relationships between different types of soils and the probable degree of saturation that can be expected for each for any given group of conditions. While this method would involve incorporating empirical considerations into an otherwise rational approach, it should be remembered that practically all other factors involved in pavement design have as their basis empirical data

Mr. Spangler mentions the fact that in the centrifuge process the sample is subjected to a compacting force that is considerable. It is possible that this difficulty can be alleviated by using a suction method to remove the water from the sample rapidly. A suction-moisture content equivalent has been developed and is used by some soil laboratories as a substitute for the centrifuge moisture equivalent

PROGRESS REPORT OF SPECIAL PROJECT ON STRUCTURAL DESIGN OF NONRIGID PAVEMENTS

SUBGRADE MOISTURE CONDITIONS BENEATH AIRPORT PAVEMENTS

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SYNOPSIS

The report presents an analysis of subgrade moisture data obtained from airfield evaluation reports of the Office of Chief of Engineers, War Department; the moisture contents beneath both rigid and flexible airport pavements in 8 Disdricts, extending from the southeastern humid area of the country to the arid southwestern section were studied. It was found convenient to divide the soils into textural classes and to express the moisture contents in terms of percentage of saturation, percentage of plastic limit, and percentage of optimum moisture content

The moisture conditions, expressed in all three ways, varied with the texture of the soil and the climate of the region. The average condition increased for a textural progression from sands through sandy loams, clay loams, and clays The percentage of the soils which were 90 per cent or more saturated or were wetter than their plastic limit or optimum moisture content was higher for the heavier textured soils than for the light ones In humid or semi-humid areas, the sands and loamy sands had low relative saturation values, the sandy loams were variable, and the heavier soils showed up to more than half their values in excess of 90 per cent saturation A majority of the soils other than sands were wetter than their optimum moisture content

The data obtained from arid or semi-arid regions showed the subgrade conditions in such areas to be definitely drier than those in humid regions. Even the heavier textured soils tended to exist at relatively low moisture contents.

Comparisons of the moisture contents in similar soils beneath rigid and flexible pavements on the same airfield generally showed the greater values for the rigid type.

In arid regions the variations of moisture content in the upper 3 ft. of subgrade were slight and showed no definite trends

The report "Survey of Subgrade Moisture Conditions"[1] presented the results of a study of moisture conditions under highway pavements. This paper is an extension of that study and is concerned with the conditions under airport runways, taxiways, and aprons. The data were obtained from the airfield evaluation reports of the U. S. Engineer Department

The airfield pavement evaluation program was initiated by the Office of the Chief of Engineers late in 1943 and continued through the following year. Its prime purpose was to determine the weight of planes that could safely use each field without overstressing the pavements. Included in the program were

[1] *Proceedings*, Highway Research Board, Vol 24, p. 497, 1944

tests on the subgrade, including density, moisture content, grading, optimum moisture content and maximum density, and Atterberg limits (liquid limit and plastic limit).

It was thought that a study of this moisture information would be a worthwhile extension of the highway study; the very existence of the airfield data was a challenge to see if it would provide a means of estimating the moisture content soils would attain when covered with pavements Pavement design would be aided if such predictions could be accurately made.

procedures for the evaluation tests were established by the Office, Chief of Engineers, the number of subgrade tests made and the completeness of the soil tests varied considerably between the districts. The data reported by the districts in the northeastern and north central sections of the country were not extensive and for that reason no districts from those areas have been included. It would be desirable to have the study based on results of all the airfields. It is felt, however, that the coverage herein is sufficiently complete to give a representative

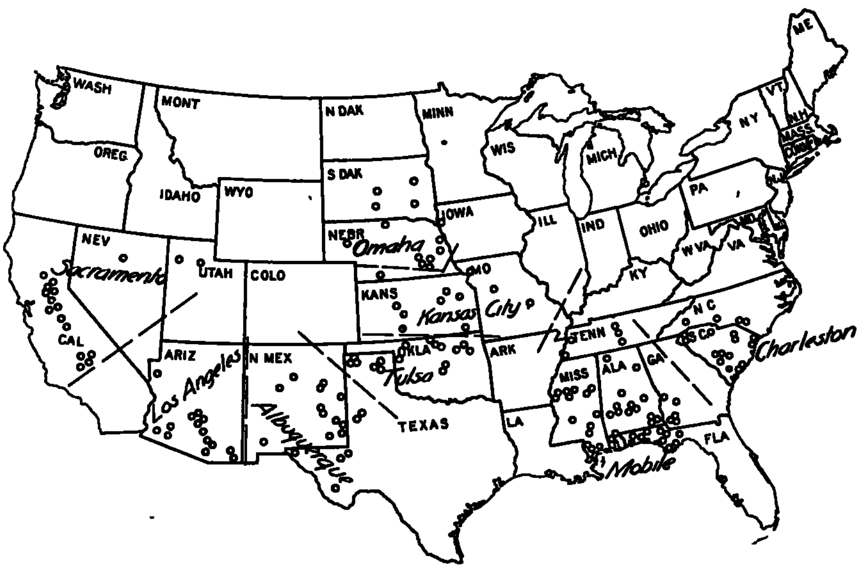

Figure 1. Location of Districts and Airfields included in Study

Permission was obtained from the Office of the Chief of Engineers to inspect and study the data of the evaluation reports Since the airports are under military occupancy no reference is made to specific airfields although their general locations have been designated.

DESCRIPTION OF DISTRICTS

The airfield evaluation investigations were performed by about 50 engineer districts. Several hundred airfields were included It was not possible in this report to include the results from all the airports or districts, instead, the data obtained by only eight of the districts in different sections of the country were selected. The areas selected and the general location of the airfields are shown in Figure 1. Although for uniformity, the

picture of the general moisture conditions. The number of airfields and the number of subgrade tests in those districts which have been selected are sufficient to give reasonable averages The analysis does not necessarily include all the airfields which were evaluated in each district.

The following paragraphs give general descriptions of the soil, airport runway pavements, and climate for the various districts studied.

Charleston, S. C. District. The 18 airfields studied in this district were all located in South Carolina except four in the southern part of North Carolina. The types of pavements on the airfields varied. About half of them had portland cement concrete pavements on the runways, in most instances without any base. The surfacing on the flexible runways were either about 1½ to 2½ in of asphaltic concrete or up to 5 in. of sand-asphalt. The bases were sand-clay, sand-asphalt, soil-cement, or crushed stone.

The subgrade soils in the district were largely sandy loams or sandy clay loams. The fraction of these soils passing the No. 200 sieve consists largely of an active clay with a relatively small silt content; they are consequently more plastic soils than would be indicated by a casual consideration of their grading. Some of the soils have high enough clay contents to be classified as clays and sandy clays. Three of the airfields had fine coastal sand subgrades.

The climate of this region is temperate to warm The average annual precipitation at the airfields varies from 43 to 60 in. and averages 48.

Mobile, Ala District This district included airfields in Alabama and Mississippi, western Florida, southwestern Georgia and Tennessee The airfield runway pavements were mostly of the flexible type, most commonly consisting of 2 or 3 in. of asphaltic concrete on a sand clay base; some gravel, slag, sand-asphalt, and soil-cement bases also were used. On about a fifth of the fields runways were of portland cement concrete, aprons, hard standings, and turnarounds were also concrete on most fields.

In such an extensive area a wide variety of subgrade soils was encountered. Among the more dominant ones were the rounded coastal sands of the Gulf coast, the heavy clays of the Black Belt of Alabama, and the loessial silty soils of Mississippi. There was a large number of soils which graded as sandy loams, particularly in Alabama.

The climate of this District varies from mild and temperate in the north to warm in the south. Annual rainfall at the airfields varies from 46 to 60 in and averages 53.

Omaha, Nebr District All except one of the 13 airfields had portland cement concrete pavements, in nearly all instances without base. One of the fields was in northwestern Iowa, the others in Nebraska and South Dakota. The soils were predominantly silty or sandy, falling largely in the sandy loam, silt loam, and silty clay loam classes. The area is one of hot summers and cold winters Annual rainfall ranges from 16 to 29 in. at the airfields, the average for the District being 24.

Kansas City Mo. District. Tests were made on seven airfields in Kansas, three in Missouri, and one in southern Nebraska. Runways on all fields except one were portland cement concrete. The soils were predominantly high in silt and clay content, many having developed from loessial parent material. The annual precipitation varies from 19 to 40 in ; the average at the eleven sites is 29

Tulsa, Okla District Tests covered 16 airfields, 10 in Oklahoma and 6 in the Texas Panhandle The pavements were of several types. On about half the fields runways were of portland cement concrete on a select soil base Flexible pavements most commonly consisted of 1½ or 3 in. of asphaltic concrete on a caliche base and a select soil sub-base.

A wide variety of subgrade soils were encountered on the fields of this district. The selected soil sub-bases were ordinarily sandy loams and these were considered in the analysis together with the subgrade soils. The subgrade soil textures varied from sands to clays. The annual precipitation varies from 19 to 42 in and averages 27.

Albuquerque, N. Mex. District Airfields in New Mexico and western Texas were tested by the Albuquerque district; results on 19 are considered herein. The runways on all the fields were bituminous, consisting generally of 1½ to 2 in of asphaltic concrete on a caliche base, or in some instances a sand and gravel base Base thicknesses varied from 5 to 11 in. The subgrade soils were predominantly sandy loams and clay loams.

The climate of this region may be described as semi-arid The annual precipitation at the airfields studied varies from 8.4 to 18 8 in and averages 13.5 in

Los Angeles, Calif. District. Only a small part of the airfields evaluated by the Los Angeles district were included in this study. Data of 14, all in Arizona, were analyzed. Only two of these had portland cement concrete runways; some had concrete aprons. The flexible runway pavements were about equally divided between field mix and plant mix asphalt surfaces, ordinarily 2 in. thick on gravel bases The soils of the area were predominantly sandy and many of the subsoils had appreciable amounts of gravel retained on a No. 10 sieve. In selecting the airports for study it was attempted to avoid stony soils, or those with more than 10 per cent retained on a No. 10 sieve. Four of the fields had subgrades of heavy texture.

The climate of the region is arid. Precipitation varies from 7.6 to 13.3 in. per year and averages 9 7 for the 14 fields

Sacramento, Calif. District The airfields studied in the Sacramento district were on a gravel base; two were described as road mixes. Three of the eight airfields in the more humid section had all or part of the runways of concrete. The others had 1 to 7, commonly 3 in. of asphalt surfacing on gravel, crushed rock, or soil-cement bases.

The soils were largely sandy loams. There were some clay loams and clays as represented by the adobe soils of central California.

TABLE 1
DESCRIPTION OF U S E D DISTRICTS AND AIRFIELDS INCLUDED IN STUDY

District	Area Included	Avg Annual Precipitation at Airfields, in — Range	Avg Annual Precipitation at Airfields, in — Aver	Number of Airfields Studied	General Description of Runway Pavements	Average Age of Pavements, Months	General Description of Subgrade Soils
Southeastern Region, Humid Climate							
Charleston, S C	So Car and Southern No Car	43-60	48	18	Approx half concrete, ordinarily no subbase Flex pavements 1½ to 2½ A C or 5 in sand asphalt on sand-clay, sand-asphalt, soil-cement, or crushed stone bases	16	Mostly sandy loams, sandy clay loams, and clays Some coastal sands
Mobile, Ala	Miss, Ala, Western Fla, Southwestern Ga, Tenn	46-60	53	47	On about a fifth, concrete Flex pavements most commonly 2 or 3 in A C on sand-clay base Some gravel, slag, sand-asphalt and soil-cement bases	19	Large number of sandy loams Also coastal sands, black clays, and loessial silt soils
Midwestern and Far West Region, Humid and Semi-humid Climate							
Omaha, Nebr	Nebr, S Dak, Northwestern Iowa	16-29	24	13	All concrete except one field	16	Sandy loams and loessial silt loams and silty clay loams predominate
Kansas City, Mo	Kan, Mo, and Southern Nebr	19-40	29	11	All concrete except one field	14	Do
Tulsa, Okla	Okla, Northwestern Tex	19-42	27	16	Approx half concrete on select soil subbase Flex pavements commonly 1½ to 3 in A C on caliche base on select soil subbase	12	Variable Sands to clays Large number of sandy loams
Sacramento, Calif	Central Calif, Utah	16-20	19	8	Three fields have all or part concrete Flex pavements commonly 3 in A C on gravel, crushed rock, or soil-cement bases	28	Mostly sandy loams and clay loams
Southwestern and Far West Region, Arid and Semi-arid Climate							
Albuquerque, N Mex	N Mex, and Western Tex	8-19	13	18	All bituminous, generally 1½ to 2 in A C on caliche or sand and gravel base	16	Mostly sandy loams and clay loams
Los Angeles, Calif	Ariz	7-13	10	14	Concrete on only two Bituminous pavements ordinarily 2 in of field or plant mix on gravel bases	20	Predominantly sandy loams Four fields with heavier textured soils
Sacramento, Calif	South-central Calif, Nev, and Utah	4-11	8	10	Concrete on only one Flex pavements ordinarily 2 to 4 in A C on gravel base	15	Mostly sandy loams Some clay loams and clays

mostly in the Central Valley of California, two were in Utah, one in Nevada. For analysis they have been divided into two groups, those at which the annual precipitation is less than 11 in. and those at which it is from 16 to 20 in. Of the 10 airports in the more arid region the runways on only one were of concrete. The flexible pavements were commonly 2 to 4 in. of asphaltic concrete

The climate for the one group of airfields is definitely arid, the annual rainfall averaging only 7.5 in. That for the other group is not less than 16 and averages 18 8 in.

For simplicity in presentation of the analysis the districts have been divided into three groups. One is composed of the Charleston and Mobile districts. This group of airfields is in the warm humid southeastern States, the annual rainfall being in the range of 43 to 60 inches. The second group includes the Omaha, Kansas City and Tulsa districts of the plains region of the Middle West, and also the Sacramento airfields with greater than 16 in annual rainfall. The yearly rainfall varies from 16 to 42 in. for all airfields in this group. The climate may be termed humid to semi-humid. The third group includes the Alburquerque, Los Angeles, and remaining Sacramento district airfields. The climate of this region is arid or semi-arid, the annual rainfall being in the range of 4 to 19 in

Table 1 presents briefly the pertinent items of the districts. The average age of pavement listed is approximate. For some airfields the pavements may have been constructed at several different times and thus pavement ages for a single field may vary It has been attempted to average these values In some instances new pavements may have been placed above old pavements In such cases the age has been based on the later construction. Thus, actually, the subgrades may have been covered for a longer period than is given by the age listed.

DATE FROM EVALUATION REPORTS

General information such as average annual precipitation, pavement description, date of construction, date of tests, and general soils information were recorded for each airfield. A detailed tabulation was then made of data of tests in the subgrade immediately below the pavement or base, including such items as depth, information on grading, liquid limit, plastic limit, optimum moisture content and maximum density, and field moisture content and density

The depth of the layer of soil for which the results were recorded varied but ordinarily was about 12 in. In most instances only one layer of soil was considered For some of the airfields in the Tulsa and Sacramento districts test data were recorded for two different depths, results of both depths are included in this study.

The information on grading was that sufficient to determine the textural classification of the soil. In the reports of some districts the percentage of silt (0 05 to 0 005 mm) and clay smaller than 0.005 mm.) were given; in others the percentage of material smaller than 0.06 and 0.002 mm. were given, in which cases it was necessary to make some assumptions to determine the textural classification according to the system used.

Method of Analysis of Data

For analysis the subgrade soils were divided into textural groups as defined by the U. S. Bureau of Chemistry and Soils.[2] To make entirely clear the classification used, the composition of the eleven classes are given in Table 2.

TABLE 2
COMPOSITION OF SOIL CLASSES

Soil Class	Clay, per cent	Silt, per cent	Sand, per cent
Soils with less than 20 per cent clay			
Sand	Less than 15, combined		85 to 100
Loamy sand	15 to 20, combined		80 to 85
Sandy loam	20 to 50, combined		50 to 80
Loam	Less than 20	30 to 50	30 to 50
Silt loam	Less than 20	More than 50	Less than 50
Soils with 20 to 30 per cent clay			
Sandy clay loam	20 to 30	Less than 30	More than 50
Clay loam	20 to 30	20 to 50	20 to 50
Silty clay loam	20 to 30	More than 50	Less than 30
Soils with more than 30 per cent clay			
Sandy clay	More than 30	Less than 20	More than 50
Clay	More than 30	Less than 50	Less than 50
Silty clay	More than 30	Less than 50	Less than 20

The clay fraction is defined as particles smaller than 0 005 mm, and silt as 0 05 to 0.005 mm. The original classification method divided the sands, loamy sands, and sandy loams each into four smaller classes according to the grading of the sand but this refinement has not been followed in this report.

Where subgrade soils were encountered which contained sufficient coarse material to be classified as gravelly soils (GW, GC, GP, GF) according to the U. S. E. D. or Casagrande method[3] they were excluded from the analysis.

In order to evaluate the stability of a soil it is necessary to know more than just its

[2] Davis, R E and H. H Bennett, "Grouping of Soils on the Basis of Mechanical Analysis," U. S. Dept. Agr, Dept. Circ 419, 1927.

[3] Army Engineering Manual, Chap XX, Part II, Exhibit 1.

moisture content expressed as a percentage of its dry weight, soils of different textures vary considerably in their ability to hold a given amount of water and still remain stable. Therefore, three other means of expression, each of which combines the moisture content with some other characteristic of the soil, have been used These are percentage of saturation, percentage of plastic limit, and percentage of optimum moisture content

The percentage of saturation is defined as the moisture content of a soil divided by the moisture content it would have if its voids were completely filled with water, times 100 For such a calculation it is necessary to know the density of the soil in place and the specific gravity of the soil particles To expedite the calculations, all soils were assumed to have a specific gravity of 2 67 This value should be sufficiently accurate for a great majority of the soils, for a few with extremely low specific gravities it is realized that the calculated saturation values may be in error

The plastic limit of a soil represents the lower limit of the moisture range in which it is plastic. It should be realized in comparing field moistures to this constant that the plastic limit is determined only on that portion of the soil passing the No 40 sieve whereas the field moisture is reported for the entire sample

The optimum moisture content to which comparisons are made is that determined by the compaction test as modified by the USED[4]

Summary tabulations for the moisture contents expressed in each of the three ways for the different textural classes of soil were prepared for each district The average moisture condition for each texture of soil was computed and also the proportion of tests which were in excess of a given value For the percentage of saturation, the proportion of values of 90 per cent or greater was determined No particular significance should be attached to the value of 90 per cent; it was merely an arbitrary selection to designate soils which are nearly saturated. In the case, of comparisons of moistures to the plastic limit and optimum moisture content, the proportions of values in excess of these constants have been determined.

[4] Army Engineering Manual, Chap XX, Part II

DISCUSSION OF DATA

The conclusions arrived at from a study of the subgrade moisture data must of necessity be general An attempt has been made to work with averages of a large number of determinations since the number of variables which affect moisture contents are many and difficult to separate

The limitations to the use of the data should be realized It would be of interest to compare the moisture conditions to those existing in the subgrade at the time the pavement was constructed. Information on the original conditions was either very meagêr or was lacking entirely, however, and consequently no such comparisons could be made

Many of the airfield pavements were only one or two years old at the time of the tests. The average age indicated in Table 1 is about 16 months Actually the subgrades had probably been under cover for a longer average period than this, for some of the new pavements were reinforcements of old runways Because of the relatively short period of coverage, it is possible that the subgrade soils were still experiencing a change in moisture content.

The time of year at which tests are made may effect the results The airfield evaluation testing program covered several months and consequently the tests were made on different airports in different seasons. The effect of this variation cannot be readily determined

In Table 3 are presented, by districts, a summary of moisture conditions in the subgrade below the pavements. The values are the averages for all the airports studied in each district, they include tests in subgrades below both rigid and flexible runways, taxiways and aprons of various ages The discussion which follows is based largely on this table.

Percentage of Saturation

The percentage of saturation varied both with the texture of the soil and the climate of the region Table 3 was arranged in a progression of textural classes from the light soils to the fine-textured and heavy ones, in-so-far as possible. The table indicates that in most districts there was an increase in the average percentage of saturation values from the sands through the loamy sands.

the sandy loams, the clay loams, and the clays. This fact is particularly apparent for the Charleston, Mobile, Tulsa, and Los Angeles districts The percentage of the tests which were 90 per cent saturated or greater also was higher for the heavier textured soils.

TABLE 3

SUMMARY OF SUBGRADE MOISTURE CONDITIONS BY DISTRICTS

Soil Class	Average Percentage of Saturation	Proportion of Tests 90% or Greater Saturated[b]	Average Percentage of Plastic Limit	Proportion of Tests Exceeding 100% Plastic Limit[b]	Average Percentage of Optimum Moisture Conditions	Proportion of Tests Exceeding 100% Optimum Moisture Conditions[b]
Charleston, S Car District						
Sand	34	0/60			59	5/59
Loamy sand	52	1/18			88	7/18
Sandy loam	73	17/69	62	1/28	109	45/69
Sandy clay loam	76	13/40	68	1/29	122	30/40
Clay loam	93[a]	5/6	87[a]	1/3	131[a]	6/6
Sandy clay	84	8/14	85	3/12	124	11/14
Clay	86	19/35	71	2/35	127	31/35
Mobile, Ala District						
Sand	35	1/79			41	14/74
Loamy sand	50	0/10	45[a]	0/9	87	4/10
Sandy loam	67	8/91	61	0/80	113	59/83
Loam	81[a]	1/8	87[a]	1/8	151[a]	8/8
Sandy clay loam	72	4/27	74	1/27	118	22/27
Clay loam	89	10/17	88	2/16	144	17/17
Silt loam	78	3/14	83	1/14	144	14/14
Silty clay loam	87	10/25	91	6/25	145	25/25
Sandy clay	68[a]	1/5	70[a]	0/5	115[a]	2/5
Clay	88	36/76	109	51/76	154	72/77
Omaha, Nebr District						
Sand	65[a]	0/6	58[a]	0/5		
Loamy sand	69	1/12	68	0/12		
Sandy loam	79	18/60	65	9/56		
Loam	77	5/14	80	3/13		
Clay loam	51[a]	0/7	68[a]	0/7		
Silt loam	92	20/27	95	6/23		
Silty clay loam	88	37/61	105	36/58		
Clay	98[a]	3/3	108[a]	2/3		
Silty clay	95	20/22	120	20/22		
Kansas City, Mo District						
Loamy sand	75[a]	1/2	68[a]	0/2		
Sandy loam	83	17/26	86	6/24		
Loam	87[a]	1/3	108[a]	2/3		
Sandy clay loam	87[a]	1/3	119[a]	3/3		
Clay loam	81	4/12	113	8/11		
Silt loam	93	12/16	118	13/16		
Silty clay loam	89	14/27	107	19/28		
Clay	89	16/31	112	21/31		
Silty clay	87	12/31	114	23/30		
Tulsa, Okla. District						
Sand	47	3/52	56	0/26	84	14/52
Sandy loam	64	4/132	74	13/122	107	77/132
Sandy clay loam	69	0/12	93	3/12	110	8/12
Clay loam	69	0/10	89	2/10	104	5/10
Silt loam	89	15/26	97	11/26	136	25/26
Silty clay loam	85	15/43	103	24/43	147	37/39
Clay	91	29/39	117	32/39	147	37/39
Silty clay	91	24/35	115	30/35	130	35/35
Sacramento, Calif District, 16 to 20 in Aver Ann Prec.						
Sand	81[a]	1/3			41[a]	0/2
Sandy loam	61	9/104	67	6/77	118	65/97
Loam	72[a]	0/6	96[a]	3/6	133[a]	3/4
Sandy clay loam	81	4/12	80	2/12	127	10/12
Clay loam	72	7/47	92	16/44	129	37/44
Silt loam	70[a]	1/3	86[a]	1/3	137[a]	3/3
Clay	81	3/13	103	4/12	146	11/11
Silty clay	98[a]	2/2	126[a]	1/2	168[a]	2/2

TABLE 3—*Concluded*

Soil Class	Average Percentage of Saturation	Proportion of Tests 90% or Greater Saturated[b]	Average Percentage of Plastic Limit	Proportion of Tests Exceeding 100% Plastic Limit[b]	Average Percentage of Optimum Moisture Conditions	Proportion of Tests Exceeding 100% Optimum Moisture Conditions[b]
Albuquerque, N Mexico District						
Sand	37	0/15	40[a]	0/9	59	0/15
Loamy sand	51[a]	0/6	51[a]	0/6	96[a]	1/6
Sandy loam	64	11/228	67	9/222	102	119/228
Loam	70	3/39	75	5/39	110	29/39
Sandy clay loam	69	5/39	74	2/39	102	22/39
Clay loam	67	9/136	81	14/134	111	99/136
Clay	62	1/28	74	1/28	97	15/28
Los Angeles, Calif District						
Sand	20	0/30			30	1/30
Loamy sand	29[a]	0/8	46[a]	0/3	62[a]	1/8
Sandy loam	42	9/215	55	0/129	79	40/215
Loam	41	0/21	50	0/10	86	6/21
Sandy clay loam	54	1/24	59	3/20	91	5/21
Clay loam	51	0/47	81	7/29	93	24/47
Silt loam	66[a]	0/2	92[a]	0/1	108[a]	2/2
Silty clay loam	45[a]	0/6	96[a]	0/1	87[a]	2/6
Clay	53	2/31	77	4/18	95	13/31
Silty clay	48[a]	0/2	61[a]	0/2	79[a]	0/2
Sacramento, Calif District, 4 to 11 in Aver Ann Prec						
Sand	42	0/26			71	2/26
Sandy loam	39	1/101	46	2/91	86	28/72
Loam	24[a]	0/7	46[a]	0/7		
Sandy clay loam	28[a]	0/4	51[a]	0/4		
Clay loam	29	0/40	53	2/38	92	7/21
Silty clay loam	25[a]	0/6	43[a]	0/6	77[a]	0/2
Clay	43	0/32	66	1/31	91	6/21

[a] These values are averages of less than 10 tests and consequently are less representative than the others

[b] The number of tests on which the average values are based is given in the denominator of the proportion of excessive values

The sands and loamy sands were definitely at low moisture contents in terms of percentage of saturation in all sections of the country. The average value for the sands was well under 50 per cent, that for the loamy sands close to 50 per cent. Considering all tests in both classes, only 8 of 325 tests had values of 90 per cent or more.

Saturation values for the sandy loams showed considerable variation. In the southeastern, humid section of the country the average value was about 70 per cent. From about 10 to 25 per cent of the test results may be equal to or greater than 90 per cent saturation, however. The high values occurred particularly in the sand clays where the dominant part of the silt and clay fraction is an active clay and the clay fraction is greater than the silt.

The saturation values for the sandy loams were much higher in the Kansas City and Omaha districts than in the Tulsa and Sacramento. Whether this was due to the differences in type of pavements, (nearly all concrete in the Kansas City and Omaha districts, bituminous in the other two), the generally wet conditions existing at the time of construction in Kansas and Nebraska, or to some other reason is not known. The proportion of tests in excess of 90 per cent saturation in the Kansas City and Omaha districts (65 to 30 per cent) is so high that such occurrences must be regarded as common. The high values in the Tulsa and Sacramento districts are both less than 10 per cent of the total number of tests.

In the arid and semi-arid region the sandy loams were relatively dry; the 64 per cent average saturation value for the Albuquerque district was the highest of the three districts. Only 21 of 544, or about 4 per cent, of the tests were as much as 90 per cent saturated.

The loams, clay loams, and sandy clay loams in the southeast and midwest sections of the country had average saturation values of roughly about 70 per cent with about 30 per cent of the test values exceeding 90 per cent saturation In the arid regions only about 2 per cent of such soils were so highly saturated.

The silt loams and silty clay loams were about equally highly saturated; omitting the dry regions the average value was about 88 per cent and about half of the individual values exceeded 90 per cent In the arid region only a few soils of this texture were tested (14 tests); none of these were highly saturated

The average percentage of saturation value for the clays was close to 90 per cent in the humid areas and 40 to 65 per cent in the arid regions, more than 50 and about 2 per cent of the values were the respective proportions of the tests in excess of 90 per cent saturation

To recapitulate briefly concerning occurrence of soils of relatively high saturation (90 per cent or greater)· sands and loamy sands attained high values in less than 3 per cent of the tests, in arid and semi-arid regions, only 42 of 1009 tests, or 4 per cent, in soils from sandy loams to clays, were highly saturated, values for sandy loams were variable for different districts, loams, clay loams and sandy clay loams in humid regions showed about 30 per cent of high values, and silt loams, silty clay loams, clays, and silty clays in the same areas were high in close to 50 per cent of the tests

Percentage of Plastic Limit

Comparisons of subgrade moisture contents to the plastic limits followed much the same pattern as the comparisons of the percentage of saturation values, since the plastic limits were not given for all the soils, the tests on which the conclusions are drawn are more limited.

The loamy sands for which plastic limits were reported (32) never had moisture contents as great as the constant

The sandy loams varied somewhat according to location In the southeastern humid districts, only 1 of 108 such soils had a moisture content greater than the plastic limit In each of the districts of the mid-west plains and the semi-humid Sacramento area about 10 to 25 per cent of these soils were in excess of this constant In the arid regions the soils had moisture contents greater than their plastic limits in only about 5 per cent of the tests.

The loams, sandy clay loams, and clay loams were progressively wetter than the sandy loams. Moisture contents in excess of the plastic limit occurred in less than 10 per cent of the tests in the southeast and in the arid section, but in about 35 per cent of the tests in the midwest.

The silt loams and silty clay loams had average moisture contents close to their plastic limits in the humid and semi-humid areas with about half of the individual results exceeding the constant Data were meager for the dry regions

The clay soils commonly had average moisture contents in excess of the plastic limit in the humid climates About two of every three tests in such soils showed a value in excess. In the arid regions, however, less than 10 per cent of the clay soils had moistures as great as the plastic limit

Percentage of Optimum Moisture Content

The optimum moisture content was determined by the U S Engineer Office modified test procedure, a variation of the A A S H O. test T 99-38 This constant was not determined for the soils in the Omaha and Kansas City districts

Considering first the areas of humid or semi-humid climate, the moisture content of the sands and loamy sands exceeded the optimum moistures in only about 25 per cent of the tests For all other soils the average moisture content was above the constant and a majority of the individual tests exceeded it; for the sandy loams about 70 per cent were in excess and for the heavier soils from 80 to 100 per cent.

In the arid regions only about 6 per cent of the sands and loamy sands were wetter than the optimum moisture content The other soils had an average moisture content close to the constant, about 40 per cent of the sandy loams and close to 60 per cent of the heavier soils had moisture contents which exceeded the optimum.

SOIL AREAS

Certain distinctive soil areas occur in the districts included in this study The following paragraphs describe the general moisture conditions of these areas.

Coastal fine sands—The airfields along the Gulf Coast in Mississippi and Florida and on the Atlantic Coast in South Carolina have subgrades of fine, clean, rounded sand In many instances the water table is at a depth of only a few feet. The moisture condition of these sands is represented by the values for sands and also loamy sands for the Mobile and Charleston districts. They had an average percentage of saturation of less than 50 with only about 1 per cent of the tests having values as great as 90 per cent. The soils were nonplastic so no comparison could be made to the plastic limit. About 20 per cent of the soils had moisture contents greater than the optimum moisture content.

Black Belt clays.—Several airfields were located in the so-called Black Belt of heavy clay soils in Alabama The moisture content of these soils represented a percentage of saturation in the high eighties, with about half exceeding 90 per cent, half the soils were wetter than their plastic limit; and nearly all of them exceeded their optimum moisture content by an average of 50 per cent

Loessial silt soils —Extensive areas of soils developed on loessial parent materials occur in Mississippi, Nebraska, Kansas, and Oklahoma These soils have high silt contents and fall into the silt loam and silty clay loam classifications These soils were characterized by a generally high saturation value with about half of them being at 90 per cent or more The moistures were usually close to the plastic limit with about half in excess Nearly all of them were wetter than the optimum moisture content, averaging about 35 per cent greater

MOISTURE CONTENTS IN ARID REGIONS

The data presented for the Albuquerque and Los Angeles districts and a part of that of the Sacramento district represent conditions in an arid or semi-arid climate The general trend of these results has already been pointed out Although this report is chiefly concerned with moisture conditions beneath airport pavements, some results obtained by the Los Angeles district of moistures below highway pavements located adjacent to or in the vicinity of airfields are valuable in increasing our knowledge of subgrade conditions in arid regions Some of the results are, therefore, discussed.

The test program, supervised by the Los Angeles district office and carried on with the cooperation of the Arizona and Nevada highway departments consisted of taking samples of the subgrade at three to six locations on highways adjacent or as close as possible to the airfields The moisture content, grading, and liquid and plastic limits were determined for the soil in increments of 6 in, plus or minus, to a depth of about 3 ft

Table 4 presents a summary of the moisture contents of the upper layer of subgrade soil, ordinarily 6 to 12 in, for tests made in Arizona, Nevada, and the arid sections of Southern California The average annual precipitation at these sites varies from 3 3 to 13 3 in and averages about 7 in Tests made near airfields in the vicinity of Los Angeles, where the rainfall is about 15 to 20 in annually, have not been included in this table

TABLE 4
SUMMARY OF MOISTURE CONDITIONS, HIGHWAY SUBGRADES, ARIZONA, NEVADA, AND SOUTHERN CALIFORNIA

Soil Class	No of Tests	Aver Moist Cont, by Wt, %	Aver Moist Cont, Per Cent of Plastic Limit	Proportion of Tests Exceeding 50% Plastic Limit	Proportion of Tests Exceeding 100% Plastic Limit
Sand	72	2 6			
Loamy sand	33	3 8	25	0/12	0/12
Sandy loam	100	5 4	36	10/64	1/64
Loam	6	4 5	26	0/5	0/5
Silt loam	1	3 6	23	0/1	0/1
Clay loam	8	10 5	61	6/8	1/8
Clay	4	6 8	57	2/3	0/3

It will be noted that a great majority of the soils were sandy loams, sands, and loamy sands. Many of these soils were quite stony Only 17 soils of texture heavier than sandy loams and with plastic limits reported are included

Since soil densities were not determined percentages of saturation could not be calculated, no optimum moisture contents were determined so comparisons to this constant could not be made either. Because of the lack of these items, average moisture contents in terms of per cent of dry weight of soil and the proportion of tests exceeding 50 per cent as well as 100 per cent of the plastic limit have been included in Table 4

It will be noted that only about 2 per cent of the sandy loams were wetter than the plastic limit; for the heavier soils only 1 of the 17 exceeded this constant and only the clay loams and clays appeared to show any tendency to exist at moisture contents of more than half the plastic limits.

From the average moisture contents one may judge that the soils did not have high percentages of saturation. To illustrate, a soil at 10 per cent moisture would require a dry density of about 128 lb. per cu. ft. to be 90 per cent saturated, a very high density for fine grained soils.

The pavements on the roads in which the tests were made were nearly all an asphaltic type, about half had gravel or other type granular bases and the others none. The ages of the pavements varied from 2 to over 30 yr.; the average was about 12 and only one was less than 5 yr. Thus the subgrades should have had sufficient time to attain a stable moisture condition.

These figures, together with those for the airports in the three districts, indicate that the subgrade moistures in arid regions are definitely less than those in humid areas

TYPE OF PAVEMENT

The subgrade moisture data in Table 3 include values for samples from beneath both portland cement concrete and nonrigid pavements. As noted in Table 1 the pavements in most districts were largely the nonrigid type, except for Omaha and Kansas City, in which case they were nearly all rigid.

To gain an insight into the comparison of the conditions beneath the two types of surfaces, the data of those airfields on which both types existed were analyzed. Direct comparisons were made between the average moisture contents of samples of the same textural class of soils existing beneath both types While it is realized that numerous factors other than pavement type may affect the results, the use of a sufficiently large number of tests should tend to dampen out such factors and indicate at least the trend of the effect of type.

Comparisons were made for all three methods of expression of moisture content. The relationships were approximately the same in nearly all instances and only the percentage of saturation values will be cited. Thirty-four comparative values from 26 airfields were found. On 21 of these the average relative saturation value was greater for the rigid pavement, on four the values were approximately the same (not more than 3 per cent difference), and on nine the values of the flexible pavement were greater.

To obtain more general results the data of the individual comparisons have been grouped according to common soil textures within each district in Table 5. This table shows the general magnitude of differences existing. Except for a few values, chiefly those in the Tulsa district, the rigid pavement relative saturation values ran from 10 to 30 per cent greater than those of the flexible type The reason for the opposite condition in the one district is not readily apparent. Considering all the values of Table 5 the average difference was about 10 per cent.

TABLE 5
RELATIVE SATURATION VALUES OF SUBGRADE AIRFIELDS WITH BOTH RIGID AND FLEXIBLE PAVEMENTS

District	Soil Class	No of Airfields	Rigid Pavement		Flexible Pavement	
			Aver Percentage of Saturation	Ratio of Tests 90% or Greater Saturation	Aver Percentage of Saturation	Ratio of Tests 90% or Greater Saturation
Charleston	Sand and loamy sand	2	60	0/6	39	0/12
	Sandy loam	1	78	0/4	42	0/3
Mobile	Sand	5	42	0/20	29	0/33
	Sandy loam	5	74	1/10	60	0/14
	Silty clay loam	2	92	4/6	79	1/6
	Clay	2	88	6/11	88	2/4
Tulsa	Sandy loam subbase	2	46	0/8	62	0/22
	Sandy loam subgrade	3	53	0/11	67	2/25
	Sandy clay loam	1	54	0/3	72	1/6
	Silty clay loam and silty clay	1	96	3/3	90	13/19
Sacramento	Sand	1	40	0/3	46	0/7
	Sandy loam	2	55	2/22	54	0/13
Los Angeles	Sandy loam	3	62	4/28	38	1/30
	Loam	1	61	0/5	32	0/5
	Clay loam	1	64	0/9	37	0/14
	Clay	1	60	0/5	47	1/15

The proportion of values in excess of 90 per cent saturation also tended to be greater for the concrete except for the Tulsa district.

VARIATION WITH DEPTH

The moisture data considered in this report have in most instances been for the upper 6 to 12 in. of subgrade. Some data were recorded for more than one layer or depth of soil and these data afford a means of ascertaining if any great differences occur for various depths.

All of such data were from the drier climates. One comparison was made for the airfields in the Sacramento district. Moisture values were recorded for the top 8 in of soil, plus or minus, and also for the next layer, ordinarily 12 in. thick but sometimes up to 36 in In 23 instances similar textural classes of soil occurred for both depths on an airfield. Considering these averages for a given textural class of soil, and taking the moistures expressed as a percentage of the plastic limit, 11 comparisons showed a greater value at a greater depth, one showed no difference, and 11 showed a lesser value Disregarding the signs, the average difference was 8 per cent of the plastic limit, or less than 2 per cent of moisture in percentage of dry weight of soil.

If the comparisons were made on a percentage of saturation basis a decided decrease occurred with an increase in depth; such a change occurred in 21 of 27 comparisons. The average difference in percentage of saturation found, with the signs considered, was 7 5 This was probably due to the difference in density existing between the two layers, the lower one being less compact

TABLE 6

Soil Description	Moisture content, per cent				
	Depth in subgrade, in				
	0–6, ±	6–12	12–18	18–24	24–30
A-2 SF	4 4	4 7	5 0	5 0	5 5
A-4 ML	6 4	7 3	7 5	7 6	7 6

On 14 airfields in the Albuquerque district, moisture tests were made at a depth of 3 ft. as well as in the top portion of the subgrade No soil description or constants were given for the 3 ft depth. Assuming that the soils were similar at the two depths and calculating the averages for each airport at common points for the two depths, 10 of the 14 fields showed a slightly lower moisture content at the 3 ft depth than in the upper portion of the subgrade. The greatest average difference was 2 8 per cent of moisture; the average, irrespective of sign, was 1 2 per cent.

The tests of the Los Angeles district in highways previously referred to may be analyzed for moisture variations with depth. Considering only those tests in Arizona and those holes in which the soil descriptions, according to the Public Roads and Casagrande or U.S.E.D. method, were identical for the entire depth, the averages in Table 6 were obtained.

The A-2, SF soils were sandy loams in nearly all instances; the moisture values are the average of 27 test holes The A-4, ML soils were also mostly sandy loams, with a few heavier soils; 25 test holes are represented.

The foregoing values indicate a slight increase in moisture content with an increase in depth The difference between that at the surface and that at 30 in. averaged only 1 to 1 5 per cent, however.

SUMMARY

This study has been based on data from the evaluation reports of the Office of Chief of Engineers, War Department; moisture contents from beneath both rigid and flexible pavements on airfields in eight districts were analyzed The districts included extend from the southeastern humid area of the country through the midwest to the arid southwestern section

The average age of the pavements on the fields was less than two years, although on many fields on which stage-construction methods were used the subsoils have been covered for a longer period than the date of final construction indicates, because of the small average age, it is possible that the subgrades were experiencing a change in moisture content.

For analysis the soils were divided into textural classes and the moisture contents expressed as percentages of saturation, percentages of the plastic limits, and percentages of the optimum moisture contents

In humid regions, as represented by the Charleston and Mobile districts, and humid to semi-humid climates, as the Omaha, Kansas City, Tulsa, and a part of the Sacramento districts, sands and loamy sands had low average percentages of saturation with less less than 5 per cent as high as 90 per cent saturated As little as 3 per cent and as high as 60 per cent of the sandy loams in the various districts were 90 per cent or more saturated; such soils are apparently quite sensitive to controlling influences and their condition may reflect weather conditions at the time of construction. The saturation values of the heavier textured soils ran progressively higher with from 30 to more than 50 per cent of the individual test results exceeding 90 per cent saturation

A similar trend occurred for the comparisons to the plastic limits, the loamy sands never exceeding it, the sandy loams being somewhat variable with an average of 10 per cent in excess, and the heavier soils showing larger excessive values up to about two-thirds of the clays

The moisture content of about 25 per cent of the sands, 70 per cent of the sandy loams and 80 to 100 per cent of the heavier soils exceeded the optimum moisture content

In arid or semi-arid regions, as represented by the Albuquerque, Los Angeles, and a part of the Sacramento Districts, saturation values were not particularly high for any of the textural classes of soil, less than 5 per cent of values were in excess of 90 per cent saturation Moisture contents in excess of the plastic limit occurred for about 5 per cent of the sandy loams and 10 per cent of the heavier soils Six per cent of the sands and loamy sands, 40 per cent of the sandy loams and close to 60 per cent of the heavier soils had moistures which exceeded the optimum moisture content

The airport data of the arid regions is supplemented by tests made in highways adjacent to airfields with pavements of an average age of 12 yr These tests showed the sandy loams to be extremely dry, only 2 per cent being wetter than their plastic limit, the heavier soils exceeded this constant in only 6 per cent of a limited number of tests.

The moisture conditions for distinctive soil areas, such as the fine coastal sands, the Black Belt clays of Alabama, and the loessial silty soils were generally quite uniform and well-defined

Comparisons of the moisture contents in similar soils beneath rigid and flexible pavements on the same airfield showed, in most instances, higher values for the concrete, on the average the percentages of saturation differed by about 10 per cent for the two types of pavement

Studies of moisture variations with depth in the subgrade for arid regions were not conclusive but indicated only slight average variations in the upper 3 ft, in general less than 2 per cent of moisture, expressed as a per cent of the dry weight of soil In some instances the soil was wetter immediately below the base than at 2 or 3 ft, in other cases the reverse was true

The subgrade moisture data which have been presented should serve as a guide in selection of moisture contents to use in tests on subgrade soils in the design of pavements Many methods of design advocate tests at conditions "as the soil will exist under the pavement" or "at the worst anticipated condition" Continual collection and analysis of data from subgrades will aid in obtaining a better understanding of what these conditions might be and which influencing factors are the most important.

DISCUSSION

MR. L. A. PALMER, *Bureau of Yards and Docks, U. S. Navy Department* Mr. Kersten has presented useful data, of the kind long needed. There is no point to assuming the "most unfavorable" subgrade conditions without available data to indicate what the most unfavorable conditions may be. In connection with a comprehensive program of pavement wheel load capacity evaluation of existing pavements at naval air stations, this writer is slowly accumulating a large fund of practical information concerning the moisture contents and densities of both base course materials and subgrades below both concrete and asphalt-surfaced pavements The results are sometimes astonishing Except those cases where the ground water is within less than 4 ft. of the pavement, a condition of 90 per cent or more void space filled with water is exceedingly rare. Where joint seals are poor and wherever there is poor maintenance, subgrades under concrete pavements tend generally to become softer and wetter under concrete than under asphalt topped pavements. However, subgrade compaction at the time of construction is an essential item, even for concrete paving and this item was neglected in all too many instances during wartime construction Every concrete pavement at airports requires a certain minimum of subgrade preparation Whatever is done beyond this minimum requirement is a question of economy, whether it is more economical to prepare an even more stable base and reduce slab thickness or to anticipate a poor subgrade support and design for it by increasing the slab thickness and raising the strength of concrete requirements etc

The data of Table A are typical of those being obtained in the Navy's present field studies

TABLE A
SUBGRADE MOISTURE CONDITIONS UNDER ASPHALT SURFACED PAVEMENTS AT NAVAL AIR STATIONS

Field	Subgrade	Natural (in place) moisture (per cent of dry wt)			Optimum moisture (per cent of dry wt)		
		Min	Max	Average	Min	Max	Average
A	Silty sand	3 3	12 5	8 9	8 7	12 5	10 0
B	Fine sand	2 9	15 5	7 2	10 8	12 5	11 6
C	Silty sand	5 0	9 0	6 8	11 2	12 1	11 8
D	Silty sand	4 6	13 2	8 4	8 9	12 8	10 1
E	Plastic clay	6 9	27 7	21 4	14 2	18 7	17 2
F	Black gumbo	13 0	21 0	17 3	13 4	18 7	16 7
G	A-4 to A-7	9 7	18 5	15 2	14 0	19 8	16 6
H	Plastic clay	14 0	21 0	18 3	12 3	16 6	15 5
K	Sandy clay	7 0	18 0	12 2	10 5	15 5	12 5
L	Sandy clay	9 4	20 4	14 2	12 8	17 8	16 1

In Table A, the soil classification is not given since analyses of the tests are not complete in all cases. At a later date, the complete subgrade data, including Atterberg limits, triaxial test data, mechanical analyses etc , will be presented together with field load test data obtained by loading with different sizes of plates on the pavement and with a 30-in diameter plate on the subgrade Sampling and loading are done at the same test locations The data of Table A were obtained from a number of test locations at each field varying from 20 to 35 and should therefore be indicative Field G is located in Oklahoma All the others are located either near the Gulf Coast or in the Carolinas where the annual rainfall is fairly high The optimum moisture was obtained by the heroic modified Proctor test as adopted by the Army Engineers

Recently, this writer visited a field in California where 15 in of rain fell during December, 1945 The field has practically no surface drainage The surfacing is thin and inferior, 1 to 1½ in of mixed in place sand-asphalt. The base course is poorly graded gravel mixed with sandy loam The subgrade is predominantly silt with a variable amount of clay Jack hammers were used in taking subgrade samples with galvanized iron tubes, 2 ft long and 4 in. inside diameter, swedged at one end and with cutting edges The dry and dense condition of the subgrade at this field in January of 1946 when sampling was done was certainly not expected.

It may be said furthermore that the test data being obtained in the Navy's pavement evaluation studies show that the density in-place of subgrades tends to increase with time, when traffic is continuous, even when only light training planes use the field. This observation applies, however, to only asphalt surfaced pavements At the same time, it is being observed that those asphalt pavements where traffic ceased altogether or was greatly reduced after V J day are rapidly deteriorating.

MR W H CAMPEN, *Omaha Testing Laboratories* I wish to emphasize that Mr. Kersten's report does not include data on the moisture content or the density of the subgrade soils at the time of construction and for this reason the significance of the conclusions is limited. For instance the degree of saturation indicates that the soils may have taken up all the water that they could hold but this does not mean necessarily that swelling had occurred during the absorption process. Complete saturation means that all the pore space is filled with water but this amount of water in itself does not indicate the strength of the soil mass The strength of a given soil mass at saturation is governed by the water capacity of the mass which in turn is governed by the density of the mass For instance a fine grained soil may require 20 per cent water for saturation and a soil-aggregate mixture may require only 5 per cent but the former may be stronger than the latter at these moisture conditions

Comparing moistures found in the field to the optimum moistures of a soil does not mean that the soils have taken up more water than their original water capacity would indicate because their original capacity is not known