exposed to sufficient moisture melts and runs together, possibly seriously and permanently damaging a well constructed top course and prime.

3. The natural bonding action is preserved and the base strengthened (especially when there is calcium chloride in both courses) by eliminating much of the repeated sprinkling made necessary by rapid evaporation of moisture by the sun. This repeated sprinkling leaches the binder clay toward the bottom and leaves a sandy brittle surface crust to receive the prime. The calcium chloride treated base tends to restore these binders through capillarity, and is in a better condition to shed water during a rain and, consequently, is easier to maintain in shape.

Accelerates Seasoning Processes:

Presence of constant moisture causes milky mineral gels to exude from most rock fragments. These gels form a small film of natural cement on the surface of the soil particles which, together with continued shrinkage compaction, greatly enhances the structural stability of the base course. Calcium chloride promotes and accelerates this action.

Extends Some Benefits to Both Courses:

Calcium chloride in solution with the moisture of the bottom layer of the base course will migrate to some extent to the top layer through capillarity and rising vapors. This will tend to improve the top course even after the bituminous surface is placed and will accelerate the knitting together of the base and the surface mat.

Affords Freeze Protection:

Decreased soil moisture film thicknesses and increased consolidation, together with the brine action, lower the susceptibility of the base to freeze damage during severe winter weather. This function is an advantage particularly during the first winter.

PROGRESS REPORT OF SPECIAL PROJECT ON STRUCTURAL DESIGN OF NONRIGID PAVEMENTS

SURVEY OF SUBGRADE MOISTURE CONDITIONS

By Miles S. Kersten, *Special Investigator, Highway Research Board*

SYNOPSIS

Information on subgrade moisture contents, chiefly below flexible pavements, was collected from several State Highway Departments, most of the data being received from States in the Mississippi Valley. An attempt has been made to assemble this information so as to give a general picture of subgrade moisture conditions and to study the variations which occur.

The moisture values are expressed in three different ways: percentage of saturation, percentage of plastic limit, and percentage of optimum moisture content. It was found that the percentage of saturation of the soils varies, in general, with soil texture, being high for clays and progressively less for clay loams, loams, and sandy loams. The moisture content of the fine textured soils, such as clays, generally exceeds their plastic limit; that of loessial silty soils is usually equal to or just under the plastic limit; and that of sandy loams rarely exceeds and is generally less than this constant. A substantial proportion of the moisture values in all textural classes of soil was in excess of the optimum moisture contents.

Only one project showed a marked change of moisture content over a period of time; in this project the base and surface courses had been placed on a relatively dry loessial silty clay soil.

Some results of studies of the effect of type of surfacing, transverse location, and depth are also presented.

Suggestions are made for the method of acquisition of further data.

The variation of stability or supporting power of a soil with changes in its moisture content has been demonstrated many times and is widely recognized. In many methods of design of pavements it is necessary to know or to assume the moisture content that the subgrade will attain in order that tests may be made at the same condition; the correctness of the design will depend in part on how well this assumption duplicates the final condition of the subgrade. Because of the realized importance of this item it was thought by the Committee in charge of the investigation of structural design of nonrigid pavements, in which the Public Roads Administration, the Asphalt Institute, and the Highway Research Board are cooperating, that it would be worthwhile to collect for analysis the existing information on subgrade moisture contents.

There are numerous questions concerning subgrade moistures to which answers would be helpful in roadway design and construction. A few of these are: Do subgrade soils undergo seasonal and yearly variations in moisture and density and if so to what extent? Do subgrades eventually arrive at a final constant condition of moisture and density and if so what is it and how long does it take to reach this condition? What is the effect of the moisture content and density at which the soil is placed on its final condition and what is the best condition for placing so that the greatest stability is finally acquired? What is the effect of such items as depth of water table, type of surfacing, climate of the region, etc., on the moisture content acquired by subgrades? What characteristics of the soil aid in predicting the moisture content which a soil will attain?

Although the analysis of the data collected thus far hardly starts to give an answer to these questions, certain trends have been found which may be enlightening and of value in planning the acquisition of further data. Also, the methods of analysis described in this paper may suggest a method for individual States to follow in analyzing accumulations of subgrade moisture information which they may have. Such individual studies might lead to much more conclusive results than was possible in this paper since one familiar with the projects and locations from which the information has been obtained is more able to explain apparent inconsistencies in the data and to find the true trends than one wholly unfamiliar with the field work.

ACQUISITION OF THE DATA

Most of the data used in this paper were received from the highway departments of several States in reply to a circular letter sent to all States requesting any information they might have available on subgrade moisture contents and accompanying soils descriptions and other related items. Some were acquired from personal contacts with materials engineers of several of the State highway departments. Table 1 lists the sources of the greater part of the data; other States sent in a very limited amount of information.

Table 1 indicates that, geographically, the bulk of the material was obtained from a group of States in the Mississippi Valley extending from Minnesota and North Dakota to Louisiana and Texas. Consequently the study is based largely on results reported from that region.

The study comprises more than 6500 moisture determinations in the upper 1 ft. of subgrade on 357 different projects. Several hundred additional results were obtained of moistures at depths greater than 1 ft., but these have not been used in the greater part of this study.

ANALYSIS OF THE DATA

The basis of this report is a compilation of reports and unworked data from several State highway departments, each of which may have collected information from several of its divisions. The original studies were initiated for widely varying purposes and consequently their completeness as far as this report is concerned is correspondingly variable. What was primarily desired in this survey was the moisture content of the subgrade soil beneath flexible or rigid pavements together with density and soils information such as texture and physical constants and information on the type and age of pavement, drainage, weather conditions, etc. The soil constants were needed to express the moisture contents in terms other than percentage by weight.

In order that reliable comparisons may be obtained, it is desirable that all tests be made at the same relative point in the road cross-section, for example the upper 6 in. of subgrade at centerline, or under the pavement some distance in from the edge. In comparing the moisture contents of different types of soils it is also desirable that the age of the surfaces be similar and that the sampling be done at the same time of year.

Most of the moisture contents included in this study represent approximately 0- to 6-in. depths; some are for less than 6 in., some for the upper foot. The comparisons presented may be considered as representative of the upper 6 in. of the subgrade.

Location with respect to centerline was given for most of the tests. For tests on roads with flexible pavements the samples were mostly taken near the center of the mat. On some concrete pavements they were taken at the edge of the slab; these may give different results than those under center portions of the slab. Since a large percentage of the information collected is for the flexible type pavement, the comparative results reported are for this type unless otherwise noted.

There are a large number of factors which determine the moisture content of a given subgrade soil. In most cases it is practically impossible to separate the effects of the various factors, particularly if the analysis is based on only a few tests. An attempt has been made, therefore, to work with the averages of as large a number of moisture determinations as possible. Thus the results at any one isolated point may deviate considerably from the average.

TABLE 1
SOURCE OF DATA ON SUBGRADE MOISTURE CONTENTS

State	No. of Projects	No of Moisture Tests in Upper 1 ft.	General Type of Surface and Base
Alabama	2	24	Bituminous & Sand-Clay
Arizona	1	6	Penetration Macadam
Arkansas	1	130	Bituminous & Stabilized Gravel
Colorado	1	26	Bituminous & Stabilized Gravel
Idaho	1	41	Bituminous & Crushed Rock
Illinois	10	73	Bituminous & Stabilized Gravel & Crushed Stone
Illinois	8	52	Concrete
Indiana	2	20	Bituminous & Stabilized Gravel, Rock Asphalt, & Macadam
Indiana	2	10	Concrete
Iowa	24	287	Bituminous & Stabilized Gravel, Soil Cement, Soil-Bituminous & Crushed Stone
Kansas	54	203	Bituminous & Stabilized Gravel or None
Louisiana	2	137	Concrete
Minnesota	50	666	Bituminous & Stabilized Gravel
Missouri	1	1,304	Bituminous & Stabilized Gravel, Soil-Cement & Soil-Bituminous
Missouri	12	186	Concrete
Nebraska	20	220	Bituminous & Stabilized Gravel
Nevada	3	27	Bituminous & Gravel
North Dakota	36	274	Bituminous & Stabilized Gravel
Ohio	1	52	Concrete
Texas	29	2,185	Bituminous & Caliche
Texas	87±	400	Concrete
Manitoba	10	276	Bituminous & Stabilized Gravel
Total	357	6,599	

In analysis of any moisture data some means of expression should be used that will signify the stability of the soil. The percentage of moisture by weight of the dry soil is rather meaningless by itself since soils vary considerably in their ability to hold water and still remain stable. Methods of expression of the moisture content of the soil used in this report are:

a. Percentage of saturation.
b. Percentage of plastic limit.
c. Percentage of optimum moisture content.

The percentage of saturation is defined as the moisture content of a soil divided by the moisture content of the soil when its voids are completely filled with water, times 100. The following example illustrates the calculation of this value. Consider a soil with a dry density (pounds of dry soil per cubic foot) of 108 lb. per cu. ft., a moisture content of 17.0 per cent of the dry weight, and a specific gravity of soil particles of 2.67.

The moisture content by weight to fill the voids completely is calculated in the following manner:

Moist. cont. to fill voids

$$= \frac{(\text{sp. gr.} \times 62.4 - \text{Density})}{(\text{sp. gr.} \times 62.4)} \times \frac{62.4}{\text{Density}} \times 100$$

$$= \frac{2.67 \times 62.4 - 108}{2.67 \times 62.4} \times \frac{62.4}{108} \times 100$$

$= 20.3$ per cent

The percentage of saturation is then obtained by the formula:

Percentage of saturation

$$= \frac{\text{Moisture Content}}{\text{Moist. Cont. to Fill Voids}} \times 100$$

$$= \frac{17.0}{20.3} \times 100 = 84$$

Subgrades are often described as being "saturated" or "nearly saturated"; these terms are sometimes used to describe a soil with an apparent high moisture content. Certain laboratory bearing tests are performed on soils which have been permitted to absorb water until they supposedly contain the maximum amount of water which the soil in the field will attain. For these reasons it is of interest to ascertain what percentages of saturation actually exist in the field.

Expression of the moisture content as a percentage of the plastic limit of the soil should be significant since the plastic limit of a soil represents the lower limit of the range in which the soil has plastic properties. Direct comparison to this constant might be criticized in that the test is run only on that fraction of the soil passing the No. 40 sieve whereas the moisture determined in the field is a percentage of the dry weight of the entire material. This could be corrected by reducing the plastic limit by the proportion of minus No. 40 to total material. However, this tends to complicate a rather simple, easily understood comparison, and has not been done in this report, since a great majority of the soils studied are comparatively fine grained and the average percentage of particles retained on the No. 40 sieve is small.

Comparison of the moisture content to the optimum moisture content of the soil is of interest because many embankments are placed at approximately that condition. This expression has the advantage that the test constant is a percentage of the entire sample, unless it contains gravel larger than ¼ inch. The optimum moisture content used in this study is that determined by the standard Proctor test, A.A.S.H.O. Method T-99-38.

Other methods of expressing moisture content than those mentioned were tried with certain parts of the data, with varying success. Comparative to the percentage of saturation was a calculation of the percentage by volume of solids, of water, and of air for each soil; this expression of all three components of the mass is rather combersome to present. The average per cent of air voids at field density has been calculated and is presented with the percentage of saturation results. This expression, for the ordinary range of densities encountered, has the same significance as the saturation values, and it is probably a matter of one's previous experience in use of the terms as to which is preferable.

Certain States have found that their moisture content data, when plotted versus the liquid limit, field moisture equivalent, and other soil constants, show bands within which a majority of the points fall. Any such comparisons, if sufficiently definite, might aid in predicting the moisture content which soils will attain.

Division of soils into textural groups was found to be helpful in studying the subgrade moisture contents. The soils were divided into groups such as sands, sandy loams, loams, silt loams, clay loams, and clays according to their percentage of sand, silt, and clay particles.[1]

In some instances comparisons were made on the basis of the Public Roads Administration soil groups (A-1 to A-8).

[1] For definition of classification see Davis, R. E. and H. H. Bennett, "Grouping of Soils on the Basis of Mechanical Analysis," U. S. Dept. Agri. Dept. Circ. 419, 1927.

RESULTS

Percentage of Saturation

Before presenting values of percentage of saturation it will be well to point out the effect of density on this value. Ordinarily a soil which is 100 per cent saturated is thought of as being in an unstable condition. If a soil is at a normal density this may be true. Consider a soil with a standard maximum dry density of 108 lb. per cu. ft. existing in the field at this density and with a moisture content of 17 per cent. If the specific gravity of the soil particles is 2.67 the percentage of saturation as shown in the previous example is 84 per cent. If, with no change in moisture content, the soil is further consolidated to a dry density of 115 lb. per cu. ft. the saturation value would be 100 per cent. If the density decreased to 100 lb. per cu. ft., the saturation value would be only 68 per cent. Thus saturation values may be high in soils which exist at higher than normal densities without the result signifying a condition of instability and low saturation values may be the result of low densities rather than low moisture contents. To be completely informative a statement of density should accompany the percentage of saturation; for soils occurring at densities ap-approximately equal to the maximum density, as determined by the standard compaction test (Method A.A.S.H.O. T-99-38), saturation values may be used alone as a measure of comparison.

In many of the tests in which densities have been reported, specific gravities have not been given; a value of 2.67 has been assumed for such cases.

In reviewing the percentages of saturation calculated in this study, only a relatively few values were found to be as high as 100 per cent. Many of course approached this value. It was necessary to select some value of less than 100 per cent in order to designate those soils which were relatively highly saturated. A value of 90 per cent was arbitrarily selected as the lower limit and in some of the tables the percentage of the tests which equal or exceed 90 per cent saturation is given. This value is not meant to represent a critical moisture condition.

To obtain a general picture of the saturation values existing in a large group of projects, Table 2 was prepared listing the average percentage of saturation for six different states in which density tests were made on a large number of projects in state-wide surveys. The average values represent conditions in subsoils of a wide range of textures, different combinations and types of flexible bases and surfaces, (no portland cement concrete pavements are included), various ages since being covered, and a range of annual precipitation from 14 to 40 in. For this variety of conditions the average percentage of saturation is about 73 with 15 per cent, or 1 test in 6 or 7, exceeding 90 per cent of saturation. The average air void content is 10 per cent.

To ascertain the types of soil which attain high moisture contents, Table 3 has been prepared listing those projects which have fairly high average saturation values or a high percentage of tests exceeding 90 per cent of saturation. This table indicates that 16 of the 22 such projects are those with clay or silty clay subgrade soils. The others are mostly

TABLE 2
AVERAGE PERCENTAGE OF SATURATION OF SUBGRADES IN STATES WHERE LARGE NUMBER OF PROJECTS WERE TESTED

State	No. of Projects	No. of Tests	Type of Soils	Aver. per cent of Satur.	Tests 90% Satur. or Greater	Aver. Air Voids
					%	%
Iowa	24	309	Mostly silty clay loams and silty clays	80	15	7
Illinois	5	51	Mostly clay loams and clays	78	10	9
Kansas	33	119	Sands to clays Mostly silty soils	76	23	10
Minnesota	28	162	Sandy loams to clays	81	10	7
Nebraska	13	93	Sandy loams to clays	60	11	16
North Dakota	36	272	Mostly clays	63	15	15
Total or Wtd. Average	139	1,006		73	15	10

silty clay loams, clay loams, and silt loams; sandy loams are mentioned for only two of the projects.

nesses and types of flexible bases and surfaces. Most of the Texas values represent tests made at the edges of concrete slabs.

TABLE 3
PROJECTS WITH RELATIVELY HIGHLY SATURATED SOILS

Location of Proj.	Soil Texture	No. of Tests	Aver. Per cent of Satur.	Tests 90 per cent Satur. or Greater	Aver. Air Voids
				%	%
Alabama	Mostly clay	18	95	83	2
Arkansas	Mostly clay loam & clay	114	86	56	5
Iowa	Clay loam & silty clay	8	90	89	3
Iowa	Silty clay	4	88	50	4
Iowa	Silty clay	22	85	36	6
Iowa	Silty clay loam	15	85	27	6
Kansas	Clay	10	93	70	3
Minnesota	Clay	22	94	77	4
Minnesota	Mostly silt loam	10	90	40	5
Minnesota	Clay	40	89	55	5
Minnesota	Silt loam & silty clay loam	83	89	58	4
Minnesota	Clay loam & sandy loam	5	89	40	4
Minnesota	Clay & clay loam	9	87	11	5
Minnesota	Clay loam & sandy loam	7	86	43	5
Minnesota	Clay	19	85	32	9
North Dakota	Silty clay	6	96	100	2
North Dakota	Clay	8	95	100	2
North Dakota	Cley	10	92	60	3
North Dakota	Clay	9	89	33	4
North Dakota	Clay loam	10	87	50	5
Manitoba	Silty clay	5	91	80	3
Manitoba	Clay	6	89	67	5

Because of the seemingly important effect of texture on saturation values indicated by Table 3, the variation of percentages of saturation in soils of different textural groups in those states which had made a sufficient number of tests so that reasonably average values could be obtained was studied. The results are shown in Table 4. It will be noted in the table that, in general, there is an increase in the average percentage of saturation and a decrease in air void content as the texture varies from the light, sandy loam soils through the progressively heavier loams, clay loams, and clays; also that the percentage of highly saturated soils becomes greater as the texture becomes heavier. The Minnesota data do not indicate this to the same degree as those of Arkansas, Nebraska, and Kansas.

The Texas tests have been presented in Public Roads Administration groups since textural information was not given. The A-1 and A-2 groups may be considered as sandy textured, the A-4 intermediate, and the A-6 and A-7 as clays. The markedly higher saturation of the clay soils can be noted.

The data of Arkansas and Minnesota are for projects with stabilized gravel bases and bituminous surfaces; those of Kansas and Nebraska are for projects with various thick-

TABLE 4
VARIATION OF PERCENTAGE OF SATURATION WITH TEXTURE OF SOIL

Soil Class	No. of Tests	Aver. per cent of Satur.	Tests 90% Satur. or Greater	Aver. Air Voids
			%	%
Arkansas				
Sandy loam	6	59	0	12
Loam	12	77[a]	8[a]	7
Clay loam	38	81[a]	26[a]	6
Clay	58	92	69	3
Minnesota				
Sandy loam	59	78	5	8
Loam	51	82	8	7
Clay loam	39	84	18	7
Clay	13	83	15	8
Nebraska				
Sandy loam	9	47	0	20
Loam & Silt loam	22	51	5	20
Clay loam & Silty clay loam	40	60	10	16
Clay & Silty clay	22	74	23	10
Kansas				
Sand	3	35	0	21
Sandy loam	10	65	0	12
Loam	10	67	10	12
Silt loam	38	73	18	11
Silty clay loam	23	80	26	8
Silty clay	3	86	0	5
Clay	16	92	63	3
Texas				
A-1	23	54	4	17
A-2	55	57	15	17
A-4	32	52	3	21
A-6 & A-7	153	74	22	12

[a] Corrected to standard maximum density.

The values of Table 4 indicate that in the lighter soils, such as sandy loams and loams, the chances of high degrees of saturation being attained are remoté, probably about 1 in 20. Tests in sandy soils exhibit a wide range of saturation values. In loessial silty soils, such as those of extensive areas in Iowa, fairly high and quite uniform saturation values are found, most being in the range from 75 to 90 per cent. The heavier textured soils, namely the clays and silty clays, have a much greater tendency to become highly saturated than any of the lighter soils.

Percentage of plastic limit

Most engineers are familiar with the plastic limit test and can picture in their minds the condition of the soil at that moisture content. This constant takes into account, to some degree, the ability of the soil to hold that given amount of moisture without extreme loss of stability and thus reflects variations in texture. Furthermore the plastic limit is a common routine test and this constant was given for nearly all the soils included in this study.

To give a general result of subgrade moisture contents in terms of percentage of the plastic limit for a large number of projects, Table 5 is presented. Average values are listed for those states in which a larger number of tests were made on a variety of projects. The second Texas listing in this table is for concrete pavements and tests were probably made at the edges of the slabs in most instances. All other data listed are for flexible pavements on which tests were made under the surface away from the edge. Except for the Texas data the moisture contents average between 73 and 82 per cent of the plastic limit of the soil with about 1 test in every 7 exceeding this constant.

Table 6 presents a compilation of test results of several States in which tests were made on soils of a wide range of textures. As was found in the similar study for percentage of saturation it is in the heavier soils, such as the clays and silty clays, that the excessive moistures are found. In most instances a definite trend of increasing average percentages of the plastic limit occurs as the texture varies from the sandy soils through the loams, clay loams, and clays; only the Nebraska data indicate no such tendency.

Table 6 shows that only an extremely low percentage of the sandy loams have moisture contents which exceed their plastic limits. When the data of all states are combined, only 4 per cent of the moisture tests in sandy loams exceeded this constant. For the loams the value is only 7 per cent, and is that high chiefly because of the Nebraska results. As a comparison, 29 per cent of the clays and silty clays exceeded the plastic limit.

The Texas data again show the A-6 and A-7 groups, which are the heavy textured soils, to be appreciably wetter than the sandy and intermediate textured soils.

The first Texas listing and the Louisiana data are of tests made at the edges of concrete slabs and should not necessarily be taken to represent conditions under the pavement. They are included to show that variation of moisture with texture also occurs at this location.

TABLE 5
AVERAGE MOISTURE CONTENT OF SUBGRADE EXPRESSED AS PERCENTAGE OF PLASTIC LIMIT IN STATES WHERE LARGE NUMBER OF PROJECTS WERE TESTED

State	No. of Projects	No. of Tests	Type of Soils	Aver. Moist. Cont. per cent of Pl. Lim.	Tests Exceeding Pl. Lim.
					%
Iowa	23	297	Mostly silty clay loams and silty clays	82	13
Kansas	54	202	Sands to clays. Mostly silty soils	78	26
Minnesota	28	169	Sandy loams to clays	81	6
Nebraska	21	293	Sandy loams to clays	73	11
North Da ota	35	272	Mostly clays	73	15
Texas[a]	29	2,163	Sands to clays	64	7
Texas[b]	Appr. 87	308	About 2/3 clays (A-6 & A-7)	90	41
Total or Average	277	3,704		77	17

[a] Projects with bituminous surfaces on caliche bases.
[b] Concrete pavements; most of samples probably taken at edge of slab.

It was noted in studying the Iowa and Minnesota data that loessial soils, which have high silt contents, in most instances attain a moisture content approaching the plastic limit, but exceed it only rarely and then by only a per cent or two of moisture. A large number of tests on projects in such soils gave very uniform results.

TABLE 6
VARIATION OF MOISTURE CONTENT OF SUBGRADES EXPRESSED AS PERCENTAGE OF PLASTIC LIMIT WITH TEXTURE OF SOIL

Soil Class	No. of Tests	Aver. Moist. Content per cent of Pl. Lim.	Tests Exceeding Pl. Lim.
			%
Arkansas			
Sandy loam	2	72	0
Loam	6	69	0
Clay loam	48	82	13
Clay	61	105	56
Minnesota			
Sandy loam	61	75	4
Loam	53	82	2
Clay loam	40	86	10
Clay	11	91	29
Nebraska			
Sandy loam	51	63	2
Loam	18	73	28
Silt loam	23	58	0
Clay loam	51	71	10
Silty clay loam	43	77	9
Clay	25	77	8
Silty clay	28	75	4
North Dakota			
Sandy loam	42	63	7
Clay loam	52	67	2
Clay & Silty clay	162	73	17
Kansas			
Sand	4	44	0
Sandy loam	23	73	4
Loam	19	85	10
Silt loam	56	82	16
Clay loam	13	100	46
Silty clay loam	33	90	33
Clay	29	103	62
Silty clay	9	91	33
Texas[a]			
A-1	25	70	4
A-2	67	64	12
A-4	39	83	18
A-6 & A-7	177	104	62
Texas[b]			
A-3	146	27	0
A-2	650	51	3
A-4	381	52	3
A-4-7	237	77	6
A-6 & A-7	716	81	13
Louisiana[c]			
Sandy loam	7	66	0
Loam	19	81	5
Clay loam & Silty clay loam	10	99	20
Clay[d] & Silty clay	17	117	60
Heavy clay[e]	38	92	21

[a] Concrete pavement; most of samples probably taken at edge of slab
[b] Projects with bituminous surfaces on caliche bases.
[c] Concrete pavement; samples taken at edge of slab.
[d] Clays with 30 to 50 per cent of particles smaller than 0.005 mm.
[e] Clays with more than 50 per cent of particles smaller than 0.005 mm.

Gumbo clay soils, as indicated by tests in Minnesota, North Dakota, and Illinois, apparently frequently exist at moisture contents greater than the plastic limit.

Percentage of optimum moisture content

Since the optimum moisture is determined for the fraction of soil passing the No. 4 sieve, which in most cases represents the total subgrade sample, comparison to this constant might be more reliable than that to the plastic limit. Furthermore, it is of interest to ascertain how the moisture content attained by soils compares to that which in present day practice is used in embankment construction. In-as-much as the optimum moisture content is that required to form sufficiently thick films on the soil particles to lubricate them so that they may be compacted to a high density, it takes into account the textural characteristics of the soil.

The standard compaction test is not a common routine test and consequently optimum moisture values were reported for only a portion of the soils included in this study. Determinations had been made on soils from a large number of projects in only three States. A summary of the average results is given in Table 7 and a textural division study is presented in Table 8. Results for Kansas and Minnesota, which represent a variety of soil textures, show that subgrade moistures may average quite close to the optimum moisture content. About a third of the soils listed in Table 7 exceed this constant.

Table 8 indicates that, although sandy loams may have somewhat lower average moisture contents (expressed in terms of percentage of optimum moisture content) than the heavier soils, the variations with changes in texture are not great and all classes have a considerable percentage of tests in excess of the constant; thus it should be considered possible for all plastic soils to attain such a condition. The data are almost too limited to substantiate the drawing of any further conclusions.

The optimum moisture content of most soils is somewhat less than the plastic limit. The Minnesota data indicated a relationship between the two constants, expressed by the equation: Optimum Moisture Content = 0.938 (Plastic Limit −3.5). In tests on 210 soils, the optimum moisture content was greater than the plastic limit in only two instances; about 90 per cent of the optimum moisture values fell between 2 and 8 per cent below the plastic limit.

The data of other states did not portray as definite a relationship between the two constants as that for the Minnesota soils. In the Arkansas, Kansas, and Nebraska data about 85 per cent of the optimum moisture values reported were between 2 per cent above to 5 per cent below the plastic limit.

Seasonal and yearly variations

In studying the seasonal and yearly variations it was found necessary to work with the average of as large a number of tests as possible. The variations which appear in a series of tests at any one isolated point ordinarily are so pronounced that it is difficult to account for them. Variation in the soil and other conditions at the sampling points, although the points may not be widely separated, may outweigh the effects of seasonal changes.

In the data submitted for this study, moisture determinations had been made on more than one date on almost a hundred projects. On some, tests had been made at only two different times while on others as many as 36 tests had been made. It has been attempted to analyze each project separately to see what changes occurred. Table 9 is a condensed compilation of the results.

Extensive tests are reported for several projects in Iowa. These are largely on loessial soils and on grades which have been in place for several years. Apparently these soils had already attained a rather stable moisture condition at the time of the initial tests, for over a period of three to five years very little change, on the average, occurred; decreases resulted about as often as increases. The moisture content of these soils was somewhat under the plastic limit and saturation values were largely between 75 and 90 per cent. This probably represents the condition that such soils tend to attain under flexible bases and bituminous surfaces.

TABLE 7
AVERAGE MOISTURE CONTENT OF SUBGRADES EXPRESSED AS PERCENTAGE OF OPTIMUM MOISTURE CONTENT

State	No. of Projects	No. of Tests	Type of Soils	Aver. Moist. Content per cent of Opt. M.	Tests Exceeding Opt. Moist.
					%
Arkansas	1	125	Mostly clay loams & clays	103	54
Kansas	21	75	Sandy loams to clays	92	31
Minnesota	38	209	Sandy loams to clays	103	64
North Dakota	35	268	Mostly clays	78	18
Manitoba	3	32	Clays	85	19
Total or Average	98	709		90	37

TABLE 8
VARIATION OF MOISTURE CONTENT OF SUBGRADE EXPRESSED AS PERCENTAGE OF OPTIMUM MOISTURE CONTENT WITH TEXTURE OF SOIL

Soil Class	No. of Tests	Aver. Moist. Content per cent of Opt. Moist.	Tests Exceeding Opt. Moist. Cont.
			%
Arkansas			
Sandy loam	6	73	17
Loam	15	102	47
Clay loam	44	100	41
Clay	60	109	70
Kansas			
Sand	1	57	0
Sandy loam	10	82	30
Loam	10	105	40
Silt loam	19	85	11
Clay loam	12	103	58
Silty clay loam	11	71	9
Clay	7	112	86
Silty clay	5	83	0
Minnesota			
Sandy loam	62	101	55
Loam	43	103	63
Silt loam	10	105	70
Clay loam	40	105	73
Clay	14	105	86

The Minnesota data indicated no significant changes in subgrades below stabilized gravel bases and bituminous surfaces.

The data reported for Missouri are from an experimental project in which several different types of bases and a bituminous armor coat were placed over a dry loessial silty clay soil. Moisture changes are shown for two periods and indicate an average moisture increase, based on a large number of tests at both 2 and 8 ft. from the edge of the mat, of almost 1 per cent per year. An increase of about 4 per cent occurred during the summer the bases were constructed; this may have been partly due to water used in the base mixing process. After four years about 40 per cent of the moisture test results were in excess of the plastic limit. Apparently soils of this nature, if covered while in a relatively dry condition, are apt to show marked increases in moisture content.

service of the projects varied from 1 to 9 years.

Some interesting data on both seasonal and yearly changes are revealed by a special study of the Iowa State Highway Commission. Three pits, each 4 by 4 by 4 ft. were filled with three different types of soil. Moisture contents and densities were determined at various time intervals for each 6-in. depth. Since the soils in the pits were not surfaced and were not subjected to the consolidating and vibrating

TABLE 9
AVERAGE CHANGES IN MOISTURE CONTENTS OF SUBGRADE SOILS

State	No. of Projects	Total No. of Points Tested	Type of Soil	Period		Aver. Change in Moist. Cont.	Range of Changes in Moist. Cont. (for Projects)
				From	To		
Iowa	19	87	Mostly silty clay	Dec. '38	Apr. '42	+0 8	−2.5 to +4.6
	2	18	Silty clay & silty clay loam	Mar. '37	Dec. '38	−1.9	−2.4 to −1.4
	3	30	Variable	Apr. '37	Apr. '42	−1.9	−2.7 to −1.5
Minnesota	1	32	Clay	Aug. '37	Aug. '39	−1.0	
	5	20	Mostly sandy loam	July '43	May '44	+0.1	−1.3 to +1.3
Missouri	6[a]	176	Silty clay	Oct. '37	Nov. '41	+3.3	+1.4 to +7.3
	6[a]	176	Silty clay	May '38	May. '40	+1.7	+0.1 to +2.8
North Dakota	26	52	Mostly clay	Apr. '41	Apr. '42	−0.7	
	18	36	Mostly clay	Aug. '40	Aug. '41	−0.3	
	18	36	Mostly clay	Aug. '41	Aug. '42	+0.2	
Texas	20	60	A-2, A-4 & A-7	Dec. '34[b]	Dec '35[b]	+0.9	−3.2 to +4.2
	20	60	A-2, A-4 & A-7	Dec. '35[b]	Dec. '36[b]	+0.3	−2.8 to +3.7
Manitoba	2	6	Clay	Fall '39	Fall '43	0.0	−3.5 to +3.5[c]
	4	12	Mostly clay	Fall '40	Fall '43	−0.1	−4.0 to +1.5[c]

[a] One project; six different types of bases.
[b] Average of Nov., Dec. and Jan.
[c] Approximate values; determined from curves.

The North Dakota, Texas, and Manitoba data are based on moisture determinations repeated at only one to five points on each project. Averages for North Dakota values show only slight changes in moisture contents over a 2-yr. period. In the case of the Manitoba data, average moisture values based on tests at from two to five points on a project were plotted versus time and an attempt made to draw a smooth curve through the points. This was also done for the Texas data in which determinations had been made almost every month for a 3-yr. period. The Texas values in the table were calculated by averaging the moistures of the November, December, and January tests and combining the results of the three test points on each project. The results are thus general; an average increase of less than 1 per cent of moisture each year is shown. Individual sampling points show increases as great as 12 per cent. The period of

effects of traffic, conditions were admittedly not similar to the subgrade of a road. The changes which occur in the soil at some depth below the surface probably similate to some degree the changes which tend to occur in a road embankment, particularly if not sealed.

Fig. 1 is a plot of the results on one of the soils, a gray loess, for the 6- to 12- and 12- to 18-in. depths. The other two soils, one a glacial till and the other a tan loess, gave similar results. It will be noted from the figure that: in 6 years the density decreased about 5 lb. per cu. ft., the moisture content after an initial drop increased to slightly over the plastic limit, and the percentage of saturation rose to 90 per cent, plus or minus. Some of the density and moisture content curves have a slight saw-tooth pattern, the densities being low in the spring and high in the fall, the moistures having the opposite trend.

Traffic might have tended to nullify or retard the loss in density and thus also might have retarded the increase in moisture content. Sealing the surface with a bituminous mat might also have caused marked changes. different moisture-retentitive characteristics than a clay of similar grading in North Dakota. Also, ground water elevations might be independent of annual precipitation and yet have

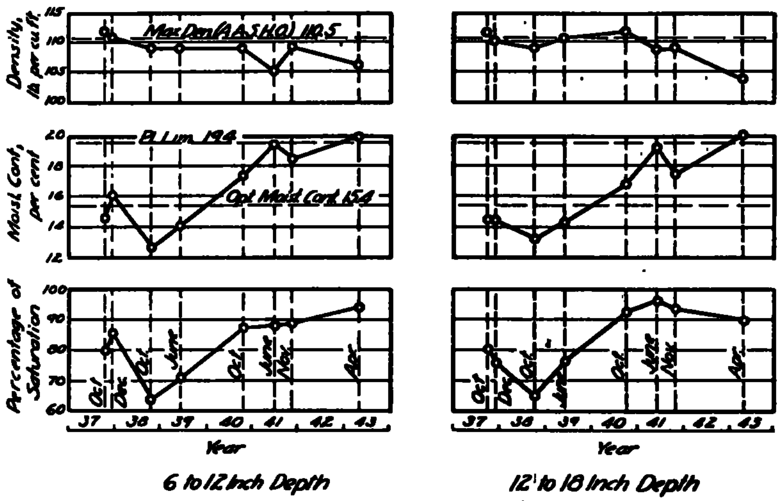

Figure 1. Soil Data from Test Pit—Loessial Silty Clay Loam Soil

TABLE 10
VARIATIONS OF SUBGRADE MOISTURE CONTENT WITH AMOUNT OF ANNUAL PRECIPITATION IN FOUR STATES

State	Type of Soil	Annual Prec. in.	No. of Tests	Aver. per cent of Pl. Lim.	No of Tests	Aver. per cent of Satur.
Kansas	Silt loam & silty clay loam	15–20	45	84	27	69
		20–25	26	95	25	73
		25–30	8	88	4	95
		30–35	7	97	5	86
Nebraska	Clay loam & clay	16–24	110	69	52	63
		24–30	66	80	19	83
North Dakota	Clay	14–16	90	79	90	58
		19–22	46	88	46	79
Texas	A-2 & A-4	5–15	12[a]	41		
		15–25	7[a]	44		
		25–35	13[a]	62		

[a] Number of test locations; approximately 32 tests at each location.

Variation With Annual Precipitation

Since the annual precipitation of a region is a partial measure of the water available to a subgrade, some correlation might be expected between rate of rainfall and subgrade moisture. In such a study comparisons must be made for approximately similar conditions, including type of soil. This is not always possible when considering wide geographical areas. A clay in Arkansas, for example, might have quite a marked effect on subgrade moisture conditions. In the study of all data on hand it was found that clays in Arkansas, Illinois, Minnesota, and North Dakota might all attain high degrees of saturation; the average annual precipitation at the locations of projects in these states are 50, 35, 20 to 30, and 14 to 20 in., respectively. No data were obtained of subgrade moistures in heavy soils for the arid regions of western United States. Three projects were reported for Nevada but the subsoils were all non-plastic and had low moisture contents.

Studies of variations within individual States which have a marked range of annual rainfall showed some tendency toward greater subgrade moisture in the wetter regions. Such data for four States are shown in Table 10. In each State only soils of similar texture were considered. Greater differences are indicated when percentages of saturation are considered rather than percentages of the plastic limit. The fact that lower averages occur in the drier regions of a State does not necessarily mean that soils on some projects in such areas do not become wet. For example, of 10 projects in the western, more arid section of North Dakota, 7 are seemingly dry but the other 3 have percentages of saturation in the eighties or nineties and in one case have moisture contents well above the plastic limit.

Not enough information on the elevation of the water table was included in the data reported by the different States for a comprehensive study of the effect of this factor upon subgrade moisture. In one project in Louisiana, a concrete pavement laid on silty clay and clay soils, elevations were reported between 3 and 8 ft. below grade. The moisture content of the upper foot of the subgrade exceeded the plastic limit at about two-thirds of the points examined and in many cases by as much as 10 per cent. The second and third feet of the subgrade were progressively wetter. This condition of extremely high moisture contents due to the high water table is thought to be characteristic of such pavements in the coastal plain area.

Effect of Type of Surfacing, Transverse location, and Depth

The types of bituminous surfacing on the projects included in this study were as a general rule either armor coats of thicknesses up to about an inch or mats 1 to 3 in. thick. Since in most cases each State has one type of surfacing on most of its projects it has been impossible to determine the effects of the different types of bituminous surfaces on subgrade moisture content. While the information received on portland cement concrete pavements was limited, it was not uncommon for the moisture contents under the central portions of the slabs to be in excess of the plastic limit.

Comparative data of subgrade moistures beneath bituminous surfaced soil-aggregate, soil-bituminous, and soil-cement bases are provided by the results from some experimental projects listed in Table 11. The Missouri data indicate that somewhat higher moisture contents exist under the soil-cement sections than under the others but the two projects in Iowa do not show any appreciable difference for the three types of base.

Certain of the data indicate that the transverse location of the sample in the roadway has an important bearing on the results. Therefore, for the purpose of drawing comparisons, only the results of tests taken close to the center line or well within the confines of the surfacing have been used.

Data obtained in the North Dakota studies included moisture determinations of the subgrade at center line, at the quarter point or about 5 or 6 ft. from centerline, at the edge of the mat, and on the shoulder. In general, moisture content is greater at the edge of the mat than toward the center line, with high but variable moisture content in the shoulders. One project in Colorado showed moisture results averaging 1½ per cent higher at the mat edge than at centerline. A Missouri project revealed moisture values 3½ per cent higher at a point 2 ft. in from the edge of the mat than near the center line, indicating that the higher moistures may extend a considerable distance in from the shoulder.

The subgrade moisture contents reported represented, as a general rule, samples obtained from depths of 0 to 6 in. Knowledge of the moisture contents at other depths may also be of importance in roadway design; the variations which occur with change of depth are therefore of interest. Such variations depend upon a number of factors and the values are directly comparable only if the character of the soil is the same for all depths; a condition only occasionally found in highway grades.

Determinations were made at several depths on a number of the projects reported. It is possible only to generalize on the results.

In most regions moisture contents seemed to increase with depth in the upper 3 ft. of subgrade. For examples: in Minnesota, in tests on 32 projects with soils varying from sandy loams to clays, the moisture content at a depth of 18 in. ran about 2 to 8 per cent greater than in the upper 6 in. of subgrade (that is, 22 to 28 per cent moisture content at 18 in. compared to 20 per cent at 0 to 6 in.); in North Dakota the moisture at 30 in. below the road surface was about 2 to 10 per cent greater than immediately below the base (approximately 9-in. depth). Results reported by Iowa included values for each inch in the upper half foot; the moisture values for 3 to 4 in. averaged 3½ per cent greater than those from 0 to 1 in. and the 12- to 36-in. values 3½ per cent greater than the top 12 in. Tests in Kansas showed a somewhat less consistent result, although about 60 per cent of the tests indicated greater moisture between 6 and 24 in. than in the upper 6 in. From comparison of moisture contents of the top 6 in. of subgrade soil to the plastic limit, it may be concluded that at depths greater than 1 ft. a majority of the soils in regions such as those discussed are wetter than their plastic limit. Since the densities of these greater depths are not known the percentages of saturation cannot be determined.

TABLE 11
COMPARISON OF MOISTURE CONTENTS OF SUBGRADES BELOW DIFFERENT TYPES OF BASES

State	Project	Type of Soil	Type of Base	No. of Tests	Aver. per cent of Pl. Lim.	Per cent of Tests Exceeding Pl. Lim.	No. of Tests	Aver. per cent of Satur.	Tests 90% Satur. or Greater
									%
Missouri	Rt. 100	Silty clay	Clay Gravel	32	85	18			
			Bituminous Road Mix	48	75	10			
			Bituminous Sub-oiled	247	89	30			
			Bituminous Machine Mix	261	98	44			
			Soil-Cement Machine Mix	48	106	77			
			Soil-Cement Road Mix	32	100	59			
Iowa	FN594	Silty clay	Soil-aggregate	13	77	0	13	84	30
			Soil-bituminous	36	83	0	36	78	17
			Soil-cement	8	84	0	8	85	25
Iowa	FN91	Silty clay	Soil-bituminous	8	77	0	8	79	0
			Soil-cement	5	82	0	7	74	0

SUMMARY AND CONCLUSIONS

This study has been based on information from several States. The data from the various sources were not uniform in character, and were incomplete for the purpose desired in several respects. Never-the-less the attempt was made to assemble the information in such a way that a general picture of the moisture contents existing in subgrades might be presented and some analysis made of the variations which occur.

Because of the number and complexity of the variables involved and the difficulty of separating the influence of each, average values of a large number of tests were used wherever possible to find trends, rather than to rely on individual test values.

Such a large proportion of the information was received from a group of states in the Mississippi Valley, extending from North Dakota and Minnesota to Louisiana and Texas, that the results must be considered as representative largely of this section of the country. Also, the conclusions are based for the most part on tests below surfaces of the so-called flexible type, consisting ordinarily of a bituminous mat or armor coat over a base of stabilized gravel, crushed stone, soil-bituminous, or soil-cement, or in some instances, directly on the subgrade soil. Unless otherwise specified, the following statements concern approximately the upper 6 in. of the soil subgrade at points well within the confines of the mat.

The degree of saturation existing in the subgrades of numerous projects in six States averaged 73 per cent; the range being from 60 to 81. Fifteen per cent of the tests showed a saturation value of 90 per cent or greater.

The subgrade soils of projects on which a high average per cent of saturation occurred were in most instances, either clay or silty clay.

Saturation percentages vary with the soil texture; in general, they are high for the clays and become progressively less for the clay loams, the loams, and the sandy loams.

Gumbo clays have a tendency to attain high saturation values. Loessial silt loams and silty clay loams have rather uniform saturation values between 75 and 90 per cent. Sandy soils exhibit a wide range of values but only occasionally are highly saturated.

Soils of groups A-6 and A-7 (Public Roads Administration classification) attain higher average percentages of saturation than those of groups A-1, A-2, and A-4.

The percentage of saturation is a fair measure of the relative stability of the soil if the soils are all approximately at maximum density as determined by the standard compaction test. High percentage of saturation values are ordinarily the result of high moisture contents but they may also result from abnormally high densities at any particular moisture content.

Subgrade moistures expressed as percentages of the plastic limit for a large variety of soils in six States averaged 77 per cent; averages for individual States varied from 64 to 82. Approximately 17 pet cent of the determinations disclosed moisture contents in excess of the plastic limit.

The fine textured soils, such as clays, exhibited a marked tendency to attain moisture contents in excess of their plastic limit. Sandy loams rarely had moisture contents as great as their plastic limit. Loessial silty soils tend to attain moistures close to their plastic limit.

The optimum moisture contents of the soils were exceeded by the field moistures in about a third of the determinations reported. Clay soils exceeded the constant most commonly but soils of all textures, including the sandy loams, have moistures greater than this value in a substantial proportion of tests.

Only slight changes in moisture content for periods of from 1 to 5 years were indicated in tests on several projects. Soils on most of these projects, at the time of the initial tests, already had moisture contents approaching the plastic limits.

A loessial silty clay soil covered with a base and armor coat while in a relatively dry condition showed a steady increase in moisture content.

Clay soils with high percentages of saturation were encountered in areas with annual precipitations as low as 14 in. Most tests in such regions, however, give relatively low saturation values.

Moisture contents are ordinarily higher under the edge than under the central portion of the surfacing.

Within the upper 3 ft. of the subgrade, the moisture content generally shows an increase with an increase in depth.

FUTURE WORK

It is desirable that additional studies of subgrade moisture conditions be made and, based on the experience gained in analyzing the data presented in this report, the following suggestions are offered.

A systematic, planned series of tests will yield useful information of seasonal and yearly changes. In such a study tests should be made at least two times each year, once during the spring and once in late summer or fall.

The results of tests at a single point on a project ordinarily are so variable that it is difficult to draw conclusions. Numerous tests should be made, therefore, in order that an average for the condition may be obtained. A minimum of ten sampling points for any project is suggested. The points should be carefully selected; locations of abnormal conditions of drainage should be avoided.

When a subgrade soil sample has been obtained from a location at which subsequent tests are contemplated, the surface should be repaired in such a manner that surface drainage will be normal. It is customary to make the subsequent tests at a point 1 or 2 ft. from the original to assure that the disturbance of the previous test does not affect the results.

If moisture tests for only one depth are to be made, 0 to 6 in. is suggested. If more than one depth is to be sampled, the uppermost one should be 0 to 6 in. This will assure that comparisons for various regions are based on the same layer of material. If the upper inch or two of subgrade soil is mixed with sand or stones from the overlying base or from an old gravel surface, the material should be discarded and the sample taken from the underlying soil.

When only one point at each location is to be sampled, it is suggested that it be from the central portion of the surfacing.

If it is desired to calculate the percentage of saturation or air void content, the density as well as the moisture content of the soil must be determined. This information is significant and it is recommended that density tests be made at least at part of the locations. In order that the field densities may be compared with standard values, moisture-density compaction tests such as A.A.S.H.O. Method

T-99-38 should be run on representative samples. It is also desirable that the specific gravity of representative samples be determined so that accurate saturation values may

In this study the textural classification of the soils was found useful. It may be that other methods of classification may be just as helpful in studying moisture trends.

Project_________ Highway_________ County_________
Pavement Section_________ _________ _________
Date Constructed: Grade_____ Base_____ Surface_____
Date of Tests_____ Gen'l Surf. Cond._________
Type of Topography_________ Aver. Ann. Prec._____

Location: Station											
Location: Distance from ℄											
Cut or Fill											
Layer	1										
Depth in Layer, Inches											
Sand, %	2										
Silt, %	2										
Clay, %	2										
Textural Class	3										
Other Classifications	4										
Liquid Limit											
Plastic Limit											
Specific Gravity											
Maximum Density	5										
Opt. Moist. Cont.	5										
Field Moist. Cont.											
Field Density											
Compaction, %	6										
Moist. Cont., % of Saturation	6										
" % of Plastic Limit	6										
" % of Opt. Moist. Cont.	6										
Remarks	7										

1. Base, Compacted Subgrade, etc.
2. Size should be designated; i.e., sand 2 to 0.05 mm., silt 0.05 to 0.005 mm., and clay under 0.005 mm.
3. U.S. Bureau of Chemistry and Soils system. See U.S. Dept. Agr., Dept. Circ. 419, 1927
4. P.R.A. or Casagrande
5. Method should be designated, such as A.A.S.H.O. T-99-38
6. These items can be calculated from other given data.
7. Height of Water Table, Special Drainage Conditions, etc.

Figure 2. Form of Report, Collection of Subgrade Moisture Data

be computed; a method such as A.A.S.H.O. T-100-38 is suggested.

Soils information should include grading and routine test constants such as the liquid and plastic limits. Other test constants may also prove of value.

Other items of information which may be important in interpretation of the moisture data are: the age of the embankment, method of placement and original conditions of density and moisture, type and thickness of base, type and thickness of surface, age of pavement, precipitation and depth of water table, and general drainage data.

To aid in an orderly collection of the data of such studies a suggested form of report (Fig. 2) is presented. This embodies most of the pertinent items discussed herein and could be modified or expanded to suit any agency's requirements.

A great deal of useful information would be obtained in state-wide surveys of the moisture content and density of subgrade soils. Since subgrade moisture is such an important item insofar as the service behavior of flexible road surfaces is concerned, accumulation of such information is highly desirable. Results found in the different soil regions would provide a sound basis for the design of pavements of comparable stability on all types of soils.

Similar studies on airports might also yield information useful in design. Conditions quite different from those on highways might be found because of the extensive width of runways.

DISCUSSION

Mr. C. M. Lancaster, *Missouri State Highway Department:* This discussion pertains only to the subgrade moisture trends, indicated by the averages of all base types, at separate subgrade depths of 0 to 6, 6 to 12 and 12 to 18 in. on the Missouri project.

As stated by Mr. Kersten in his excellent report, subgrade moisture determinations were not made at the time of base construction,

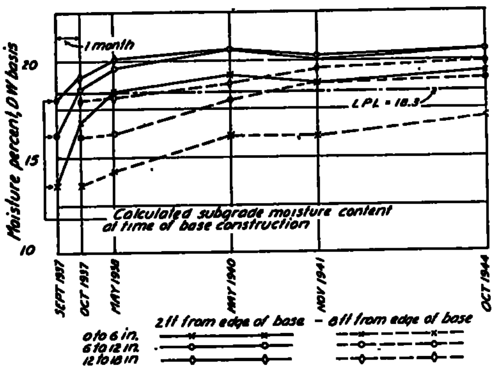

Figure A

therefore, the moisture changes which occurred during the first month after construction could not be factually determined. However, as this road had been maintained with an unsealed gravel surface, since original grading, we believe it is reasonable to conclude that at the time of base construction the subgrade moisture content 2 ft. from the edge approximated closely the subgrade moisture content 8 ft. from the edge, at like subgrade depths.

In line with this reasoning, the calculated subgrade moisture content, which is shown on the graph as the moisture content, 2 ft. from the edge at the time of base construction, is the actual subgrade moisture content, 8 ft. from the edge, determined one month after construction, plus or minus the monthly average change in moisture which occurred 8 ft. from the edge between the first and eighth month after base construction.

Referring to Figure A, showing the subgrade moisture trend for the average of all base types, perhaps the two most significant facts are, first, the rapidity of increase in moisture content of all three layers, 2 ft. from the edge as compared to that which occurred in like layers, 8 ft. from the edge during the first eight-month period following base construction, and second, the persistently higher subgrade moisture content, 2 ft. from the edge as compared to that 8 ft. from the edge, throughout the 7-year period.

At the time of base construction, an increase in subgrade moisture was noted with increasing subgrade depth, i.e., the moisture content of the 12- to 18-inch layer was highest, with a decrease in moisture content in each successive layer above. Seven years after base construction, this same moisture gradient prevailed, although to a slightly lesser extent. Eight months after base construction, the moisture content of all three layers, 2 ft. from the edge, had risen to or exceeded the plastic limit moisture content. Whereas, 8 ft. from the edge, the moisture content of the 12- to 18-in. layer did not reach the plastic limit moisture percentage until 21 months after base construction, the 6- to 12-in. layer 40 months after base construction and the moisture content of the zero to 6-in. layer was only 93 per cent of the plastic limit moisture percentage 85 months after construction.

The subgrade moisture contents, 8 months after base construction and 85 months after base construction, expressed as percentages of the plastic limit moisture are as follows:

Layer Thickness	2 ft. from Edge		8 ft. from Edge	
	8 Months	85 Months	8 Months	85 Months
in.				
0– 6	100	105	78	93
6–12	107	112	89	104
12–18	110	111	97	108

Considering this information, in view of the fact that the plastic limits of cohesive soils are approximately equal to the critical moisture content, i.e., the moisture value above which increments of moisture result in much greater reductions in load bearing power than do similar increments of moisture below this value, we are of the opinion that a uniform cross section thickness is unbalanced for bases of these types unless some auxilliary means is provided for either stabilizing the outer edge of the subgrade or preventing the excessive accumulation of water at this location.

Limited additional data are available which indicate a possibility that the type of base or even the method of construction may critically influence the subgrade moisture content and its relation to the lower plastic limit of the subgrade soil. Such data need to be supplemented before they can be considered significant, but further studies of this phase of the subject are considered desirable.

STUDIES OF MOTOR VEHICLE OPERATION ON LIGHTED AND UNLIGHTED RURAL HIGHWAYS IN NEW JERSEY

A Project of the Committee on Highway Lighting Research

Reported by O. K. Normann,[1] *Senior Highway Engineer, Public Roads Administration*

SYNOPSIS

As part of the program of the Committee on Highway Lighting Research, the Public Roads Administration in cooperation with the Electrical Division of the New Jersey State Highway Department conducted studies to determine the effect of highway lighting on the movement of vehicles over 2-lane, 3-lane, and wider rural highways.

Driver-behavior data were obtained simultaneously on adjacent sections of lighted and unlighted highway by employing electrical equipment which recorded the travel speeds and transverse and longitudinal spacings and clearances between vehicles traveling in the same and opposing directions.

Preliminary tests were also conducted employing apparatus designed to compare the daytime nervous tension of drivers and passengers with their nervous tension at night on the lighted and unlighted sections. During these tests, a car equipped with a number of special recording devices was used for the first time. It appeared to be a normal five-passenger sedan but in back of the front seat were located the devices used to record the readings of a number of well concealed instruments. These instruments obtained information on a number of items that could be measured which it was believed would be related to the nervous tension of the driver and the nervous tension of a passenger in the front seat.

[1] Chairman, Subcommittee on Test Projects. Other members include Mr. H. F. Ilgner, Superintendent and Chief Engineer, Bureau of Electric Service, Milwaukee, Wisconsin and Mr. E. J. Reeder, Head, Public Safety Section, U. S. Engineer Department, Oak Ridge, Tennessee.