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EVALUATION OF FLEXIBLE PAVEMENTS FOR AIRFIELDS

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In the latter part of 1940 the Corps of Engineers, U.S. Army, was assigned the task of designing and constructing military airfields in the United States. The program involved training fields and fields intended primarily for defense. Construction was under pressure for two reasons: (1) to train an adequate air force quickly, and (2) to provide fields capable of sustaining the ever increasing weight of military airplanes. At the outset design loads were for only 25,000-lb. gross weight but rapidly increased through various stages to 300,000-lb. gross weight before the war was over. It became obvious that to be most effective, the overall planning for the construction and the training programs would require careful coordination since the rapidly increasing size and weight of airplanes were causing many of the early constructed fields to become obsolete.

As a basis for developing such coordination with respect to the thickness and quality requirements of the base and pavement, it was decided that under conditions of high pressure construction design values might not be reliable, and each airfield should be carefully investigated to determine the ultimate load carrying capacity as actually constructed. The load carrying capacity assigned an airfield on the basis of the investigation was termed the "evaluation" of the field. The evaluation of the airfields was performed by the field offices of the Corps of Engineers under the direction of the Airfields Branch, Engineering Division, Military Construction, Office, Chief of Engineers, U.S. Army. They have evaluated 603 airfields of which 426 included flexible pavements and have kept current the evaluation of all fields which have been named for permanent occupancy by the U.S. Air Force. By means of the field evaluations it was possible to coordinate training requests with actual field load carrying capacities and to some extent designate the mission of defense airfields. This resulted in a smoothly operating training program with relatively few pavement failures. The behavior of the pavements since the war continues to validate the evaluations that were made.

The evaluations were conducted in accordance with a uniform procedure established and published by the Office, Chief of Engineers, which permitted the results to be appraised without regard to geographical location or jurisdictional boundaries. The basis for the uniform procedure was the design method employed by the Corps of Engineers and published in its Engineering Manual 1). Details of the evaluation tests have been published elsewhere 2) 3). Only that portion of the evaluation program and procedure concerning flexible pavements is pertinent to this paper. In the evaluation test procedure three subgrade conditions were recognized and considered in obtaining the CBR values used for the purpose of evaluation. These were: (1) well compacted subgrades with moisture contents approaching the ultimate expected, in this case in-place CBR tests were conducted and used in the evaluation; (2) well compacted subgrades with moisture contents that were low and might increase, in this case CBR tests were made on undisturbed soaked samples; and (3) subgrades composed of low P.I. material of a type and density such that an increase in compaction could be expected, in this case CBR tests were made on samples recompacted to maximum density and soaked in the laboratory. The CBR method of design is expected to insure a design to prevent shear deformation in the base and subgrade, but it is not expected to insure against settlement due to compaction of the underlying soils by traffic. The latter is covered by compaction design and construction requirements.

In addition to the evaluation program, data are currently being obtained through a carefully organized program of condition surveys and pavement behavior studies. The ultimate aim of these studies, together with a stress distribution investigation now under way at the Waterways Experiment Station, Vicksburg, Mississippi, is to develop a rational method of flexible pavement design which will eliminate some of the uncertainties which are inherent in the existing method. In the current surveys and studies, particular attention is given to fields which failed contrary to expectations and to those which did not fail though reasonably expected to do so. Data are also collected on fields which indicate proper design for their expected use. The studies itemize traffic, pavement materials, and design thickness, and include tests for CBR, moisture, density, and Atterburg limits of base and subgrade, and gradation, percent asphalt, voids relationships, flow, and stability of the wearing courses. Only these fields are considered which have received traffic from airplanes having wheel loads of 15,000 pounds and greater. Satisfactory pavements were included only when they had received at least 30,000 cycles of traffic with no visible evidence of traffic failure. A traffic cycle is defined as a landing and take-off of one aircraft. Failed pavements were tested only when it was reasonably certain that the conditions for failure still existed. Failed pavements were tested without regard to the number of cycles of traffic that had been applied. The data obtained from the failed pavements include: (1) the identity of the failing member, (runway, taxiway, or apron), (2) the wheel load causing failure, (3) the pavement cross-section showing the depth of base and wearing courses, (4) the quality of the materials in the individual elements, and (5) comparable information from an adjacent satisfactory area. The identity of the failing member is established by visual inspection, photographs, and cross-sections. When the failure is characterized by ruts or by ruts and upheavals of the base or subgrade, the failing element can be determined from trenches excavated across the failed area at right angles to the path of traffic.

The data obtained from the evaluation studies and from the current behavior studies are being utilized in investigations for the refinement of presently used procedures for future evaluation studies and for the design of flexible pavements. A few of the pertinent findings that have been made to date are presented and discussed in the following paragraphs.

The term "saturated" used in connection with the CBR method of design does not necessarily mean that 100 per cent of the voids in the soil are filled with water. The term is applied to the maximum degree of saturation which is expected to ever occur in the soil under the pavement. The results of hundreds of tests made on samples of base courses and subgrade show that when the samples are compacted and soaked in accordance with the specified procedures, the degree of saturation (volume of water to volume of voids) ranges from about 75 to 100 per cent. The in-place per cent of saturation of soils from under pavements 5 to 6 years old and older has been obtained at a large number of fields. Tests have been made at several locations at each field and on not less than 5 samples from each location. Where the annual rainfall is high the degree of saturation is generally in the same range as has been found for the soaked samples. Also, where the annual rainfall is low, the degree of saturation is usually lower although there are instances in regions of low rainfall where the degree of saturation approaches that of the soaked samples. Table 1 shows the results of tests on field which were sampled in 1946-1947. These results are typical of other results which have been obtained by the Corps of Engineers and other agencies, see 4) and 5), except that a preponderance of field in arid and semi-arid regions is included. It is noted that the first 12 fields listed in table 1 are in regions where the annual rainfall is 25 inches or less. The percent of saturation of the subgrade at these fields in 1946-1947 (3 to 10 years after construction) is generally low but a few locations showed values rang-

TABLE I.

Name of Field	Facility	Percent Saturation		Rainfall in Inches Per Year	Depth to Water Table in Feet
		In-Place	Remolded Specimen x)		
1	2	3	4	5	6
Woodward	Taxiway 3	50,78	-	25	100
Dodge City	Taxiway 4	80,90	-	21	Localized Perched Tbl
La Junta	E.W Runway	27,37,42,59	96	15	100+
	Taxiway 5	26,48	-	15	100+
Rocky Ford	E-W Runway	35,35,39,41,44,48	97	12	100+
Pueblo	E-W Runway	76,77,84,87,90	100	12	6
	Taxiway 6	66,65	--	12	6
Kirtland	Taxiway 2	25,42,52,71,75	--	8	200+
	N-S Runway	27,31,33,57,72	96	8	200+
Douglas	Taxiway 5	55,82	-	13	115
	N-S Runway 4	46,50,58,61,64,66 66,87	100	13	115
Yuma	Taxiway 7	15,18	--	4	60
	N-S Runway	25,25,31,34,37,39	82	4	60
Las Vegas	Taxiway 3	53,56	-	5	38
	N-S Runway	46,49,60	-	5	38
Blythe	N-S Runway	32,36,37,41,43	-	4	139
Clovis	N-S Runway	38,71,88	-	18	100+
Santa Fe	N-S Runway	42,47,73	-	14	Apparently low
Jackson	NNW-SSE Runway	80,67	100	52	14
Camp Campbell	N-S Runway	91,94,94,97,100	100	49	20
Berry	N-S Runway	87,88,90,95	98	46	Over 15
Bergstrom	NW-SE Runway	90,90,91,94,94,98	94	41	20
Lawson	Taxiway 4	53,69	93	51	9
	Taxiway 6	73,80	-	51	9

x) Average obtained from top inch and bottom inch of at least 15 specimens compacted to various densities and soaked top and bottom for 4 days.

ing as high as 90 per cent. By contrast the next 5 entries in the table represent fields where the annual rainfall is in excess of 40 inches per year. The percent saturation at these fields in 1946-1947 was consistently high. With respect to the fields in the arid and semi-arid regions, the reason for some fields showing high and some low degrees of saturation has not been definitely determined, but there is considerable evidence that the lower degrees of saturation are attributable to low water table, excellent drainage, and type of subgrade, in addition to low rainfall. Provision is made in the Corps of Engineers design to reduce thicknesses 20 per cent for these conditions. It is realized that this approach is arbitrary and therefore considerable study has been made and is being made to devise a more definite and scientific method of evaluating these conditions.

The evaluation of ultimate field conditions is extremely difficult. The method employed by the Corps of Engineers of soaking the specimens 4 days prior to testing is not perfect by any means. Up to the present time, however, the Corps of Engineers has been unable to develop a better method, nor has anyone suggested any positive method of determining the condition which will ultimately occur under a pavement. A study of results from numerous fields shows that the methods employed by the Corps of Engineers are reasonably valid. Table 2 shows a comparison of CBR values for the 17 fields investigated in 1946-1947. The fields have been constructed long enough so that conditions should be reasonably well adjusted. Column 3 shows the results of tests made on undisturbed soaked samples in 1943. Column 4 shows the value selected as critical for the evaluation of the field. Column 5 shows the in-place CBR in 1946-1947. It will be noted that in 1946-1947 an in-place CBR value equal to or less than the originally selected CBR (based on the 1943 undisturbed soaked samples) was found to exist in one or more pits at 10 airfields (Camp Campbell, Bergstrom, Woodward, Dodge City, Rocky Ford, Lawson, Douglas, Clovis, Santa Fe, and Blythe).

TABLE 2.

Name of Field	Facility	CBR Values			Soil Classification Corps of Engrs
		Undisturbed and Soaked - 1943	Evaluation	In-Place 1946-47 x)	
1	2	3	4	5	6
Woodward	Taxiway 3	7,14	10 xb)	11,21	CL, ML
Dodge City	Taxiway 4	5,6 xa)	4	4,14	CL
La Junta	E-W Runway	2,2,10,11	3 xb)	7,9,15,31	CL
	Taxiway 5	2	3 xb)	7,9	CL
Rocky Ford	E-W Runway	2,3,6,16	3 xb)	3,6,6,8,10,11	CL
Pueblo	E-W Runway	2,5,6,9	5	8,11,16,17,20	CL
	Taxiway 6	5	5	25,33	CL
Kirtland	Taxiway 2	6,7	14 xb)	19,22,23,37,59	SF
	NE-SW Runway	9,12,14,27	14 xb)	16,24,26,30	SF
	N-S Runway	5,8,11,15,17	14 xb)	36,39,47,56,64	SF
Douglas	Taxiway 5	3	5 xb)	4,27	CL
	N-S Runway	3	5	3;4,24,30,38	GF,ML,CL,CH
Yuma	Taxiway 7	16	20 xb)	36,89	SP
	N-S Runway	12,49	20	29,33,38,44,47,50	SP
Las Vegas	Taxiway 3	—	7 xa)	28,32	CL, ML
	N-S Runway	—	7 xa)	8 to 32 xc)	CL
	NE-SW Runway	--	7 xa)	15 to 62 xc)	SP, SF
Blythe	N-S Runway	--	20	15,60,60,65,66	SP
Clovis	N-S Runway"B"	7,19,24,25,26	25 xb)	12,20,28	CL
Santa Fe	N-S Runway	7,9,11	8 xb)	5,7,28	ML, CL
Jackson	NNW-SSE Runway	5,8,25	6	24,25	CL
Camp Campbell	N-S Runway	7,7½	8	7,8,11,15,17	CL
Berry	West N-S Runway	7,11	10	16,23,27,43	ML, CL, CH
Bergstrom	NW-SE Hunway	17	10	6,6,6,10,11,12	CH
	Taxiway 1	10,11,10,11	10	8,10	CH
Lawson	Taxiway 4	11,14 xa)	9	22,25	SC
	Taxiway 6	11,14 xa)	9	8,9	CL

x) Each figure represents the average value for a test pit and is the average of not less than 3 individual tests.

xa) CBR value lower under other pavements and the evaluation is based thereon.

xb) A reduction of 20 percent in thickness is permitted because of low water table and good drainage.

xc) Range of 12 values.

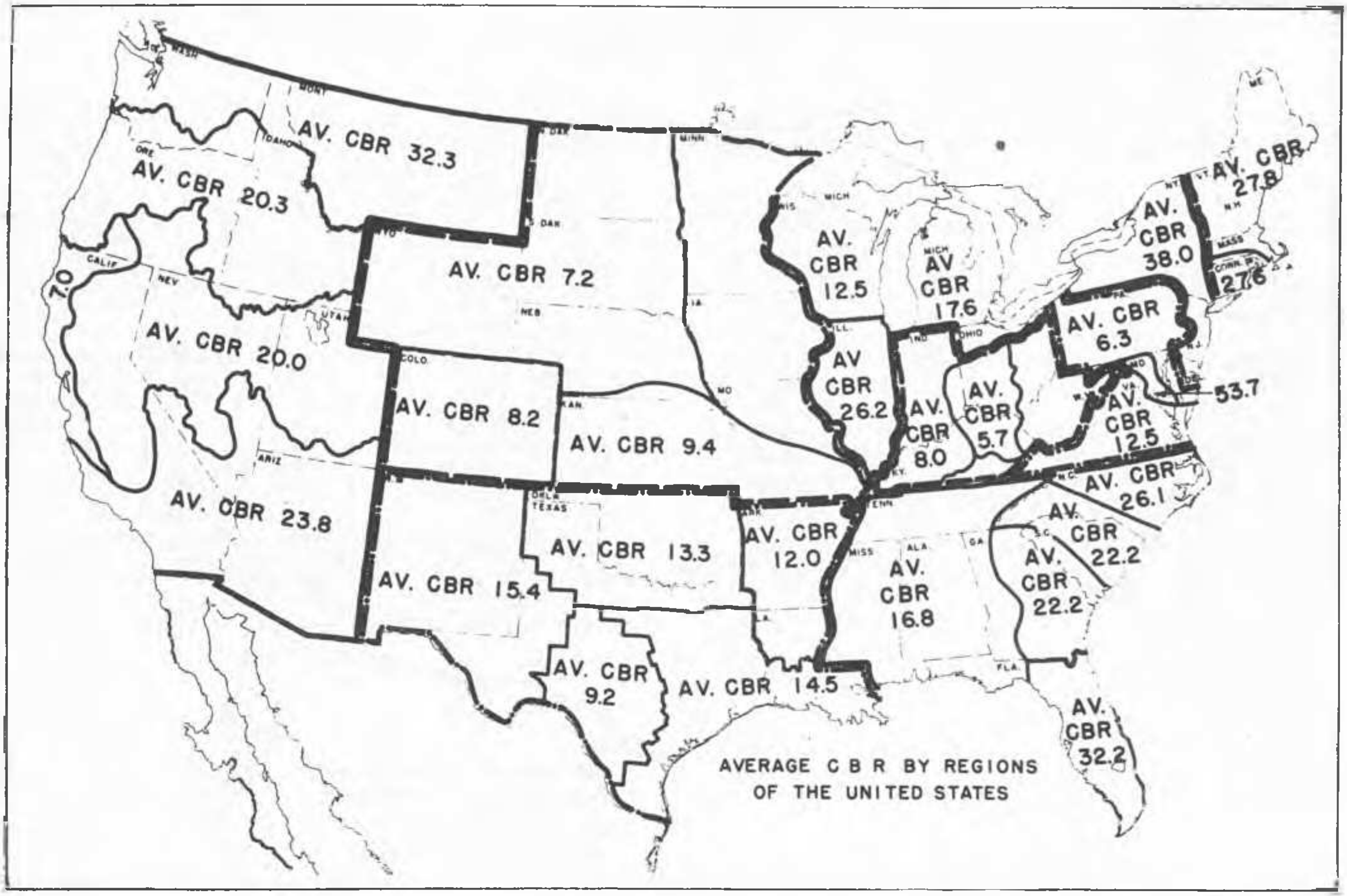


Plate 1

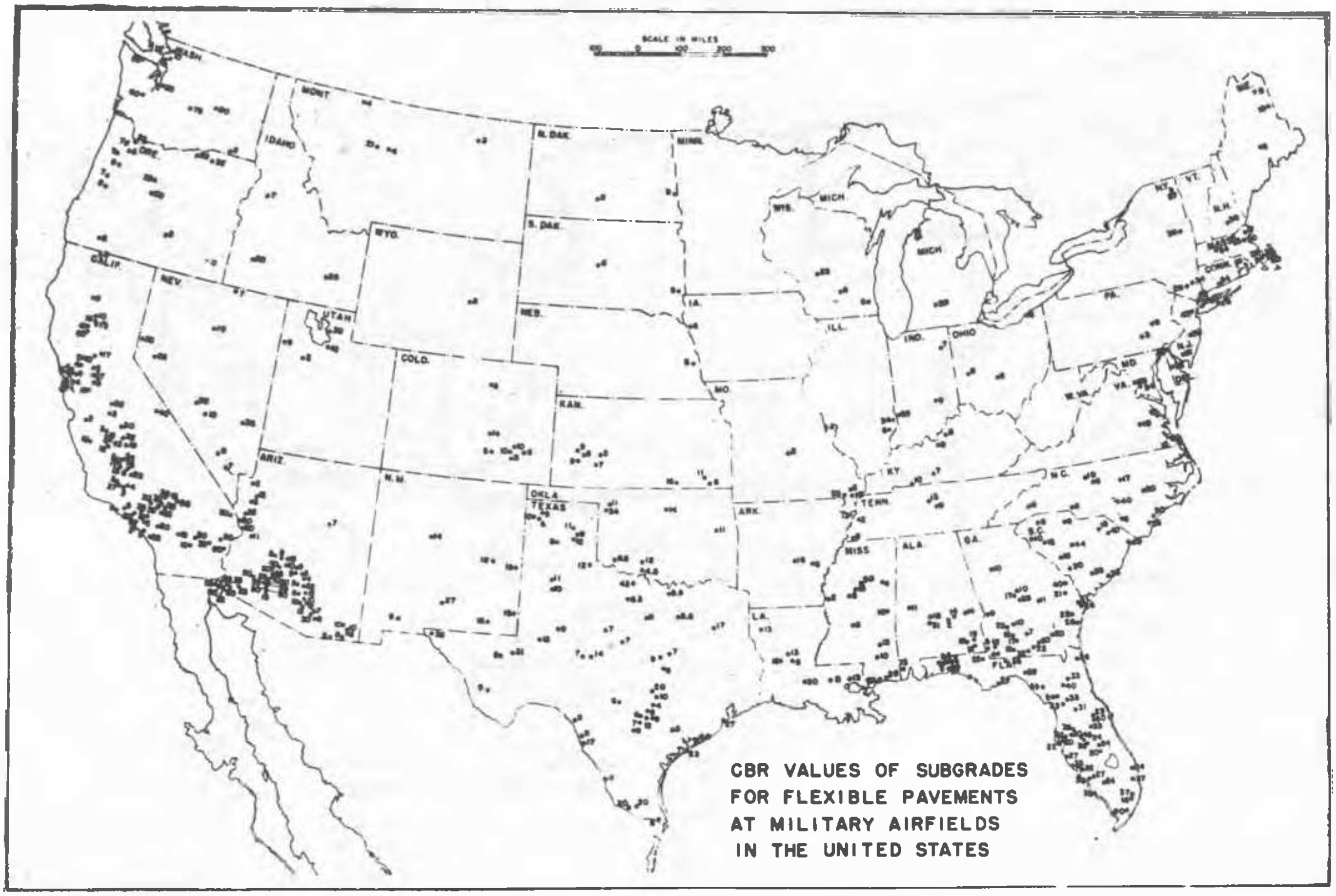
At the other 7 fields, the inplace CBR in 1946-1947 was higher than the selected evaluation CBR. Five of these 7 fields are in arid or semi-arid regions and conditions have been such that the subgrades are at a relatively low degree of saturation, with the exception of Pueblo. This field has a relatively high water table. The other 2 fields, Jackson and Berry, are in areas of relatively heavy rainfall. The subgrades at these 2 fields appear to be better than would be expected on the basis of the present degree of saturation. A high degree of subgrade consolidation from plane traffic without the occurrence of hydrostatic excess pressures may account for the increased subgrade CBR.

Accurate information is not available for all pavements that have failed, but where sufficient data are available, the analysis usually showed that the pavements failed because they were overloaded. The data also show that when conditions occur such that the pavement is overloaded, failure follows relatively rapidly. It has been found that 90 per cent of the pavement failures occurred before 1,000 coverages had been applied and that 95 per cent occurred before 1,500 coverages had been applied. A coverage is defined as one load application over every point in a given area. With a normal pattern of distribution on a runway an airplane with 30,000-lb. single wheel loads will produce about 2,500 coverages in the center portion of the facility in 30,000 cycles of operation. An average of 250 cycles of operations per day is not uncommon at training fields using this size of plane; thus a total of 30,000 cycles could occur in about 120 days.

A considerable amount of data has been obtained for use in comparing actual thickness requirements with the CBR design curves. Details of the comparisons have been prepared as a paper to a symposium on the CBR method of design which will be published in the near future. The comparison is based on in-place CBR values during the period of traffic since it is considered that the in-place value is indicative of the load carrying capacity of the material at the time traffic was applied. Under these conditions the actual thickness requirements and the design curves are in very good agreement.

A summary of CBR's used for the evaluation of all flexible pavements on military airfields in the United States is shown on plates 1 and 2. Plate 1 shows the average CBR for geographical areas. Plate 2 shows the evaluation CBR of each airfield in the United States having flexible pavements. From these plates it can be seen that there is a wide range of CBR's and that to some extent they follow a geographical pattern as is demonstrated by the high CBR of the sandy soils in the Great Lakes region and Florida and the New England States. Relatively high values are shown for the dry regions of the Southwest and lower values are shown for the great river valleys such as Missouri, Ohio, and Mississippi.

The popular conception that most CBR values are very low especially for the clayey and silty soils is erroneous as can be seen from a review of the CBR's of the Ohio, Mis-



CBR VALUES OF SUBGRADES FOR FLEXIBLE PAVEMENTS AT MILITARY AIRFIELDS IN THE UNITED STATES

Plate 2

souri, and Mississippi River valleys. The subgrade soils of the airfields in these regions are generally the fine grained, silty clays and clayey silts but only 8 per cent of the CBR's in these regions are 5 and below. **Approximately 5 per cent of all airfield subgrades in the United States are 5 and below. The very** low CBR's in the order of 3 are found for the most part in areas such as mud flats, for example, the bay mud in the San Francisco area. The influence of low rainfall and low water table can be seen from a review of the CBR's for airfields in the Southwestern United States. In this area subgrades are mostly fine grained soils.

The study of base courses has shown a very good correlation between plasticity index and capacity to resist shear deformation. Base courses with plasticity indexes less than 6 per cent have given very little trouble from shear deformation. Correlation of the CBR with ability of the upper base materials to resist shear deformation has also been reasonably good. In general, upper base materials with CBR values in excess of 80 per cent are satisfactory under minimum thicknesses of high quality wearing courses. By increasing the thickness of the high quality wearing course (pavement) it is possible to use base materials with somewhat lower CBR values. A high quality wearing course is generally considered to refer to dense, well graded, hot-mix bituminous concrete pavement. The following combinations have been found to be satisfactory where the tire pressures do not exceed 100 lbs. per sq. in.

CBR of upper base	Thickness of high-quality wearing course in inches	
	15,000-lb. Wheel Load	37,000 and 60,000-lb. Wheel Load
40	4	5
50	3	5
60	2	4
80	2	3

Another interesting finding has been with respect to sand subgrades. The behavior of clean sand subgrades has been remarkable in that they have stood up very well under relatively thin thickness of base and wearing course. Clean sand subgrades have given some trouble from compaction under traffic but there have been very few failures from shear deformation. One reduction in the thickness requirements as shown by the CBR curves has previously been made in the range of sand subgrades (CBR in excess of 20). Further reductions would be very limited except for the very heavy wheel loads since generally only minimum thickness are now required for this range of CBR values. The minimum thicknesses are established for water-proofing and abrasion resistance rather than prevention of shear deformation in the subgrade.

In general, the wearing courses have been satisfactory. Instances have been found where the failure of the pavement was due to a poor wearing course but the large majority of the

wearing courses have given satisfactory service. This is believed due in part to the fact that hotmix wearing courses were used extensively.

From the results of the evaluation and pavement behavior studies it is considered that the CBR method is reasonably satisfactory for both evaluation and design. The thickness requirements indicated by the design curves are satisfactory. The method of preparing the sample to meet the condition which is expected to ultimately obtain under the pavement is not entirely satisfactory. The indications are that it may be slightly on the conservative side even in conditions of heavy rainfall and high water table. As these conditions improve the conservativeness increases. In areas of low rainfall with excellent drainage and low water table the method is definitely conservative without the provision to reduce pavement thickness 20 per cent for these conditions.

As previously stated, steps are being taken to evaluate these conditions. The highway departments of several of the states have worked out numerical indices which certainly have merit and are worthy of consideration. The studies of moisture conditions under pavements in areas of different rainfall, conditions of ground water, and drainage conditions are improving our knowledge of flexible pavements and will lead to improved design. The general procedures employed by the Corps of Engineers have demonstrated they give good results. More data are being collected daily and as they are analyzed and correlated a more scientific method of design and evaluation may be developed.

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THE USE OF PLATE BEARING TESTS IN THE EVALUATION OF SUBGRADES FOR HIGHWAYS

VIII b 9

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INTRODUCTION

The use of load tests to test the strength of soil foundations has been made for many decades, as it was necessary for the builder to know if the foundation was strong enough to support the building or structure he proposed to construct. At first, the tests were rather crude and often performed without proper knowledge of the behavior of soils as foundation materials, with the result that in many instances the load carrying capacity of the foundation was exceeded and the structure suffered collapse or excessive settlement. As time went on, engineers learned more and more about the behavior of soils as foundations and more how to test them, until testing technique has now been developed to the point where engineers are able to measure quite accurately the load carrying capacity of soil foundations and their settlement characteristics.

Soil foundations for structures in most cases are several feet below the surface of the ground where they are protected from the action of the elements, such as moisture and frost action. In highway work the pavement foundation or subgrade is near the ground surface where fluctuations in moisture content and the effects of frost action are to be expected. This presents a problem to the pavement designing engineer who must taken into consideration the effects of these conditions. The extent of the fluctuations in moisture must be known and the effect they have on the bearing capacity of the particular soils determined. The depth to which frost penetrates and its effect must also be determined. This means that the engineer responsible for the determination of the correct bearing value of the subgrade must either conduct his loading test on the soils at the conditions anticipated or be able to intelligently adjust the values obtained at a certain condition to the condition anticipated.

When field loading tests are made on subgrade soils, they must be made at the conditions of moisture and density that exist at that time. It is on rare occasions that the existing conditions coincide with the conditions desired for the test and it is quite dificult to produce these conditions in the field if they do not exist. Some engineers adjust the bearing value obtained under the existing conditions to other conditions by the use of supplementary shear tests. A shear test is first made on a sample of the soil, either undisturbed or disturbed, having the same density and moisture content as the soil tested in the field loading test; and another shear test is made of the soil at the density and moisture content desired. These two shear test values are assumed to bear the same relationship with one another as the two bearing values.

Another method of obtaining bearing values