SOIL TESTS FOR DESIGN OF RUNWAY PAVEMENTS

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SYNOPSIS

This report reviews the soil tests employed by the U S. Engineer Department and the Aviation Engineers, for the design of runway pavements. The tests are the result of extensive investigations into the application of soil mechanics to the design of both flexible and rigid pavements. A portion of these investigations, covering field bearing tests and their application to flexible pavement design, was reported upon at the December, 1941, meeting of the Highway Research Board in a report entitled "Field Investigations for Flexible Pavement Design" In addition to the investigations outlined in that report, extensive investigations have been made into the application of the field bearing tests to rigid pavement design and the use of the California bearing ratio test for flexible pavement design.

The field bearing test, with the results modified for increase in moisture using the consolidation test, has been adopted for design of rigid pavements. The California bearing ratio test on compacted and soaked specimens has been adopted for the design of flexible pavements. The writers point out that these tests have been adopted as the best methods presently available, after a review of all available methods and after extensive field investigations, including traffic or service behavior tests using wheel loads up to 50,000 lb They do not represent an inflexible standard of design, since the problem is being continuously studied and changes will be made as they are proven to be justified. In addition to the tests specified for design, field bearing test data for flexible pavements and California bearing ratio test data for rigid pavements are being obtained along with other test data in special cases, in order that full information will be available on each pavement for future correlation and study. It is considered possible that major changes may be necessary after a sufficiently long service record is available It is desired, therefore, that enough test data be available in order that all possible methods of improving the design criteria can be investigated

In the application of these tests to the design and construction of runway pavements by the Aviation Engineers, it is recognized that the time element is an important factor, and that there will seldom be time in advanced areas to conduct all the laboratory and field tests desired for design purposes Therefore, this evaluation has been set up on the basis of field and simple laboratory tests for quick classification of the soils. The soils are divided into fifteen (15) separate groups, and each group is assigned a bearing ratio value and a modulus of soil reaction value to be used in design. It is anticipated that in some instances, where airfield construction is accomplished in base areas of theaters of operation, there will be time available for conducting the necessary tests, and in these cases the Aviation Engineer Troops will be equipped with the necessary soil testing apparatus to make complete investigation into the soil characteristics

In the paper presented last year, "Field Investigations for Flexible Pavement Design,"[1] investigations were reviewed which had been conducted by the Engineer Department up to that time. These investigations on flexible pavements have been continued, and in addition extensive investigations have been made into the application of the field bearing tests to rigid pavement design and the use of the California bearing ratio test for flexible pavement design. The purpose of this re-

[1] *Proceedings,* Highway Research Board, Vol 21, p 137 (1941).

port is to outline the soil tests which have been tentatively adopted by the Engineer Department and the Aviation Engineers, for the design of runway pavements.

SUMMARY OF INVESTIGATIONS

At the time of the last report, field bearing tests had been conducted on the Williamsburg test road and on a number of airfields. It was concluded from these tests that the critical deflection of the subgrade in the design of flexible pavements should not exceed 0 2 in. However, it was pointed out that this critical deflection might approach 0 1 in. where a large number of repetitions were to be expected.

Following these studies, a test section was constructed at an airfield in Virginia consisting of seven different types of pavements with two thicknesses of each, totaling 14 different units. It was originally intended that these pavements would be subjected to field bearing tests only. However, after it became apparent that the critical deflection for flexible pavements would be much less than 0 2 in., as previously reported, it was decided to subject the pavement to a traffic test on one half and to conduct field bearing tests on the other half. After less than 100 passes of a 20,000-lb. wheel load, the pavement on all but four of the units failed. The average static deflection determined by the field bearing test on the pavement surface for all of the sections which failed, was less than 0 15 in. for the tire pressure and contact areas of the 20,000-lb. wheel load used for traffic. Recognizing that there was some consolidation in the pavement, and allowing for a considerably greater number of repetitions, it was obvious that the critical deflection of the subgrade for the flexible pavement at this site would be less than 0.1 in.

In the meantime, as mentioned in the 1941 report, the possibility of using the California bearing ratio test was being investigated. After comparing this method and its proven background with the field bearing test method and its numerous complications, it was decided, for the present at least, to stop theorizing as to the best way of interpreting field bearing test results and to adopt the empirical California bearing ratio test method for design of flexible pavements. With the assistance of Dr. Arthur Casagrande, Harvard University, and Mr. O. J. Porter, California Highway Department, the Office of the Chief of Engineers extrapolated the California highway experience for wheel loads up to and including 75,000 lb. Before submitting these curves to the field, they were checked by traffic tests on specially constructed test sections, and on airfield pavements already constructed.

Investigations parallel to the flexible pavement investigations were conducted by load bearing tests and traffic tests on concrete pavements Concrete slabs, which had been in place for several years, were tested with static loads at an airfield in Virginia and at one in Ohio. Special test slabs were constructed at the airfield in Ohio and subjected to static load bearing tests. In addition, traffic tests were conducted on 5-in., 6-in , and 7-in. pavements at other airfields.

The results of these investigations were checked against Westergaard's formula for the design of concrete pavements. Although all detail constants in his formula could not be checked, the resulting overall thicknesses compared favorably with the results of the foregoing tests. It was decided, after a thorough study of these investigations, that the field bearing test for determining the modulus of soil reaction and the use of this value in Westergaard's center loading formula was at present the best method of design for rigid pavements.

Before going into the details of the various soil tests for the design of both flexible and concrete pavements, it is desired to point out that the California bearing ratio and the field bearing tests have been adopted as the best test methods presently available, after a review of all methods in general use and after extensive field investigations including field bearing tests and traffic tests using wheel loads up to 50,000 lb They do not represent an inflexible standard of design, since the problem is being continuously studied and changes are being made as they are proven justified. In addition to the tests specified for design, field bearing test data for flexible pavements and California bearing ratio test data for rigid pavements are being obtained along with other test data in special cases, in order that information will be available on each pavement for future correlation and study It is considered possible that major changes may be necessary after a sufficiently long service record is available. It is desired, therefore, that sufficient test data be available, in order that all possible methods of improving the design criteria can be investigated

TESTS FOR FLEXIBLE PAVEMENTS

The California bearing ratio test was first adopted without change in either the test procedure or the test equipment Both of these have been adequately described in articles by Mr O J. Porter.[2] Therefore, it is unnecessary here to go into detail concerning this original procedure and equipment

After using the California bearing ratio test for several months, it was found that certain modifications were necessary in order that the testing technique and the results obtained might be comparable for all types of soils encountered in the United States It was also found that a period was necessary for the various laboratories to gain experience in the use of this method. The major modifications were the method of compaction and the use of confining load for testing granular materials

Considerable difficulty was experienced in using the static load for compaction Densities comparable to the Modified A A S H.O. were not obtained on all soils, and it was found to be most difficult on a large number of soils to correctly locate the optimum moisture content. It was decided, therefore, to compact the samples by the A.A.S H O procedure as modified by the Engineer Department. This method, although satisfactory for cohesive materials, still is not entirely satisfactory for sandy soils, and it may be necessary in the future to adopt a method other than the Modified A A S H O for compaction of sands

It was apparent at once that the bearing ratios obtained on sandy soils in various sections of the country such as Michigan, Florida, and New England, did not give results comparable to highway and airport experience in those areas. After a brief investigation, the test procedure was changed to require a confining load around the penetration piston on all cohesionless soils, equal to the weight of pavement and base course above the material involved The latest test procedure as modified, and as it is now being used by the Department, is covered in Appendix B (from Part II, Chapter XX, of the Engineering Manual). California bearing ratio tests are made on both subgrade and base course materials. The subgrade materials are tested in the compacted state where compaction is practicable, and in the undisturbed state where field compaction is impracticable or where weak strata exist below the compacted layer. All base course materials are tested in the compacted state

Very few modifications have been found necessary in the equipment for conducting the tests It has been found desirable in

[2] O J. Porter, "The Preparation of Subgrades," *Proceedings*, Highway Research Board, Vol 18, Part II (1938) (out of print); also, O. J. Porter, "Foundations for Flexible Pavements," *Proceedings*, Highway Research Board, Vol 22 (1942) page 100 (this volume)

connection with the compaction of the sample by the Proctor method, to provide a collar on the penetration loads in order that the sample may be compacted above the desired thickness and shaved off to present a smooth surface. However, for most types of soils, much more uniform results are obtained by testing the bottom of the sample rather than the top, since it presents a smooth surface without manipulation

It is recognized that the above modifications in the test procedure are not necessarily all of the modifications which may be found desirable for the application of this test to airport construction Therefore, in order to eliminate as far as possible the variables in the California test itself, and to answer numerous questions raised by the field, it was decided to conduct a comprehensive investigation into the different factors influencing the test results. Some of these factors are as follows:

(1) Effect of density on the California bearing ratio.
(2) Effect of surcharge during soaking and penetration.
(3) Effect of gradation and shape of particles.
(4) Effect of moisture

This investigation has been assigned to the U. S. Waterways Experiment Station at Vicksburg, Miss. They will conduct a series of tests including the California bearing ratio, triaxial, and other standard laboratory tests on a wide variety of soils ranging from fat inorganic clay to well graded gravel-sand-clay mixtures Some 15 different types of soils will be tested, the greater percentage being sands, since it is already apparent that some modification in the testing of sands and the application of the California bearing ratio to design of flexible pavements on sand are necessary.

Application of the California bearing ratio test to design is explained fully in Appendix B. The example given of its use shows that the California bearing ratio test allows rapid investigation of the economic possibilities and the use of locally available materials

One of the main advantages of the California test is the rating of subgrade and base course materials on a comparative basis. It provides an excellent means of selecting the best base course material for use directly under the pavement, and allows the use of inferior materials on the bottoms of base courses. In this manner, locally available base course materials can be used to a much greater extent in obtaining a balanced design than has heretofore been employed. The field grading operations can be controlled, in a large number of cases, by this method, so that the best material is selected to finish off the subgrade For instance, if the subgrade is a plastic clay, a sandy clay or a silt might be used directly over the plastic clay to reduce the required imported material

TESTS FOR DESIGN OF CONCRETE PAVEMENTS

The field bearing test has been adopted for design of concrete pavements. This test is used to determine the modulus of soil reaction, "k," which is then substituted in Westergaard's center thickness formula as modified for the design of concrete slabs for runways. Considerable work had previously been done by the Portland Cement Association on the application of Westergaard's analysis to the design of runways Investigations by the Department have shown that Westergaard's formula is sufficiently close for all practical purposes, even though it has not been possible to check the various constants individually.

Before adopting the field bearing test and Westergaard's center thickness formula for the design of concrete slabs, extensive field investigations were conducted. These field investigations included field bearing tests (to failure) on old airfield pavements and on special test slabs. Traffic tests were conducted at three airfields on slab thicknesses of 5, 6, and 7 in. Failures in each of these traffic tests occurred at and along the joints. There were no failures in the centers of the slabs.

Both traffic and field bearing tests on concrete slabs showed that Westergaard's formula gives a slab thickness approximately correct for doweled edges and corners, but is conservative for the center thickness. However, since the edges and corners are the controlling factors in design, the use of Westergaard's formula was considered satisfactory.

The complete investigation into the design of concrete pavements was assigned to the Ohio River Division, where it was placed under the direction of the soils laboratory. All the tests in this connection, except some field bearing tests at an airfield in Virginia and traffic tests at a field in Michigan, were conducted in the Ohio River Division.

Field Bearing Test

For design, field bearing tests are made on representative subgrade soils in their compacted state where compaction is practicable and on the undisturbed soil where compaction is impracticable. It is not necessary to run field bearing tests at every site, since test results at other localities which typify the conditions to be met may be applied in the design. Field bearing tests to determine the load bearing capacity of the soil in its natural and compacted state are made in accordance with the procedure outlined in Appendixes B and C (from Parts II and IV, Chapter XX, of the Engineering Manual).

The evaluation of the modulus of soil reaction, "k," of the subgrade, to be used in the Westergaard analysis to determine the required thickness of a pavement, is determined by field bearing tests and laboratory tests. Tests should be made in sufficient number to obtain representative values of "k" for various areas of the cut and fill subgrade

The field bearing test is conducted on the prepared subgrade with the underlying soil at its natural moisture content. It has been found that artificial saturation on most soils is impractical or produces conditions which are unfavorable for field testing, and for this reason adjustments to represent reduction in subgrade bearing capacity due to saturation are made by laboratory test. However, it may be feasible to saturate some soils satisfactorily by ponding, and in these cases the "k" value may be determined directly from the field tests. The results of the tests are prepared in the form of deformation curves

Evaluation of Modulus of Soil Reaction

The modulus of soil reaction, "k_u," with the soil at its natural moisture, is determined by the formula "k_u" $= \frac{p}{0.05}$, in which "p" is the load intensity in pounds per square inch causing a deformation of 0 05 in as determined from the load deformation curve. The modulus of soil reaction is defined as the slope of the chord extending from the origin to a given load intensity on a stress deformation curve. Since the stress deformation curve is not a straight line, the modulus of soil reaction varies with the load intensity. It is necessary for use in the Westergaard analysis to select one value for the modulus of soil reaction, which will give the most satisfactory design results A study of the results of many tests indicates that the most representative value of the modulus of soil reaction for concrete pavement design may be obtained using the load intensity causing a deformation of 0 05 in. as above required.

In order to approximate the "k" value for the subgrade soil after it has reached its maximum moisture content, standard consolidation tests are performed on representative subgrade soil samples in the laboratory. The soil for one test is placed in the consolidation device at a density and moisture content equivalent to those at the time of field testing. The soil for a second test is placed in the same manner as the first, after which it is saturated by immersion. During the immersion period, a load is applied to prevent surface expansion of the sample The results of each test are plotted to show the relation between load intensity in pounds per square inch and deformation in inches. A sufficient number of tests are conducted to obtain satisfactory average curves.

Until a more suitable method is established, the modulus of soil reaction "k" for a saturated subgrade to be used in design is computed by reducing the soil modulus "k_u," for a subgrade compacted at its natural moisture, in proportion to the ratio of the loads producing the same consolidation obtained in the two consolidation tests. Since the critical deflection in the slab is small, the soil movement underneath is not due to shear failure but to compression, and may be more closely represented by the results of consolidation tests. The most applicable procedure for using the results of the consolidation tests to obtain a modulus of soil reaction for a saturated condition has not been formulated. However, since the ratio of the loads, to produce the same deformation in the two consolidation tests, is approximately equal to the ratio of the loads required to produce the same deformation on an unsaturated and saturated subgrade, "k" may tentatively be determined by the formula:

$$k = \frac{p_s}{p} k_u$$

in which:

k = modulus of soil reaction for saturated subgrade.

k_u = modulus of soil reaction for the subgrade at its natural moisture content.

p = load intensity used to determine k_u.

p_s = load intensity required in consolidation test on saturated soil to produce the same deformation as the load intensity "p' in consolidation test on soil placed with a moisture content equivalent to that during the field bearing test

The modulus of soil reaction "k" is then used in determining the slab thickness from previously developed curves, such as those given on Figure 1, or by substituting the "k" value directly in Westergaard's formula. For example, if it is desired to design a concrete pavement on a subgrade or base which has a "k" of 300 lb. per sq. in. per in., it will be found that approximately a 7-in. slab is required for a 37,000-lb wheel load, whereas approximately a 9-in slab is required for a 60,000-lb wheel load, assuming the concrete has a working strength in flexure of 350 lb. per sq. in.

Again it should be pointed out that this method of design is tentative and that additional investigations are being conducted to improve the design methods. In this connection, field bearing test investigations are being conducted at the U. S. Waterways Experiment Station in connection with the study previously mentioned on the California bearing ratio test. These tests are being conducted to determine what relationship, if any, exists between the California bearing ratio and Westergaard's "k," and to determine the best method for evaluating the effect of moisture variations on the modulus of soil reaction or the bearing capacity determined by the field bearing test.

In addition to these investigations to be conducted at the U. S. Waterways Experiment Station, the concrete investigation being conducted by the Ohio River Division will be continued along special lines indicated by the results of the past tests. One of the most important items to be further investigated is the design of concrete pavements on base courses. At the present time, it has been found to be impractical to determine the "k" value on top of base course materials without actually conducting the field bearing test on the finished surface Attempts have been made by the Department and various other investigators to arrive at a bearing capacity on top of the base by assuming an angle of spread through the base material, and the results obtained are entirely too erratic for application to the design of pavements.

quired for a 60,000-lb wheel load if placed directly on the subgrade. By this procedure, 14 in. of base course material could be placed and the slab reduced to 6 in. It is apparent that if this solution is proven satisfactory, the design of concrete pavements will be considerably simplified, since a well balanced design between base course materials and slab thickness can be readily obtained Further investigations are to be conducted in the Ohio River Division for the specific purpose of determining whether this design procedure is practical.

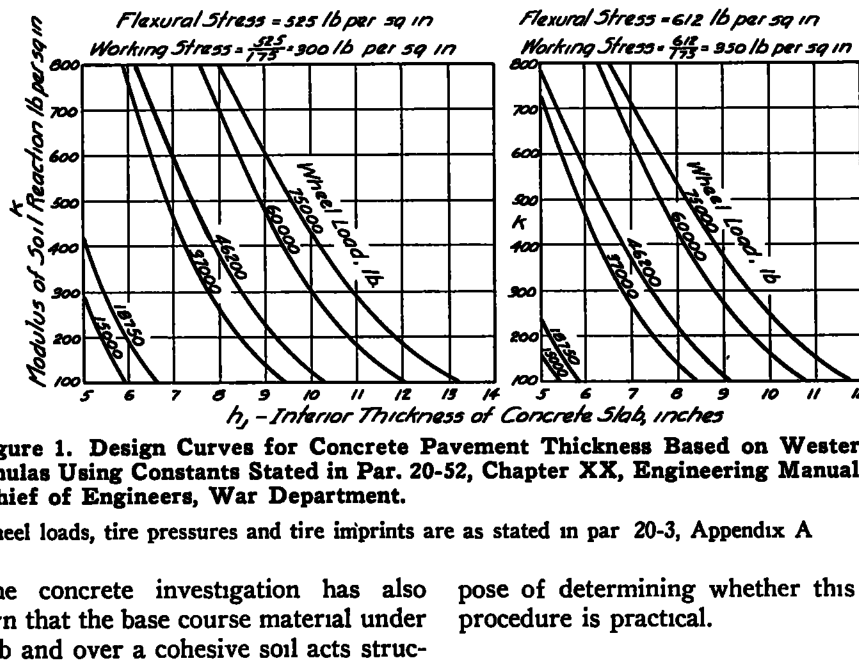

Figure 1. Design Curves for Concrete Pavement Thickness Based on Westergaard's Formulas Using Constants Stated in Par. 20-52, Chapter XX, Engineering Manual, Office of Chief of Engineers, War Department.

Wheel loads, tire pressures and tire imprints are as stated in par 20-3, Appendix A

The concrete investigation has also shown that the base course material under a slab and over a cohesive soil acts structurally with the slab, and therefore adds more structural strength than the increase in "k" value which results from the base course. It has been suggested, therefore, by the Ohio River Division, that consideration be given to the design of concrete pavements, using the "k" value for the subgrade only, and allowing a reduction of 1 in. in concrete thickness for each 4 in. (5 in. used by Aviation Engineers) of base course material The minimum allowable thickness of slab is 6 in For example, if we have a "k" value of 200, approximately a 9½-in. slab will be re-

FROST ACTION

A most important factor in the design of flexible pavements, which is not covered by the California method, is the treatment required in soils which are affected by frost action. This problem can be divided into two distinct phases.

First, the prevention of frost heaving; actual lifting of the pavement surface.

Second, the reduction in bearing; due to the effect of frost action on cohesive soils.

It is of course essential that exceptional or extreme heaving of the pavement should be prevented However, for heavy airplane wheel loads it is considered that the most important effect of frost action is the reduction in bearing

The bearing value of a subgrade soil susceptible to frost action will be reduced during periods of thaw. Where climatic and moisture conditions are favorable, silt and clay soils will be adversely affected by frost action Although cohesive soils heave only slightly, their bearing value will be greatly reduced The design of a pavement will depend upon the reduced bearing value of such a soil, unless it is removed and a base course is constructed to a sufficient depth to provide suitable reinforcement. Accurate methods of evaluating the actual bearing value in soils affected by frost action are not known. Highway experience indicates that, in areas which are subject to frost action, the base course of non-frost heaving material under a pavement used for highway loads, should extend to a depth of at least 50 per cent of the average frost penetration, in order to provide suitable subgrade reinforcement. For the heavier wheel loads used in airfield pavement design, it is logical to assume that the base thickness should be increased. The base course thickness so determined will govern only when it exceeds the thickness as required by the California bearing ratio test.

At this time, the effect of frost action on the bearing capacity can only be approximated from highway experience It is reasonable to assume that if the thickness required for highway wheel loads is 50 per cent of the average frost penetration, it will have to be considerably greater than that, possibly 100 per cent of the frost penetration, for the 60,000-lb. wheel load. This problem is being investigated by the Department, and it is anticipated that in the near future a more definite criteria of design for soils affected by frost action can be set up It appears possible that in frost areas the maximum compaction of the soil cannot be considered permanent, since the swelling accompanying frost action will decrease its density. It is considered possible, that the results of the investigation now under way may show that the best method of design in frost areas is one based on undisturbed samples of the natural soil which has been subjected to frost action over a period of years. This assumes, of course, that all soils will revert to the natural density as a result of frost action, regardless of the degree of compaction which is obtained during construction. This approach, if true, will of course simplify design, since laboratory tests such as the California bearing ratio can be determined on undisturbed samples of the soil at various depths for the design of flexible pavements, and the "k" value of the soil can be determined at different depths for design of concrete pavements

USE OF THE SOIL TEST BY AVIATION ENGINEER TROOPS

These tests and their application to design and construction of runways have been included in the Technical Manual for Aviation Engineer Troops. It was recognized in this manual that in nearly all cases there would be insufficient time to conduct the necessary tests. Therefore, the use of the soil constants derived from the tests would have to be accomplished principally by field identification of the soils For this reason, identification of soils has been stressed in this manual and design curves have been included which give the range of bearing ratio and "k" values for various types of soils. Figure 2 shows the tentative design curves for total thickness of flexible pavements, on which there has been super-imposed Dr. Casagrande's new soil classification which is being taught the aviation engineer officers at Harvard. The Bureau of Public Roads' classification is included only for the information of those who are familiar with this classification. You will note that the "k" values range from 100 for the fat clay to approximately 800 for an excellent well graded gravel. These values are considered only approximate, although to date some very good checks have been obtained. However, they are not considered close enough for use in construction in this light bituminous seal or other dust palliative.

It is anticipated that the aviation engineers, in using these soil constants, will first make a field identification of the soil, probably with a few simple tests, and will classify the soil and base course materials

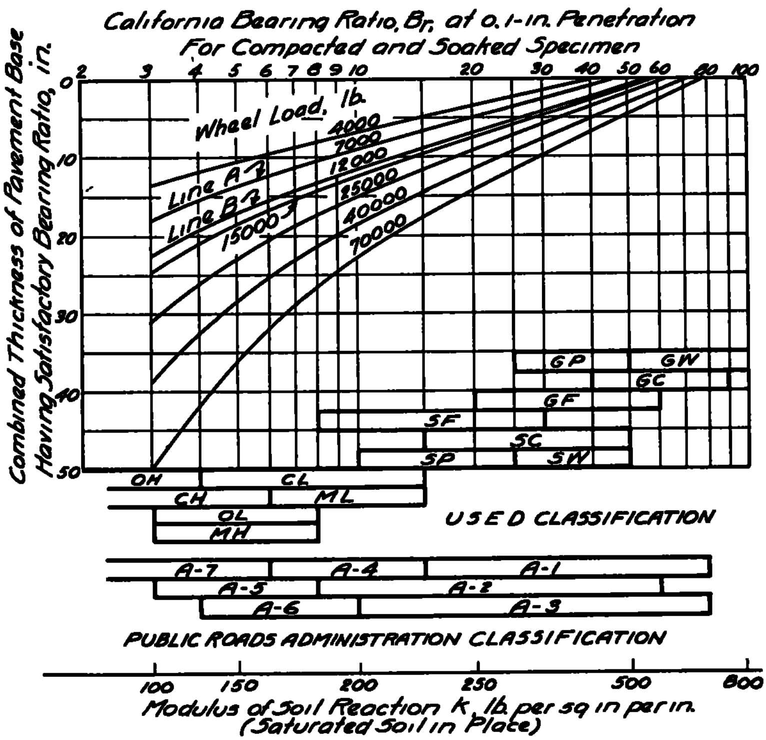

Figure 2. Curves for Design of Foundations for Flexible Pavements

The range of bearing ratios given is for typical soil and is approximate Design should be based on tests where practicable. The bearing ratio, Br, is for individual soils whereas the modulus of soil reaction, K, is for a uniform mass of soil

country, where there is sufficient time available for a more accurate determination of the "k" values

Aviation engineers will omit bituminous surface courses wherever possible. Therefore, the curves (Fig. 2), for design of foundations for flexible pavements, intersect the zero thickness line at bearing ratio values representative of materials which are considered satisfactory with only a in accordance with the new soil classification for airport projects. However, where time is available, California bearing ratio tests will be performed in order that a more accurate design can be made.

For an example of the use of the soil constants in design, let us assume the soil involved is classified as a sandy silt (ML); the bearing ratio value would be approximately 10 and the resulting flexible pavement thickness for a 37,000-lb. wheel load would be approximately 17 in. (Fig. 2) For the concrete design on this same material, the "k" value would be approximately 200, and if a working stress of 350 lb. per sq in is used, the pavement thickness would be about 7½ in (Fig. 1). If approximately 8 in. of good base course are used, the thickness could be reduced to about 6 in., since 5 in. of base are allowed to be substituted for an inch of concrete

CONSTRUCTION CONTROL

Compaction

It should be emphasized in the application of these or any other criteria of design, that the results actually obtained during construction are of utmost importance. For example, in designing for 95 per cent compaction if only 85 per cent is obtained, it is obvious that the thicknesses determined from the laboratory test on compacted samples will not be representative of the actual condition in the field. Therefore, it is essential that all laboratory tests be made as near as practicable to the conditions which can be and are obtained during actual construction. If greater compaction than is indicated by the Modified A.A.S.H.O. can be obtained in the field, then the design should be based on this increased compaction If it can not be obtained, due to the lack of heavy equipment or for other reasons, then the design should be based on a density comparable to that actually obtained. Rigid compaction control, found to be so essential in earth dams and other embankment constructions, is considered to be of equal importance in runway construction. Therefore, every attempt has been made to set up compaction requirements which are the maximum that can be obtained in the field Past experience of the Department had shown conclusively that better compaction than was indicated by the Standard A.A.S.H O. Proctor test could and in most cases was actually being obtained in the field. Therefore, the Modified A A.S.H.O. (comparable to California Highway requirements) method of compacting the soil in the laboratory was adopted. Subsequent investigations have shown that the maximum possible compaction which can be obtained by the presently available equipment is still considerably less than will result after the pavement has been subjected to a large volume of traffic. Every attempt should be made, therefore, further to develop the methods and equipment for increasing the density obtained during construction

Type of Soil

Idealized subgrade and base materials often used in design are seldom found in nature. Natural deposits usually vary widely in composition, which necessitates rapid evaluation of the soil characteristics in order that the control may keep pace with the construction. The inspector must become thoroughly familiar with the soils involved, in order that he may be able to decide quickly how much stripping is necessary and what portion of the borrow is unsuitable The California bearing ratio test is excellent for rapid evaluation of the subgrade and the selection of base course material If typical samples of various soils on the site are tested at the start of construction, and these samples are made available to the inspector for frequent comparison, it will be necessary to make only routine check tests at infrequent intervals. Where soils, which differ from those tested at the start of construction, are encountered, they should be tested and added to the collection of typical samples

A quick check rating of cohesionless soils may also be made by comparison of the mechanical analysis curves, since the bearing ratio value varies with the slope of the curve The uniformity coefficient, is a good index for comparing the slopes.

The bearing ratio value for cohesive soil varies with the percentage of expansion when saturated; therefore, small expansion tests may be used to provide a relatively quick check of the bearing ratio of these soils These relationships can be determined from tests on a relatively few samples Usually, the results of the typical samples referred to will suffice.

Modulus of Soil Reaction "k"

In the construction of concrete pavements, check field bearing tests should be made on typical subgrades as construction is started, and if base courses are used on typical bases, additional bearing tests need be made only at infrequent intervals for routine check, and to check on special conditions encountered Usually, some rough guide, such as action of trucking or rolling equipment, can be worked out by the inspector to obtain a quick appraisal of the final product, in order to reduce the number of field bearing tests to a minimum.

The Engineer Department, with its wide experience in embankment construction, realized at the beginning of the airport construction program that close field control was a prerequisite to good engineering design. It has, therefore, made every effort to set up criteria and test methods which will insure adequate field control during construction It has been necessary to recognize, however, that the degree of control, which would have been considered desirable in normal construction, has not always been possible under the emergency construction program.

ACKNOWLEDGMENTS

The investigations referred to were performed and the criteria of design were established, under the direction of the War Construction Section, Engineering Branch, Office, Chief of Engineers, with Major General Eugene Reybold, Chief of Engineers, Colonel James H Stratton, Chief of Engineering Branch, and Lt Colonel L C Urquhart, Chief of the War Construction Section Mr Gayle McFadden is Assistant Chief of the War Construction Section, in charge of airports Mr J L Land is Chief of the Runways, Roads and Railroads Unit, and Mr T A Middlebrooks is Chief of the Soil Mechanics Unit Captain G E Bertram is Assistant Chief, Engineering and Intelligence Branch of the Engineer Section, Directorate of Base Services, Headquarters, First Army Air Forces The "Technical Manual for Aviation Engineer Troops" was prepared by The Engineer School

APPENDIX A[1]

DESIGN OF RUNWAYS, APRONS AND TAXIWAYS AT ARMY AIR FORCES STATIONS

PART I—GENERAL PROVISIONS AND CRITERIA

20-1 GENERAL These instructions are published for guidance in the design and construction of pavement for runways, taxiways, aprons, hardstandings and turnarounds and for runway and taxiway shoulders at Army Air Forces Stations When local conditions or other factors require changes in the design criteria stated herein, prior approval should be obtained from the Office of the Chief of Engineers The decision as to the type of pavements to be used by aircraft is an engineering matter and therefore is the responsibility of the Corps of Engineers, provided, however, that the type of construction will comply fully with the stated functional requirements of the Army Air Forces

20-2 DEFINITIONS: Definitions of general terms used in this chapter are given below

a Airfield: The term "airfield" is generally applied to landing fields for aircraft with a military establishment including housing, repair and maintenance facilities.

b Auxiliary Field An auxiliary field is a minor airfield accessible to a main airfield and established for the purpose of relieving congestion at the main field In general, very limited or no repair and maintenance facilities are provided at these fields

c Landing Strip A landing strip is a graded and improved area, generally 500 feet wide It consists of a runway, shoulders, and graded areas as shown on Exhibit No 1 of this Part, Figure 3 The components of the landing strip are defined as follows

(1) *Runway* A runway is the center strip, usually 150 feet wide, improved by paving or other means to provide a suitable area for the landing and take-off by aircraft

[1] From Engineering Manual, Chapter XX, March 1943, War Department, Office of the Chief of Engineers

(2) *Runway Shoulder* A runway shoulder is an improved strip lying on either side and immediately adjacent to the runway Unless otherwise stipulated in the directive, runway shoulders are seventy-five (75) feet in width

(3) *Runway Graded Area* A runway graded area is a strip between the shoulder and the outer edge of the landing strip

d Taxiing Strip A taxiing strip is a graded and improved area, generally from 90 to 155 feet wide It consists of a taxiway,

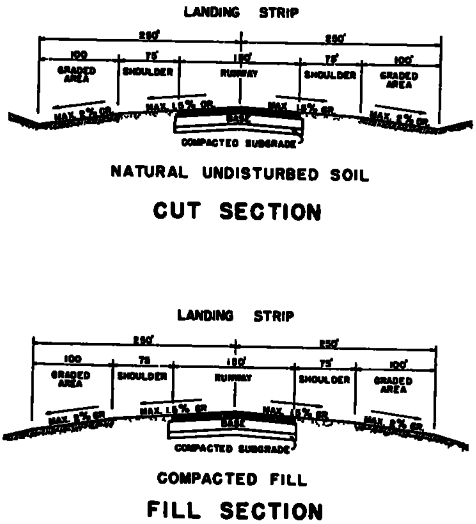

Figure 3. Transverse Section Through Landing Strip. Exhibit 1, Engineering Manual, Chapter XX, Part 1.

shoulders and graded areas These parts are defined as follows

(1) *Taxiway* A taxiway is the center strip, usually from 50 to 75 feet wide, improved by paving or other means to provide a suitable surface for planes to travel on, under their own power, between runways and other areas of an airfield

(2) *Taxiway Shoulder* A taxiway shoulder is an improved strip on either side and immediately adjacent to the taxiway, 12½ feet in width unless otherwise specified in the construction directive

(3) *Taxiway Graded Area* A taxiway graded area is an improved strip between the shoulder and the outside edge of the taxiway strip

e Stub-End Taxiways Stub-end taxiways are the taxiways that lead from major or peripheral taxiways to hardstandings

f Peripheral Taxiways Peripheral taxiways are taxiways that serve dispersed areas and connect runways with the stub-end taxiways

g Turnarounds Turnarounds are the portions of runways and taxiways especially prepared for the habitual turning of planes Spread-or enlarged-turnarounds are special sections built by constructing bulges on one or both sides of runways or taxiways to facilitate the turning of planes with a minimum amount of wheel locking

h Hardstandings Hardstandings are pavements or surface treated bases used for dispersed parking of planes These may be circular or polygonal areas for parking only one or two planes Hardstandings are equipped with tie-down rings to secure the parked planes

i Warm-Up Areas Warm-up areas are portions of taxiways or runways on which planes rest while motors are warmed up or reved up before take-offs These areas comprise about 300 feet of the ends of runways or taxiways and may coincide with the turnarounds

j Aprons Aprons are pavements or surface treated bases in the vicinity of maintenance and repairs buildings or adjacent to runway or taxiway pavements on which planes are parked or serviced The types of aprons are as follows

(1) *Service Aprons* Service aprons are aprons on which planes are greased, fueled, gassed, repaired, and on which general service is performed Since gasoline and oil are spilled on the surface of service aprons, the pavements should preferably be concrete or other type not detrimentally affected by these fluids

(2) *Parking Aprons* Parking aprons are aprons or portions of aprons on which planes are parked when not in service

(3) *Traffic Portion of an Apron.* Traffic portion of an apron is the portion over which planes travel to the taxiway or runways This portion is generally at the front of the apron (the area next to the flying field) or down the center of very large aprons

k Surfaced All-Over Fields Surfaced all-over fields are large areas improved by paving or other means to provide a suitable area for the simultaneous landing and take-off of large numbers of small aircraft

l Subgrade The term "subgrade" applies to the natural soil in place or to fill material upon which a pavement or base is constructed

m. Compacted Subgrade The term "compacted subgrade" applies to the upper part of the subgrade which is compacted to a density greater than the portion of the subgrade below, to provide increased stability In the sense used herein and depicted on Exhibit No 1 of this Part, Figure 3, the term applies only to the zone immediately underlying a base or pavement (if base is not provided) as distinct from the remainder of the subgrade

n Base The term "base" applies to the course or combined courses of specially selected soils, mineral aggregates, or treated soils, placed and compacted on the compacted or natural subgrade to provide greater load carrying capacity (See Exhibit No 1 of this Part, Figure 3)

o Surface Treated Base Bases treated with prime and seal coats of bituminous or other materials, which will bind and waterproof the surface, are termed "surface treated bases." Surface treated bases are used when pavement is not required.

p. Pavement The term "pavement" is defined as a covering of a prepared or manufactured product superimposed upon a subgrade or base to serve as an abrasion and weather resisting structural medium.

20-3 LOAD INTENSITY The load intensity to be used in the design of bases and pavements depends on the type of airfield required by the Army Air Forces The gross wheel load and other factors in the pavement design will be limited to those listed in the table below unless specific instructions to the contrary are issued by the Chief of Engineers

These values should be used for the design of pavements and surface treated bases except as stated in paragraph 20-4 below

20-4 FREQUENCY OF OPERATION The actual frequency of use in the future of any particular pavement at a field cannot be accurately estimated For this reason, all designs should be based on either "Capacity Operation" or "Limited Operation" The term "Capacity Operation" as used in this chapter is defined as the maximum possible frequency of use by planes of such major pavements as the runways, taxiways and aprons "Limited Operation" is defined as infrequent usage (by planes) or use for a relatively limited period The term "occasional use" has a special significance and is defined in paragraph 20-5 below

20-5 DESIGN CATEGORIES · Pavements, surface treated bases and shoulders are divided into the following categories which should be used in the preparation of all designs:

a Design for Capacity Operation· RUNWAYS, TURNAROUNDS, WARM-UP AREAS. HARDSTANDINGS, APRONS AND TAXIWAYS (other than stub-end taxiways and portions of peripheral taxiways used only infrequently) at airfields, and at auxiliary fields for basic and advanced single engine schools, will be designed for capacity operation unless otherwise specified in construction directives. Loading design criteria to be used will be set forth in each directive in accordance with the classes of loading stated in 20-3 above To compensate for increase in stress in the

Class	Type	Wheel load (pounds)	Contact pressure (pounds per sq in)	Contact area (sq in)
I	Heavy bombardment stations (include their auxiliary fields), air depots, certain air transport command stations	60,000[a]	75	800[a]
II	Technical schools, medium bombardment stations (and their auxiliary fields) (medium bombardment stations) and certain air transport command stations	37,000[a]	65	570[a]
III	Single engine schools, ground air support bases, light bombardment bases dispersal fields, cross country flight fields, patrol fields, OTU (pursuit, light bombardment, and dive bombardment)	15,000	55	273
IV	Auxiliary fields for basic and advanced single-engine schools Main fields for these schools if specific in directives	5,000	45	111

[a] These values should be used as one load and one area in the design of single or dual wheel loadings

pavement, base and subgrade caused by the vibration of slow moving or "warming up" planes, the loads given for capacity operation should be increased 25 per cent for the design of TURNAROUNDS, WARM-UP AREAS, HARDSTANDINGS, TAXIWAYS (other than stub-end taxiways and portions of peripheral taxiways used only infrequently) AND APRONS

b Design for Limited Operation Where the operation of aircraft will be infrequent, the design requirements for thickness of pavement and base will be reduced as stated in sub-paragraphs (1) and (2) below. Unless otherwise stated in the directive, a design based on limited operation will be used for STUB-END TAXIWAYS, PORTIONS OF PERIPHERAL TAXIWAYS USED INFREQUENTLY, SURFACED ALL-OVER FIELDS, DESIGNED SHOULDERS, AND PAVEMENTS AND BASES (when specially authorized) at auxiliary fields other than for basic and advanced single engine schools. The loading design should not be increased to compensate for increase in stress caused by vibration as in the case of capacity operation

(1) *Flexible Pavements* The total thickness of the base and pavement will be 80 per cent of the thickness as determined by the design method stated in Part II of this Chapter, but the quality and bearing value of the foundation course and pavement employed shall conform to all the other requirements stated in this Engineering Manual

(2) *Concrete Pavements* A design factor of 1 40 will be used in place of 1 75 as stated in Part V of this Chapter.

c Treatment for Occasional Use RUNWAY AND TAXIWAY SHOULDERS, where "limited operation" is not provided for in the construction directives, will not be structurally designed but will be "turfed" in all cases unless climatic, soil, or other local conditions render such treatment impracticable or uneconomical. Where "turfing" is impracticable or uneconomical there will be provided a dust palliative which insofar as practical will have a different texture and color than the runways

20-6 SURFACE REQUIREMENTS

a Runways, Parking Aprons, Warm-Up Areas and Taxiways Runways, parking aprons, warm-up areas and taxiways other than stub-end taxiways and portions of peripheral taxiways used infrequently are subject to the frequent stresses and vibration caused by operating planes. The purposes of these pavements are described in paragraph 20-2 above and in Part IV of Chapter III, Site Planning, Army Air Forces Stations They should consist of pavements constructed for great durability and of high shearing resistance The surface finish of the pavements should be such that it will not cause unnecessary wear on tires, will insure uniform high resistance to skidding and will be dust proof The surface aggregates of the pavements should be well-bonded in order to prevent damage to airplanes by loose particles. Concrete or bituminous pavements having proper texture and finish are satisfactory and should be used. However, surface treated bases are considered satisfactory at auxiliary fields designed for class III and IV. (See paragraph 20-3 above)

b. Turnarounds Turnarounds are subject to the same stresses as are main taxiways, and in addition, the surface layer is subjected to high shearing stresses caused by the turning of locked wheels Because of the high shearing stresses at the surface, concrete pavements are desirable for turnarounds.

c. Stub-end Taxiways and Peripheral Taxiways Stub-end taxiways and portions of peripheral taxiways that are used infrequently are subject to stresses as are taxiways described in a above Pavements similar to those required for taxiways in a above are desirable; however, since these taxiways are not used extensively, surface treated bases will serve satisfactorily.

d Hardstandings and Service Aprons Hardstandings and service aprons are subjected to the stresses and vibration of slow moving, turning and stationary planes In addition, the surfaces are subject to the action of oil and gasoline which are inevitably spilled upon them, and the surface material should not be adversely affected by the action of these fluids For this reason, bituminous pavements are not considered satisfactory for service aprons Concrete pavements for hardstandings are also desirable, but due to the limited use and isolation of these areas, well constructed bases, designed in accordance with Part II of this Chapter, and surface treated with prime and seal coats of bituminous material are satisfactory Tar should be used for prime and seal coats, if available, since it is not as greatly affected as is asphalt by gasoline and oil A shoulder 12½ feet wide, designed for limited operations, is required for all hardstandings.

e Runway and Taxiway Shoulders· Runway or taxiway shoulders may be improved, where authorized, by either of two following design methods

(1) *Limited Operation* Shoulders for limited operation (see paragraph 20-5 above) are designed to provide a safety zone where planes may land or taxi infrequently, without causing damage to the plane "Designed shoulders" should only be constructed when specified in the construction directive Since the shoulder is not subjected to frequent traffic, surface bases designed for limited operation are considered satisfactory If the shoulder is constructed as a surface treated base, it should be designed so that the runway or taxiway pavement may be widened to take in "designed shoulders" as part of the runway or taxiway at some future date The subgrade under the shoulder and pavement bases should conform to a continuous grade line Adjustment in thickness should be made by a transition of the top of the base course This should be accomplished in such a manner that future widening of the adjacent pavement will require the removal of minimum quantities of existing base material

(2) *Occasional Use* Whenever runway and taxiway shoulders for limited operation are not specified in construction directives, such shoulders should be turfed, or, if this is not feasible, treated with a dust palliative (See paragraph 20-6 above)

f Surfaced All-Over Fields The pavement and surface treated base for surfaced all-over fields are subject to the same stresses as runways and taxiways However, since all-over fields are used only by light weight aircraft and the traffic is dispersed over the entire area, high quality pavement is not required Surface treated bases should be constructed unless a concrete pavement is more economical

20-7 REQUIREMENTS FOR DIMENSIONS, GRADES AND CLEARANCES For detailed discussion of dimensions, grades and clearances, see Part IV of Chapter III, Site Planning, Army Air Forces Stations The length and width requirements for all pavements are usually defined in the program of consruction accompanying the directive

20-8 DRAINAGE The drainage system will be designed to provide adequate surface drainage of pavements and shoulders and all-over landing areas, without introducing danger of ground looping of airplanes or damage to pavements Observations indicate that subgrades and bases under impervious pavements will eventually become saturated by capillarity and condensation of moisture, regardless of ground water level Therefore, since subdrainage cannot prevent the saturation of subgrade and base materials from these sources of moisture, the base course and pavement designs should be satisfactory for saturated foundation conditions For a detailed discussion of the design and construction of drainage systems, see Chapter XXI, Design of Drainage Facilities for Airfields

20-9 DEFERRED CONSTRUCTION It may be desirable in certain regions due to conditions existing in the current period of emergency to defer the construction of bituminous pavement on well constructed bases If the construction of the surface pavement course is deferred, additional base course thickness equivalent to the required thickness of pavement course should be constructed, except for pavements on well drained sand foundations to be used by planes with gross weight of 30,000 pounds or less The surface of the base should be treated with prime and one or two seal coats of bituminous material (see Part III of this Chapter) of sufficient thickness to make the surface dustproof and keep the large particles of the base material in place during propeller blasts Periodic maintenance of the seal coat will be necessary

20-10 SUBMISSION OF DESIGN ANALYSIS · In accordance with the provisions of Paragraph 703 33 of Orders and Regulations, plans and specifications for military airport pavements submitted to higher authority for approval will be accompanied by a "Design Analysis" which will describe in *complete detail* all steps and conclusions in the design and other data such as the results of field and laboratory investigations and tests, and stability computations Copies of all "Design Analysis" for pavement, including summaries of all field and laboratory tests data, will be furnished to the Office of the Chief of Engineers for study and record purposes

APPENDIX B[1]

PART II—SUBGRADES AND BASE COURSES FOR FLEXIBLE PAVEMENT

SECTION I—SUBGRADES

20-11 GENERAL Subgrades should be stripped of all sod, muck, and other deleterious material Compaction, in general, greatly increases the stability of the subgrade soils and

[1] From Engineering Manual, Chapter XX, March 1943, War Department, Office of the Chief of Engineers

provides a more uniform foundation upon which the base for the pavement may be constructed The effect of compaction is generally to reduce the design requirement of pavement and base course thickness However, scarifying, reworking, and rolling certain types of clay soils in cut areas may produce a lower bearing value than that of the natural soil in place When such clay soils are encountered, the reworking of the subgrade should be avoided (see paragraph 20-14 below) Soils with expansive characteristics should be treated to eliminate excessive expansion after construction caused by increased moisture content (see paragraph 20-15 below).

20-12 Subgrade Investigations

a Field Explorations Field investigations will be of sufficient scope to enable full consideration to be given to all factors affecting the design and construction of pavements and base courses as well as the compaction and treatment of the subgrade Explorations should determine the location of ledge rock, elevation and slope of the water table, soil profiles, and should provide soil samples for testing The soil survey of the subgrade should be carried to a depth of at least twice the equivalent diameter of the tire contact area but in no case less than the maximum depth of frost penetration or less than four feet below the final elevation of grading at each point where grading is contemplated

b Laboratory Tests Laboratory tests should be conducted on soil samples taken from the subgrade in the area of the proposed pavement to determine the physical and behavior characteristics The types and number of tests required depend upon the characteristics and locations of the subgrade soil strata but will generally include the following

(1) Mechanical analysis and soils classification
(2) Atterberg limits
(3) Moisture content
(4) Natural density
(5) California bearing ratio
(6) Expansion
(7) Permeability
(8) Compaction control

Shear strength and consolidation tests may be required if the pavement is to be supported on an embankment fill, or as a part of a special soils investigation

20-13 Soil Classification All soils will be classified in accordance with the Casagrande Soil Classification for Airfields as given in Exhibit I of this Part (Table I and Fig 4) Local classifications should be used to supplement this general classification, where necessary to adequately describe the soil. It is anticipated that experience with this soil classification will lead to its modification The Office of the Chief of Engineers will request recommended changes and comments on this classification after it has been in use for a period of one year

20-14 Compaction Tests and Control.

a Methods of Compaction Tests·

(1) *Modified A A S H O. Method* The compaction of soils shall be determined, wherever applicable, by the test termed herein as the Modified American Association of State Highway Officials (A A S H O) Method The test procedure to determine the optimum moisture for compaction and the standard unit weight shall be in accordance with the A A S H O Method, T-99-38 (often termed the Proctor Control Method), with the following modifications

(*a*) Weight of the rammer or metal tamper will be 10 lb instead of 5½ lb

(*b*) The tamper will be dropped from a height of 18 in above the sample instead of 12 in

(*c*) The samples will be compacted in five equal (approximately 1-in) layers instead of three equal layers as now specified.

(2) *Other Compaction Test Methods* Compaction tests other than described above will be required for certain types of soil The Modified A A S H O Method should not be used if the soil contains particles which are easily broken under the blow of the tamper unless the field method of compaction will produce a similar rupture of the soil particles The unit weight of certain types of uniform cohesionless sands and gravels as obtained by the Modified A A S H O Method is often not representative of the unit weight that can be obtained by field methods, hence the Modified A A S H O Method is not applicable to these soils Compaction tests for such types of soils are usually conducted under some other modification of the A A S H O. Method, using the standard mold and compacting by tamping, static pressure, or vibration (alone or in combination) The method adopted should produce the maximum unit weight that can be obtained by the

field compaction equipment to be used in the construction For a discussion of field compaction, see Part VI of this Chapter.

b. Methods of Compaction Control: The compaction control of soils in subgrades (which include embankments in fill sections) will be by the Modified A A S H O Method (see paragraph 20-14 *a* above) for each soil type encountered or used in the construction except as noted in paragraphs 20-14 *a* above and 20-15 below Experience has shown that an increase in compaction over that obtained by the *Standard* A A S H O Method can be obtained and greatly increases the bearing of the subgrade, and for this reason the *Modified* A A S H O. Method is established for subgrade and fill compaction control. If the type of soil and available compaction equipment indicate that a test different from the Modified A.A S H O. Method, as described in paragraph 20-14 *a* above, is required for control purposes, the procedure used should be described in the design analysis. The unit weight of the soil in the natural and compacted conditions should be stated as a percentage of the maximum unit dry weight at optimum moisture as determined by the control test

(1) *Compacting Fill Sections* In fill sections the embankment will be constructed in layers not exceeding nine (9) inches in thickness before compaction and compacted to at least 90 per cent of the maximum unit weight at optimum moisture as determined by the Modified A A S H.O. Method (or other tests) described in paragraph 20-14 *a* above, except that directly beneath the base course or beneath the pavement the subgrade shall be compacted to at least 95 per cent of the maximum unit weight at optimum moisture, for a depth of not less than six (6) inches

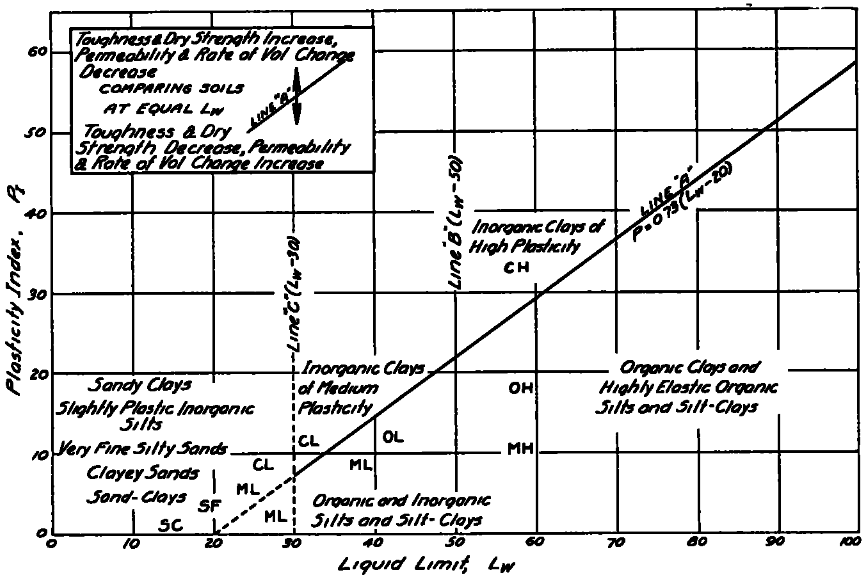

Figure 4. Plasticity Chart. To Accompany Table 1

(2) *Compacting Cut Sections.* In cut areas most subgrade soils will be scarified and recompacted so that the unit weight of the top six (6) inches will be at least 95 per cent of the maximum unit weight at optimum moisture. It is anticipated that this compaction will be accomplished in one layer without removal, stockpiling, wind-rowing, re-laying or spreading of the subgrade material. Scarifying, reworking, and compacting certain types of clay soils will produce a lower bearing value than that of the natural clay in place If clay is present in the cut section, tests (see paragraph 20-18 below) should be made to determine the relative bearing values of the recompacted soil and of the undisturbed soil If the undisturbed soil has the

higher bearing value, construction operations should be conducted to produce the least possible disturbance of the subgrade soil

20-15 TREATMENT OF SOILS WITH EXPANSIVE CHARACTERISTICS A common method for treating a natural subgrade with expansive characteristics is to compact it at a moisture content and to a unit weight which will minimize expansion The proper moisture content and unit weight for compaction control of a soil with a marked expansion characteristic are not necessarily the optimum moisture and unit weight determined by compaction control tests (see paragraph 20-14 *b* above) but have been found to be equal to the moisture content and unit weight of an expanded sample after the soil is compacted and saturated The required moisture content and unit weight may be determined as part of the California Bearing Ratio Test described in paragraph 20-18 *d* or from separate expansion tests Field control of the moisture content must be carefully exercised, since, if the soil is compacted too dry, the expansion will increase, and, if compacted too wet, low unit weight will be obtained and the soil will shrink during a dry period and then expand during a wet period This method requires detailed testing and careful control of compaction, hence, in many cases, it is desirable to construct a base of sufficient thickness to insure against the detrimental effects of expansion

SECTION II—BASE COURSES

20-16. GENERAL The construction of flexible pavements generally involves the use of base courses to provide supporting and stress distributing media on the subgrades Several rational formulas have been proposed to determine the total thickness of base course and bituminous pavement required above the natural or prepared subgrade soil for various wheel loads and tire imprint areas To use these formulas, the bearing capacity of the subgrade must be determined. It has been shown by investigations carried on by the Bureau of Public Roads (see "Present Knowledge of the Design of Flexible Pavements" by A. C Benkelman, Public Roads, January 1938) and later studies and investigations by the Corps of Engineers that the bearing capacity of a given subgrade soil depends on many factors, including the type of soil, the number of load repetitions, the rate of application of the load, the stress distribution, the size of contact area and load, and the thickness of the pavement and base course The results of simple plate field bearing tests using a rigid plate, do not appear sufficiently reliable for the determination of the bearing capacities of the subgrade to be used in the formulas Studies, conducted by the Department, indicated that in airfield design an established empirical method offered the most reliable procedure Such an empirical method of design is that of the California Highway Department which has been adopted and further developed to include the higher loadings involved at airfields Field investigations of sufficient scope to provide complete knowledge of the characteristics, amounts, proximity and availability of materials suitable for base courses, as hereinafter discussed, is of utmost importance in the use of the California Highway method of design, as it would be for any other proper method of design

20-17 CALIFORNIA METHOD OF DESIGN The empirical method of design of base courses for flexible pavements as developed and used by the California State Highway Department is described in the paper, "The Preparation of Subgrades" by O. J Porter, Proceedings, Highway Research Board, Part II, December 1938 [2] The method is applicable to design of flexible pavements (combined thickness of base and pavement) and surface treated bases over subgrade soil, except as stated in paragraph 20-23 below The method may also be used to evaluate the various base course layers, in proper construction sequence, to utilize various types of soils in producing the most economical design The procedure consists of determining by an arbitrary penetration method (California Bearing Ratio Test) the relative stability of a subgrade soil or base course material, and the application of the data so obtained to empirical design curves (see Exhibit 3 of this Part, Fig 5) to determine base course thickness The relative stability, as determined by the California Bearing Test, is known as the California Bearing Ratio This ratio, denoted herein as CBR, is expressed as a percentage of the standard stability values for crushed stone For the penetration test, the soil is placed in a cylinder mold and is compacted and saturated to produce the same moisture content and unit weight as will occur in the prototype Experience and field observation have shown that subgrade and base course soils (except clean sand) under impervious pavements will eventually become saturated by capillarity and condensation of moisture regardless of ground water elevation. For this reason, the California Bearing Ratio of silty and clayey soils is determined for the saturated condition

[2] See also O J Porter, "Foundations for Flexible Pavements," this volume page 100

20-18 California Bearing Ratio Test

a Equipment The laboratory equipment used to conduct CBR tests consists of the following and is shown on Exhibit 2 [3] of this Part

(1) Testing machine equipped with a circular vertical piston, 3 sq in in area, which moves at the rate of 0 05 in per min in the standard test

(2) Cylinder mold 6 in in diameter and 7 in high provided with a collar extension about 2 in in length and a perforated base plate The base plate, spacer plate, and collar should fit and clamp on either end of the cylinder

(3) Compacting tamper similar to that used in the Modified A A S H O Test (see paragraph 20-14)

(4) Adjustable stem and perforated plate, frame and dial gauge (reading to 0 001 in) suitable to measure the expansion of the soil

(5) Disc weights suitable to apply loads on soil surface during the expansion and penetration tests

(6) Other general laboratory equipment such as scales, ovens, spatulas, mixing bowls, etc

b CBR Test Procedure for Compacted Sample The definite procedure for the CBR test, developed by the California State Highway Department, has been found applicable to conditions and highway construction methods used in the State of California However, the soil density control methods and specifications used by the Corps of Engineers are different from those used by the California State Highway Department In view of these differences and of the many varied types of soils used in construction throughout the Continental United States and elsewhere, it has been found necessary to modify the California procedure to insure representative and consistent results As more tests are performed, it may be necessary further to modify the test procedure The following procedure for compacted samples has been formulated as a result of studies made to date by the Corps of Engineers and should be generally followed

(1) Remove all material over ¾ in in size and replace with an equal proportion of material between 0 18 in (No 4 sieve) and ¾ in in size

(2) Conduct applicable control compaction tests (see paragraph 20-14 above) to

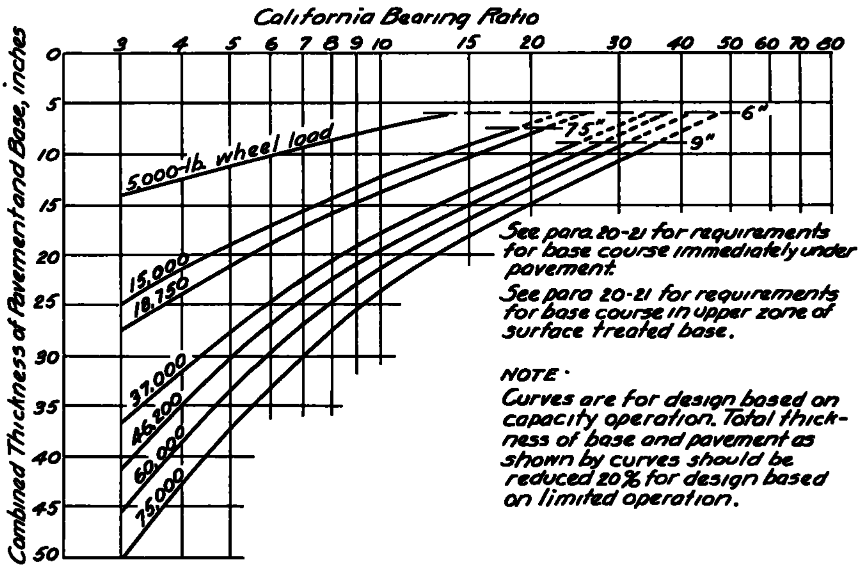

Figure 5. California Method Tentative Design Curves Exhibit 3, Engineering Manual, Chapter XX, Part II

[3] Exhibit 2 is not included For a drawing of the apparatus used in California see page 124 of this volume

determine the method that should be used to obtain the required unit weight and moisture content (see step (4) below) If a large percentage of the soil particles are larger than 0 18 in, it is considered advisable to use the 6-in diameter CBR test mold for the test

(3) Clamp the mold with fitted extension collar to the base plate and insert the spacer disc over the base plate

(4) Compact sample in the test mold to a uniform density which will develop in the prototype Cohesive or partially cohesive soils (Plasticity Index greater than approximately 2) should be compacted to the unit weight and at the moisture content specified in paragraphs 20-14 and 20-25 below Cohesionless soils (P I less than approximately two (2)) which will readily compact under traffic should be placed at a unit weight equal to the maximum as obtained by the control tests (see paragraph 20-14 above) providing that during construction the soils are compacted as specified in paragraphs 20-14 and 20-25

(5) Remove collar, trim sample, place screen over top of sample and clamp perforated base plate to top of test mold

(6) Invert test mold, remove base plate and spacer disc and determine density of sample

(7) Place adjustable stem and plate on the surface of the sample and apply annular weight to produce an intensity of loading equal to the weight of the base material and pavement, if a pavement is to be constructed, which will overlie the soil in the prototype represented by the sample, except that a weight of less than 10 lb shall not be used. The weight applied must be estimated, and, if it does not produce the intensity present in the final design, the test should be repeated On fine-grained soil it is desirable to place filter paper on the soil surface before placing the plate

(8) Saturate the sample by placing the test mold in water with the water surface about ½ in from the top The sample should be saturated by permitting water to rise through the sample by capillarity A damp cloth or paper should be placed over the test mold to prevent evaporation from the soil surface During the saturation period, the per cent of expansion should be determined and recorded The test mold should remain in the water until free water appears at the soil surface or until expansion ceases Some soils may be saturated by immersion, providing that a soft mushy surface condition is not produced It may be necessary to soak some very impervious clay soils from the top if the time for saturation by capillarity is excessive

(9) Remove the free surface water and allow drainage downward for a period of 15 minutes The object is to remove all free water from the top of sandy samples, so that a quick condition will not occur under the piston when the sample is penetrated rapidly It may be necessary to permit a longer drainage period for some fine sandy soils Care should be taken in removing the free water from the surface not to change the density conditions After drainage remove the annular weights, stem and plate

(10) For all cohesionless soils (basically sandy soils with a plasticity index less than approximately 2) apply an annular weight to the surface equivalent to that stated in step (7) above

(11) Seat penetration piston with a 10-lb load and set dial gauge to zero The purpose of a 10-lb load before starting the penetration test is to insure satisfactory seating of the piston and should be considered as the zero load when determining stress-strain relations

(12) Apply load on penetration piston so that the rate of penetration is approximately 0 05 in per min Obtain load readings at 0 025, 0 050, 0 075, 0 1, 0 2, 0 3, 0 4, and 0 5 in deformation

(13) Determine the moisture contents in the upper one inch and for the entire depth of the sample

(14) Determine the relative bearing value in per cent for 0 1 inch increment of penetration compared with the following standard load (penetration loads for crushed stone)

Penetration in inches	Standard load in lb per sq inch
0 1	1000
0 2	1500
0 3	1900
0 4	2300
0 5	2600

In order to obtain true penetration loads from the test data, the stress-deformation curve should be drawn, and the zero point adjusted to eliminate the effect of surface irregularities

(15) The California Bearing Ratio, usually selected for design, is the relative

bearing value in per cent as obtained above in step (14) at 0 1-in. penetration If the relative bearing value at 0 2-in penetration is greater than that at 0 1-in penetration, the test should be re-run If check tests give similar results, the relative bearing value at 0 2 in penetration should be taken as the California Bearing Ratio for design

c. CBR Test Procedure for Undisturbed Samples. A sample of undisturbed subgrade material for testing should be obtained by forcing a California test mold fitted with a cutting edge collar into the ground, at the same time carefully trimming away the soil from around the outside of the cylinder to prevent disturbance. The ends of the sample should be trimmed, and paraffined if tests will not be conducted immediately For the test, the paraffin should be removed and a perforated base plate should be clamped into position After the testing surface is carefully prepared, the procedure for the test should be as described in steps (7) to (15) in *b* above

d. CBR Test on Soils in Place: The CBR Test may be performed on soils in place The field CBR test is often useful for the evaluation of the carrying capacity of existing flexible pavements However, since the ultimate bearing capacity depends on the moisture condition of the subgrade, the test results should be interpreted in the light of the moisture condition of the subgrade and base course It usually requires several years after completion of a pavement before conditions of moisture equilibrium are attained in the subgrade and base soils. The field CBR test may be conducted by using a hydraulic jack and piston arrangement mounted on the underside of a light truck The procedure for the tests should be as described for steps (10) to (15) in *b* above

20-19 Tentative Design Curves The tentative design curves shown on Exhibit 3 (Fig 5) of this Part were developed by the Corps of Engineers. These curves are based on data obtained by the California Highway Department, on laboratory tests, and on the results of large scale traffic tests of actual airfield pavements and of specially constructed test sections Experience to date and additional traffic tests have shown the desirability of modifying the curves published in an earlier issue of this Chapter, in the range of cohesionless soils, to require less total thickness of base and pavement Additional laboratory and field traffic tests are being conducted and the service behavior of actual fields is being studied to determine whether further modifications of the design curves are necessary Each curve on Exhibit 3 (Fig 5) of this Part shows, for a given wheel load, the ***total thickness*** of more stable material (including pavement) required above a layer of material with a given CBR, except as stated in paragraph 20-21 below The curves are used for the design of base course and pavements and surface treated bases and are applied as follows:

a Capacity Operation When used in the preparation of a design for capacity operation, as defined in paragraph 20-5 of this manual, the total combined thickness shown by the curves will be employed

b. Limited Operation: When used in the preparation of a design for limited operation (see paragraph 20-5), the same principles of use will be employed as stated for capacity operation except that a reduction of 20 per cent in the total combined thickness will be made This reduction will be applied first to the layers or courses of material having the lowest bearing ratio

20-20 Application of CBR Test Data to the Design:

a Testing: CBR tests should be made on both subgrade and base course materials The subgrade materials should be tested in the compacted state where compaction in the field is practicable and in the undisturbed state where field compaction is impracticable, or where unusually weak subgrade material strata below the compacted subgrade layer may materially reduce the bearing capacity of the compacted subgrade All base course materials should be tested in the compacted state (see paragraph 20-14 above). The number of CBR tests required depends upon the variation in the subgrade and base course soils, the availability of base course materials, and the types of materials to be tested and used in the construction A sufficient number of tests should be made on each type of subgrade and base course material to obtain representative test results. If a soil sample contains large stone particles, results of duplicate tests may be erratic and a large number of tests may be required before a representative value can be determined It may be necessary, for some gravelly soils, to estimate the CBR based on results of CBR tests of other similar types of soils.

b Total Thickness. The required total thickness of the base and pavement will be determined by the tentative design chart, reference Exhibit 3 (Fig 5) of this Part, unless additional thickness is required due to potential frost action (see paragraph 20-23 below) The combined base and pavement thickness determined by the California method will not result, ordinarily, in overstressing the underlying subgrade if the design is predicated on an accurate CBR evaluation of the compacted subgrade Where subgrade or other conditions do not permit compaction of the upper zone of the subgrade, the design of base course and pavement thickness should be based on the CBR of the uncompacted subgrade as it will exist in the construction. The California method of determining total thickness takes into account the conditions of the subgrade when saturated, the plasticity of the subgrade, and other features affecting its stability. Therefore, the values obtained from the CBR test should be applied directly to the curves of Exhibit 3 (Fig 5) of this Part without modifications for these factors except as prescribed in paragraph 20-19 *b* above If subgrade conditions vary appreciably, sufficient CBR tests should be made to accurately determine average conditions and consideration should be given to changes in design between areas of high and low bearing ratio, or equitable adjustment should be made in the whole to insure a rational design

c Base Course Thickness The design of the thickness of each layer in the base, except as stated in paragraph 20-21, depends upon the value of the California Bearing Ratios of available base course materials and an economic study of the costs of the various materials The combined thickness of the base courses and pavement is governed by the CBR of the subgrade The minimum combined thickness of base course layers and pavement above any given base course layer is dependent upon the CBR of the material in the given base course layer and may be determined from the curves on Exhibit 3 (Fig 5) of this Part If the base course is designed to use several layers of material, the economic thickness of each layer should be determined It should be noted that a suitable base course can be constructed using soils of relatively low bearing ratios in the lower layers The use of a material with a low CBR in the lower sections may be found economical if materials with high California Bearing Ratios are costly to process or must be transported from more distant sources

20-21 Material in Top Base Course

a Base Course Immediately Under Pavement. The base course immediately under the pavements should be sufficiently stable to withstand the high stresses produced in the zone directly under the wheel of a plane The required stability depends upon the type and thickness of pavement, the action and effect of a moving or skidding wheel, the type of plane, etc, and cannot be determined by the curves shown on Exhibit 3 (Fig 5) of this Part Experience has shown that for highway pavements used by heavy trucks, it is desirable that the base course material immediately under a bituminous pavement have a CBR of at least 80 per cent Traffic tests are in progress to determine the requirements of base materials immediately under a pavement used by planes Observation and tests to date indicate that a 6-in base course of material with a CBR of at least 80 per cent placed directly under bituminous pavements of the minimum thickness specified in Part III of this Chapter will have satisfactory stability Until the results of the current tests are available, six (6) inches of material with a CBR of at least 80 per cent should be placed directly under the bituminous pavement if the minimum required pavement thickness is employed However, if material with a CBR of 80 per cent is not available locally and transportation facilities are inadequate for importing suitable material, the requirements for the base under pavements used by the lighter weight planes may be reduced, but in no case shall the CBR of the top six (6) inches of base course material directly under the pavement be less than as follows

Gross weight of plane in lb	Minimum allowable CBR for upper base material in per cent
10,000, 30,000	50
74,000	65
120,000	80

b Base Course Material in Upper Zone of Surface Treated Base Tests are in progress to determine the CBR required of the base course material in the upper zone of a surface treated base Until the results of these tests are available, the upper course of surface treated bases permitted in paragraph 20-6 of this Chapter should be at least six (6) inches thick and composed of material as required immediately under bituminous pavements as stated in *a* above If surface treatment is used in lieu of a required pavement (see paragraph 20-9 above), the upper base course should have a thickness at least equivalent to the combined thickness required for the upper base course and pavement

20-22 Example of Design by the California Method To show the analysis of design by the California Method when the subgrade soil is not affected by the frost, assume that a main taxiway is to be designed for capacity operation with a 37,000-pound wheel load which corresponds to a design load of 46,200-pounds (see paragraph 20-5), and that the top six (6) inches of subgrade will be compacted The CBR of the compacted subgrade and of the materials available for base course construction are as follows

Material	Soil group	CBR of samples at unit weights and moisture conditions expected in prototype in per cent
Compacted subgrade	CL	8
No 1	SF	15
No 2	SP	30
No 3	GW	80

The total thickness and thicknesses of the various base course layers are determined as follows·

a Total Thickness The total combined thickness of the base course and pavement will be governed by the bearing ratio of the compacted subgrade From the curves, on Exhibit 3 (Fig 5) of this part, the required total thickness of base course and pavement above the compacted subgrade (CBR of 8 per cent) is twenty-two (22) inches

b. Thicknesses of Base Course Layers. The total combined thickness of twenty-two (22) inches of base course and pavement may be composed of Materials Nos 1, 2 and 3, and a wearing course (pavement) The design thickness of each layer of material will depend upon the relative cost of construction and the bearing ratio of each material The first step in design is to determine the individual layer thickness required, with reference to its location in the structure, if all three materials are used Material No 1 which has the lowest CBR would form the lower layer, and Material No 3 which has the highest CBR would form the upper layer The minimum depth of more stable material required above a layer of No 1 material is fifteen (15) inches, corresponding to a CBR of 15 per cent according to the curves shown on Exhibit 3 (Fig. 5) of this part. Likewise, the minimum depth required above a layer of No 2 material is 9 inches (CBR of 30 per cent) (see paragraph 20-21 above) If the cost of placing Material No 1 is the least and that for Material No. 3 is the highest, the most economical base course design would be as shown in Figure (a) of Exhibit 4 (Fig 6) of this part However, the base course may also be designed, if economical, using only No 3 material or Nos 2 and 3 in combination, as shown in Figures (b) and (c) on Exhibit 4 (Fig 6) of this part, since material with a higher CBR may be used in place of a material with a low CBR *However, using a base course material with a high CBR in place of a base course material with a low CBR does not permit a decrease in the total thickness of base course, which is governed solely by the CBR of the subgrade.* This example shows that the California Method of design allows the rapid investigation of the economic possibilities and the use of locally available materials

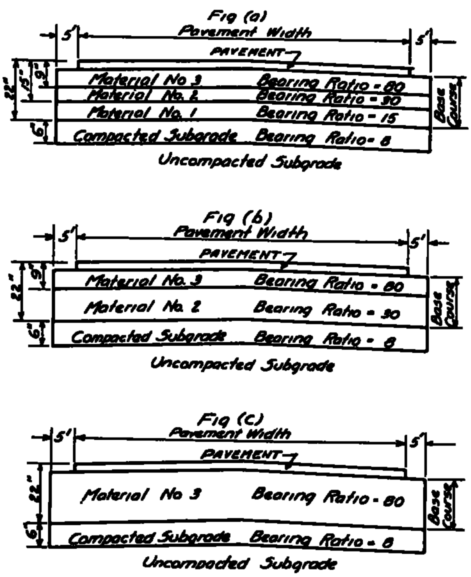

Figure 6. Design Example, See Paragraph 20-22 of Text. Exhibit 4, Engineering Manual, Chapter XX, Part II.

20-23 Design of Base Over Soils Affected by Frost The stability of some soils is greatly reduced by frost action The detrimental effect of frost action occurs during the thawing periods when the moisture in the subgrade, accumulated in the form of ice segregation, is released, thereby softening the soil. The frost action of some soils also causes detrimental heave of pavement or treated surface The degree to which soils will lose their stability and heave will depend upon the type of soil, variation of temperature during freezing and thawing, the permeability of the soil, and the drainage conditions Observations have shown that a high ground water table is not necessary to cause a soil to lose stability due to frost, since soils affected by frost always retain, in the deeper (lower) zones, moisture which will rise during frost action

a Soils Affected by Frost The only practical method of determining the frost-action characteristics of a soil, without exhaustive laboratory tests, is by reference to the grain size distribution Several investigators have established limiting grain size curves defining the boundary between frost-action and non-frost-action soils for uniform and nonuniform grading For design purposes, soil containing 3 per cent or more of grains smaller than 0 02 mm in diameter should be considered as potentially capable of serious frost action In all questionable cases, the percentage (by weight) of sizes below the critical diameter of 0 02 mm should be determined Very plastic soils heave only moderately due to the extremely low permeability and consequently limited volume of moisture which can be supplied, but the contained moisture may be sufficient to induce a reduction in bearing value during periods of thaw

b. Base Requirements for Stability. The most generally accepted method of insuring pavement or base course stability over a potential frost action soil is to provide a sufficient thickness of insulating material not affected by frost action (clean, well-graded gravelly or sandy soils, or fine grained soils treated by proven methods). The required thickness of base course material as determined by the California Method may not be sufficient to preclude frost penetration in the subgrade or lower zones of the base course, even though the base course material itself is relatively nonfrost heaving, hence it is often required that additional thickness of insulating material be provided to insure proper protection against frost action Prior to the determination of the required thickness of nonfrost action soil, the range and average of frost penetration beneath pavements in the region should be determined from local records In general, to insure stability of flexible pavements and surface treated bases, the combined thickness of pavement and nonfrost action base material should be equal to the average depth of frost penetration except that the maximum required thickness (in locations where frost is a factor) is as follows

Gross weight of plane used for design	Maximum required combined thickness of pavement and nonfrost-action base material
120,000 lb	40 in
74,000 lb	30 in
30,000 lb or less	20 in

The above maximum thickness should be used whenever the underlying soil affected by frost is fine-grained, see Exhibit 1 of this Part (Table 1) If the soil affected by frost is a coarse-grained soil (see Exhibit 1 of this Part) or the base is composed of insulating material such as slag, cinders, etc, the maximum required thicknesses may be less than the values shown above depending upon the character of the insulating, soils and drainage conditions, but in no case should the maximum required thickness be less than 75 per cent of the above values. Nonfrost-action material used to insure stability of underlying soil, subject to frost action, should be thoroughly drained (see Chapter XXI, Design of Drainage Facilities for Airfields) and should conform with the requirements of paragraphs 20-20 and 20-21 above In lieu of providing an insulation layer over a frost heaving subgrade it may be feasible and desirable to remove the frost-action subgrade material, particularly where it is of local occurrence.

20-24 Evaluation and Reinforcement of Existing Flexible Pavements The load carrying capacity of existing flexible pavements can be approximately determined by the California method or the California method supplemented by actual traffic tests. However, all factors and characteristics of the paving, base course, and subgrade materials should be considered in the evaluation The CBR tests should either be made on undisturbed samples or on the subgrade and base course soils in place (see paragraphs 20-18 *c* and *d* above) When actual traffic tests are conducted, the width of the test strip should be at least 3 times the width of the tire imprint used, and the wheel load repetitions should be such that each tire width of the strip will be covered at least 3500 times before the pavement is considered satisfactory for capacity operation Both the CBR and traffic test results should be interpreted with due consideration for moisture conditions in the subgrade and base course soils at the time of testing as compared to moisture conditions after several years when equilibrium has been reached Using the results obtained from the CBR tests or the CBR test supplemented by traffic tests, additional reinforcement required for the desired load carrying capacity may be determined from the curves on Exhibit 3 (Fig 5), together with the requirements stated in paragraphs 20-19, 20, and 21 above

20-25 Base Course Materials and Compaction

a. General A complete investigation should be made to determine the location and characteristics of suitable natural and processed materials for base course construction The California Bearing Ratio should be determined for each type of economically available material, using the method described in paragraph 20-18 above. If suitable run of bank materials are not available, investigations should be made on various mixes of available materials, including commercial admixtures, to determine the mixture which will be most satisfactory. The total thickness of flexible pavements and base courses and their proper orientation to each other will be determined by the procedure outlined in paragraph 20-20 above Base courses may consist of the following, used singly or in combination

(1) *Stabilized Subgrades*· The term "Stabilized Subgrade" applies to the natural soil in place to which has been added and intermixed other soil, gravel, caliche, shells, or other suitable natural materials, an admixture of Portland cement, cutback asphalt, emulsified asphalt, tar, or other material to stablize the top layer of the subgrade Stabilized subgrades may be used singly or may be supplemented by an imported base course, or courses, but the distinction in their construction should be recognized.

(2) *Imported Base* The term "Imported Base" applies to a base course composed of specially selected natural soils, gravel, or other materials such as shells or caliche, singly or blended, or of processed materials. Where the required stability cannot be obtained from imported natural soils, stabilization by an admixture can be accomplished as set forth in the above paragraph, provided the soil is suitable for stabilization as outlined in Part VI of this Chapter.

b. Type of Suitable Materials:

(1) *Natural Materials* A wide variety of gravels, sands, and gravelly and sandy soils, of the GW through GF and SW through SF groups, as well as limerock, shell, caliche, etc, can be used alone or blended, see Exhibit 1 of this Part (Table 1) to provide satisfactory base courses In some instances, natural materials will require crushing or the removing of the oversize fraction to control grading This can often be done, economically, by mixing crushed and pit-run materials together to form a satisfactory base course material. The required gradation of a base course material should be determined by test It has been found that the CBR varies with the gradation and that a rough relationship may be set up between the Hazen's uniformity coefficient (D_{60}/D_{10}) and the CBR, which may serve as a guide in initial investigations Ideal grading may not be required to produce high bearing value, since the particle shape and mechanical interlocking of the particles may produce high shearing resistance (high CBR) to provide a CBR of 80 per cent. The most suitable base course materials, from the standpoint of frost action as well as stability, are well-graded clean sands and gravels In nonfrost areas, however, fines in the base course materials are not objectionable, as long as the required CBR is obtained On the other hand, in frost areas, the amount of fines in the material equal to the depth of average frost penetration definitely should be limited to less than 3 per cent smaller than 0 02 mm as required in paragraph 20-23 above

(2) *Processed Materials* Processed materials such as crushed stone, gravel, shell and similar materials which usually have high bearing ratios are ideal for foundation reinforcement directly beneath the surface course. Materials of this type are not of definite structural advantage in the lower portion of thick base courses as compared to material of lower strength However, at some locations their use will be economically justified due to the absence of suitable less expensive material

(3) *Material Stabilized with Commercial Admixtures* Where natural or processed materials with a satisfactory CBR are not economically available, the available materials may sometimes be stabilized with commercial admixtures to produce satisfactory results. Portland cement, cutback asphalts, emulsified asphalts, and tars are commonly employed for this purpose. (See Part VI of this Chapter) Such admixtures can be used to best advantage with relatively sandy or friable soils For such soils, pulverization and thorough mixing of the soil and admixture may be readily accomplished. The values of these admixtures decrease with increasing clay content due to the additional amount of admixture required and the increased difficulty of control. Sufficient admixture should be used to insure that the base course material will have a satisfactory CBR The California Bearing Ratio of soil-cement, when used under conditions suitable for this material, may be considered greater than 80 per cent and

TABLE 1

Soil Classification for Airfields. Engineering Manual, Chapter XX, Part II, Exhibit 1

SOIL CLASSIFICATION FOR AIRFIELD PROJECTS — MARCH 1943

1		2	3	4		5	6	7	8	9	10	11	12	13	14	15
Major divisions		Soil groups and typical names	Suggested group symbols	General identification: Dry strength	General identification: Other pertinent examinations	Observations and tests relating to material in place	Principal classification tests (on disturbed samples)	Value as foundation when not subject to frost action	Value as base directly under wearing surface	Potential frost action	Shrinkage, expansion elasticity	Drainage characteristics	Compaction characteristics and equipment	Solids at opt compaction lb per cu ft and void ratio, e	California bearing ratio for compacted and soaked specimen	Comparable groups in public roads classification
Coarse grained soils	Gravel and gravelly soils	Well graded gravel and gravel-sand mixtures, little or no fines	GW	None	Gradation, grain shape	Dry unit weight or void ratio,	Mechanical analysis	Excellent	Good to excellent	None to very slight	Almost none	Excellent	Excellent, tractor	>125 e<0 35	>50	A-3
		Well graded gravel-sand-clay mixtures, excellent binder	GC	Medium to high	Gradation, grain shape, binder exam wet and dry	Degree of compaction,	Mechanical analysis, liquid and plastic limits on binder	Excellent	Fair to excellent	Medium	Very slight	Practically impervious	Excellent tamping roller	>130 e<0 30	>40	A-1
		Poorly graded gravel and gravel-sand mixtures, little or no fines	GP	None	Gradation, grain shape	Cementation, durability of grains,	Mechanical analysis	Good to excellent	Poor to good	None to very slight	Almost none	Excellent	Good tractor	>115 e<0 45	25-60	A-3
		Gravel with fines, very silty gravel clayey gravel, poorly graded gravel - sand - clay mixtures	GF	Very slight to high	Gradation, grain shape, binder exam wet and dry	Stratification and drainage characteristics,	Mechanical analysis, liquid and plastic limits on binder if applicable	Good to excellent	Poor to good	Slight to medium	Almost none to slight	Fair to practically impervious	Good, close control essential, rubber tired roller, tractor	>120 e<0 40	>20	A-2
	Sands and sandy soils	Well graded sands and gravelly sands, little or no fines	SW	None	Gradation, grain shape	Ground water conditions,	Mechanical analysis	Good to excellent	Poor to good	None to very slight	Almost none	Excellent	Excellent, tractor	>120 e<0 40	20-60	A-3
		Well graded sand-clay mixtures, excellent binder	SC	Medium to high	Gradation, grain shape binder exam wet and dry	Traffic tests,	Mechanical analysis, liquid and plastic limits on binder	Good to excellent	Poor to good	Medium	Very slight	Practically impervious	Excellent tamping roller	>125 e<0 35	20-60	A-1
		Poorly graded sands, little or no fines	SP	None	Gradation, grain shape	Large scale load tests or	Mechanical analysis	Fair to good	Not suitable	None to very slight	Almost none	Excellent	Good, tractor	>100 e<0 70	10-30	A-3
		Sand with fines, very silty sands, clayey sands poorly graded sand-clay mixtures	SF	Very slight to high	Gradation, binder exam wet and dry	California Bearing tests	Mechanical analysis, liquid and plastic limits on binder if applicable	Fair to good	Not suitable	Slight to high	Almost none to medium	Fair to practically impervious	Good close control essential, rubber tired roller	>105 e<0 60	8-30	A-2
Fine grained soils containing little or no coarse grained material	Fine grained soils having low to medium compressibility	Silts (Inorganic) and very fine sands, Mo, rock flour, silty or clayey fine sands with slight plasticity	ML	Very slight to medium	Examination wet (shaking test and plasticity)	Dry unit weight, water content and void ratio,	Mechanical analysis, liquid and plastic limits if applicable	Fair to poor	Not suitable	Medium to very high	Slight to medium	Fair to poor	Good to poor, close control essential, rubber tired roller	>100 e<0 70	6-25	A-4 A-6 A-7
		Clays (Inorganic) of low to medium plasticity, sandy clays, silty clays, lean clays	CL	Medium to high	Examination in plastic range	Consistency—undisturbed and remolded,	Liquid and plastic limits	Fair to poor	Not suitable	Medium to high	Medium	Practically impervious	Fair to good, tamping roller	>100 e<0 70	4-15	A-4 A-6 A-7
		Organic silts and Organic silt-clays of low plasticity	OL	Slight to medium	Examination in plastic range, odor	Stratification, root holes, fissures, etc Drainage and ground water conditions,	Liquid and plastic limits from natural condition and after oven drying	Poor	Not suitable	Medium to high	Medium to high	Poor	Fair to poor, tamping roller	>90 e<0 90	3-8	A-4 A-7
	Fine grained soils having high compressibility	Micaceous or Diatomaceous fine sandy and silty soils, elastic silts	MH	Very slight to medium	Examination wet (shaking test and plasticity)	Traffic tests, Large scale load tests,	Mechanical analysis, liquid and plastic limits if applicable	Poor	Not suitable	Medium to very high	High	Fair to poor	Poor to very poor	<100 e>0 70	<7	A-5
		Clays (Inorganic) of high plasticity, fat clays	CH	High	Examination in plastic range	California bearing tests or	Liquid and plastic limits	Poor to very poor	Not suitable	Medium	High	Practically impervious	Fair to poor tamping roller	>90 e<0 90	<6	A-6 A-7
		Organic clays of medium to high plasticity	OH	High	Examination in plastic range, odor	Compression tests	Liquid and plastic limits from natural condition and after oven drying	Very poor	Not suitable	Medium	High	Practically impervious	Poor to vey poor	<100 e>0 70	< 4	A-7 A-8
Fibrous organic soils with very high compressibility		Peat and other highly organic swamp soils	Pt	Readily identified		Consistency, texture and natural water content		Extremely poor	Not suitable	Slight	Very high	Fair to poor	Compaction not practical			A-8

NOTE In Column 7, values are for subgrade and base courses, except for base courses directly under wearing surface

NOTE Values in Columns 7 and 8 are for guidance only Design should be based on test results in accordance with text

NOTE Unit weights in Column 13 apply only to soils with specific gravities ranging between 2 65 and 2 75

LEGEND FOR GROUP SYMBOLS

G — Gravel
S — Sand
M — Mo very fine sand, silt, rock flour
C — Clay
Pt — Peat

F — Fines, material <0 1mm
O — Organic
W — Well graded
P — Poorly graded
L — Low to medium compressibility
H — High compressibility

will serve very satisfactorily for the upper base course layer of surface treated bases

c Compaction of Base Course Materials All base courses will be compacted to the maximum density obtainable with heavy field compaction equipment. Tests, as described in paragraph 20-14 above, should be made to control the compaction during construction If the Modified A A S H O. Method is applicable for the control of compaction, the base course shall be compacted to at least 95 per cent of the maximum density at optimum moisture content

APPENDIX C[1]

Design of Runways, Aprons and Taxiways at Army Air Force Stations

PART IV—SUBGRADE TREATMENT AND BASE COURSES FOR RIGID TYPE PAVEMENTS

Section I—General

20-38 General Design Procedure The design of a concrete pavement will be based on the Westergaard Analysis, using the modulus of soil reaction "k" (defined by Westergaard as the modulus of subgrade reaction) as described in Part V of this chapter. The structural strength as indicated by the modulus of soil reaction of a subgrade is increased by compaction, and is decreased both by saturation and by frost action if certain conditions exist Prior to the design of the pavement, the modulus of the soil reaction of the subgrade, corrected for a saturated condition, shall be determined by field bearing tests, and laboratory tests If the modulus is low and, according to the Westergaard Analysis, a concrete slab thicker than the minimum permissible value of 6 inches, is required, if constructed directly on the compacted subgrade, the construction of a base course should be considered By constructing a base course with material of relatively high bearing value compared with that of the natural compacted subgrade, a thinner pavement slab may be used than required if the base course is not constructed Studies and tests should be made to determine if the cost of construction of a base course is less than the cost of the additional thickness of pavement required if constructed directly on the subgrade. During the economic studies, consideration should be given to the other possible advantageous features as stated in paragraph 20-44 below. A pavement should not be constructed directly on subgrade soil that is adversely affected by frost action The subgrade in such cases should be reinforced with a base course of material which will not frost-heave or be weakened by frost action

20-39 Load Intensity and Drainage Design Criteria The load intensity and drainage design criteria for rigid type pavements, shall be the same as for flexible type pavement These requirements are stated in paragraphs 20-3 and 20-8 respectively, of Part I of this chapter.

20-40. Design Analysis. The requirements of paragraph 20-10 above, for submittal of a design analysis, apply also to rigid type pavements

Section II—Subgrades

20-41. General: The term "subgrade" and "compacted subgrade" as used in Part IV are defined in paragraph 20-2*l* and *m* Investigations and laboratory tests similar to those described in paragraphs 20-12, 20-17 and 20-14 should be conducted to determine the characteristics of the subgrade soils prior to the design of rigid pavements. California bearing tests as described in paragraph 20-17 should be conducted on the subgrade soils In addition, the compression characteristics should be determined by conducting consolidation tests Although at the present time the results of consolidation tests are only used as stated in paragraph 20-43*e* below, and the results of the California bearing tests are not used for design, it is considered possible, after sufficient correlation has been obtained, that the results of laboratory tests, mainly consolidation and California bearing, may be sufficient for design purposes, thus obviating the field bearing tests. All soil and field bearing test data should be forwarded to the Office of the Chief of Engineers, attention Engineering Branch, Construction Division, accompanied by pertinent correlation, studies, and comments.

20-42 Subgrade Preparations. The subgrade shall be prepared to form a suitable foundation for the pavement slab or base course Unsatisfactory subgrade materials such as top soil, muck, and peat, shall be removed from the foundation area If conditions exist that will cause the subgrade soil to be adversely affected by frost action, the soils so affected shall be removed and/or a base course of suitable material shall be constructed (see paragraph 20-48 below). Subgrade material shall be placed at optimum moisture content in layers not exceeding 9 inches and shall be compacted to at least 90 per cent density as obtained by the Modi-

[1] From Engineering Manual, Chapter XX, August 1942, War Department, Office of the Chief of Engineers.

fied A A S H O Test Method (see paragraph 20-14), except that the top 9 inches of soil in all fill and natural subgrade areas shall be compacted to at least 95 per cent density as obtained by the Modified A A S H O Test Method (see paragraph 20-14). In areas where thickened edges of pavements are to be placed, the subgrade should be scarified and compacted after grading for the thickened edges, to insure a satisfactory depth of compaction under these edges

20-43 EVALUATION OF SUBGRADE REACTION The evaluation of the modulus of soil reaction "k" of the subgrade, to be used in the Westergaard Analysis to determine the required thickness of a pavement (if placed directly on the subgrade) shall be determined as heretofore stated, by field bearing tests and laboratory tests Field bearing tests to determine the load bearing capacity of the soil (subgrade) in its natural and compacted state (compacted subgrade) will be made in accordance with the procedure outlined as follows·

(1) *Loading Plate* Loads should be applied through a rigid circular bearing plate 30 in in diameter Care should be exercised in placing the bearing plate to prevent local stress concentrations caused by non-uniform bearing of the plate A thin layer of fine dry sand may be used to level the bearing plate

(2) *Test Load* The test load, if a truck or trailer is used, should be so assembled that the bearing plate will be at least eight feet from the nearest wheel load The test load should be applied by a jack having a ball joint between the test load and the jack to avoid eccentricity in loading The jack should be capable of increasing and decreasing the load in increments

(3) *Load Procedure* A load of 5 lb per sq in should be applied and released to seat the equipment before the actual test load is applied The test load should be applied in 5 lb per sq in increments, allowing practically complete deformation for each increment before another is applied After the maximum load is reached, the load may be released in one increment The tests should be carried beyond the "yield point" of the material; or to approximately one and one-half (1 5) times the static tire pressure of the heaviest plane to use the field

(4) *Deflection Measurements.* The deflection should be measured by two dial gages, diametrically opposed, bearing on the circular plate The support for the dial gages should rest on the ground at right angles to the truck wheels at least 8 feet away from the bearing plate in order to prevent deflection of the immediately adjacent pavement from influencing the readings

The procedure for the evaluation of the load bearing test data and the correlation of laboratory test results are described below If it is contemplated to place the pavement directly on the compacted subgrade, tests should be made in sufficient number to obtain representative values of the modulus of soil reaction "k" for various areas of the natural and fill subgrade The value of "k" for a specific subgrade area shall be determined as follows

a A small area of the subgrade shall be stripped to the proposed elevation of the subgrade surface If the subgrade is to be composed of fill material, a test embankment of about 30 inches in height shall be constructed after stripping off the top soil The subgrade shall be compacted at optimum moisture to the densities specified in paragraph 20-42 If ordinary compaction equipment is not available, approximate compaction may be obtained by hand tamping in thin layers

b. The field bearing test shall be conducted on the prepared subgrade in accordance with the procedure stated above The test should be conducted with the subgrade at or close to its optimum moisture content It has been found by tests that artificial saturation of most soils is infeasible or produces conditions which are unfavorable for field testing, and for this reason adjustments to represent reduction in subgrade bearing capacity due to saturation will be made as described below However, it may be feasible to saturate satisfactorily some soils by ponding, and in some cases the modulus of soil reaction may be determined directly from the field tests.

c The results of the tests shall be prepared in the form of load deformation curves (see Fig 7) .

d The modulus of the soil reaction, with the subgrade at or near its optimum moisture, "k_u" shall be determined by the formula "k_u" = p/0 05 in which "p" is the load intensity in pounds per square inch causing a deformation of 0 05 inches as determined from the load deformation curve (see Fig 7) The modulus of the soil reaction is defined as the slope of chord extending from the origin to a given load intensity on a stress deformation curve Since the stress deformation curve is not a straight line, the modulus of soil reaction varies with the load intensity It is necessary for use in the Westergaard Analysis to select one value for the modulus of soil reaction, which will give the most satisfactory design results A study of the results of many tests indicates that the most representative value of the modulus of soil reaction for concrete pavement design may be obtained using the load intensity causing a deformation of 0 05 inches as above required

e Standard consolidation tests shall be performed on representative subgrade soil samples in the laboratory The soil for one test, No 1, shall be placed in the consolidation

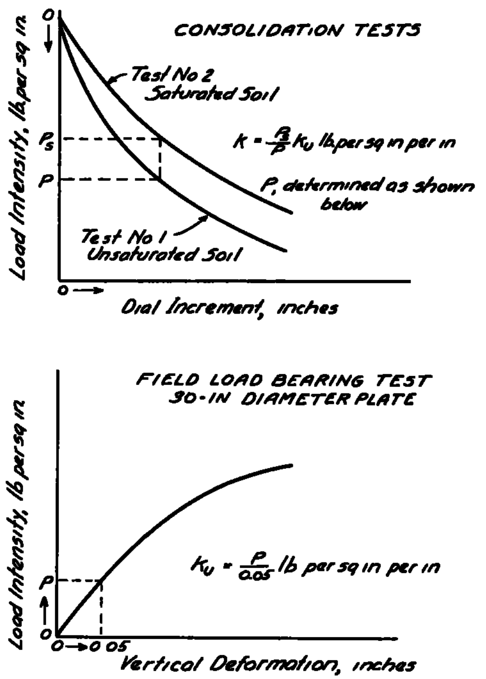

Figure 7 Load Deformation Curves. Inclosure No. 10, Chapter XX, Engineering Manual, August 1942.

device at a density and moisture content equivalent to those at the time of field testing The soil for a second test, No 2, shall be placed in the same manner as the first, after which it shall be saturated by immersion During the immersion period, a load of 5 pounds per square inch shall be applied to restrain the surface of the sample The results of each test should be plotted to show the relation between load intensity in pounds per square inch and deformation in inches similar to the curves shown on Figure 7 A sufficient number of tests should be conducted to obtain satisfactory average curves

f Until a more suitable method is established, the modulus of soil reaction "k" for a saturated subgrade to be used in design shall be computed by reducing the soil modulus "k_u" for a subgrade compacted at or near its optimum moisture, in proportion to the ratio of the loads producing the same consolidation, obtained in the two consolidation tests (see Fig 7) Since the critical deflection in the slab is small, the soil movement underneath is not due to shear failure but compression and may be more closely represented by the results of consolidation tests It appears that the results of consolidation tests should be used to determine the reduction of "k_u" due to saturation in place of a shear failure test, similar to the California bearing test However, as stated in paragraph 20-41, California bearing tests should be performed for the purpose of providing correlation with the view of improving the design procedures The most applicable procedure for using the results of the consolidation tests to obtain a modulus of soil reaction for saturated condition has not been formulated However, since the ratio of the loads to produce the same deformation in the two consolidation tests should be approximately equal to the ratio of the loads required to produce the same deformation on an unsaturated and saturated subgrade, "k" may tentatively be determined by the following formula

$$k = \frac{p_s}{p} k_u$$

in which

k = modulus of soil reaction for saturated subgrade

k_u = modulus of soil reaction determined as stated in *d* above

p = load intensity used to determine k_u as stated in *d* above

p_s = load intensity required in consolidation test No 2 as stated in *e* above, on saturated soil to produce the same deformation as the load intensity "p" in consolidation test No 1 on soil placed with a moisture content equivalent to that during the field bearing test (see Fig 7)

Section III—Base Courses

20-44 General Base courses are generally constructed underlying airport pavements for one or more of the following reasons

a. To provide directly under the pavement slab a more rigid layer compared with the subgrade which permits the use of a thinner pavement slab

b To aid in the reinforcement of joints

c To provide a drainage layer which will enable rapid consolidation of the subgrade soil

d. To produce a uniform bearing surface for the pavement slab

e. To replace soft, highly compressible or expansive soils

f. To insure stability in areas subject to detrimental weakening of the subgrade by frost action

g. To produce uniform movement in subgrade areas subject to detrimental frost heaving

h To prevent fine subgrade material from being pumped upwards into the pavement cracks

i To produce a suitable surface for operating construction equipment during all weather conditions.

If conditions exist at a proposed airfield which indicate that a base course is desirable, a complete investigation should be made to determine the source, quantity and characteristics of the available suitable materials for base course construction. A study should be made to determine the most economical thickness and material for a base course which will meet the above requirements The base course thickness required to provide a more rigid layer over the subgrade which will permit the use of thinner slabs should be such that the combined cost of base course and pavement will be a minimum

20-45 Base Course Materials The base course may consist of stabilized subgrade or imported base, as defined in paragraph 20-25. A wide variety of natural processed and stabilized material may be used, similar to that used for flexible pavement base courses The base course material in general should be a well-graded, high stability material, with a low percentage of fines If crushed stone is used, the surface should be covered with screenings to provide a suitable slippage plane for the expansion and contraction of the pavement Suitable pervious materials for base courses should be used in frost-action areas (see paragraph 20-48)

20-46 Compaction The base course material should be thoroughly compacted to produce a material of low compressibility Soil base course mixtures shall be compacted to at least 95 per cent density at optimum moisture with control by the Modified A A S H O Method (see paragraph 20-14)

20-47. Design of Base Course to Reduce Required Pavement Thickness:

a. The design of the base course to reduce the required pavement thickness depends upon the characteristics of the subgrade and base course materials, and the relative cost of construction of various thicknesses of base course compared with the required thicknesses of concrete slab. To determine the most economical design, the structural effect of various base course thicknesses must be determined. The proper method of evaluation of the effectiveness of the base course on the stability of the pavement has not been formulated The evaluation should be done in such a manner that the results can be used in the Westergaard Analysis which was formulated for uniform soil conditions The effort of the soil reaction of a base course on the stability of a pavement may be considerably different than if uniform soil conditions exist However, tests have shown that if the soil reaction of the base course is evaluated by determining the modulus of the soil reaction "k" by field bearing tests using a 30-inch diameter plate, the value may be used in the Westergaard Analysis to determine satisfactorily the required thickness To evaluate the effectiveness of various thicknesses of base courses, it will be necessary, at the present time, to construct test sections of various thicknesses and determine the modulus of soil reaction by field bearing tests on each section. It may not be necessary to conduct a series of tests at each proposed site if data are available that shows the relation between base course thickness and the increase of the modulus of soil reaction for conditions similar to those encountered In such cases, bearing tests should be conducted only on the subgrade. Using the results of tests on the subgrade, and previous tests on base courses at other sites, an approximate evaluation of the base course can be obtained

b The test procedure and method of evaluation to determine the modulus of soil reaction "k" of the base course shall be similar to that described in paragraph 20-43 above The modulus of soil reaction "k_u" as determined by the field bearing test for the base course and subgrade soil compacted at optimum moisture shall be reduced to account for saturation of the subgrade soil Since base course materials will generally contain a large percentage of granular material, saturation of the base course will not appreciably affect the bearing value at the surface of a base course and may be neglected However, subgrade saturation must be taken into account even though base course construction is used. The modulus of soil reaction "k_u" shall be reduced for the effects of saturation similar to the method described in paragraph 20-43 except that the value of "p" should be the load intensity at the surface of the subgrade The value of "p" will depend upon the stress distributing effects of the base course; it cannot be determined either by test or computation, and must be estimated. The load intensity at the surface of the subgrade may be estimated by assuming that the effective stress zone under the bearing plate lies within a locus of a line making an angle of 45 degrees with the horizontal and passing through the edge of the bearing plate The angle depends upon the type of material and varies between 30 and 60 degrees, but may be assumed to be 45 degrees The stress distribution on any horizontal plane within the zone of the influence may be assumed uniform Based on these assumptions, the load intensity at the surface of the subgrade equals $\left(\frac{15}{d+15}\right)^2$ times the load intensity on a 30-inch plate at the surface of the base course in which "d" is the thickness of the base course After the modulus of soil reaction for various thicknesses of base course has been determined, the corresponding required concrete pavement thicknesses can be determined by the formulae or curves contained in Part V of this chapter With these data, a cost study can be made to determine the most economical design.

20-48 Design of Base Course Thickness on Soils Affected by Frost Actions

a Reduction in Bearing The bearing value of a subgrade soil susceptible to frost action will be reduced during periods of thaw. Where climatic and moisture conditions are favorable, soils described in paragraph 20-23 of this chapter and cohesive soils, will be adversely affected by frost action. Although cohesive soils heave only slightly, their bearing value will be greatly reduced The design of a pavement will depend upon the reduced bearing value of such a soil, unless it is removed and a base course is constructed to a sufficient depth to provide suitable reinforcement Accurate methods of evaluating the actual bearing value in soils affected by frost action are not known Highway experience indicates that in areas which are subject to frost action the base course of non-frost heaving material under a 6 or 7-inch slab, as used for highway loads, should extend to a depth of at least 50 per cent of the average frost penetration, in order to provide suitable subgrade reinforcement For the heavier wheel loads being used in airfield pavement design, the base course thickness required will be greater than that used in highway design The base course thickness so determined will govern only when it exceeds the thickness determined as outlined in paragraph 20-47

b Frost Heaving. Under conducive climatic and moisture conditions, certain subgrade soils (see paragraph 20-23 of this Chapter) will heave due to frost action, causing the pavement to rise during a freezing period and settle during the spring or thawing period If the movement is not uniform for the total area, cracking of the pavement will occur. To prevent cracking, a base course should be constructed to produce uniform movement If the subgrade consists of both frost-heaving and non-frost-heaving soils, highway experience has indicated that all of the frost-heaving soil should be removed to the full depth of the average frost penetration The areas should be back-filled with a compacted select material to provide uniformity It should be noted that cohesive soils may be used in the lower layers of thick base courses, if the soil has sufficient bearing value to provide a suitable modulus of soil reaction at the surface of the base course for pavement design

DISCUSSION ON SOIL TEST FOR THE DESIGN OF RUNWAY PAVEMENTS

Mr. W. H. Campen and Mr J R. Smith, *Omaha Testing Laboratories*: We wish to compliment Mr. Middlebrooks for his efforts in trying to formulate a simple method for designing flexible runway pavements. However, we do not believe some of the assumptions and tests used to be correct and therefore, wish to criticize them.

1. We cannot see where any relationship has been established between the bearing ratio and the rate at which the soil distributes load to the subgrade. It is an established fact that compacted soils must not only possess certain resistance to penetration, but also ability to distribute load. The former is necessary to prevent surface deformation and the latter to reinforce the subgrade. Furthermore, the former is independent of depth, while the latter varies directly as the depth with a given mixture It seems to us that the

bearing ratio measures only resistance to displacement

2 The fact that the design does not consider distributive strength of saturated soil mixtures, compacted to different densities, seems very unsound to us. Thus if 20 in of 80 bearing ratio material, (c) Figure 6, is required to handle a certain load above a given subgrade, the thicknesses called for in (a) and (b) Figure 6 will not be adequate, because they contain thicknesses of much weaker mixtures. If, on the other hand, (a) Figure 6 represents sufficient strength, the thickness in (c) Figure 6 should be much less than it is and in (b) Figure 6 somewhat less. We believe that in order to construct economically and adequately, the distributive ability of compacted layers should be measured and then applied in designing

3 The method of saturating compacted samples does not simulate field conditions. These types of pavement are usually water-proofed on top If water ever reaches them, it must do so from the bottom Therefore, laboratory tests should be made with this in mind Our experience shows that saturation tests made by applying water at the bottom are much less severe. In fact, selected soils, compacted to maximum density at optimum moisture, show hardly any absorption when tested by our method for a period of 7 days

4 We cannot see the logic of modifying the laboratory compaction test and then requiring only 95 per cent of the maximum density so obtained. It is true that 95 per cent of the density obtained with the modified method usually gives denser and stronger mixtures than 100 per cent by the Proctor method, but why not adjust the procedure to give desired strength of 100 per cent density? This would save money and energy in the laboratory.

5 We wonder if Mr. Middlebrooks gave any attention to the compaction of soil mixtures in the field, before he modified the laboratory method. Our own experience shows that the methods of compaction now being used can barely produce 100 per cent of Proctor density. The modified method requires a compactive effort which is about 4½ times that of the present method. If this additional effort is to be used in the field, it will not only increase the cost of construction enormously but it will also require a new type of equipment.

CAMPEN-SMITH METHOD OF DESIGNING FLEXIBLE RUNWAY PAVEMENTS

We had planned on presenting our method for the design of flexible runway pavements at the 1943 meeting. In view of the fact, however, that there seems to be an immediate demand and because of the widespread interest shown, we have decided to include this method as part of our discussion of Mr Middlebrooks' paper.

Fundamentally, all of us, trying to solve the problem, are concerned with devising methods of constructing low cost pavements, which will handle large wheel loads The stabilization of ordinary soils or soil-aggregate mixtures by compaction, or admixtures plus compaction, to impart structural properties to the mixtures, has received the attention of all researchers Our own method has been developed by much laboratory and field testing, coupled with field observations on compaction stabilization.

In order to provide adequate and permanent runway surfaces, we consider four major factors These are (1) the relationship between tire contact area and the unit strength of flexible surface; (2) the strength of the natural subgrade at its weakest anticipated condition, (3) the rate at which load bearing value can be increased by superimposing on the subgrade layers of stabilized soil or soil-aggregate mixtures and bituminous mixtures, and (4) the stability or durability of the stabilized mixtures, when subjected to the three natural destructive forces of drying, freezing or water absorption

Since our method presupposes that soils can be made stable by compaction and that compacted soils superimposed on subgrades will act the same as subgrades when tested with plates of different sizes, we wish to call attention to our papers entitled "Measuring the Load Supporting Values of Flexible Pavements"[1] and "Some Properties of Densified Soils,"[2] both of which have been presented to this Organization. Briefly, we have found that selected soils, compacted to maximum density at optimum moisture by the Standard Proctor Method are essentially stable In regard to load bearing values, the combination of subgrade and compacted soil layers behave in accordance with the perimeter-area theory advanced by Prof. W. H. Housel[3]; and Prevost Hubbard[4] showed that the combination of subgrades and bituminous mixtures follow the same law

Evaluation of subgrade strength requires a great deal of judgment in addition to the tests. Not only the conditions of the materials as they exist at the time of examination must be considered, but, also, the probability of additional water getting into them and thereby lowering their strength. Therefore, if it is anticipated that the soils will become saturated, they should be tested in this condition If, however, it is known that no additional water will reach them, they should be tested at whatever moisture condition exists at the time of construction. In our design we assume that surface water can be kept out by the bituminous wearing surface By following this discriminating procedure, adequate runways can be constructed at minimum cost.

[1] *Proceedings*, Highway Research Board, Vol 21, Vol 21, p 142 (1941)

[2] *Proceedings*, Highway Research Board, Vol. 22 (this Volume) p 460 (1942)

[3] W S. Housel, "Load Tests on Fexible Surfaces" *Proceedings*, Highway Research Board, Vol 21, p 118 (1941)

[4] Prevost Hubbard and F C Field, "A Direct Method of Determining Thickness of Asphalt Pavement with Reference to Subgrade Support," *Proceedings*, Association of Asphalt Paving Technologists, Vol 12, p 317 (1940)

Testing the Subgrade

In specific designs, after we have anticipated a subgrade condition, we create the condition and proceed to make the tests. Whenever possible, we use a plate representing the tire contact area of the vehicle for which a design is being made, otherwise we use two smaller plates The subgrade value for the desired plate is then estimated by the perimeter-area $\left(\frac{p}{a}\right)$ ratio method. Up to the present time we have used the values obtained at $\frac{1}{4}$-in. deformation as a basis of design. We have arrived at this figure by field observations

We should point out here that the only equitable way to test a subgrade is in its natural state of formation. We have seen subgrades, in which the gradation of the soils varied continually to a depth of several feet. An average compacted sample in this case could in no way represent the actual subgrade Probably the best way to bring a subgrade to a saturated condition is to cover it with sand sufficient to represent superimposed layers, and then apply water for a sufficient length of time The sand is removed before testing is done.

Strength Increase Due to Superimposed Layers

The rate at which superimposed layers of subbases or bases will increase the strength of subgrade can be measured either in the laboratory or in the field In the laboratory the subgrade under construction is reproduced in a steel box 4 ft. by 4 ft. by 1 ft. This is done by compacting the soil to field density at a moisture content equal to saturation. If the artificial subgrade is stronger than the natural subgrade, its water content is adjusted until the desired strength is obtained. Six-inch layers of subbase and base are next prepared in 4 ft. by 4 ft. boxes with materials selected for the project. They are compacted to maximum density at optimum moisture content. Now tests are made on the subgrade with circular plates, having areas of 72 and 216 sq in. Similar tests are made after the subbase and base layers have been placed above the subgrade

In the field the subgrade is prepared to meet anticipated conditions and tested with at least two circular plates having areas of from 144 to 432 sq in. Two or more 6-in. layers of subbase and base are constructed upon it and tested in the same manner as the subgrade By either the laboratory or field procedure the rates at which the subgrade strengths can be increased are expressed in lb per sq. in. per inch of superimposed material.

In order to show what might be accomplished in a quantitative manner by superimposing compacted layers on weak subgrades, we are including some typical tests made in the laboratory and in the field. In Table 1 are given the strengths of a subgrade and its combination with 6 in. of subbase and 6 in. of base, when tested in the laboratory with plates having areas of 72, 144 and 216 sq in. This and other similar tests show that on the average, with our soils, 6 in. of subbase will increase the load bearing value of ordinary subgrades 14 lb. per sq in. or 2.33 lb. per in. of thickness, when tested with a 216 sq. in. plate. With other plates the strength increase will be as shown in Figure 1. By superimposing 6 in. of base on the subgrade or the subbase, the strength increase is about 22 lb. or 3.67 lb. per in of thickness Table 3 shows the results of tests made in the field in connection with a particular design. It will be noted that 12 in. of subbase increased the load bearing value 27 lb or 2.33 lb per in. of thickness, and 6 in. of base increased the subbase strength 26 lb. or 4.3 lb. per in. of thickness with a 216 sq. in. plate.

To coordinate laboratory design with field tests and performance we include the following: (1) One runway which had been designed to have a strength, on top of the base, of 75 lb. per sq. in. with a 216 sq in. plate was tested with the same plate three years after construction. The tests obtained ranged from 63 to 87 lb, with an average of 73 lb. (2) A number of tests were made on this runway after the base had been removed. It was found that on the average 5 in. of clay-sand-gravel base added 20 lb. per sq. in. strength to the subbase or 4 lb. per sq. in. per in. of thickness. (3) One small section of this runway performed satisfactorily for about two years under a maximum wheel load of 13,500 lb. (55 lb tire pressure and 245 sq in. contact area). Soon after the wheel load was increased to 25,000 lb. (60 lb tire pressure and 417 sq. in. tire contact area), the surface began to show excessive deformation, which was soon followed by cracking of the bituminous surface. Load bearing tests made on this area showed from 49 to 61 lb. with a 216 sq. in. plate, or an average of 54 lb. It can be shown by calculations that the strength of the base with plates of 245 and 417 sq. in. areas will be about 51 and 41 lb., respectively. From these figures the area should have failed under both loads. The fact that it stood up under the lighter load shows that the design is conservative and that the bituminous wearing surface (2-in.) does help.

It should be pointed out, also, that a base testing 75 lb. with a 216 sq in. plate will test about 70 lb with a 245 sq. in. plate and about 58 lb. with a 417 sq. in. plate. These figures are mentioned to show that while the runways are amply constructed for the 13,500-lb. wheel loads, they are really being overloaded, according to the design formula, by the 25,000-

lb. wheel loads. The fact that they are performing satisfactorily again shows that the design is conservative.

Design Procedure

1. Judge the worst subgrade condition by making a soil survey.
2. Test the subgrade at its worst anticipated condition with at least two circular plates, having areas of from 72 to 216 sq. in., in the laboratory and from 144 to 432 sq. in. in the field.
3. Superimpose at least 6 in of selected subbase and base, successively, on the prepared subgrade and test as under subgrade.
4. Plot the unit strengths obtained in 2 and 3 against the $\frac{p}{a}$ ratios of the plates and extend the curves. From these curves the unit strengths of other plates can be determined. The strength increase produced by superimposed layers per inch of thickness can also be determined for plates of any desired area
5. Assume that the contact area of plane tires is a circle, which is equivalent to the tire load divided by the tire pressure.
6 To calculate the thicknesses necessary above a given subgrade to handle a tire of given contact area and pressure, use the curves in 4 as follows: Assume that the tire contact area is 417 sq. in. and the pressure is 60 lb This means that the finished surface must be able to withstand 60 lb. per sq. in with a plate of 417 sq. in. area at a ½-in. deformation. Assume also that the subgrade strength is 16 lb per sq in with a contact area of 417 sq. in., that 1 in. of subbase will increase this strength 1.7 lb. and 1 in. of base will give 3.3 lb. increase. If 6 in. of base is desired, the subgrade plus base will give 36 lb Therefore, the subbase must contribue 24 lb., and it will be necessary to use 14 in. of it $\left(\frac{24}{1.7}\right)$.

TABLE 1

LOAD BEARING VALUES OF SUBGRADE AND ITS COMBINATION WITH SUBBASE AND BASE

	Load bearing value—lb per sq in		
	72 sq in plate	144 sq in plate	216 sq in plate
Subgrade	11	8	7
Subgrade + 6 in. subbase	35	25	21
Subgrade + 6 in. subbase + 6 in base .	73	49	43

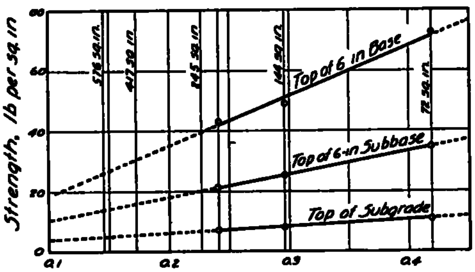

Figure 1. Load Bearing Values of Subgrade and Superimposed Layers

To illustrate how thicknesses of subbase and base vary with different subgrades and wheel loads, the following examples are included.

Example 1: We have a subgrade which has the strength shown in Table 1 and Figure 1. Layers of subbase and base superimposed on this subgrade develop strengths shown in Table 1 and Figure 1 We wish to use thicknesses capable of handling vehicles whose tires have the characteristics shown in Table 2 The calculated thicknesses are shown in Table 2.

It may be used to determine the strength of superimposed layers of all types of mixtures, such as plastic soils, sands, gravels, crushed rock and combinations of these with cement and bituminous materials

TABLE 2

THICKNESSES OF SUBBASE AND BASE REQUIRED TO HANDLE DESIRED LOADS—CALCULATED FROM CURVES IN FIGURE 1

	Thicknesses required, inches		
	13,500-lb wheel load	25,000-lb wheel load	37,500-lb wheel load
Combination No 1 Base	6	6	6
Subbase	13.0	23.0	32 0
Combination No 2 Base	14 5	21 5	30 0
Subbase	0	0	0
Combination No 3 Base	0	0	0
Subbase	22 0	32.0	40 0

TIRE DATA FOR ABOVE

Wheel load	13,500 lb.	25,000 lb	37,500 lb
Air pressure	55 psi	60 psi	65 psi
Contact area	245 sq in.	417 sq in	576 sq in

TABLE 3

LOAD BEARING VALUES OF SUBGRADE AND SUPERIMPOSED LAYERS

	Load bearing value—lb per sq in	
	72-sq in plate	216-sq in plate
Subgrade	32	20
Subgrade + 12-in subbase	75	47
Subgrade + 12-in subbase + 6-in base	116	73

Example 2 The data used in solving this problem are shown in Table 3, Figure 2 and Table 4.

Application of Method

The method outlined can be used to obtain data either in the laboratory or in the field

It may also be used to determine the strength of pavements already constructed.

It is possible that classes of materials, from different sources, such as plastic soil mixtures, sands, gravels, crushed rocks, and bituminous mixtures, may possess load distributive values sufficiently uniform to assign them definite values For instance, 6 in of ordinary selected fine

TABLE 4

THICKNESSES OF SUBBASE AND BASE REQUIRED TO HANDLE DESIRED WHEEL LOADS—CALCULATED FROM FIGURE 2

Combination	Thicknesses required, inches		
	13,500-lb wheel load	25,000-lb wheel load	37,500-lb wheel load
No. 1 Base	6 0	6.0	6.0
Subbase	5 5	14 5	22 0
No. 2 Base	9 0	13 5	17 0
Subbase	0 0	0 0	0.0
No 3 Base	0.0	0 0	0 0
Subbase	16.5	26 0	34.0

Tire data for above are given in Table 2.

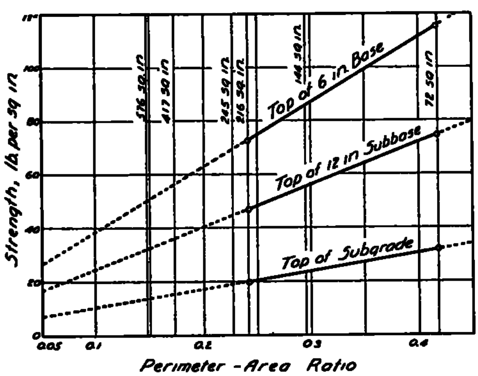

Figure 2. Load Bearing Values of Subgrade and Superimposed Layers

grained soils might be expected to increase the load bearing value of a weak subgrade 15 lb. per sq in. when tested with a 216 sq in. plate.

Conclusions

We believe this method of design is sound because:

1. It considers the unit strength-area relationship of flexible pavements

2. It considers the selection of soils with respect to their volume change and water absorption characteristics after consolidation

3. It considers the resistance to penetration and load distributing ability of superimposed layers

4. It enables the designer to plan adequately and economically

MR A. T. GOLDBECK, *National Crushed Stone Association*

COMPARISON OF CALIFORNIA BEARING RATIO AND BEARING VALUE OF SOIL

In Volume 20 of *Proceedings*, Highway Research Board, there is a paper by the writer entitled, "A Method of Design of Non-Rigid Pavements for Highways and Airport Runways." The method for determining flexible pavement thickness described in that paper involved the use of the so-called bearing value or bearing resistance of the soil and the thickness required to support a wheel load on a single tire was expressed by the formula which may be written·

$$T=\sqrt{\frac{2P}{\pi M}}-\tfrac{1}{2}(L_1+L_2) \quad \ldots \quad (1)$$

where

T = thickness of surface required
P = wheel load on a single tire
M = subgrade bearing value
$L_1 = \frac{1}{2}$ major axis of tire contact area
$L_2 = \frac{1}{2}$ minor axis of tire contact area

Mr. Middlebrooks makes use of curves showing the relationship between thickness of pavement and the "California Bearing Ratio." It has been stated that the curves for 7000- and 12,000-lb. wheel loads have been drawn as the result of field observations of pavements of different thickness, in comparison with the California Bearing Ratio values applicable to those pavements.

connection with the California curves and in order to base the present calculations on the same tire condition as assumed in the California method, a 60 psi tire pressure has been used.

The subgrade bearing values in the first column then correspond to the California Bearing Ratios in the last column and their relationship is shown in Figure 1.

Thus the relationship is now established

Calculations for Determining Relation of California Bearing Ratio to Subgrade Bearing Value

Based on 60-lb tire pressure for 12,000-lb. load, single tire.

$$\text{Contact Area} = \frac{12{,}000}{60\times 1.10} = 182 \text{ sq. in.} = \pi L_1 \times \tfrac{1}{2} L_1 = \frac{\pi L_1^2}{2},\ L_1 = \sqrt{\frac{2\times 182}{\pi}},$$

$$= \sqrt{116} = 10.77 \text{ in.}$$

$$T = \sqrt{\frac{2\times P}{\pi M}} - \tfrac{1}{2}(L_1 + L_2) \qquad L_2 = \frac{5.37}{16.14},$$

$$\tfrac{1}{2}(L_1 + L_2) = 8.1 \text{ in.}$$

$$= \sqrt{\frac{2\times 12{,}000}{\pi}}\sqrt{\frac{1}{M}} - 8.1 = \sqrt{7639}\sqrt{\frac{1}{M}} - 8.1 = 87.4\sqrt{\frac{1}{M}} - 8.1$$

Bearing value $(M) = \frac{1}{M}$	Thickness	California bearing ratio
$10 = \sqrt{0.1} = 0.316\times 87.4 = 27.6 - 8.1 =$	19.5	4
$20 = \sqrt{0.05} = 0.224\times 87.4 = 19.6 - 8.1 =$	11.5	10
$30 = \sqrt{0.033} = 0.182\times 87.4 = 15.9 - 8.1 =$	7.8	20
$40 = \sqrt{0.025} = 0.158\times 87.4 = 13.8 - 8.1 =$	5.7	36
$50 = \sqrt{0.02} = 0.141\times 87.4 = 12.3 - 8.1 =$	4.2	57
$60 = \sqrt{0.0167} = 0.129\times 87.4 = 11.3 - 8.1 =$	3.2	90

Assuming that the thicknesses thus obtained as the result of field observations of highway behavior are correct, a way then becomes available to determine the subgrade bearing values which correspond to the California Bearing Ratios. This is accomplished by calculating the thicknesses required using the foregoing formula with different bearing values, then from the California 12,000-lb wheel load curve, the California Bearing Ratios corresponding to these same thicknesses are determined. Evidently a 60 psi tire pressure was assumed for all tire loads used in

between California Bearing Ratios and Bearing Values for use in the formulas proposed by the writer for determining flexible pavement thickness.

Table 1 shows calculated thicknesses using formula No 1, assuming a single tire with 60-lb. tire pressure, 70,000-lb. and 25,000-lb. loads.

In both cases the thicknesses are quite concordant, the calculated thicknesses, however, being somewhat greater than those determined by the California method.

It is not correct to assume the same tire pressure, irrespective of wheel load or size of tire, nor is it correct to ignore the fact that dual tires affect the required pavement thickness These effects can be taken into accout by the methods described by the writer in 1940 [1]

It is rather remarkable that two methods for obtaining flexible pavement thickness, based on radically different procedures should give results which are so close to one another when the methods are correlated. In making this correlation, the California observations as to pavement thickness required for a 12,000-lb. wheel load are assumed to be correct.

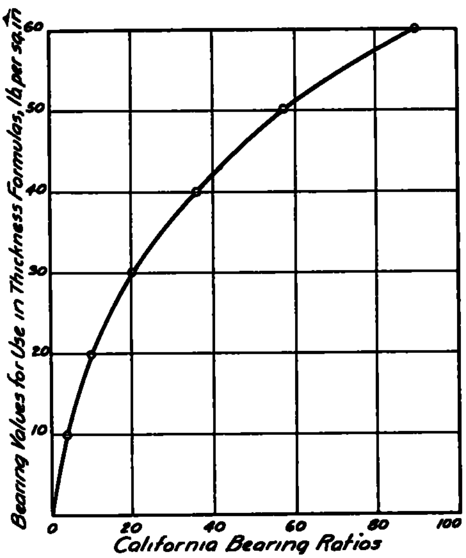

Figure 1. Relation Between California Bearing Ratio and Subgrade Bearing Value for Use in Flexible Pavement Design Formulas Suggested by A. T. Goldbeck, Proceedings, Highway Research Board, Vol. 20, p. 258 (1940).

The fact that relatively good concordance of pavement thickness values is obtained with these two different methods doesn't prove that either is correct The California Bearing Ratio method, if correct, now becomes a convenient method of indirectly arriving at the bearing value to use in the design formulas and these formulas are very useful for calculating the required pavement thickness no matter what the wheel load, tire pressure, tire size, or tire spacing may be if dual tires are used.

[1] A T. Goldbeck, "A Method of Design of Non-Rigid Pavements for Highways and Airport Runways," *Proceedings,* Highway Research Board, Vol. 20, p 258 (1940).

TABLE 1

California bearing ratio	Corresponding bearing value	Pavement thickness, in	
		California Method	Calculated with formula (1)
70,000-LB. LOAD, 60-LB. TIRE PRESSURE			
4	10	42	47.2
10	20	23	28.0
20	30	14.5	17.3
36	40	10	14.2
57	50	7 5	10.8
90	60	5.5	8.1
25,000-LB LOAD, 60-LB. TIRE PRESSURE			
4	10	26.5	28.2
10	20	15	16.8
20	30	10	11.4
36	40	7	8.4
57	50	5.5	6.4
90	60	4.0	4.8

MR. MIDDLEBROOKS AND CAPTAIN BERTRAM: Mr. Campen and Mr. Smith have questioned a number of items in the flexible pavement design method presented by the authors (Middlebrooks and Bertram). Most of these points I believe can be easily clarified. They are covered in subsequent paragraphs in the same order as was used in the discussion.

Item 1. No direct relationship between the bearing ratio and load distribution has been established. This and other factors have, of course, had their influence on the empirical curves. The bearing ratio test is merely a classification test by which the soils may be rated as to their relative stability. The cone test used by North Dakota serves the same purpose Other types of stability tests such as the triaxial, the direct shear, etc , properly correlated with service behavior, could be used also.

Item 2 A base course of 80-bearing material for the full depth of the base is preferred, naturally, to a less stable material in the lower portion of the base. Although this fact has been generally recognized, up to the present time there have been no conclusive data showing how much the thickness might be reduced where 80-bearing material is used for the full depth of the base. A comprehensive investigation on a specially constructed traffic test section is just being completed. Use of 80-bearing material for the full depth of the base was one of the major factors included in this investigation. After these test data have been digested, a thickness reduction factor will be set up for 80-bearing material These test data include 20,000-lb and 50,000 lb wheel load traffic on separate sections, dynamic and static deflection of subgrade and pavement surface, earth pressure on subgrade, and all pertinent soil tests

Item 3. The revised method of saturation allows for saturation of the sample from the bottom where practicable, and from the top and bottom where necessary to expedite the process In some dense clay soils, 4 days or even "7 days" are not sufficient time to insure complete saturation Some samples have required over 20 days to reach saturation by this procedure. It is obviously necessary, therefore, to speed up the rate by soaking from top and bottom. The use of thinner samples may also be desirable and this is being investigated at the present time.

Item 4 Ninety-five per cent compaction by the modified laboratory compaction test in a number of cases is greater than 100 per cent of the standard Proctor Method To use the standard method, some soils would require over 100 per cent compaction A compaction requirement of over 100 per cent has been found, and naturally so, to be confusing to contractors and construction engineers It was considered preferable, therefore, to modify the test and keep the compaction requirement below 100 per cent.

Item 5. The modified compaction requirements were not picked out of thin air, as intimated by the discussion On earth dam compaction, the Department has required the maximum compaction possible, and in this connection has increased the weight requirement of sheepsfoot rollers on most of this work, from the usual maximum of 250 lb per sq in. to over 400 lb per sq. in., and in practically all cases has constructed test sections to determine the thicknesses of layers and number of rollings which would give the maximum compaction It should be recognized that these modified compaction requirements can not be met in some soils by use of the conventional light highway rollers having a foot pressure of 150 to 250 lb per sq in It should be recognized, also, that for the higher wheel loads still greater compaction is going to be necessary, if natural soils are used to the greatest advantage possible It is a known fact that the "B_r" (bearing ratio) value or strength of most soils is greatly increased by compaction. For instance, an inorganic silt has been found to have a "B_r" value of 20 per cent when compacted by the standard Proctor Method and approximately 60 per cent when compacted by the modified method Other soils show similar increases, the amount depending upon the type of soil It is apparent, therefore, in the interest of economy alone, that the additional compaction is justified, since much thinner base courses could be used Some soils do not require heavier equipment In one instance, sheepsfoot compaction of a silt obtained a density of only 105 lb per cu ft. or 90 per cent of the modified density, whereas the same silt placed in 3-in layers and compacted with a rubber-tired roller gave a density of approximately 120 lb. per cu. ft or 100 per cent of modified density However, with other types of soil, such as clays, the additional compaction can be obtained using heavier sheepsfoot rollers The modified density can be obtained relatively easily in clean granular soils by using plenty of water and compacting with a heavy tractor

Mr Campen and Mr Smith are to be complimented on their excellent study into the use of the field bearing test for designing flexible pavement They have approached the problem in a logical and straight-forward manner They have, I am glad to see, emphasized the importance of compaction of the soils involved in the design and construction of airfield flexible pavements.

However, there are a number of comments that the authors would like to make relating to the "Campen-Smith Method of Designing Flexible Runway Pavements." Earlier, the authors would have been in general agreement with this procedure, but the more data that have been gathered from actual service behavior of airfield pavements and from special service behavior test sections, the more elusive becomes the allowable or critical deflection, which is the backbone of this procedure. During the initial investigations conducted by the Engineer Department (see article in July, 1942, issue of Civil Engineering and in Highway Research Board *Proceedings*, Vol. 21), the authors were convinced that the field bearing test was the proper solution to this problem The data available at that time showed that 0 2-in was the maximum allowable deflection; however, it was apparent even at that time that this deflection might be as low as 0 1-in

Subsequent service behavior tests, conducted on a number of airfields and specially constructed pavement test sections, have shown that this allowable deflection may be expected to vary from 0 05 in. to 0.15 in., depending upon the tire contact, type of soil, rigidity of pavement (base and surface), number of repetitions, etc It must also be recognized, as pointed out by Mr Porter in his paper, that deflections due to consolidation and elastic deformation do not usually have a great influence on flexible pavement design. The deflection resulting from plastice deformation (deformation due to shear) is the major deformation to be considered. The fact that all of these deflections are measured by the field bearing test, and at the present time it is impossible to separate them, is one of the greatest drawbacks to the use of this method.

The authors fully agree with the importance placed on compaction, however, it should be recognized that it is not a cure-all and is probably not permanent where the soil is affected by frost action.

It is agreed that the soil should be tested at a moisture content comparable to that which will occur eventually in the field. However, the assumption that "water can be kept out by the bituminous wearing surface" is completely in error. Even though no water gets through the pavement, the moisture content of the subgrade and base material will increase. Where the soil is affected by frost action, the moisture content of the soil is increased to a point above optimum in some cases after only one freeze This moisture increase may be even greater than that obtained by soaking or saturation of the sample by the procedure set up in Appendix B. In non-frost areas, the time required to obtain this increase depends principally on the amount of rainfall and drainage conditions The authors have records of numerous cases where this moisture increase occurred, but none where it has been conclusively shown that it has or will not occur It is essential that this moisture increase be taken into account, regardless of the design method used.

Mr. Goldbeck's comparison, between

flexible pavement thicknesses required by the Engineer Department curves and as determined by his formula, is most interesting. These results are not too surprising, since Mr. Goldbeck has always used much lower deflections in determining his bearing values than any of the engineers using similar methods. It is concluded from investigations conducted by the Department, that the allowable deflection will always be less than 0.2 in., varying approximately from 0.05 in. to 0.15 inch.

The authors were particularly interested in Mr. Goldbeck's relation between the California bearing ratio and the bearing value used in his formula (see curve 3 of Fig. 8). From actual field bearing test results and California bearing bearing ratio values on the same soil, the authors have set up a similar relationship (see curve 2, Fig. 8). In addition, the authors have arrived at a very rough relationship between California bearing ratio values and North Dakota cone bearing value (see curve 1, Fig. 8) based on Mr. Boyd's relationship between subgrade values and North Dakota cone bearing values.

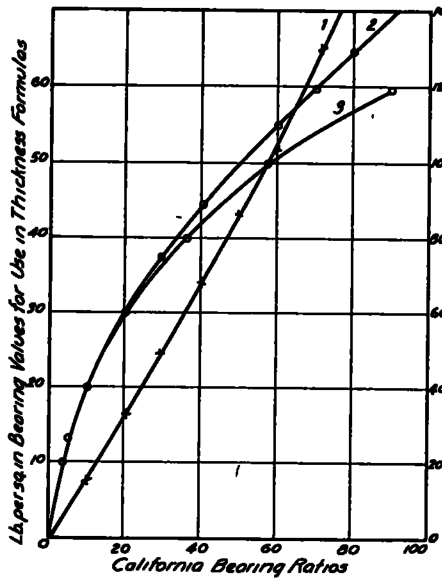

Figure 8. Relations Between California Bearing Ratios and Subgrade Bearing Values.

Curve 1. Between CBR and North Dakota Cone Bearing Value.

Curve 2. Between CBR and Bearing Value (Defl. 0.1 in.) by Middlebrooks.

Curve 3. Between CBR and Bearing Value (Defl.?) by Goldbeck.