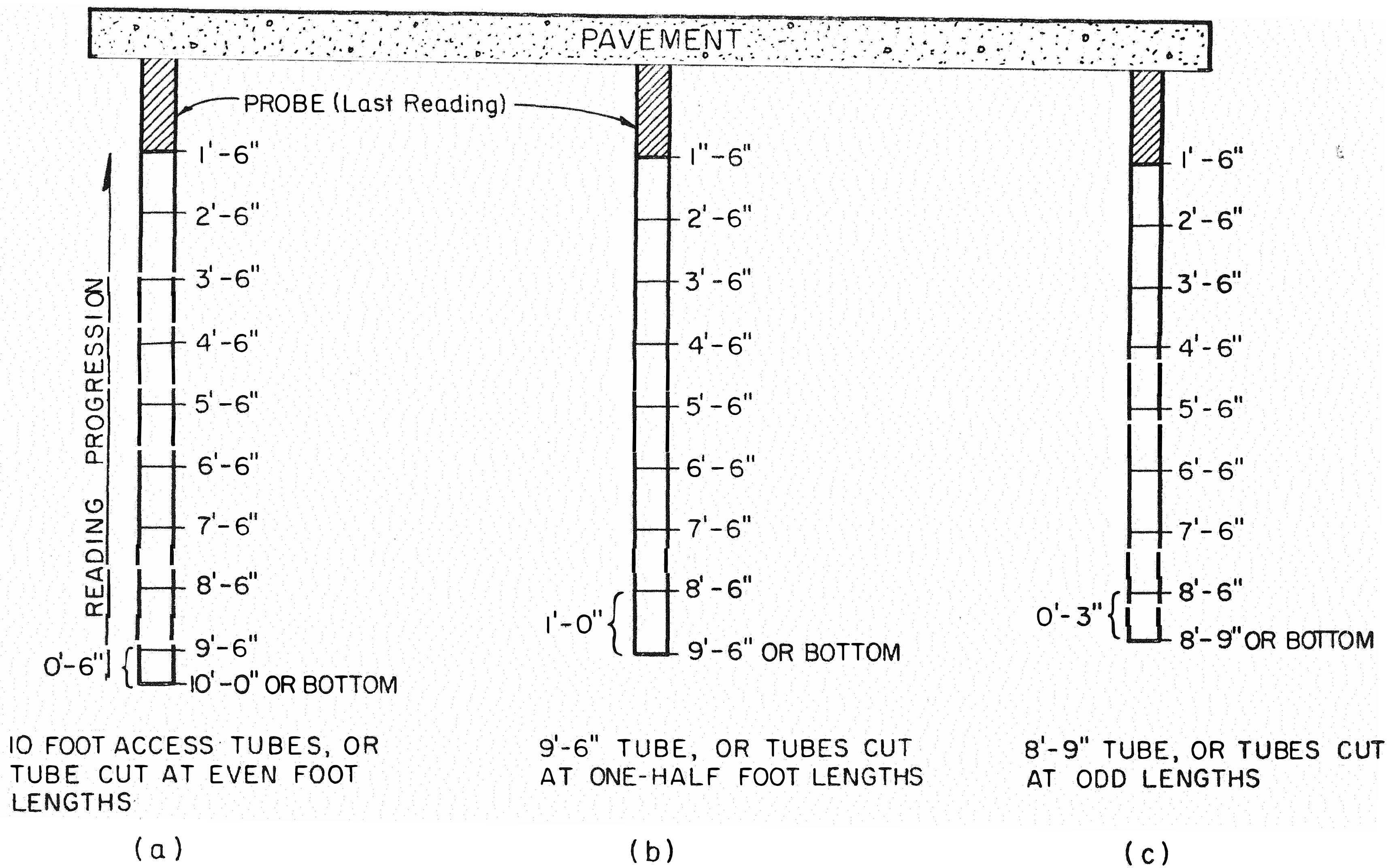


Figure 4.3 Reading Level Adjustments for Access Tube Length

cut on half-foot intervals presented the best case since no adjustment was necessary. One-foot intervals were used from bottom to top (Fig 4.3b). For access tubes with lengths of odd inches, indicated by Fig 4.3c, the correction interval was found by subtracting from total tube length the next half-foot length, thus 9 ft 9 in. minus 9 ft 6 in. equals three inches, which is the correction interval.

Two readings were taken at each level to minimize gross reading errors, to acquire the desired statistical accuracy {95% confidence level (Ref 21, p 39)} and as an economical compromise between a small amount of increased accuracy and considerably increased time and expense in obtaining more readings.

Moisture and Density Measurements

After initial moisture and density measurements at the time of site installation, moisture data were collected on a six-to-eight week time interval. Moisture data collection schedules were selected by application of engineering judgement and economy. Field moisture data should be collected often enough to depict any appreciable moisture variations occurring at research sites. However, readings taken at very short time intervals would be uneconomical if no appreciable variations occurred during the time lag. Trial readings were taken at very short time intervals from an observation site located near project headquarters. Variations that occurred during intervals of less than six weeks were found to be small. Based on these observations, costs involved in reading all sites on less than a six-week schedule did not appear to be justified. The selected schedule also provided ample time for project equipment to be maintained in good working order.

Moisture data were collected in the same manner as initial moisture measurements made at the time of installation. Raw data were recorded in tabular form on a standardized field data sheet shown in Fig 4.4.

Wet density readings were scheduled on a six-month time interval. The longer density measurement interval was selected on the assumption that dry density of in-situ subgrade soils would not change over short periods of time. Assuming that dry density remains relatively constant, wet densities may be obtained utilizing moisture contents obtained at shorter time periods. Raw density data were recorded on forms identical to those used for moisture readings.

The quantity of data collected over short periods of time necessitated reduction of data by computer, as manual calculations would have been impractical and uneconomical. A rather elaborate program was devised to reduce raw data to moisture content and density values. Weight-volume relationships were also programmed to facilitate conversion of volumetric to engineering moisture content. Hold-data options in the program allowed dry density values, collected during a density collection period, to be held in computing percent moisture contents until new density measurements were taken. Engineering moisture content, volumetric moisture content, dry density, and wet density values were printed out in tabular form according to site number, hole number at each site, and depth at which the readings were taken.

Percent moisture contents were plotted against time, giving typical moisture variations as shown in Fig 4.5. This method of presentation was selected for its simplicity and clarity. Variations plotted in this manner may be easily compared to rainfall and temperature data

Form: SMV-F3

SCHOOL OF CIVIL ENGINEERING

OKLAHOMA STATE UNIVERSITY

Stillwater, Oklahoma

SUBGRADE MOISTURE VARIATION STUDY

Installation: Muskogee (County) | US 62 (Highway) | #9 (No.) Hole: a [x] b [ ] c [ ]

Scaler 2008 SN 256 Depth Moisture [x] Depth Density [ ]

Date 16 | 8 | 66 (Day Mon. Yr.) Gain Setting 30 Voltage 1250

Reading Taken By: Marks Depths measured from pavement surface

Depth	Bottom	0'-6"	1'-6"	2'-6"	3'-6"		Std
1	6324	8497	9761	8606	9073	1	11,766
2	6235	8457	9814	8764	9179	2	11,700
3						3	11,923
Σ						4	11,695
Av						5	11,905
						6	11,915
Depth	4'-6"	5'-6"	6'-6"	7'-6"	8'-6"	7	11,602
1	9743	9931	10,104	10,166	11,280	8	11,669
2	9715	9811	9,945	10,266	11,196	9	11,794
3						10	11,790
Σ						Σ	
Av						Av	

Depth						
1						
2						
3						
Σ						
Av						

Depth						
1						
2						
3						
Σ						
Av						

Remarks: All reading levels reference to bottom of the tube.

Starting battery voltage = 19.4 Final battery voltage = 19.1

Figure 4.4 Typical Raw Data Sheet for Recording Nuclear Readings

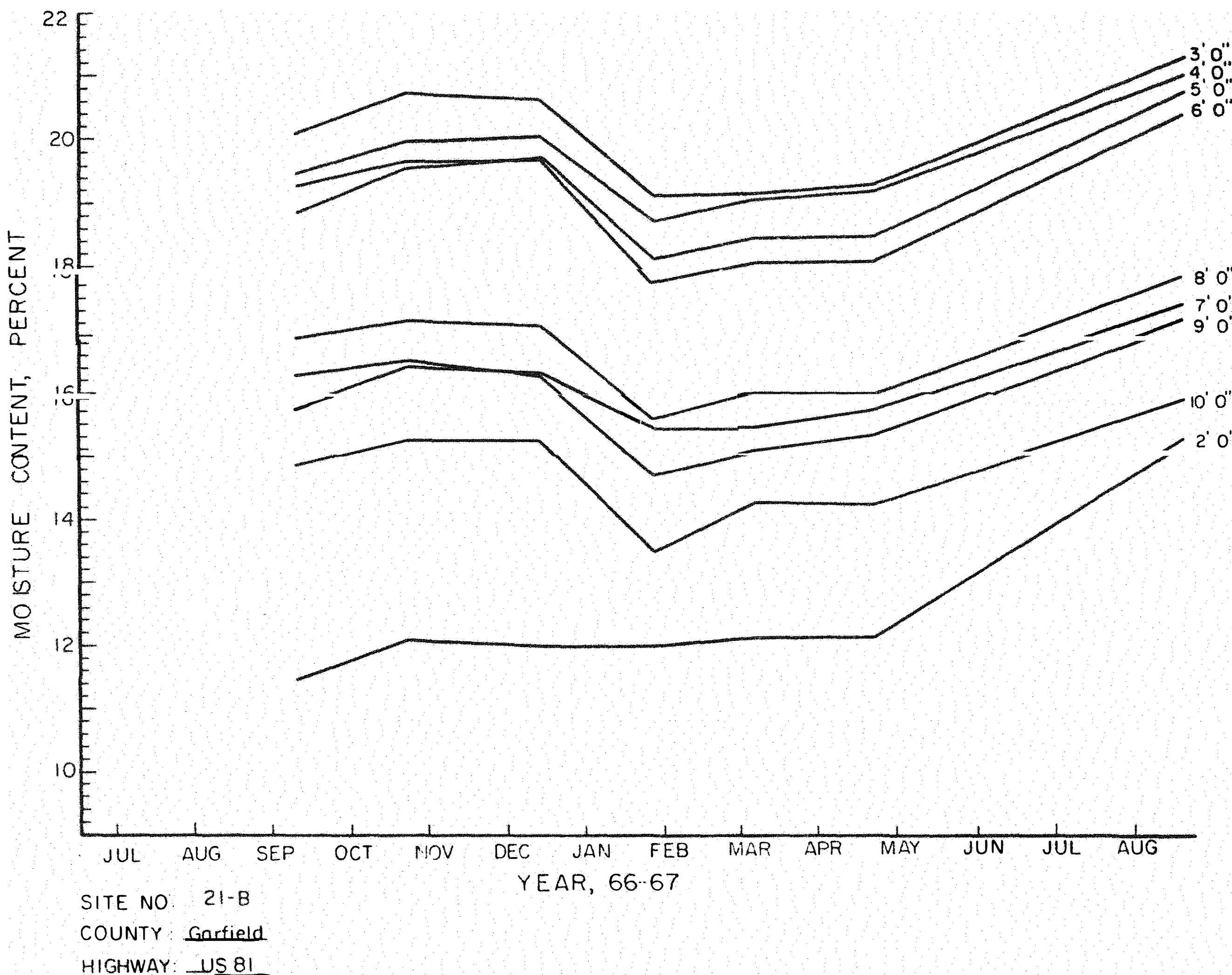


Figure 4.5 Typical Moisture Variations from Site No. 21

plotted over comparative time periods. Any cyclic moisture variations which occur in highway subgrades are readily detectable. Comparisons between each hole at test sites may be easily made from such moisture variation graphs.

Measured dry density values are presented in tabular form; typical values are shown in Table 4.1. Dry densities were tabulated rather than plotted since only three points would appear on a graph with a one year time interval. Also, variations in dry density were found to be very small so that graphical representations would not have been of value. Variations which did occur in dry density will be discussed in the following chapter.

Subgrade Soils Data

Soil samples were obtained from subgrades at each site during installation of access tubes. Samples were taken at one foot intervals as access tube holes were augered. Although the method of sampling by augering soil from test holes may not be the most effective method of soil exploration, samples obtained in this manner were adequate for classification of the subgrade soil. Drilling proceeded rapidly between levels at which samples were to be taken. At each level, the auger was turned rapidly to allow soil to be brought to the surface from the sample depth. Drilling crew personnel felt that soil samples obtained in this manner were within at least one foot of indicated sample depth. At locations where the water table was encountered, soil would not feed from the auger below the water table. In this case, samples were obtained by removing the auger and sampling soil caught between auger flights.

Site No. 9 Hole A	Dry Density (pcf)		
Reading Depths	August, 1966	January, 1967	August, 1967
1'-6"	111.09	104.11	96.82
2'-6"	100.44	101.97	94.13
3'-6"	99.34	101.86	93.66
4'-6"	96.13	98.96	91.72
5'-6"	102.73	104.08	95.74
6'-6"	103.16	103.44	95.21
7'-6"	103.06	106.16	95.98
8'-6"	100.50	101.21	92.35
9'-6"	102.53	101.32	92.80
10'-6"	99.11	98.09	92.03
Average	101.81	102.12	94.04

Table 4.1 In-Situ Dry Density Measured at Site No. 9

Soil samples were placed in self-sealing pint jars to retain natural water content. Natural water contents were obtained for each sample in the laboratory. Quantities of sampled soil were limited by the size of hole being drilled for tube installation, thus only limited testing could be done. However, engineering classification of subgrade soils was thought to be the primary concern at this time, and only a small amount of material was required for such tests. Soil tests for classification included specific gravity, Atterberg limits, and lineal shrinkage. Subgrade soils were classified by the Unified and AASHO classification systems.

Initial soil testing procedures involved testing each sample taken from all three holes at each site. Nine hundred samples were obtained from the installation of the first thirty test sites. In order to provide economical preliminary soil testing results for evaluation and correlation, testing procedures were modified. Investigation of soil test results at comparative depths in each of the three holes at any one site indicated subgrade soils to be relatively uniform in horizontal layers. Based on these observations, subsequent soil testing was conducted only on those samples obtained from centerline holes at each site. This procedure reduced the number of required soil tests by two-thirds.

Subgrade soils data are presented as shown in Fig 4.6 to allow comparison of soil types and subgrade moisture conditions at similar depths. Subgrade soil profiles may be observed at first glance by this method.

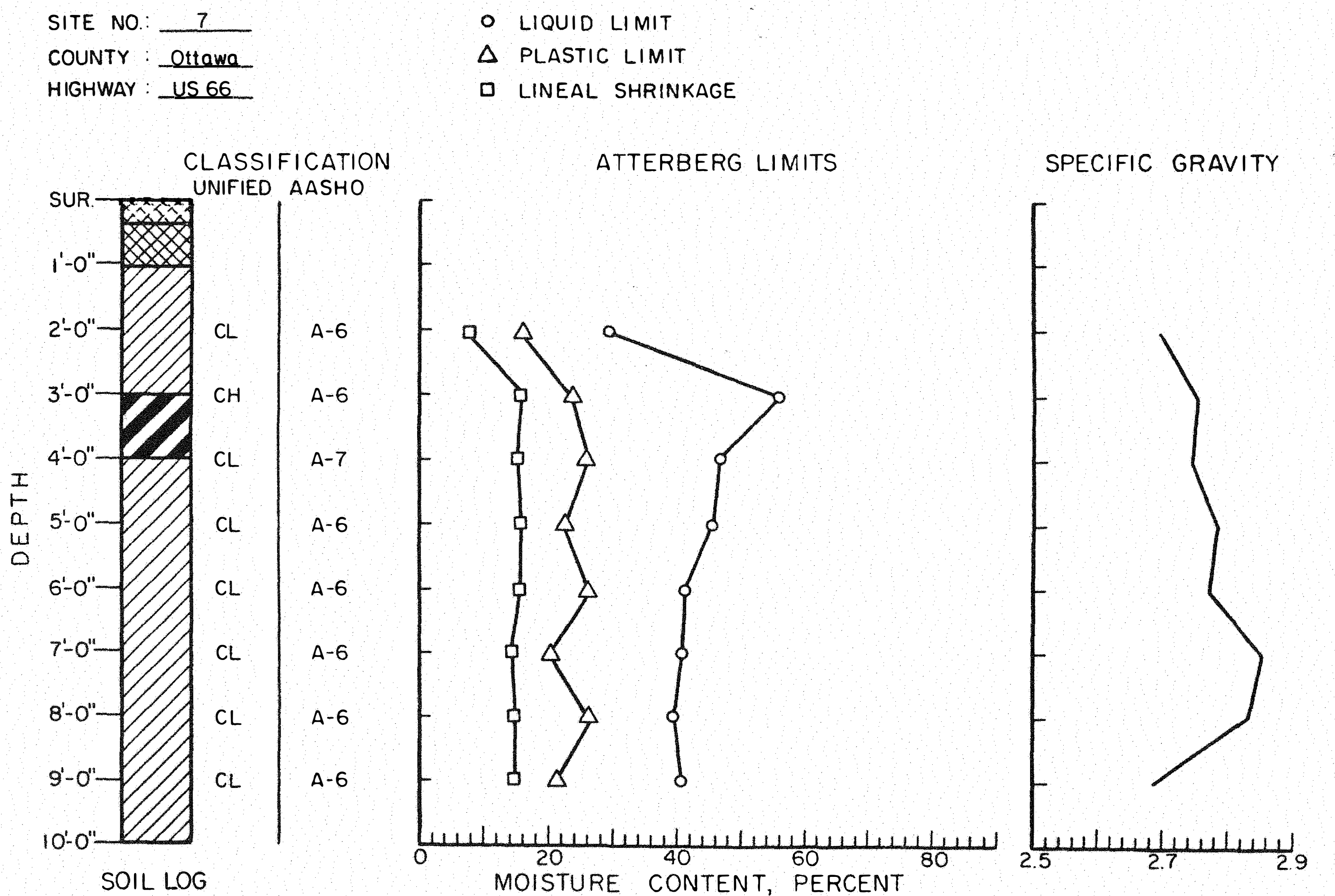


Figure 4.6 Typical Soil Profile from Field Research Site No. 7

Climatological Data

Location of research sites near climatological recording stations was a major criterion in site selection. Monthly mean high and low temperatures, as well as precipitation quantities, were extracted directly from Climatological Data - Oklahoma. These monthly bulletins were supplied by the U.S. Department of Commerce, National Records Center, U.S. Weather Bureau, Asheville, North Carolina.

Conventional methods were selected for presenting climatic conditions at each research site. Mean high and low temperatures were plotted and monthly precipitation, indicated by bar graphs, was superimposed on the same sheet as shown in Fig 4.7.

Pavement, Cross-section, Traffic, and Historical Information

Highway pavement and shoulder conditions were obtained from the Oklahoma Department of Highways, Research and Development Division. They rated pavements and shoulders within 0.2 mile of each site, thus pavement ratings provided may not be representative of highway sections outside the rating limits. The rating system consists of a visual inspection of section conditions. Frequency of adverse conditions such as rutting, cracking, and differential heaving or settlement provided qualitative section ratings. A detailed explanation of rating procedures is presented in Appendix 2. Pavement and shoulder ratings for each site are shown in Table 4.2.

Typical cross-sections at each site were obtained from construction blueprints. These cross-sections were compared to cross-sections indicated by cores taken during site installations. Traffic volumes were obtained from a traffic volume map supplied by the Oklahoma

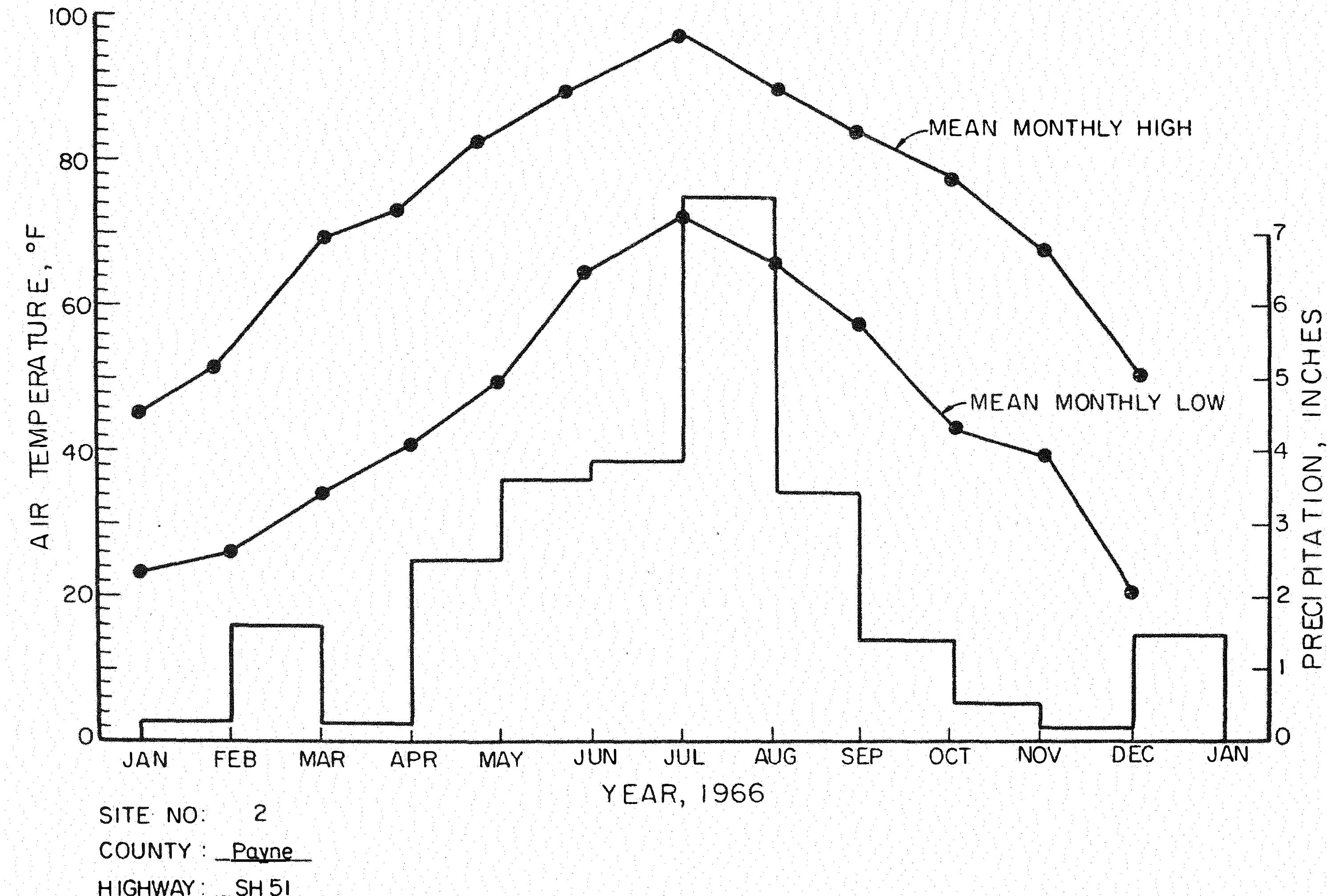


Figure 4.7 Typical Climatological Data for Site No. 2

Site Number	Condition Rating Surface	Condition Rating Shoulders
1	91	Unimproved
2	81	94
3	93	96
4	50	Unimproved
5	64	65
6	85	Unimproved
7	85	91
8	60	85
9	95	92
10	87	79
11	90	91
12	97	95
13	79	Unimproved
14	Abandoned	Abandoned
15	91	94
16	90	90
17	75	80
18	Abandoned	Abandoned
19	82	93
20	96	93
21	95	92
22	89	95
23	92	90
24	90	85
25	65	80
26	97	94
27	88	92
28	94	90
29	93	91
30	97	90

Table 4.2 Pavement and Shoulder Ratings for Each Test Site

Department of Highways, Research and Development Division. Construction and maintenance history of pavement at each site was obtained from records kept on file by the Oklahoma Department of Highways.

Data collection procedures discussed in this chapter were devised by Subgrade Moisture Variations project personnel to obtain information and data related to any factors affecting subgrade moisture movement. Quality of collected data was maintained at a high level throughout the investigation.

Presentation methods were designed to present as much pertinent information as possible in the clearest, most concise manner. It is felt that individuals interested in subgrade moisture movements beneath highway pavements should be able to obtain a complete and concise picture of behavior from presented data. Only examples of collected data have been presented here. Data collected from each individual site may be found elsewhere (Ref 22).

CHAPTER 5. DATA CORRELATION AND EVALUATION

This chapter discusses methods employed in correlation of compiled data, relationships between subgrade moisture variations and contributing factors as obtained from data correlation, and evaluation of data collected to date by the Subgrade Moisture Variations research project.

Correlation Procedures

Large quantities of compiled data necessitated use of a mechanical sorting procedure for initial general data correlation. Broad categories were selected to describe conditions existing at each research site. Features such as type of pavement, base material, subgrade soil classifications, drainage conditions, as well as climatological data, moisture variations, and dry densities collected from each site were coded on IBM cards. Table 5.1 summarizes conditions found at each research field site. General trends and relationships were found by sorting cards in many arrays, holding different parameters constant. A detailed explanation of coding and sorting schemes is presented in Appendix 3.

Once a general trend had been indicated by initial sorting, investigation of individual sites involved was begun. The process was similar to that employed by a criminal investigator. Hints were followed until firm relationships were produced or clues were found to be misleading. The process was found to be most effective if a small

Site No.	Pavement Type	Shoulder Type	Base Course Material	Unified Soil Classification	Typical Cross-section	Pavement Rating	Shoulder Rating	Maximum Rainfall Occurrence	Maximum Moisture Occurrence at Center Line	Drainage Conditions	Liquid Limit	Plastic Limit	Specific Gravity	Maximum Moisture Occurrence at Hole A	Maximum Moisture Occurrence at Hole C	Date of Completion	AASHO Classification	Traffic Volume (ADT)	Truck Traffic
1	PCC	Open	SBC	ML	Grade	Exc.	Poor	July	Feb.	Fair	M.	M.	M.	Aug.	Feb.	1931	A-4	L.	L.
2	AC/PCC	Imp.	SBC	SF	Trans.	Good	Exc.	July	Dec.	Good	L.	L.	L.	Aug.	Dec.	1955	A-3	M.	M.
3	AC	Imp.	SABC	CL	Grade	Exc.	Exc.	July	Dec.	Good	H.	M.	H.	Mar.	Sept.	1963	A-4	V.H.	H.
4	AC/PCC	Open	SBC	CL	Grade	Poor	Poor	Sept.	Nov.	Fair	H.	M.	H.	Nov.	Sept.	1930	A-6	L.	M.
5	AC/PCC	Open	SABC	CL	Trans.	Poor	Poor	Sept.	Nov.	Good	H.	M.	L.	Sept.	Sept.	1962	A-6	L.	M.
6	PCC	Open	SBC	CL	Fill	Good	Poor	May	Nov.	Fair	H.	M.	M.	Aug.	July	1930	A-6	L.	H.
7	AC/PCC	Imp.	SABC	CL	Cut	Good	Exc.	Aug.	Feb.	Good	V.H.	H.	V.H.	Feb.	April	1965	A-6	M.	M.
8	AC/PCC	Imp.	SABC	CH	Grade	Poor	Good	Aug.	Oct.	Good	V.H.	H.	M.	Mar.	Aug.	1962	A-7	H.	H.
9	PCC	Imp.	SBC	CH	Cut	Exc.	Exc.	April	Aug.	Good	V.H.	M.	H.	Aug.	Aug.	1959	A-7	V.H.	H.
10	AC	Imp.	SBC	CL	Cut	Good	Fair	April	Aug.	Good	M.	M.	H.	Aug.	Aug.	1963	A-6	H.	M.
11	AC	Imp.	SBC	SF	Grade	Exc.	Exc.	Aug.	Oct.	Fair	L.	L.	M.	May	May	1952	A-3	H.	M.
12	AC	Imp.	SBC	CL	Grade	Exc.	Exc.	May	Dec.	Fair	H.	M.	H.	Dec.	Dec.	1965	A-6	M.	M.
13	AC/PCC	Open	SBC	SP	Fill	Fair	Poor	July	Sept.	Fair	L.	L.	M.	Aug.	Sept.	1951	A-3	L.	L.
15	PCC	Imp.	SBC	SF	Cut	Exc.	Exc.	Sept.	Nov.	Good	M.	M.	M.	Feb.	Nov.	1952	A-4	M.	H.
16	AC	Imp.	SABC	CL	Fill	Exc.	Exc.	Aug.	Feb.	Good	H.	H.	H.	Nov.	April	1947	A-6	V.L.	L.
17	AC	Open	SABC	CL	Grade	Fair	Good	July	Feb.	Fair	H.	M.	H.	Feb.	Jan.	1954	A-6	V.H.	H.
19	AC/PC	Imp.	SBC	CL	Grade	Good	Exc.	Aug.	Dec.	Good	M.	H.	V.H.	Aug.	Aug.	1966	A-4	H.	H.
20	AC	Imp.	SBC	CL	Cut	Exc.	Exc.	Sept.	Dec.	Good	H.	M.	V.H.	Dec.	Dec.	1964	A-6	V.H.	H.
21	PCC	Imp.	SBC	CL	Grade	Exc.	Exc.	Aug.	Nov.	Good	H.	M.	H.	Dec.	Oct.	1959	A-6	L.	M.
22	AC	Imp.	SABC	SP	Grade	Good	Exc.	July	Nov.	Fair	L.	L.	H.	Dec.	Dec.	1957	A-3	M.	H.
23	PCC	Imp.	SABC	CL	Grade	Exc.	Exc.	Aug.	Oct.	Good	V.H.	H.	V.H.	July	Mar.	1961	A-7	L.	M.
24	PCC	Imp.	SBC	CL	Grade	Exc.	Good	Aug.	Dec.	Good	H.	H.	V.H.	Dec.	Dec.	1955	A-7	V.H.	H.
25	AC/PCC	Open	SBC	CL	Cut	Poor	Poor	Sept.	Nov.	Fair	H.	M.	V.H.	Nov.	Nov.	1929	A-6	V.L.	M.
26	PCC	Imp.	SBC	SP	Trans.	Exc.	Exc.	Sept.	Nov.	Good	H.	M.	H.	Sept.	Nov.	1963	A-6	L.	M.
27	PCC	Imp.	SABC	CH	Cut	Good	Exc.	July	Nov.	Good	V.H.	H.	H.	Oct.	Oct.	1960	A-7	V.H.	H.
28	AC/PCC	Open	SBC	CL	Fill	Fair	Poor	Aug.	Nov.	Fair	H.	M.	H.	Nov.	Nov.	1963	A-6	M.	M.
29	PCC	Imp.	SBC	CL	Fill	Exc.	Exc.	April	Oct.	Good	H.	H.	H.	Oct.	Oct.	1960	A-6	H.	H.
30	PCC	Imp.	SBC	SF	Fill	Exc.	Exc.	Sept.	Nov.	Good	L.	L.	M.	Nov.	Nov.	1963	A-4	L.	L.

PCC - Portland Cement Concrete Pavement

AC - Asphaltic Concrete Pavement

AC/PCC - Portland Cement Concrete Modified with Asphaltic Concrete Overlay

Trans. - Transition Cross-Section

Imp. - Improved Shoulders

SBC - Sand Base Course

SABC - Stabilized Aggregate Base Course

L. - Light

Exc. - Excellent

V.H. - Very Heavy

H. - Heavy

M. - Medium

V.L. - Very Light

Table 5.1 Data Summary for Field Research Sites amount of sorting was done, followed by visual inspection of any trends obtained, and then additional sorting. Use of this procedure prevented an overwhelming amount of general correlations from obscuring specific relationships. Personal knowledge of every research site was of the utmost benefit in correlation and evaluation of collected data.

Correlations Between Subgrade Moisture Variations and Related Factors

Relationships and trends in subgrade moisture variations presented in this section are based on correlation of data collected from thirty research sites during the period of June, 1966 to August, 1967.

Moisture variations were found to occur in an annual cycle with maximum moisture contents occurring during winter months. Cyclic variations were affected considerably by precipitation at sites which were located on poor pavements. Most sites where precipitation affected subgrade soil moisture were located on pavement sections modified by an asphaltic concrete overlay. Although variations were cyclic, the general trend appears to be an increase in subgrade moisture content (Fig 5.1).

Moisture variations beneath pavements with high ratings were found to be predominently temperature dependent. High moisture contents existed during cold seasons and same decreased during summer months, but variations could not be correlated to measured precipitation. Moisture variations resulting from temperature changes were usually between one and five percent. Smallest moisture variations were found beneath newly constructed highways with excellent pavement and shoulder ratings.

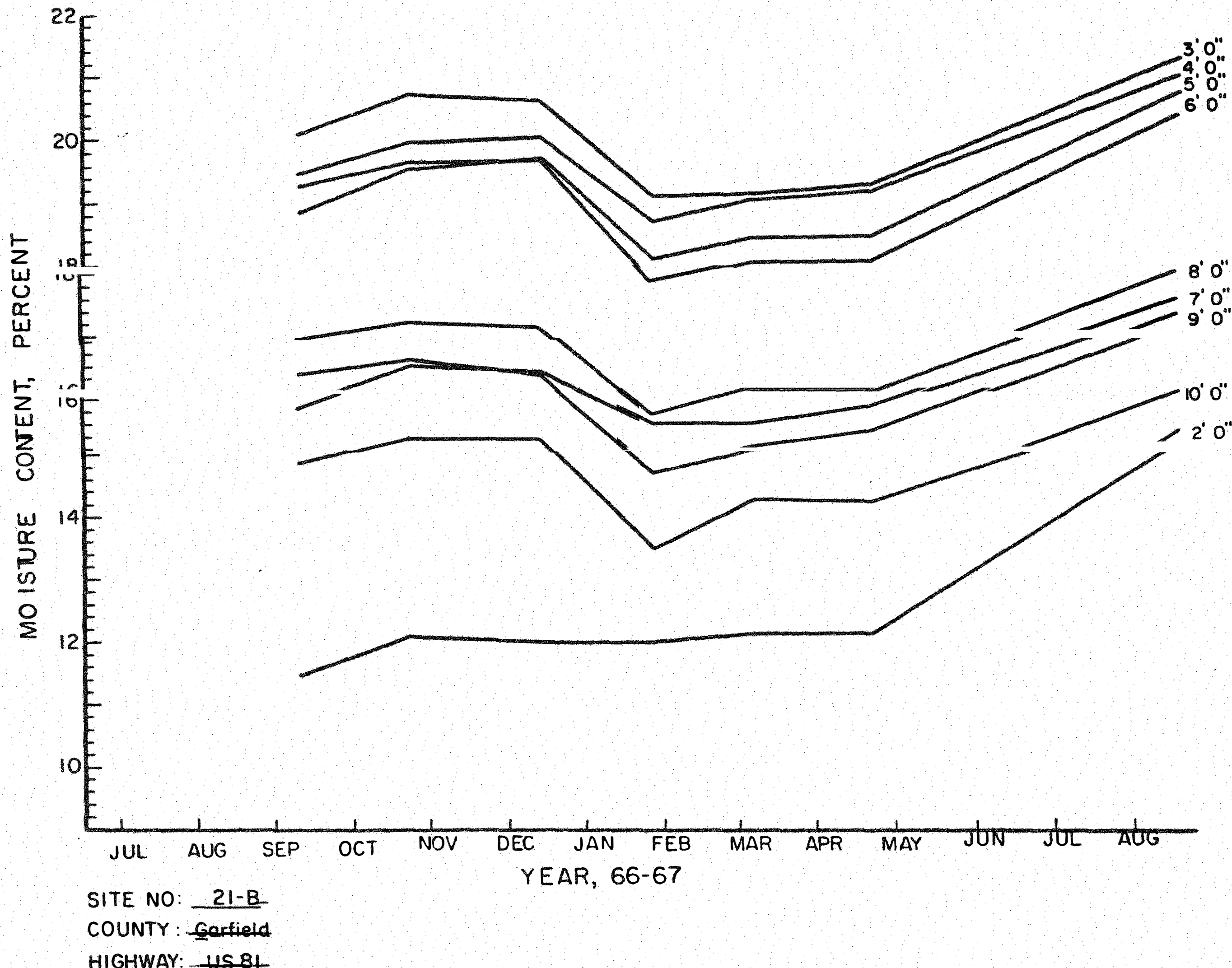
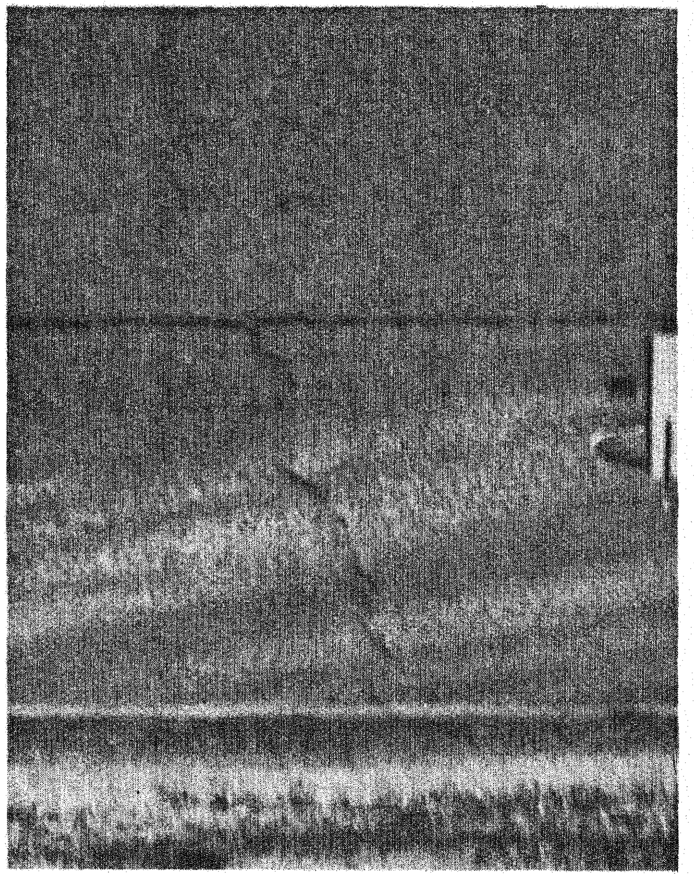


Figure 5.1 Subgrade Moisture Variations Beneath Pavement Centerline at Site No. 21

Typical correlations between rainfall and moisture variation beneath asphaltic concrete overlay pavements may be shown by reference to Site No. 13. Runoff may infiltrate directly through the pavement surface into the subgrade through cracks in overlay pavements (Fig 5.2). Results of infiltrating runoff may be seen by comparing moisture variations beneath the pavement (Fig 5.3) to precipitation and daily mean temperature data shown in Fig 5.4. Moisture contents at Site No. 13 and at most other sites on overlays are highest during seasons of large precipitation.

Conditions existing at Site No. 13 result from major maintenance operations, in the form of asphaltic concrete overlay, being undertaken before corrections were made to the faulty subgrade. Subgrade soil at this site consists of sand with some fines. The ground water table fluctuates with seasonal precipitation. Problems causing failure of initial pavement and later failure of asphaltic concrete overlay result from densification of sandy soil by traffic and fluctuating water table.

Variations in moisture content resulting from infiltration of runoff lagged rainfall occurrences by four to six weeks. This was particularly noticeable at highway shoulders. Fig 5.5 shows variations beneath the pavement at Site No. 4 which has open shoulders, resulting in high runoff infiltration. Sealed shoulders reduced infiltration, resulting in smaller variations beneath pavements as indicated by moisture variations at Site No. 3 (Fig 5.6). Effects of sealed shoulders may be seen by comparing variations in Figs 5.5 and 5.6. As shoulder widths increased, moisture variations under pavement centerlines were found to decrease and be less dependent on precipitation.



(a)

(b)

Figure 5.2a Transverse Crack Relative to Pavement Section at Site No. 13

Figure 5.2b Close-up of Same Transverse Crack in Overlay Pavement

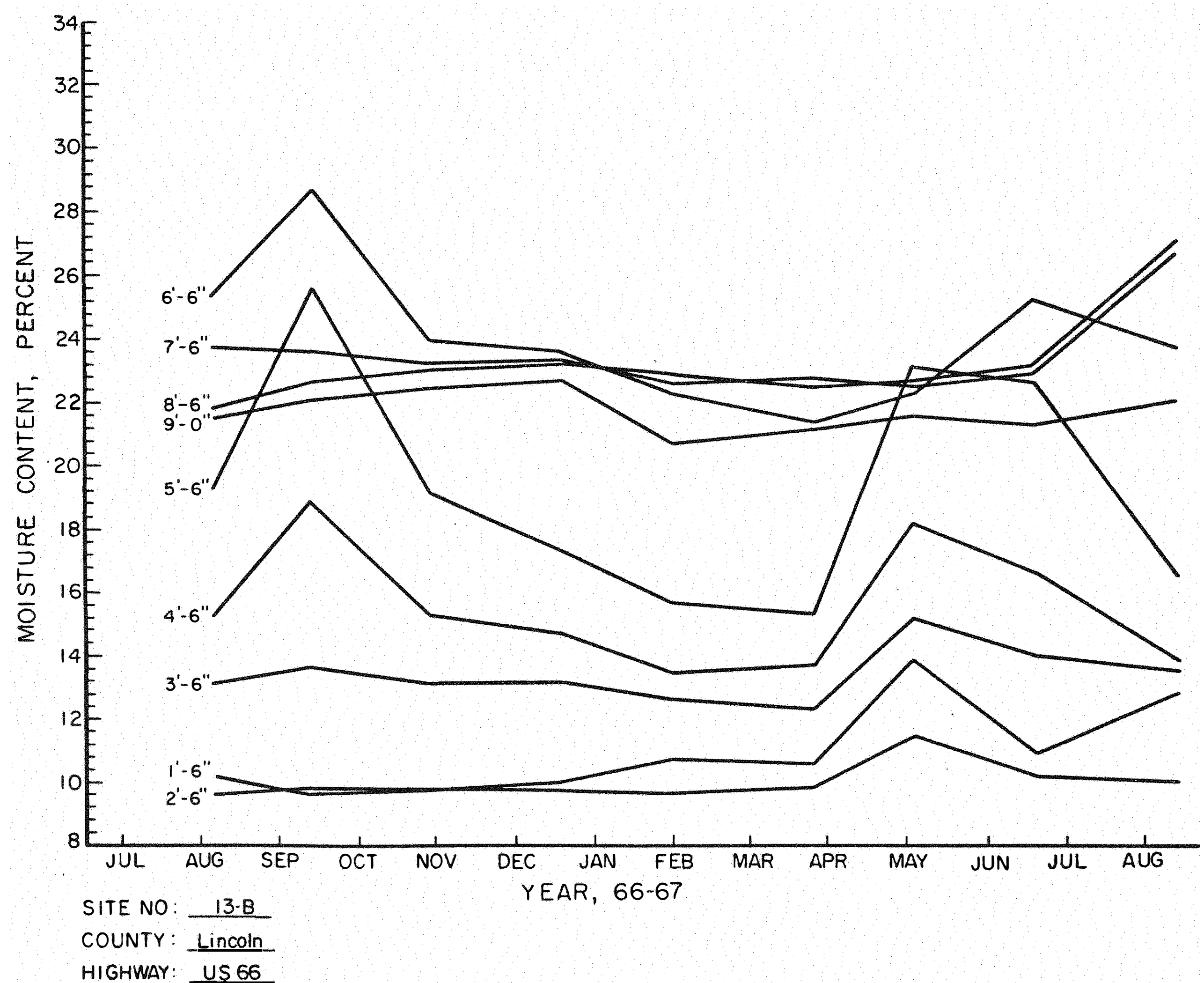


Figure 5.3 Moisture Variations Beneath Pavement Centerline at Site No. 13

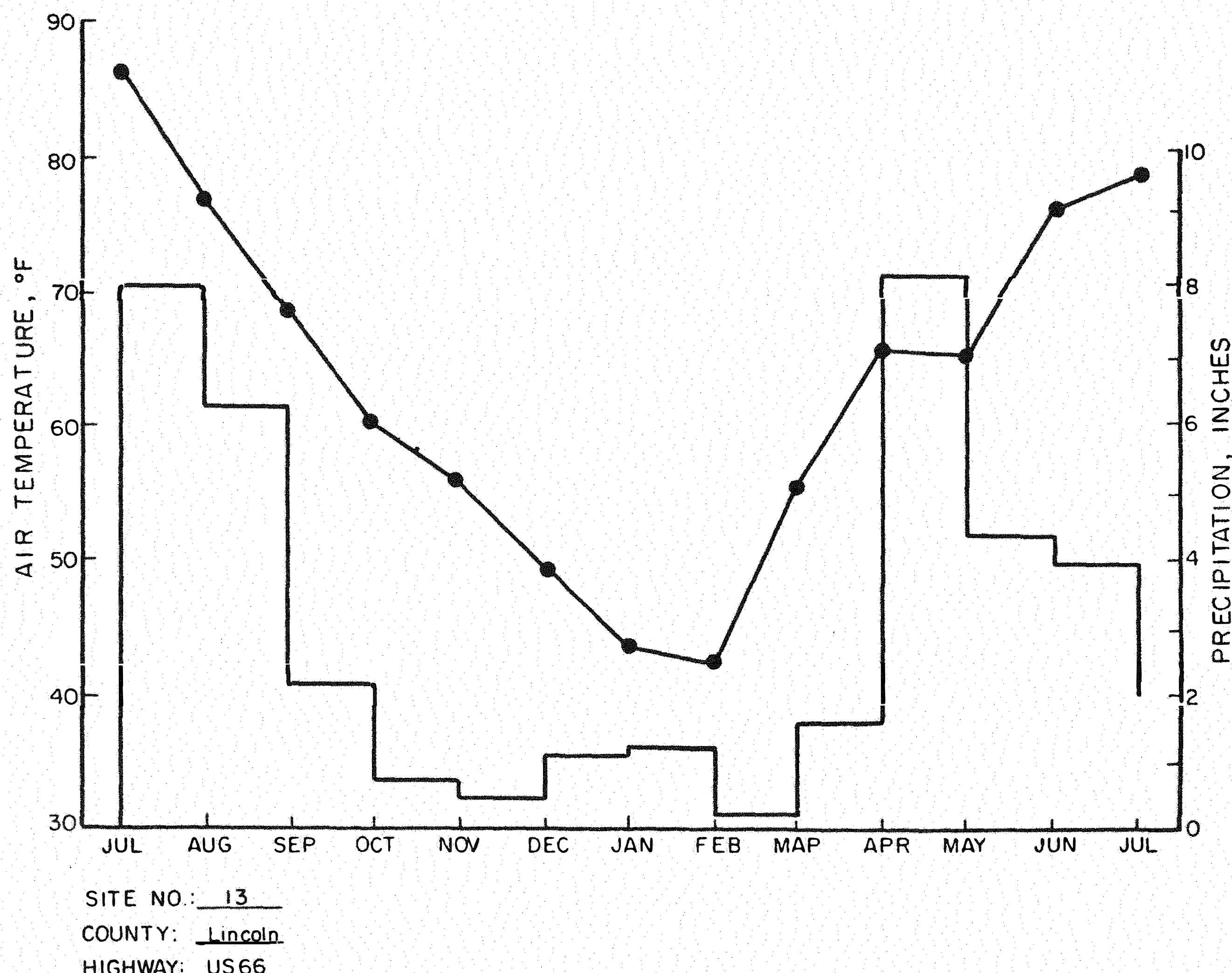


Figure 5.4 Climatological Data from Site No. 13

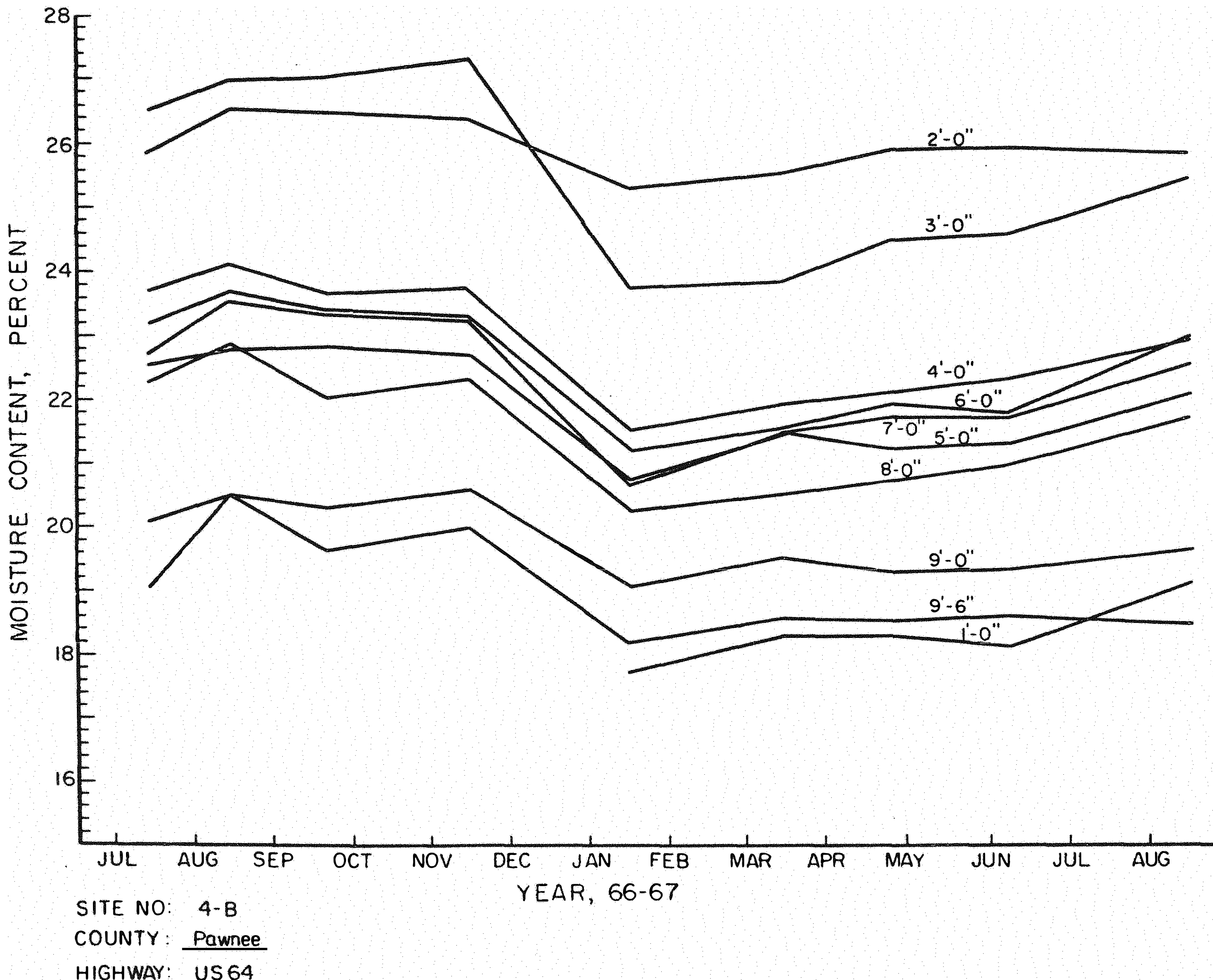


Figure 5.5 Moisture Variations Beneath Pavement
at Site No. 4

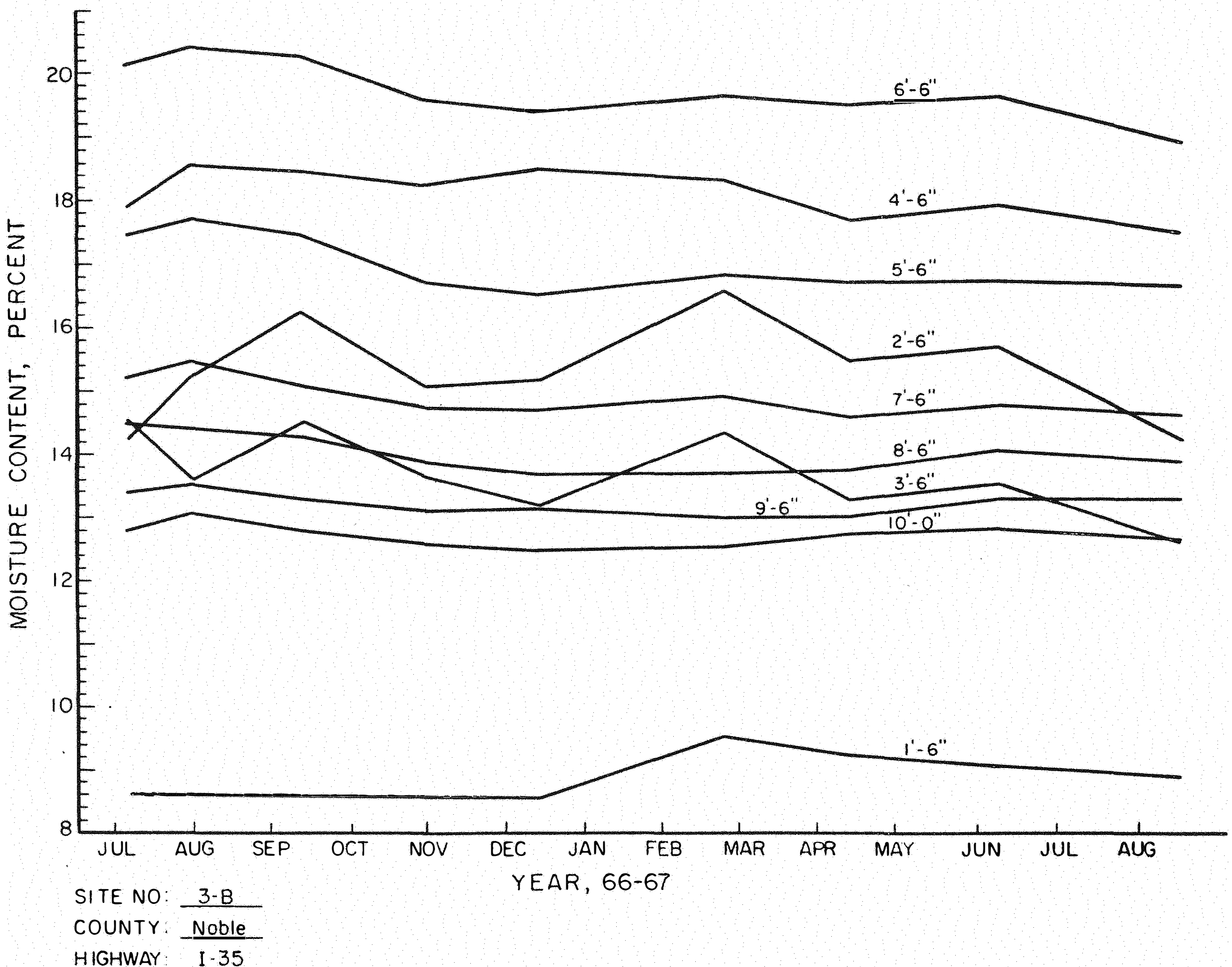


Figure 5.6 Moisture Variations Beneath Pavement at Site No. 3

Moisture contents in shoulders do not always increase as do those of subgrade soils under pavement. Phenomena such as those existing at Site No. 29 (Fig 5.7) often occur in fill sections. Moisture variations at this site indicate downward moisture migration in the shoulders. Moisture contents at shallow depths are decreasing while those at greater depths increase (Fig 5.8). As moisture content decreases with time, shoulders will shrink or settle. Subgrade soil used as a fill material is a clay soil of low plasticity but relatively large lineal shrinkage, as shown by the soil log at Site No. 29 (Fig 5.9). As moisture migration continues, shoulders will continue to creep away from the pavement, allowing direct infiltration of runoff into pavement subgrade. Such conditions may be prevented by placing fills at moisture contents equal to those of original subgrade soils. Moisture equilibrium between fill and original soil will reduce moisture migration, reducing settlement and maintenance problems.

Compacted sand base courses were found to be predominent beneath pavements with excellent ratings, regardless of age. Sand blankets may disperse moisture, preventing large infiltrations directly into subgrade soils. Compacted sand is capable of holding relatively large quantities of moisture by capillary action or tensile stresses. Runoff infiltration through pavement cracks and joints may be held by the sand and spread over the entire pavement cross-section, resulting in negligible effects of infiltration on subgrade soils. Moisture held by capillary forces is drawn from the sand by stronger forces of subgrade clayey soils. Distribution of moisture by sand base courses produce more nearly uniform moisture conditions in subgrade soils. In cases where sand base courses were present but pavements had not performed satis-

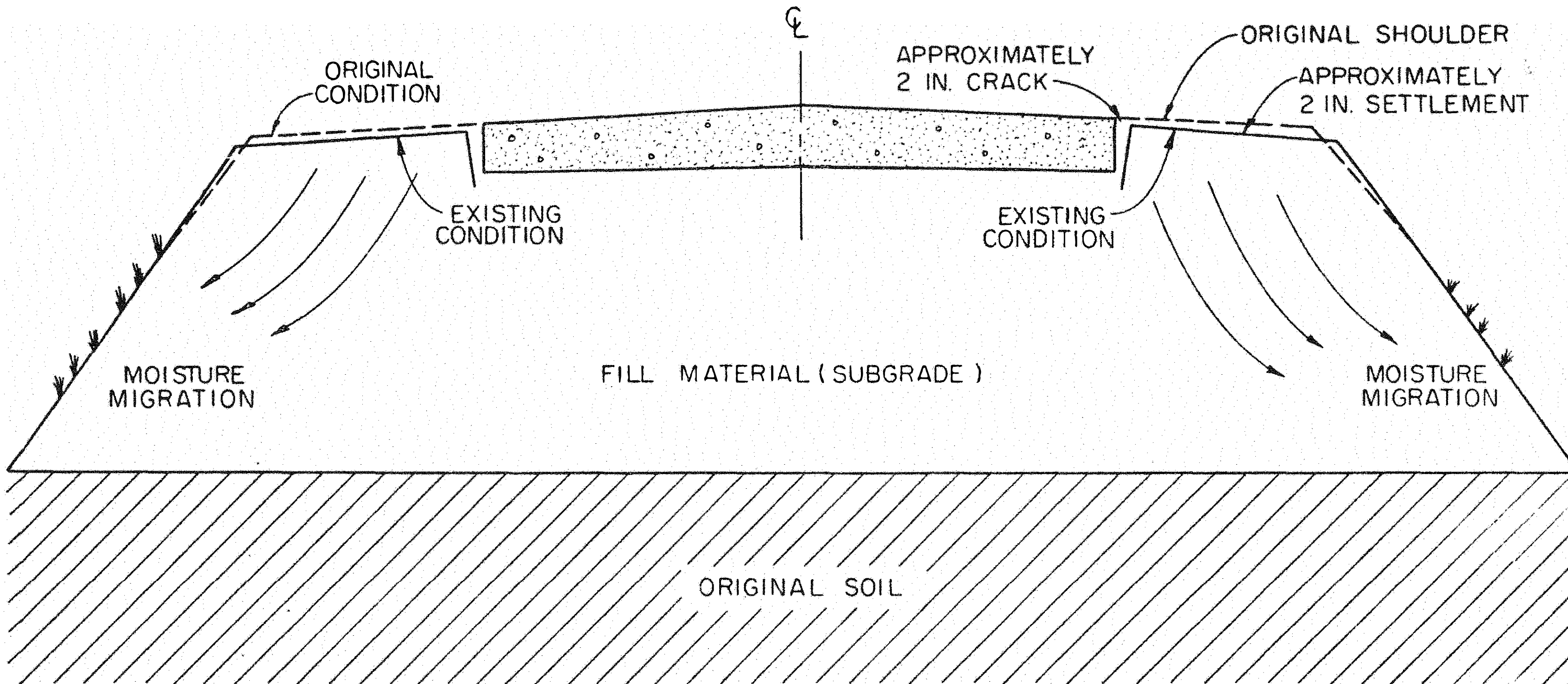


Figure 5.7 Shoulder Conditions Existing at Site No. 29

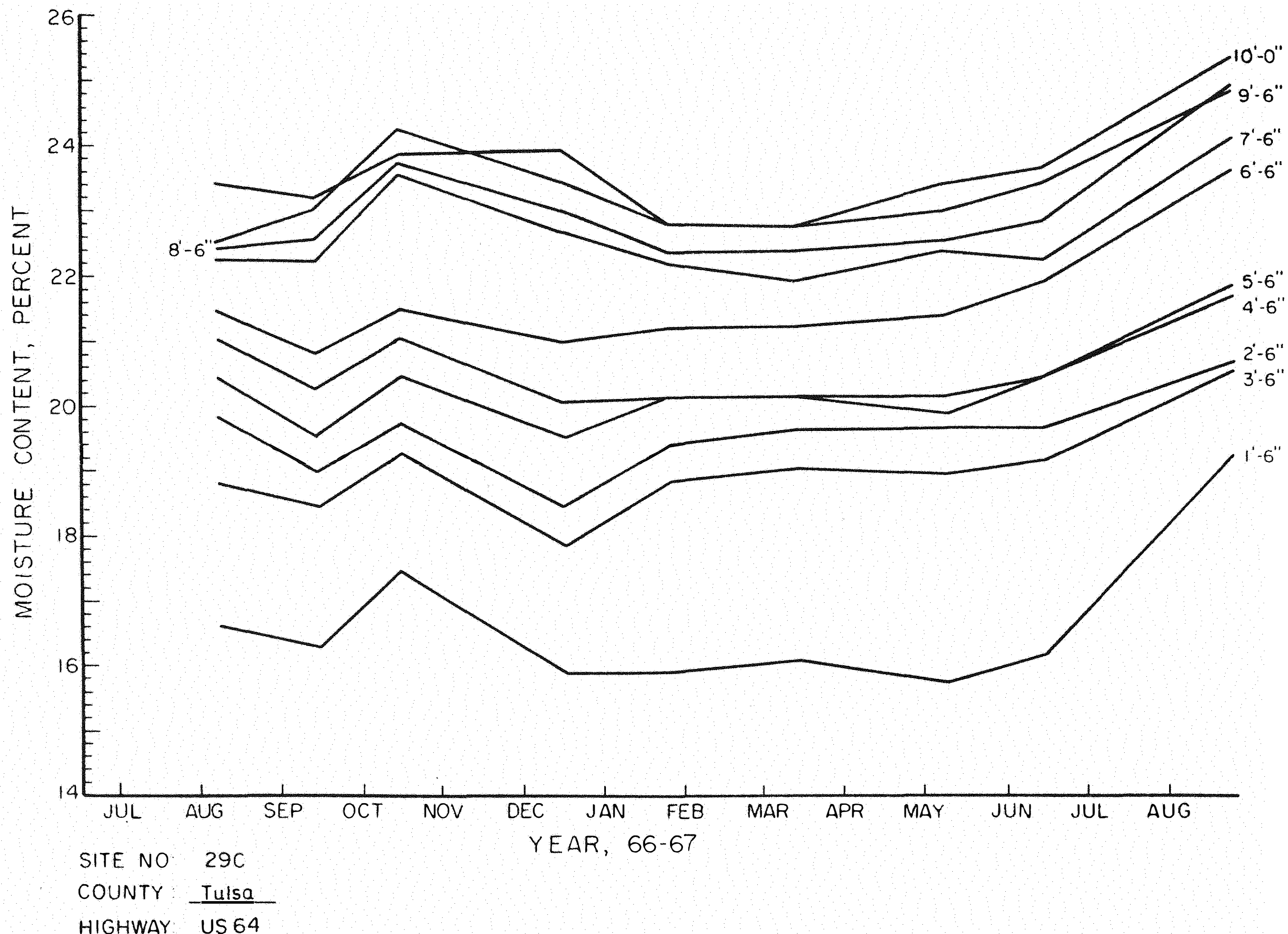


Figure 5.8 Moisture Variations in Shoulder at Site No. 29

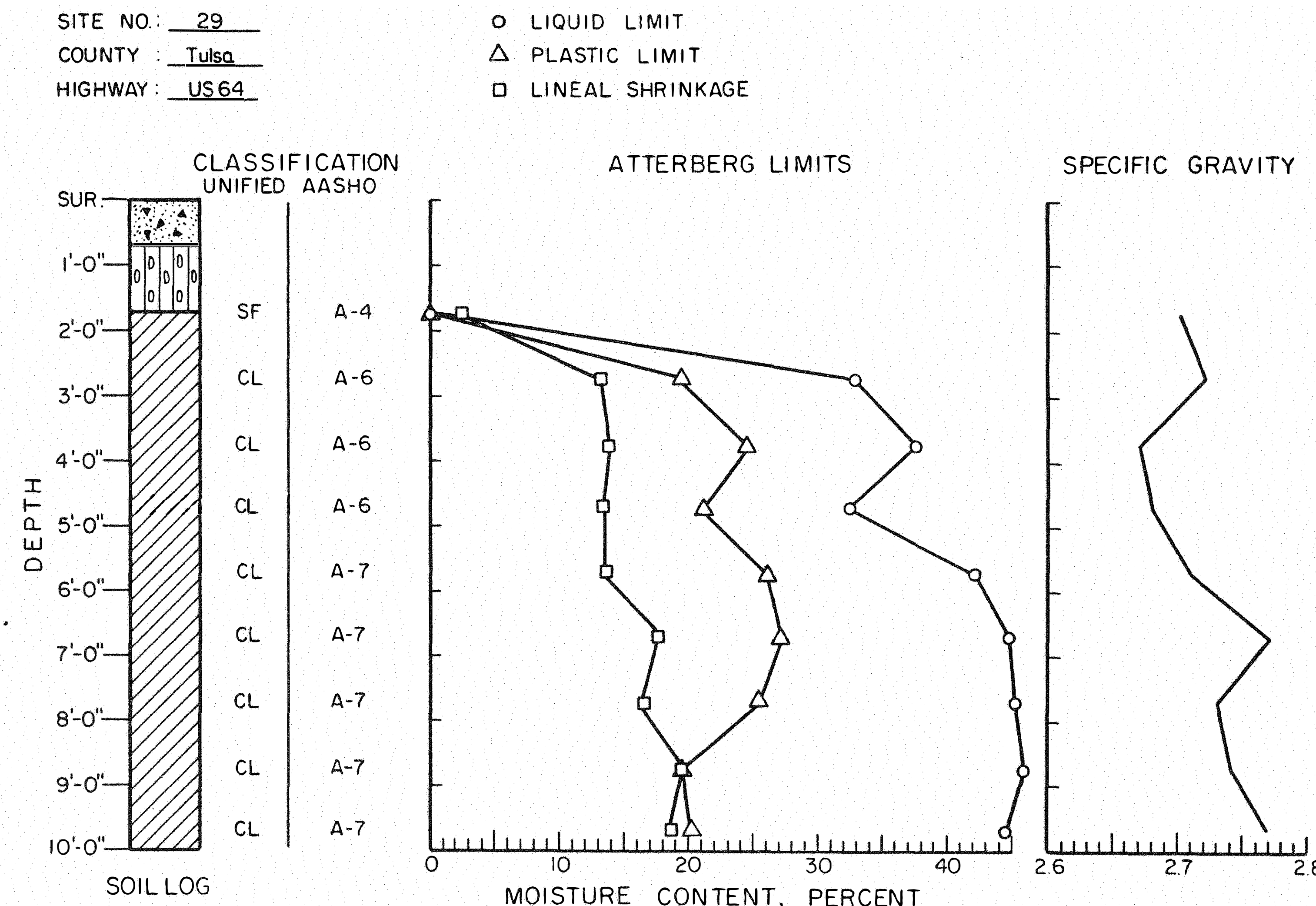


Figure 5.9 Soil Log from Site No. 29

factorily, subgrade soil was found to have intruded into the base course. Intrusion of soil, especially clay, into sand blankets increases moisture levels directly beneath the pavement. Conditions of this nature beneath portland cement concrete slabs result in "mud pumping". Asphaltic concrete pavements may show signs of rutting or complete failure. Sand base courses may produce adverse conditions if moisture is permitted to collect in the sand blanket from improperly designed shoulders. Site No. 28 is a very good example of improper use of sand blankets beneath pavement. Figure 5.10 indicates phenomena which occurred during site installation. The test site was installed the day after an evening rainstorm. Once holes were cored through the pavement, water flowed from the sand blanket directly beneath the pavement. Infiltration of rainwater had saturated the open shoulders resulting in formation of an artesian aquifer. Flow was estimated to be at least 2.0 cubic feet per minute. French drains or tile drains to remove moisture from the open shoulders during periods of large rainfall would solve problems such as those at Site No. 28.

Subgrade soil type was found to have no relation to subgrade moisture variations. Absence of any observed correlation of soil type to moisture changes may result from the presence of fairly uniform deposits of Permian and other Paleozoic clay soils in Oklahoma. Although these soils vary somewhat, their origin and stress history are similar.

Drainage conditions have effects on moisture variations at all sites. Pavements in good condition were associated with good drainage conditions for quick removal of surface runoff. Site No. 3, located on Interstate Highway 35, has typical interstate drainage conditions. Hole A of Site No. 3 is located near the median where runoff may

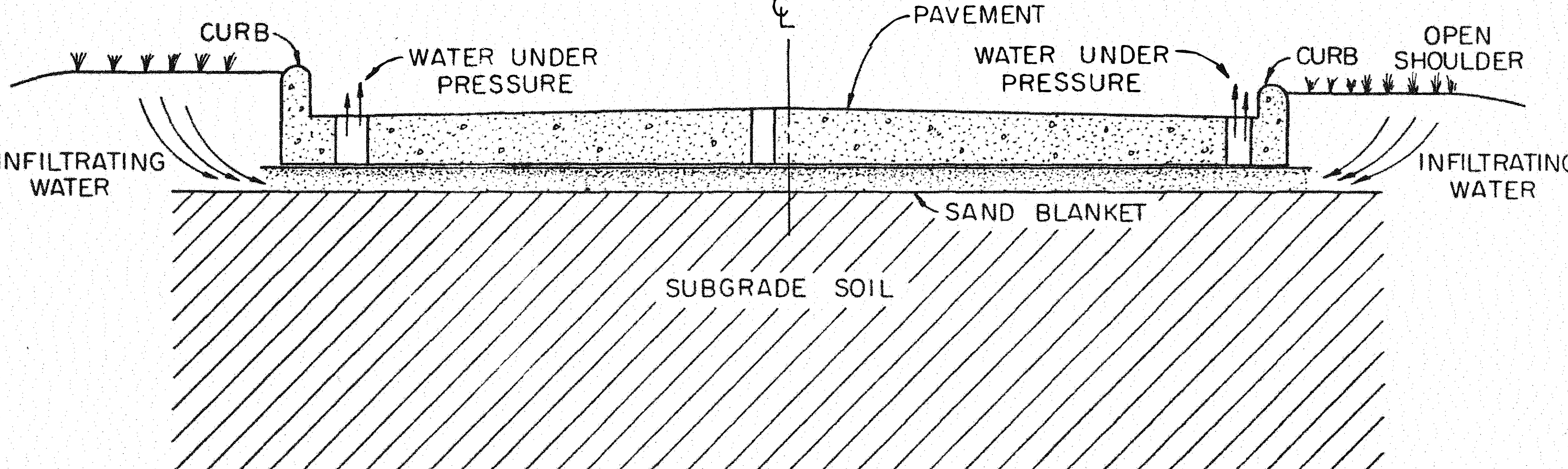


Figure 5.10 Conditions at Site No. 28 During Installation

collect and infiltrate into the shoulder. Moisture variations obtained from this hole (Fig 5.11) indicate the effect of infiltration. However, moisture conditions at Hole C, located on the outside shoulder where drainage is very good, are affected very little by rainfall, as indicated in Fig 5.12. Although drainage conditions at Site No. 3 are good, comparison of moisture variations at each shoulder (Figs 5.11 and 5.12) indicate the large effect of slight differences in drainage conditions on moisture variations.

Type of highway cross-section had some effect on subgrade moisture variations. Fill and transition sections were found to produce the worst moisture conditions, resulting in poor pavement ratings for these sections. Pavements constructed on grade or in slight cut sections had smaller moisture variations. Moisture conditions at eight to ten foot depths in these sections were found to be relatively constant. Based on these observations, it appears that moisture variations are reduced appreciably when initial moisture content of compacted subgrades is similar to the natural water content of existing soil. Moisture migration between subgrade and existing soils results from large differences in moisture contents of subgrades and existing soil. Moisture variations were found to be smallest in subgrade where average moisture contents were below the plastic limit and greatest in soils where moisture contents were within the plastic range.

The rate at which pavements are affected by moisture conditions was found in relating pavement age to pavement ratings or conditions. Pavements receiving excellent ratings were all constructed since 1960 as might be expected; however, several pavements constructed during this time period have shown signs of distress, indicating that adverse

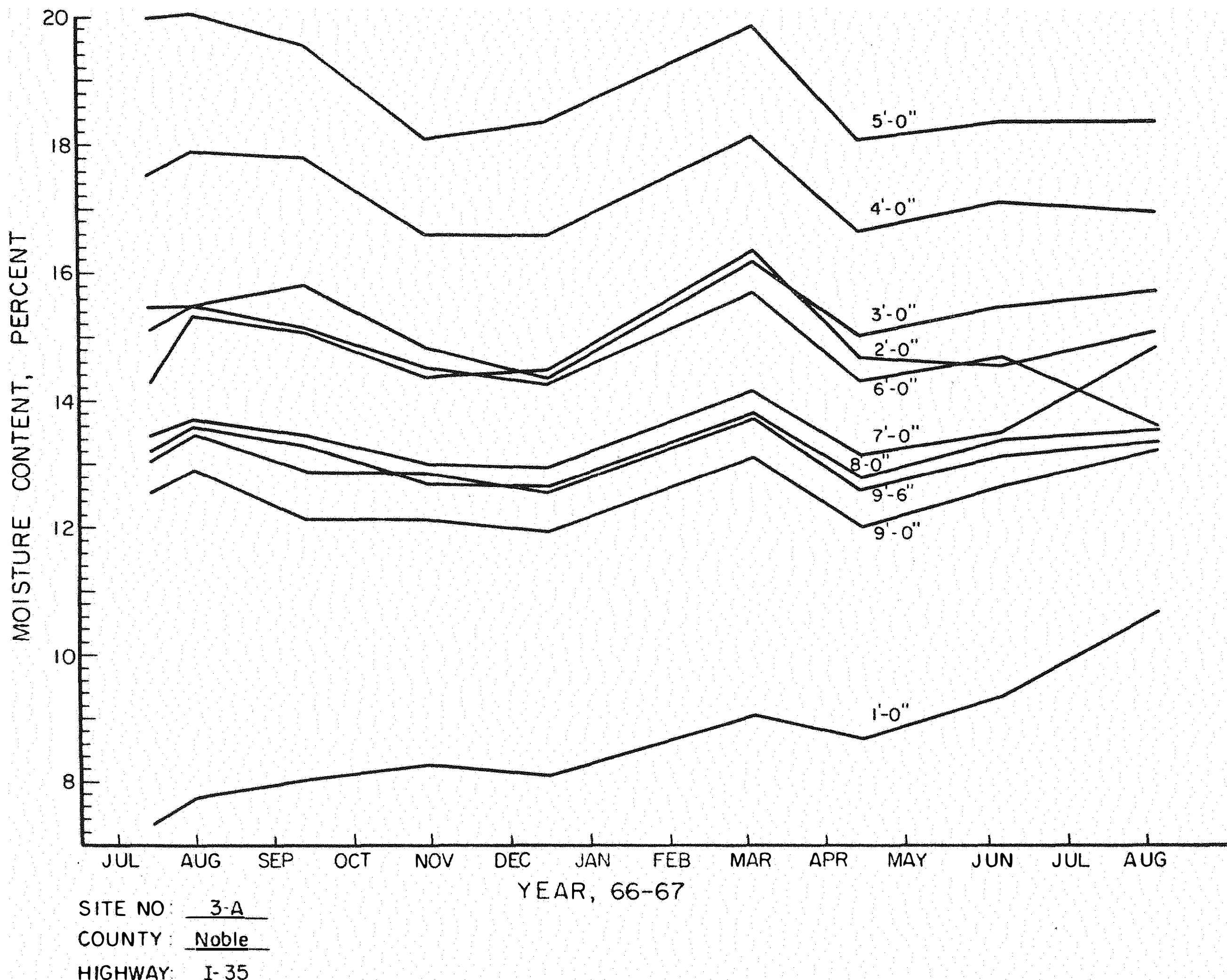


Figure 5.11 Moisture Variations in Shoulder
Near Median at Site No. 3

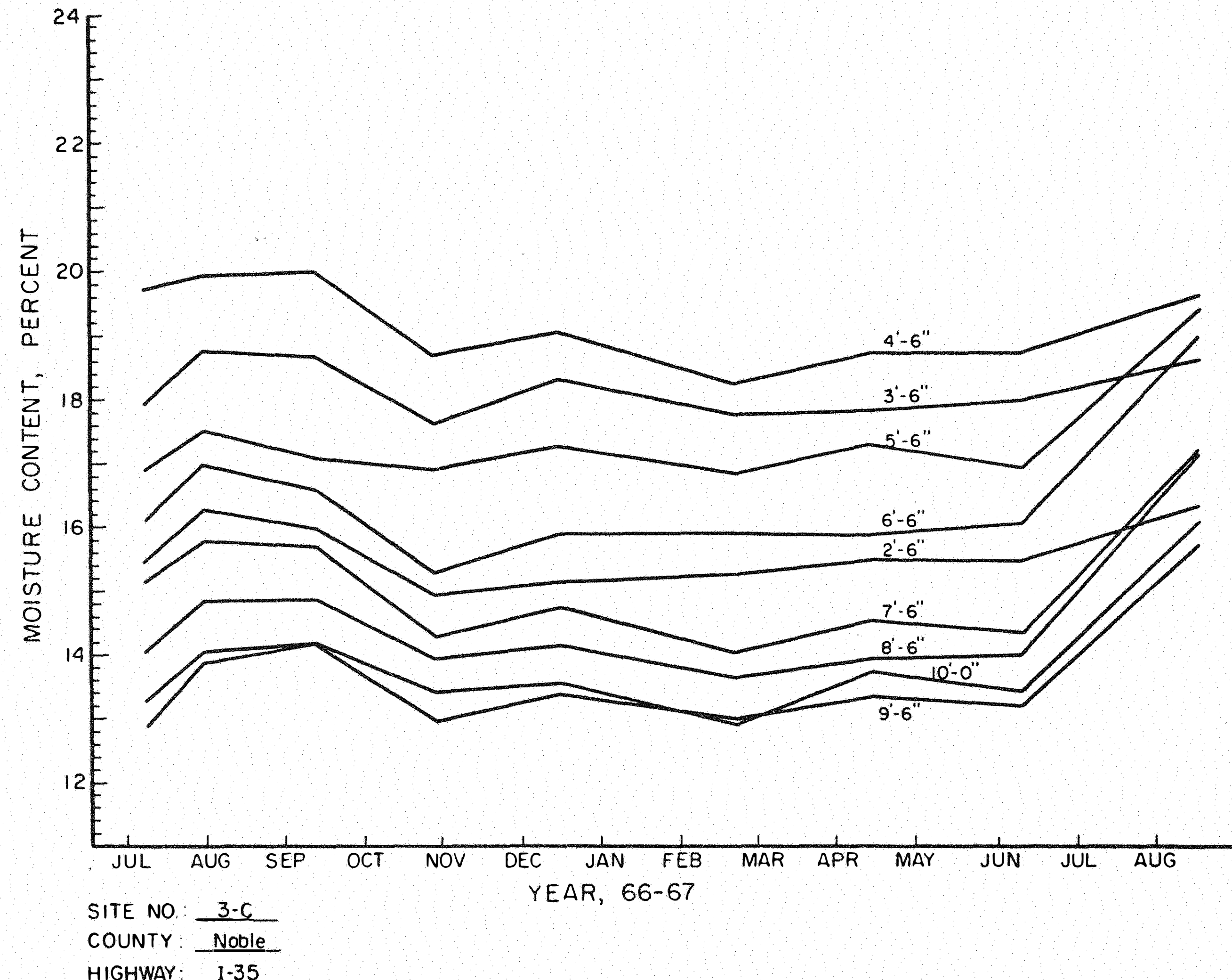


Figure 5.12 Moisture Variation in Outside Shoulder at Site No. 3

moisture conditions causing pavement failures are dependent on individual section conditions.

Traffic volume and truck traffic studies produced no relationships except the human factor involved. Pavements with good to excellent ratings showed very heavy traffic volumes, resulting from the selection of the best highway possible for passenger vehicle travel. Truck traffic, however, was found to be less selective about pavement conditions, indicating that destination and time controlled the selection of truck routes.

Dry density measurements obtained from test sites in conjunction with moisture data produced small variations which require some discussion. Dry density values were found to increase at a majority of sites during winter months. Average variations in density were from 4.0 pcf to 6.0 pcf with worst changes being as much as 10.0 pcf. Variations in dry density were strange in that one would assume dry density to decrease by a small amount in winter months as moisture content increased. Since variations were opposite to any anticipated changes in dry density, an investigation was made. Decrease of dry density in summer months was found to be the result of small air gaps around access tubes in the summer, resulting from decrease in moisture content and thus soil volume. Based on these conclusions, the dry density values obtained during winter months appear to be more nearly accurate.

Additional Considerations

Research Site No. 2, east of Stillwater, was modified to check the repeatability and accuracy of nuclear depth gages in the field. Modification involved the installation of two centerline access tubes.

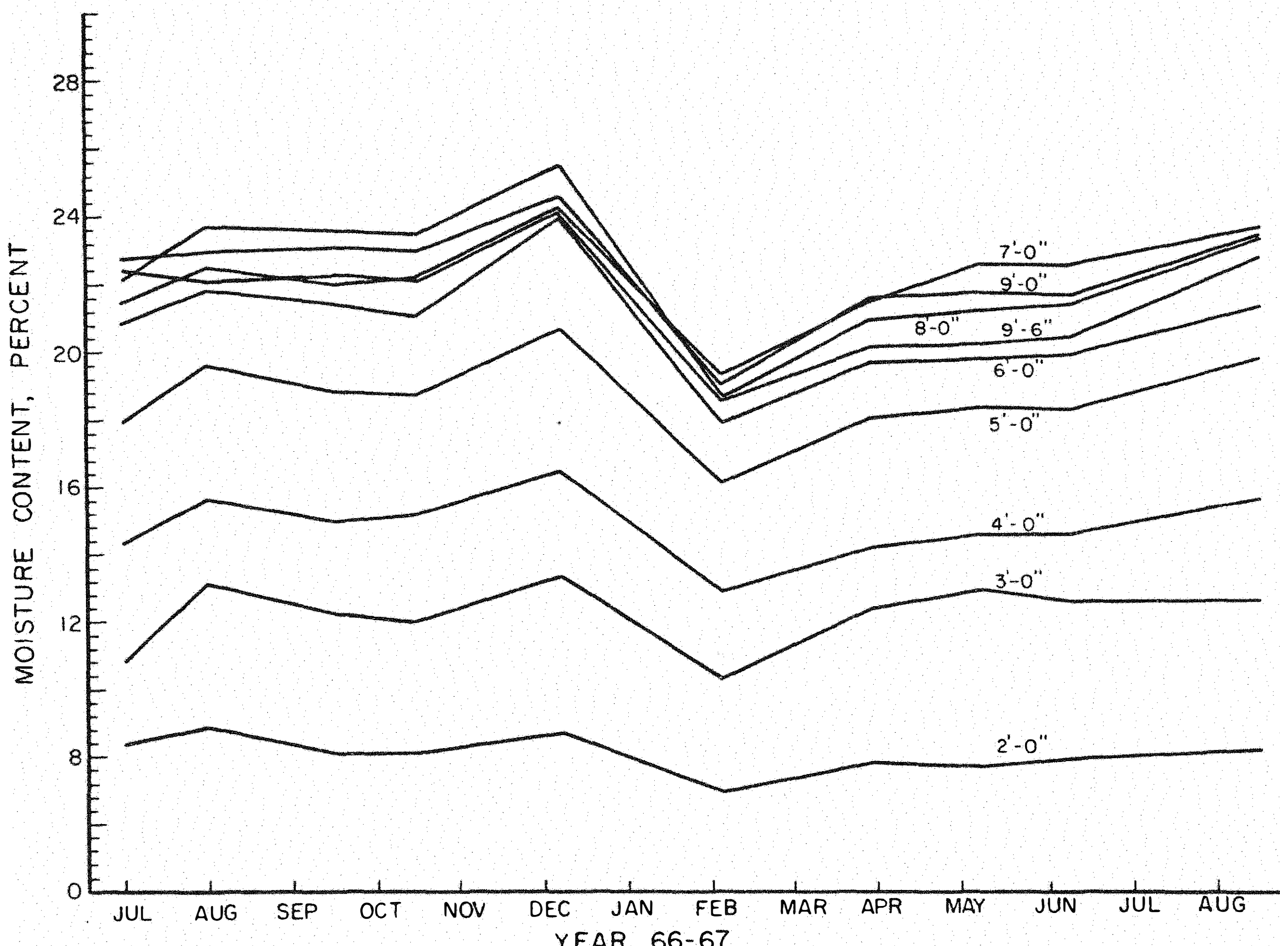
The tubes were located approximately ten feet apart, thus no appreciable soil type change was expected nor would either test hole interfere with measurements made at the other. Moisture variations are shown for each installation in Figs 5.13 and 5.14. Variations are practically identical for the two test holes, indicating that moisture and density depth gages may be used with confidence. Repeatability is also indicated by the moisture contents measured at ten feet below the pavement at Site No. 9 (Fig 5.15). Moisture content variations at this level are less than one percent as would be expected in the slight cut section beneath a wide sealed cross-section with good drainage.

Inspection of moisture variation data obtained from Site No. 14 indicated that this site should be abandoned. The site was located on an asphaltic concrete overlay pavement whose total thickness was 24 inches. Subgrade material was a fine sandy soil and the water table was very high. Large pavement settlements resulted in continuous maintenance operations, producing the thick pavement section. No moisture variations were found at this site after one year of data collection, thus the site was abandoned.

Site No. 18 was abandoned as a result of an unfortunate accident. Soil samples obtained from this site were destroyed during a subsequent site installation. A research site with incomplete soils data did not warrant continued cost of moisture and density measurements.

Summary

Data analysis procedures were discussed in this chapter, as were correlations which resulted from investigation of collected and compiled subgrade moisture variations research project data. Information



SITE NO: 2-B
COUNTY: Payne
HIGHWAY: State 51

Figure 5.13 Moisture Variations Beneath Pavement at Site No. 2, Hole B

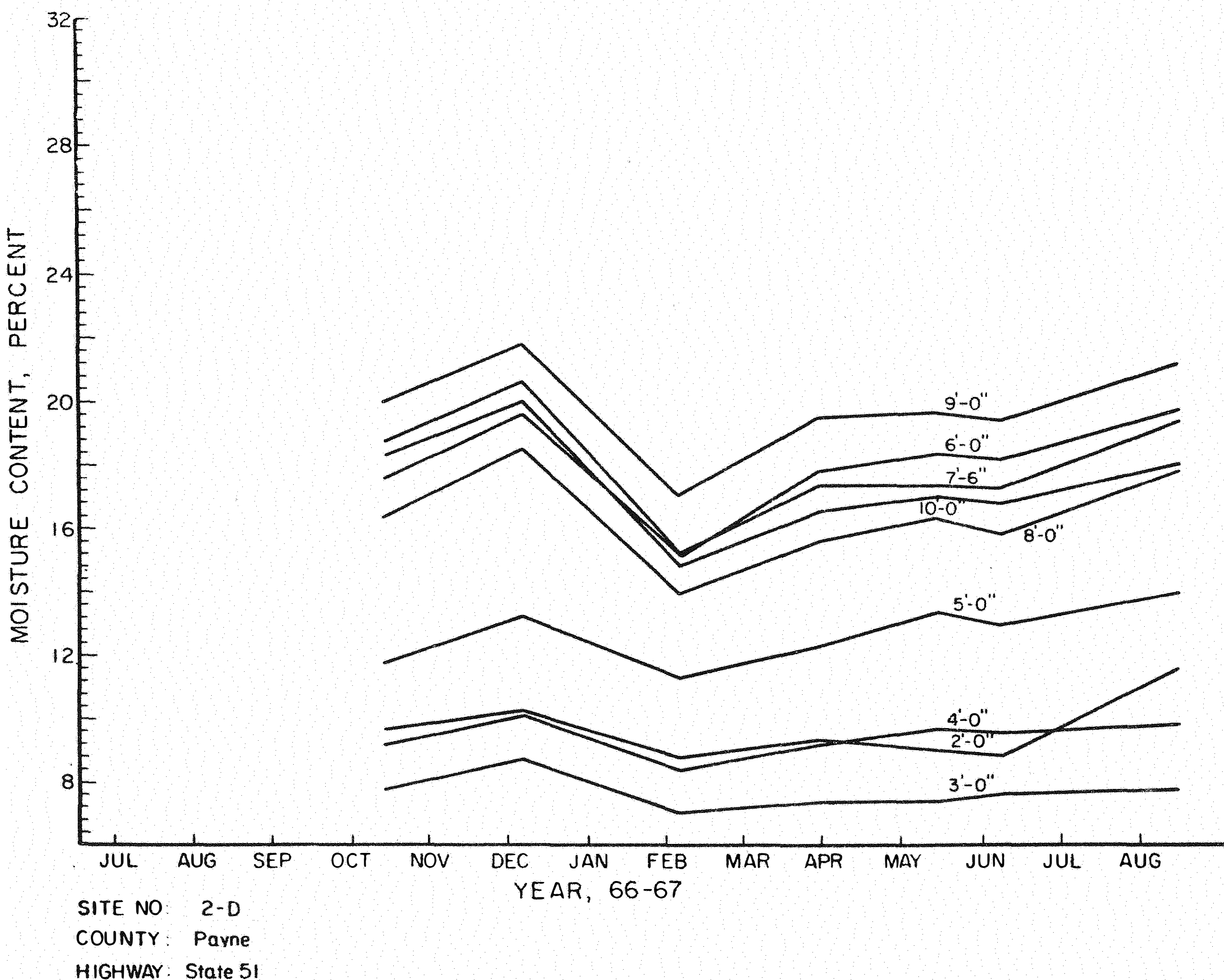
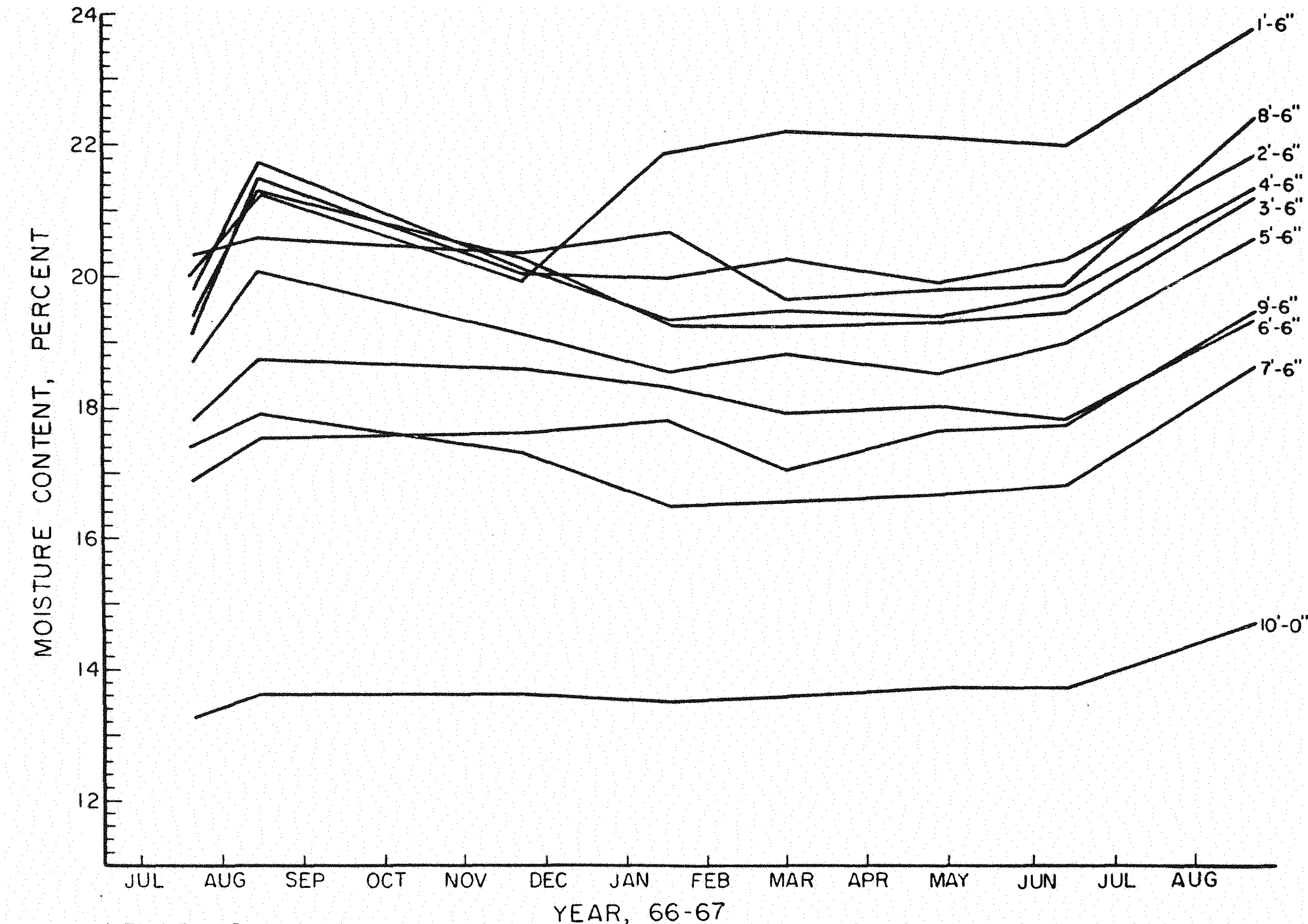


Figure 5.14 Moisture Variations Beneath Pavement at Site No. 2, Hole D



SITE NO: 9-A
COUNTY: Muskogee
HIGHWAY: US 62

Figure 5.15 Moisture Variations in Shoulder at Site No. 9

found during this research and of interest to highway design engineers was also presented in detail. Conclusions and recommendations based on relationships and trends found in correlation and evaluation of research data are presented in the following chapter.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Available data concerning moisture variations beneath Oklahoma highways have been compiled and correlated during this study. Correlation of related factors affecting subgrade moisture movement has produced relationships and trends of subgrade moisture behavior. From the analysis of data discussed in Chapter 5, the following may be concluded:

1. Most moisture variations occur beneath highway pavements on an annual cycle with maximum moisture contents occurring during winter months. Magnitude and frequency of variations are greatly affected by infiltration of runoff where pavements are not impervious.
2. Moisture variations resulting from infiltration, such as those found in shoulders and beneath most overlays, lag rainfalls by four to six weeks.
3. Subgrade moisture contents appear to be gradually increasing beneath pavements. No stable conditions were indicated by collected data except at sites where the ground water table was consistently high.
4. In cases where proper design and gradation of sand base courses were employed moisture variations resulting from infiltration were reduced, producing good pavement performance.

5. Good drainage conditions, necessary to remove runoff completely and quickly, reduce moisture variations from infiltration through shoulders.
6. Soil type was found to have no noticeable effect on subgrade moisture variations beneath Oklahoma highway pavements.
7. Volume changes associated with moisture variations were large enough to form air gaps around access tubes, thus reducing measured values of dry density in summer months.
8. Procedures employed by the Subgrade Moisture Variations research project for measurement of soil moisture by nuclear methods have proven to be accurate, dependable, repeatable, and economical.
9. Installation of field research sites has not been detrimental to highway pavements nor has it obstructed or reduced traffic volumes of pavement sections containing research sites.

With respect to future Subgrade Moisture Variations research, the following recommendations are made:

1. Instrumentation of selected research sites to record subsurface soil temperatures should produce additional information related to temperature controlled moisture migration.
2. Additional access tubes should be installed at some sites where wide pavement sections or wide sealed shoulders exist. These holes would produce information better relating amount of shoulder infiltration to moisture variations beneath pavements.
3. Subsurface bench marks (a rod inside an access tube) should also be installed at selected sites to determine relations

between pavement movements and subgrade moisture conditions. Results of these data should also help to clarify the effects of soil type on pavement performance.

4. Correlations between moisture conditions and soil type may be obtained from additional soil sampling at each site. Soil samples obtained from such a program should be of sufficient size to allow extensive testing.
5. Available information concerning highway design should be collected from the Oklahoma Department of Highways for proposed site locations prior to actual installation of future research sites.
6. None of the research sites from which data are presently being collected should be abandoned at this time.
7. Collected data should be reduced and compiled as quickly as possible to allow continuous investigation of site behavior.

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APPENDIX 1

RESEARCH SITE LOCATIONS

SITES 1-30

FIELD TEST SITE LOCATIONS, SITES NO. 1 - 30

Site No. 1

In Payne Co. northwest of Perkins, 0.3 mile north on US 177 from wye jct. of US 177 and S 33, adjacent to mileage sign indicating 10 miles from Stillwater. Marker on west fence row. Site on level upland

Site No. 2

In Payne Co. east of Stillwater, approximately 300 yds east on S 51 from GRDA sub-station. Site in rolling upland area. Marker on south fence row. GRDA sub-station is approximately 1.5 miles east of Stillwater on S 51.

Site No. 3

In Noble Co. northwest of Perry, 1.8 miles north on I 35 from jct. of I 35 and US 64. Site in east lane, approximately 100 yds south of "Tonkawa 31, Wichita 101" mileage sign. Marker on east fence row. Site on open, gently rolling upland terrain.

Site No. 4

In Pawnee Co. southeast of Pawnee, 4.8 miles east on US 64 from Oklahoma Highway Department division yard on outskirts of Pawnee, ¼ mile east of bridge over Bear Creek, ¼ mile west of Santa Fe railroad bridge overpass. Marker on south fence row. Site in creek-bottom area.

Site No. 5

In Osage Co. northeast of Pawhuska, 1.5 miles southwest on US 60 from jct. of US 60 and S 99, approximately 100 ft southwest of US 60 - S 99 route marker facing southwest. Marker on northwest fence row. Site on open upland terrain.

Site No. 6

In Washington Co. east of Bartlesville, 6.2 miles east on US 60 from jct. of US 60 and US 75, approximately 200 yds west on US 60 from Hog Shooter Creek. Site on fill section in creek-bottom area. Marker on south fence row.

Site No. 7

In Craig Co. west of Vinita, 0.6 mile east on US 66-60 from wye jct. of US 66 and US 60. In south lane of divided highway, approximately 30 ft west of entrance to Martin ranch. Marker on south fence row. Site on open, gently rolling upland terrain.

Site No. 8

In Mayes Co. south of Pryor, 0.2 mile north on US 69 from jct. of US 69 and US 69A. Approximately adjacent to billboard facing north on west side of highway. Marker on east fence row. Site on open, fairly level upland terrain.

Site No. 9

In Muskogee Co. northeast of Muskogee, in west-bound lane of US 64 0.7 mile west from Arkansas River bridge. Marker on north fence row. Site in rolling upland area.

Site No. 10

In Okmulgee Co. north of Okmulgee, 2.0 miles north on US 75 from railroad crossing, end of divided highway, and Okmulgee north city limit. Site in west lane of divided highway, marker on west fence row. Site on upland terrain in slight cut.

Site No. 11

In Creek Co. west of Sapulpa, 1.3 miles east on US 66 from jct. of US 66 and S 33, adjacent to an "Animal Clinic". Marker on south fence row. Site in creek-bottom area.

Site No. 12

In Creek Co. north of Bristow, 2.6 miles north on US 66 from jct. of US 66, S 48, and S 16, 0.3 miles north of bridge over Sand Creek. Marker on west fence row. Site on upland terrain in slight cut.

Site No. 13

In Lincoln Co. west of Chandler, 0.8 mile west on US 66 from jct. of US 66 and S 18, 200 ft west of Champlin service station. Marker on south fence row. Site in rolling hilly terrain.

Site No. 14

This site has been abandoned.

Site No. 15

In Osage Co. east of Ponca City, 1.6 miles east of US 60 from jct. of US 60, S 11, and US 177. Marker on north fence row. Site on level upland terrain.

Site No. 16

In Nowata Co. east of Nowata, 0.3 mile south on S 28 from jct. of US 60 and S 28. Marker on west fence row. Site on upland terrain.

Site No. 17

In Ottawa Co. north of Miami, 2.5 miles north on US 69 from jct. of US 66, US 69, and S 10, adjacent to Sacred Heart Catholic Church. Site on four-lane undivided highway, marker on east fence row. Site on level upland terrain.

Site No. 18

This site has been abandoned.

Site No. 19

In Wagoner Co. north of Wagoner, 3.9 miles north on US 69 from jct. of US 69 and S 51, 100 yds south of east-west powerline crossing. Marker on east fence row. Site on upland terrain.

Site No. 20

In Tulsa Co. northwest of Broken Arrow, 0.5 mile northwest on S 51 (Broken Arrow Expressway) from Lynn Lane overpass and exit. Site in north lane of divided highway, north of unusual church. Marker on north fence row. Site on rolling upland terrain.

Site No. 21

In Garfield Co. on the northwest edge of Enid, 100 yds north of Atwood's Farm and Home Supply store on US 81. Marker on west fence row. Site in upland area.

Site No. 22

In Kingfisher Co. south of Hennessey, 3.9 miles south on US 81 from jct. US 81 and S 51. Marker on west fence row. Site in slight cut on rolling upland terrain.

Site No. 23

In Rogers Co. north of Talala, 1.6 miles north of Talala city limit on US 169. Approximately 100 yds north of beginning of portland cement concrete pavement with improved shoulders. Marker on west fence row. Site on level upland terrain.

Site No. 24

In Rogers Co. southwest of Claremore, 1.5 miles southwest on US 66 from jct. of US 66 and US 66 truck route. Site in southeast lane of divided highway, marker on southeast fence row. Site on upland terrain.

Site No. 25

In Osage Co. east of Barnsdall, 1.4 miles east from jct. of S 11 and S 123. Approximately 50 yds east of bridge. Marker on north fence row. Site in creek-bottom area.

Site No. 26

In Pawnee Co. southeast of Cleveland, 2.4 miles southeast on US 64 from jct. of US 64 and S 99, 0.5 mile southeast of Cleveland drive-in theater. Marker on southwest fence row. Site on hilly upland terrain.

Site No. 27

In Logan Co. northeast of Guthrie, 6.0 miles north on I 35 from jct. of I 35 and S 33. Approximately 100 yds south of overpass. Site in west lane of divided highway. Marker on west fence row. Site in slight cut on rolling, upland terrain.

Site No. 28

In Payne Co. east of Cushing, 1.5 miles east on S 33 from jct. of S 33 and S 18, at end of four-lane undivided highway. Marker on north fence row. Site in creek-bottom area.

Site No. 29

In Tulsa Co. southeast of Bixby, 5.5 miles south and east on US 64 from jct. of US 64 and S 67, 0.8 mile east of bridge over Snake Creek. Marker on south fence row. Site on slight fill in creek-bottom area.

Site No. 30

In Tulsa Co. east of Sand Springs, 0.5 mile east on US 64 from US 64 - S 151 overpass, 100 ft east of "Keystone Dam - ST 51" exit sign. Site in north lane of divided highway ½ mile north of Arkansas River, marker on north fence row. Site on slight fill in Arkansas River bottom.

APPENDIX 2

PAVEMENT RATING SYSTEM

PAVEMENT RATING PROCEDURE

The Oklahoma Department of Highways used conventional procedures to rate highway pavement and shoulders for use in this research study. Their method consisted of a visual inspection and evaluation of pavement and shoulder surfaces, based on type and total number of surface defects. Profilometer and Benkleman beam data were not collected.

Ratings are expressed as a percentage with 100% being perfect. Excellent pavements rate from 90-100%, while lesser ratings of good (80-90%), fair (65-80%), and poor (50-65%) are also assigned. Major defects which affect pavement rating are

1. number of patches,
2. surface cracking,
3. raveling in flexible pavement,
4. localized base failures,
5. mud or water pumping by rigid pavement,
6. faulting or differential vertical displacement of rigid pavement,
7. corner breaks on rigid pavement, and
8. spalling or chipping at rigid pavement joints.

Shoulders are rated in similar manner, though total number and type of defects may be less on wide shoulders.

Additional information concerning actual methodology may be obtained from the Oklahoma Department of Highways, Research and Development Division, Jim Thorpe Building, Oklahoma City, Oklahoma.

APPENDIX 3

CODING AND INPUT SCHEME FOR DATA CORRELATION

MECHANICAL DATA SORTING PROCEDURE

Organization and basis for the data analysis sorting procedure of this report was more the result of engineering judgement than routine sorting procedure. Data for each site were organized as tabulated on the following pages. Categories 1-10 were selected initially as being the most logical factors influencing measured moisture changes.

Data from the first 10 categories were sorted in a systematic manner. As the evaluation process began to produce various relationships, additional categories (11-19) were added to substantiate, clarify, or refute initial correlations. Thus the order of categories 11-19 reflects only the sequence in which additional data were required to further examine relationships found in initial sorting.

The numbering sequence for various test site conditions is shown in Table A3.1, while the standard input format for IBM card data coding is shown in Fig A3.1. Each IBM card contained all data conditions for one field test site. Correlations were established by sorting with an IBM 709 mechanical card sorter.

DATA CODING SYSTEM

I. Type of Pavement

1. Portland cement concrete
2. Asphaltic concrete
3. Asphaltic concrete overlay on portland cement concrete

II. Type of Shoulders

1. Improved
2. Open

III. Base Material

1. Stabilize aggregate base course
2. Sand base course
3. No base other than natural material

IV. Unified Subgrade Soil Classification

1. CL - clay with low plasticity
2. CH - clay with high plasticity
3. SF - sand with some fines
4. ML - inorganic silts of low plasticity
5. SP - sand, poorly graded, fairly clean

V. Typical Cross-section

1. Cut
2. Fill
3. Grade
4. Transition

VI. Pavement Rating

1. Excellent
2. Good
3. Fair
4. Poor

VII. Shoulder Rating

1. Excellent
2. Good
3. Fair
4. Poor

VIII. Maximum Rainfall Occurrence

1. April
2. May
3. June
4. July
5. August
6. September
7. October
8. November
9. December

IX. Maximum Moisture Occurrence at Centerline

1. Constant
2. September
3. October
4. November
5. December
6. January

7. February
8. March
9. April

X. Drainage Conditions

1. Good
2. Fair
3. Poor

XI. Liquid Limit

1. Below 20%
2. 20% to 30%
3. 30% to 40%
4. Above 40%

XII. Plastic Limit

1. Below 10%
2. 10% to 20%
3. Above 20%

XIII. Specific Gravity

1. 2.60 - 2.65
2. 2.65 - 2.70
3. 2.70 - 2.75
4. 2.75 - 2.80

XIV. Maximum Moisture Occurrence at Hole A

1. August
2. September
3. October
4. November
5. December

6. January
7. February
8. March
9. April
10. May

XV. Maximum Moisture Occurrence at Hole C

1. August
2. September
3. October
4. November
5. December
6. January
7. February
8. March
9. April
10. May

XVI. Date of Completion

1. 1930 - 1940
2. 1940 - 1950
3. 1950 - 1960
4. 1960 to present

XVII. AASHO Subgrade Soil Classification

1. A-1
2. A-2
3. A-3
4. A-4
5. A-5

6. A-6

7. A-7

XVIII. Traffic Volume (ADT)

1. Very heavy: over 8000

2. Heavy: 5000-8000

3. Medium: 3000-5000

4. Light: 1000-3000

5. Very Light: less than 1000

XIX. Truck Traffic

1. Heavy

2. Medium

3. Light

Site No.	Pavement Type	Shoulder Type	Base Material	Unified Subgrade Classification	Cross-section	Pavement Rating	Shoulder Rating	Maximum Rainfall Occurrence	Max. Moist. Occurrence at Center Line	Drainage Condition	Liquid Limit	Plastic Limit	Specific Gravity	Max. Moist. Occurrence at Hole A	Max. Moist. Occurrence at Hole C	Date of Completion	AASHO Classification	Traffic Volume	Truck Traffic
1	1	2	2	4	3	1	4	4	1	3	2	2	2	1	7	1	4	4	3
2	3	1	2	3	4	2	1	4	5	1	1	1	1	1	5	3	3	3	2
3	2	1	1	2	3	1	1	4	1	1	3	2	3	8	2	4	4	4	1
4	3	2	2	1	3	4	4	6	4	2	3	2	3	4	2	1	6	1	2
5	2	2	1	1	4	4	4	6	4	1	3	2	1	2	2	4	6	4	2
6	1	2	2	1	2	2	4	2	4	2	3	2	2	1	0	1	6	4	1
7	3	1	1	1	1	2	1	5	7	1	4	3	4	1	1	4	6	3	2
8	3	1	1	1	3	4	2	5	3	1	4	3	2	8	1	4	7	2	1
9	1	1	2	2	1	1	1	1	1	1	4	2	3	1	1	3	7	1	1
10	2	3	2	1	1	2	3	1	1	1	2	2	3	1	1	4	6	2	2
11	2	1	2	5	3	1	3	5	1	2	1	1	2	9	9	3	3	2	1
12	2	1	2	1	3	1	1	2	5	2	3	2	3	5	5	4	6	3	2
13	3	2	2	5	2	3	1	4	2	2	1	1	2	1	2	3	3	4	3
15	1	2	2	3	1	1	1	6	4	1	2	2	2	7	4	3	4	3	1
16	2	1	1	1	2	1	1	5	7	1	3	3	3	4	9	2	6	5	3
17	2	1	1	1	3	3	2	4	7	2	3	2	3	7	6	3	6	1	1
19	3	1	2	1	3	2	1	5	5	1	2	3	4	1	1	4	4	2	1
20	2	1	2	1	1	1	1	6	1	1	3	2	4	5	5	4	6	1	1
21	1	3	2	1	3	1	1	5	4	2	3	2	3	5	3	3	6	4	2
22	2	1	1	5	3	2	1	4	1	1	1	1	3	5	5	3	3	3	1
23	1	1	1	1	3	1	1	5	1	1	4	3	4	0	8	4	7	4	2
24	1	3	2	1	3	1	2	5	5	1	3	3	4	5	5	3	7	1	1
25	3	2	2	1	1	4	2	6	4	2	3	2	4	4	4	1	6	5	2
26	1	1	2	5	4	1	1	6	4	1	3	2	3	2	4	4	6	4	2
27	1	1	1	2	1	2	1	3	4	1	4	3	3	3	3	4	7	1	1
28	3	2	2	1	2	4	1	5	4	2	3	2	3	4	4	4	6	3	2
29	1	1	2	1	2	1	1	1	3	1	3	3	3	3	3	4	6	2	1
30	1	1	2	3	2	1	1	6	1	1	1	1	2	4	4	4	4	4	3

Table A3.1 Input Data for Each Research Site

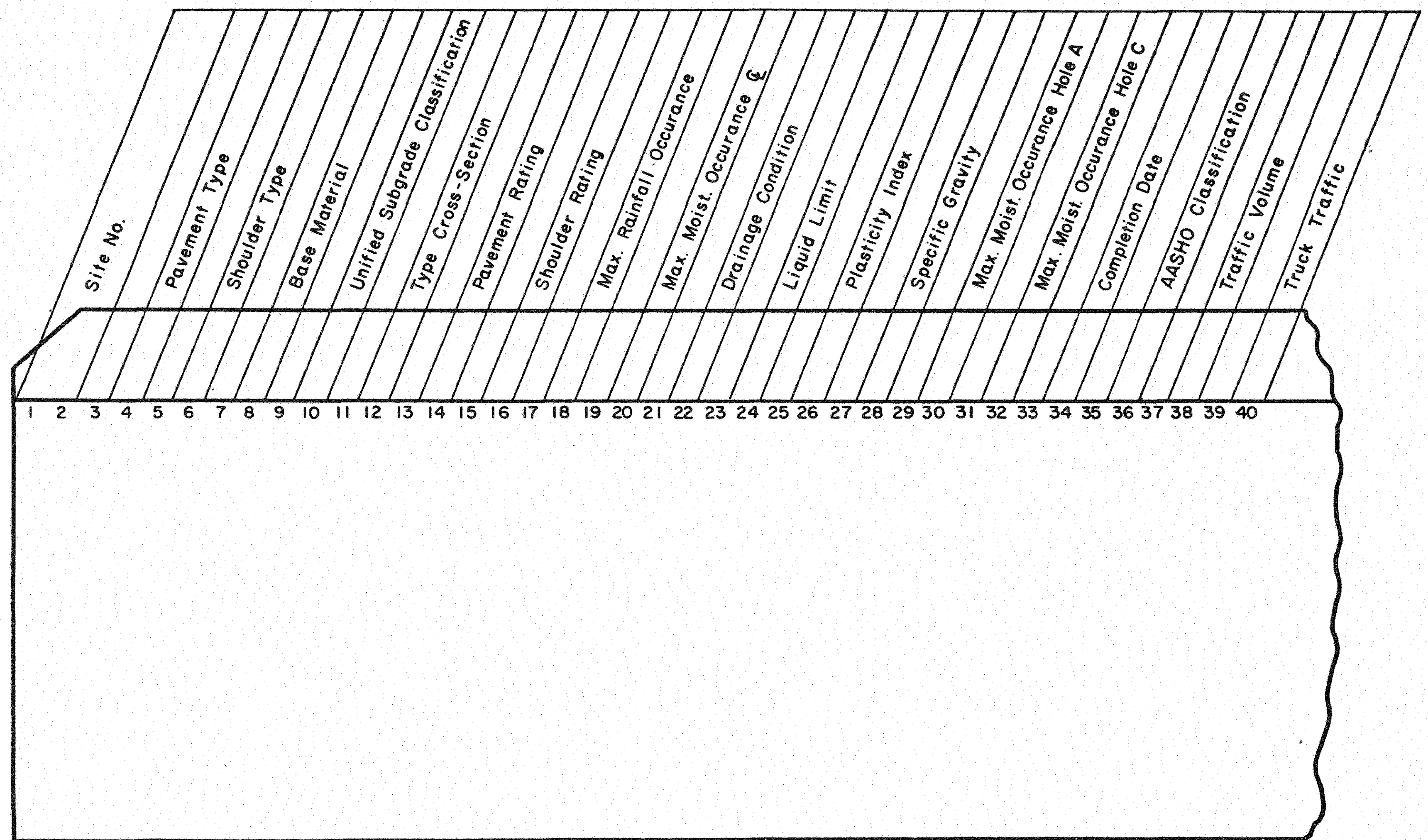

Figure A3.1 IBM Card with Coded Data Locations