are variations in the properties of concrete, water collected over a small area, uneven drying, and shadows In this case the restraint due to the weight of the pavement and its resistance to bending may then result in a maximum value of the coefficients of restraint, c_{rx} and c_{ry}, approximately 1.

Among sources of strain conducive to transverse cracking at an edge of a runway is a distribution of temperature or moisture changes uniform through the thickness but varying transversely to the longitudinal axis of the runway.

REPORT OF COMMITTEE ON FLEXIBLE PAVEMENT DESIGN

METHODS OF DESIGNING THICKNESS OF FLIGHT STRIPS AND AIRPORT RUNWAYS FOR WHEEL LOADS EXCEEDING 10,000 LB.

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SYNOPSIS

Present construction practices disclose that there is a wide divergence of opinion among engineers concerning the problem of design of airport runways.

This paper describes the methods of design that are at present in use and outlines a method based on large-scale loading tests of trial pavement sections

Three sections of pavement are constructed on a prepared section of the subgrade. The thickness of one of the sections is that estimated to be necessary for the wheel loads in question by any desired method, such as used by the Army, the Navy or by the use of soil bearing test data. The thickness of the second section is 50 per cent greater and of the third 30 per cent less than that estimated. These are tested using a repetitional method of loading The thickness necessary to support the design load for a specified deflection is obtained by plotting the thicknesses of the trial sections against the recorded deflections.

The report stresses the fact that the success of the method is largely dependent upon the correct evaluation of the load bearing test data. It is pointed out that in many cases, due to inadequate construction compaction of the subgrade and pavement courses, a large portion of the initial load settlement may be due to mere consolidation of the component parts of the structure The method makes it possible to consider the total settlement or only that portion of the settlement which is of primary importance as far as the ultimate load carrying capacity of the structure is concerned.

For runways and flight strips designed for wheel loads of not over 10,000 lb. the thickness values published in Wartime Road Problem No. 8 "Thickness of Flexible Pavements for Highway Loads" are recommended. However, wheel loads far greater than those accommodated by highways must often be considered. Records of experience with flexible pavements under such wheel loads are limited. Although many airports have been built recently it will be some time before the lessons they have to teach will become apparent. In the meantime it is necessary to build as best we may in the light of highway experience, research and theoretical considerations.

Three methods are described in this report.

1. The Office of the Chief of Engineers of

the War Department determines thickness by using the California bearing ratio test in conjunction with curves for various wheel loads extended from those developed for highway loading.

2. The Bureau of Yards and Docks, U S. Navy, bases design upon the results of field loading tests on specially constructed trial pavement sections.

3 A method is proposed by the Committee which also utilizes field loading tests on trial pavement sections. It differs from the Navy method in procedure although not fundamentally.

There are several other solutions which have been proposed on the basis of research They include.

A method of design advanced by W. S Housel [1]

A method of design used by the Omaha Testing Laboratories [2]

A method based on the theory of elasticity.[3]

A method based on the cone soil bearing test developed in North Dakota [4]

A method devised by Prof. M. G. Spangler.[5]

A method based on determination of bearing value by means of tests on bearing blocks.[6]

APPLICATION OF CALIFORNIA BEARING RATIO TEST TO AIRPLANE RUNWAY DESIGN[7]

The California bearing ratio method as used by the U. S. Engineer Department is an empirical method based upon an extension of data secured by studies of the service behavior of highway pavements. The ability of the subgrade to support load is expressed by a soil bearing value, termed the bearing ratio Values of the bearing ratio were correlated with those thicknesses of pavement which had given satisfactory service in California under light and medium-heavy traffic. Thicknesses corresponding to different values of the bearing ratio were then extrapolated for wheel loads up to 75,000 lb. The method of extrapolation was based in part upon the elastic theory and in part upon such information as was available concerning load distribution or the angle of spread of the load through flexible pavement structures

In design the bearing ratio is determined and the thickness for the design wheel load corresponding to the bearing ratio is obtained from the curves of thickness The thickness thus determined is used for design of runways. To compensate for increase in stress due to vibration of slow moving or warming up planes, the U. S Engineer Department recommends that the wheel loads for design of turnarounds, warm up areas, hardstandings, taxiways and aprons be increased by 25 per cent For stub end taxiways, portions of peripheral taxiways used infrequently, surfaced-all-over fields and designed shoulders, the thickness is made 80 per cent of that for runways.

The method takes into consideration the fact that stresses imposed by the surface load decrease in unit intensity as thickness increases. As a result, the structure may be composed of layers of material having successively less support in the lower portion of the composite structure.

TRIAL SECTION METHOD USED BY U. S. NAVY[8]

In this method the thickness is determined from loading tests made upon trial sections of the pavement The sections are constructed upon a representative area of the

[1] "Design of Flexible Surfaces," *Proceedings*, Twenty-third Annual Highway Conference, University of Michigan, 1937, "Design of Flexible Pavements," Vol 13, *Proceedings*, Association of Asphalt Paving Technologists

[2] W H Campen, discussion on "Soil Tests for Runway Pavements," *Proceedings*, Highway Research Board, Vol. 22, p 173 (1942)

[3] L A Palmer and E. S Barber, "Soil Displacement Under a Circular Loaded Area," *Proceedings*, Highway Research Board, Vol. 20, p. 279 (1940).

[4] Keith Boyd, "An Analysis of Wheel Load Limits as Related to Design," *Proceedings*, Highway Research Board, Vol 22, p 185 (1942)

[5] M G Spangler, "The Structural Design of Flexible Pavements," *Proceedings*, Highway Research Board, Vol 22, p 199 (1942)

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

[7] Chapter XX, Engineering Manual, Office of Chief of Engineers, War Department Also, O J. Porter, Foundations for Flexible Pavements, *Proceedings*, Highway Research Board, Vol 22, p 100 (1942) (Also, T A Middlebrooks and G E. Bertram, "Soil Tests for Design of Runway Pavements", *Proceedings*, Highway Research Board, Vol 22, p. 144 (1942).

[8] U. S Navy Department, Bureau of Yards and Docks, "Procedure for Determination of Thickness of Flexible Type Pavements."

subgrade prepared in accordance with specifications governing the project. An initial section is built, the thickness of which, exclusive of surface course, is equal to the radius of the equivalent circular tire imprint area for the design load in question. This section is then incrementally loaded through a circular bearing block until the design load is reached. If the recorded deflection exceeds 0.2 in., the assumed design value, the trial section is too thin and if it is less than 0.2 in. it is too thick.

From the thickness, load and deflection values of this trial section, the necessary thick-

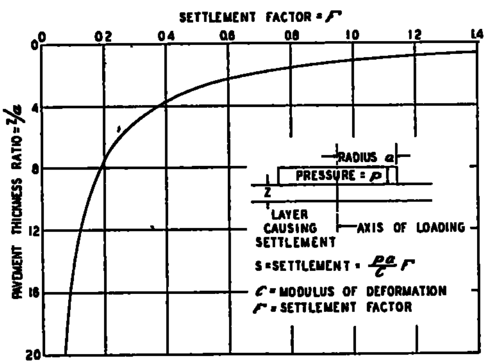

Figure 1. Settlement Under Center of Uniform Circular Load

ness to give 0.2 inch deflection is computed from the formula:

$$S = \frac{pa}{C} F \tag{1}$$

Wherein:

S = pavement deflection, in.
p = contact pressure, lb. per sq. in.
a = radius of contact area, in.
C = modulus of vertical deformation.
F = settlement factor (from Fig. 1).
Z (Fig. 1) = thickness of section, in.

Values of S, p, a and F from the first trial section are substituted in formula (1) and C, the modulus of vertical deformation, is determined. The settlement factor F is taken from Figure 1, for $\frac{Z_1}{a}$ in which Z_1 is the thickness of the first trial section and a is the radius of contact area

Assuming that C is constant, the formula is again solved, this time for the settlement factor (F), corresponding to the value of C as determined and S = 0.2 in. For this value of F the thickness (Z_2), presumably corresponding to 0.2-in. deflection, is determined from Figure 1.

A second trial section is then built and tested of thickness Z_2. This will most likely be too thick since C tends to increase with pavement thickness and does not remain constant as assumed. If the measured deflection of the second trial section is appreciably less than 0.2 in. another computation should be made to determine a new value of C. For a closer approximation, the two values of C are averaged and this average value substituted in formula (1) with S = 0.2 inch to determine a new value of F and hence, from Figure 1, the required thickness.

PROPOSED TRIAL SECTION METHOD

The Committee proposes that design of overall thickness of flexible type pavements be made on the basis of load tests of trial sections as follows:

1. Estimate the thickness required on the subgrade at the site by any desired method, such as used by the Army, the Navy, or by the use of soil bearing test data.

2. Construct three trial sections; the first of the estimated thickness, the second of a thickness 50 per cent greater and the third 30 per cent less than the estimated value.

3. Make load bearing tests and measure the deflections under load of the three trial sections.

4. Determine the thickness necessary to support the design load as follows: First, plot the supporting value of the trial sections against the deflections; second, analyze these results as described under "Evaluation of Test Results" on page 96; third, plot the selected supporting values for the three thicknesses, to produce a curve showing the relation of thickness to support. In case it is necessary to extend the curve appreciably beyond the observed values in order to obtain the design thickness, it is recommended that a fourth trial section be built and tested to verify the results.

The success of the trial section method of design depends upon correct evaluation of the results of the load bearing tests. Methods for estimating trial thickness, for constructing test sections and for making load tests on trial pavement sections will be described

When loads are vibrating as when an airplane is "warming up", a pavement is subjected to unusually severe conditions. Extra thicknesses and the selection of subbases of high stability, noncapillary material is recommended for this type of loading.

INITIAL ESTIMATE OF THICKNESS

Since the final selection of thickness is to be based upon actual full-sized load bearing tests, the initial estimate of required thickness is not a vital factor. It should, however, approximate the actual thickness as closely as possible.

The initial thickness may be assumed, as is done by the Navy Department method by using a value equal to the radius of the equivalent circular tire contact area, or it may be estimated by the California bearing test and curves or by one of the methods listed in footnotes 1 to 6 inclusive or by means of loading tests on the subgrade soil.

Estimate of Thickness by Load Tests

The estimated thickness is computed by the following procedure, after making load tests on trial pavement sections to determine the subgrade bearing value for use in formulas (2) and (3).

When the wheel load is carried on a single tire,

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

T = required overall thickness of nonrigid pavement, inches
P = maximum wheel load on single pneumatic tire, lb.
M = subgrade bearing value determined as described in a later paragraph.
L_1 = ½ major axis of ellipse of tire contact area, inches.
L_2 = ½ minor axis of ellipse of tire contact area, inches.

Dual Tires. When dual tires are used the effective tire contact area is assumed equal to the area of one tire plus that of the rectangle whose area equals the center to center tire spacing multiplied by the length of major axis of the tire contact area. Both formulas (2) and (3) for pavement thickness result from equating the load to the uniform pressure on the subgrade over an area defined by 45-deg. lines extended to the subgrade from this effective tire contact area. This uniform pressure is assumed to be one-half the bearing value of the subgrade.

$$T = \sqrt{\left(\frac{B}{2\pi}\right)^2 + C} - \frac{B}{2\pi} \qquad (3)$$

T = required thickness of nonrigid pavement, in.
$B = 2S + \pi(L_1 + L_2)$
$C = \frac{2P}{M\pi} - \frac{2SL_1}{\pi} - L_1 L_2$
P = maximum wheel load supported on dual pneumatic tires, lb
M = subgrade bearing value determined as described in a later paragraph.
L_1 = ½ major axis of ellipse of tire contact area, in.
L_2 = ½ minor axis of ellipse of tire contact area, in.
S = center to center spacing of tires.

It will be noted that formulas (2) and (3) take into account the influences of tire dimensions, tire pressure and spacing of dual tires.

The tire contact area (sq. in.) = tire load (lb.)/tire inflation pressure (lb per sq. in) × tire load supporting factor. It is sufficiently accurate to consider the tire load supporting factor as 1.10.

The tire contact area is an ellipse which has a major axis equal approximately to twice the minor axis Therefore, tire contact area $= 2\pi L_2^2$, from which L_2 and L_1 may be calculated

In the case of airplane tires L_2 may be assumed, with sufficient accuracy, equal to $0.6L_1$ If dual tires are used on large planes of future design, the spacing of the tires may be such that a single tire load may govern the required pavement thickness and this possibility should be investigated by using both formulas (2) and (3).

Relation of Surface Course to Thickness Design

For wheel loads greater than 10,000 lb., only bituminous plant mix and bituminous penetration macadam are recommended

Cold Laid Plant Mix Types. A 2-in. finished layer of cold laid plant mix will generally prove adequate Little or no advantage is gained by making such surfaces thicker than this, as the additional load supporting value which they impart to the total structure is probably no more than that imparted by an equal thickness of well compacted dense graded mineral aggregate such as gravel, broken stone, or slag In general, their use should be limited to wheel loads of not over 15,000 lb.

Penetration Macadam. Hot penetration macadam primarily employs a large one-sized crushed aggregate which controls its minimum thickness, usually 2½ in It is placed ordinarily on gravel or stone bases and in estimating the thickness may be considered to have approximately the same structural strength per inch thickness. Unless constructed of very hard rock, such as trap, its use should be limited to maximum wheel loads of 25,000 lb.

Dense Graded Hot Mix Pavements. The minimum thickness of this type pavement surface for highway traffic is usually 2 in.

(a) On pavements where the torsional stresses imposed by heavy wheel loads making sharp turns are very great, thicknesses of dense graded hot mix pavements greater than 2 in. are advisable.

(b) Until more information is developed, it seems advisable to adopt a minimum thickness of 2½ in. of dense graded hot mix pavement for wheel loads between 15,000 and 25,000 lb.; a 4-in. minimum thickness for wheel loads of from 25,000 to 60,000 lb.; and a 5-in. minimum thickness for heavier wheel loads. For the purpose of thickness design estimate, each inch of dense graded hot mix pavement may be considered as the equivalent of not less than 2 in of granular base material.

METHOD OF CONSTRUCTING TEST SECTIONS

Three test sections should be constructed, each not less than 20 ft. square. One section should be of the estimated total thickness and design A second section should have a thickness 30 per cent less than the estimated total, and a third section 50 per cent greater than the estimated total. The entire structure should be embankment and the reduction or increase in total thickness should be accomplished by variation in the bottom portion of the pavement structure, which usually will be the subbase.

These sections ordinarily should be built as a continuous structure and to the same elevation above existing subgrade. The variation in thickness of the bottom portion of the sections should be adjusted by placing subgrade material above the existing subgrade level. Figure 2 shows the embankment and the necessary construction steps to produce an estimated total thickness of 30 in, with adjacent test sections 30 per cent less and 50 per cent greater. In all sections the bituminous wearing course is 4 in. and the base course 8 in. thick, for the particular example illustrated in Figure 2.

For ease of access to the sections, a ramp should be constructed at each end having a maximum grade of 6 per cent. The base course should extend 5 ft. beyond each side of the wearing course and at least 10 ft. beyond each end Side slopes of the embankment should be approximately 2 to 1, with suitable drainage provided at the bottom of the slope.

Prior to constructing the embankment, the upper 6 in of the subgrade, if it consists of fine grained silts and clays, should be scarified and recompacted at a moisture content about 2 per cent above the optimum as determined by the American Society for Testing Materials Tentative Method of Test for Moisture-Density Relations of Soils, D 698 - 42 T.[9]

During construction of the sections, subgrade material from adjacent areas should be hauled in and compacted, (with a like moisture content) for the purpose of raising the subgrade level as may be required for thickness adjustment of the sections.

Subgrade, subbase and base materials should be placed and compacted in layers not exceeding 6 in. thick. In the example (Fig. 2) thicknesses of 4½ and 5 in have been selected as a matter of convenience during construction. Extreme care should be exercised to obtain, uniform compaction throughout and suitable tests should be made to insure this result Construction methods should conform to recognized standard practice in the locality where the work is being done. As a rule final compaction should be obtained by rolling. Tarpaulin or roofing paper of

[9] See also "maximum density," Standard Laboratory Method of Test for the Compaction and Density of Soil, American Association of State Highway Officials, T 99 – 38.

sufficient area should be provided to protect unfinished areas from rainfall.

Where subbase or base courses are placed which would ordinarily require application of water for bonding, this should be accomplished by pre-mixing water with the aggregate in the required amount, in order not to

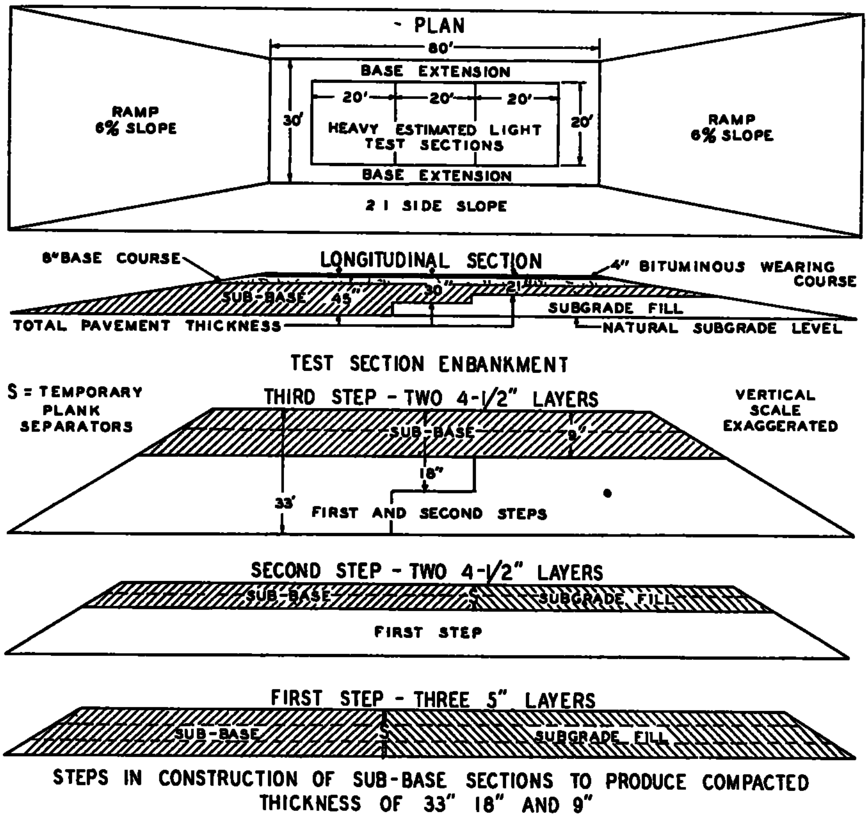

Figure 2. Construction Details of Typical Pavement Test Sections

saturate the subgrade under the embankment through excess surface application

METHOD OF MAKING LOAD TESTS ON TRIAL PAVEMENT SECTIONS

Equipment

(a) Hydraulic jack assembly with ball joint attachment capable of applying and releasing the load in increments.

(b) Set of circular steel bearing plates, 1 in thick, 12, 16, 20, 24 and 30 in in diameter, machined so that they can be arranged in pyramid fashion to insure rigidity.

(c) Two dial gages capable of recording deflections of 0.001 in. up to a maximum of 1 in.

(d) Trailer or truck assembly to provide reaction load. Point of application of load to be at least 8 ft. from the nearest wheel.

(e) Deflection beam, 3 by 3 by $\frac{1}{4}$ in. steel angle, 16 ft. long, to rest upon supports located at least 8 ft. from the nearest wheel of truck or trailer.

Testing Procedure

Testing Objectives. In this discussion, deflection is defined as the lowering of the loaded area while still subjected to load. Settlement is the permanent lowering of the area after the load is removed.

Unless it is abnormally weak with respect to the load applied, a flexible pavement seldom fails upon the first application of load. The first load frequently compacts one or more courses of the pavement more thoroughly than the original construction compaction, thus developing greater resistance to subsequent repetitions of the load than is indicated by the initial settlement. Additional settlement produced by the second load application may be, and frequently is, very much less than the original settlement. A third load application will usually develop further settlement but, unless complete failure is imminent, the increment of settlement under the third repetition of load will be slightly less than that for the second repetition. Subsequent repetitions then show decreasing increments of settlement in an orderly manner which makes it possible to estimate total settlement for any number of repetitions. About four load repetitions are usually required to develop this information, which is graphically illustrated in Figure 3. In this illustration, cumulative settlements are plotted against four load applications which are spaced on a logarithmic scale. It will be noted that the cumulative settlements for the second, third and fourth applications are connected by a straight-line that may be projected to any desired number of load repetitions for the purpose of estimating total settlement for that number of loadings. Cumulative deflections produced under each load repetition may be plotted in the same manner.

The effect of repetitional loading is believed to be more significant from the standpoint of design than the mere determination of settlement under a first load application. Unless the structure fails, the initial settlement should be evaluated as a measure of the compaction produced by the first test load in addition to that obtained in the original construction.

From the single cycle load deflection curve on soil materials, a critical deflection of about 0.2 inch has been frequently selected as the basis of evaluating the load support of a flexible pavement placed upon the soil. Such assumption should, however, be corrected for additional compaction produced by the first load application on the soil itself, as well as upon the superimposed flexible structure. This is especially true in the case of design for wheel loads exceeding 15,000 lb, where the initial compaction under loading is likely to exceed that produced by construction equipment commonly used at present. A bituminous hot-mix surface course, such as recommended for the heavy wheel loads, may moreover deflect under one load to 0.5 inch or more before incipient failure occurs.

The following detailed testing procedure is recommended for the purpose of taking into account the various factors which have been discussed.

Recommended Procedure for Applications of Loads to Test Sections. (a) The bearing plate shall be set in a thin bed of plaster to insure bearing with the surface course. The smallest load that can be accurately recorded (less than 1 lb. per sq. in.) shall be applied before setting the dials at 0 deflection.

(b) All load increment applications shall be maintained until not more than 0 001 in. per min. increased deflection occurs. At this point, total deflection is recorded, after which the load shall be reduced to that originally selected for the zero dial setting. The zero dial setting load shall be maintained until not more than 0 001 in. per min. increased recovery occurs. The dial reading at this point shall be recorded as settlement.

(c) Four applications and releases of each load increment shall be made, as described in paragraph (b), before proceeding to the next increment of loading.

(d) While the selection of load increments may be varied according to the judgment of the engineer, the following procedure is recommended to develop the maximum amount of information with the minimum of effort: The first increment is selected by slowly applying load until an initial deflection of 0.1 in. is obtained or the design load reached, whichever occurs first. After this load has been applied and released four times, as described in paragraphs (b) and (c), the second increment is selected by increasing the load until initial deflection is either 0.1 in. greater than the last recorded deflection for the preceding increment, or the design load is reached, whichever occurs first. Successive load increments are selected in the same manner until the final deflection is approximately 0 5 in.

EVALUATION OF TEST RESULTS

Cumulative deflections and cumulative settlements for each individual load increment are first plotted on semilog paper as illustrated in Figure 3. The straight lines, connecting values for the second, third and fourth repetitions, may be extended to any desired number of repetitions, or from the slopes of the lines, deflections and settlements may be calculated for the desired number of repetitions.

A composite diagram may then be prepared from the test data, as illustrated in Figure 4.

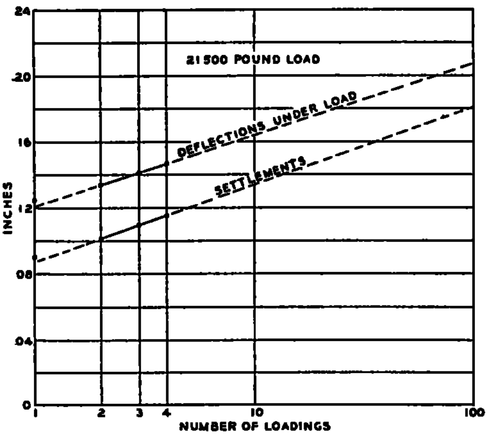

Figure 3. Cumulative Deflections and Settlements Produced by Repetitions of the Same Load

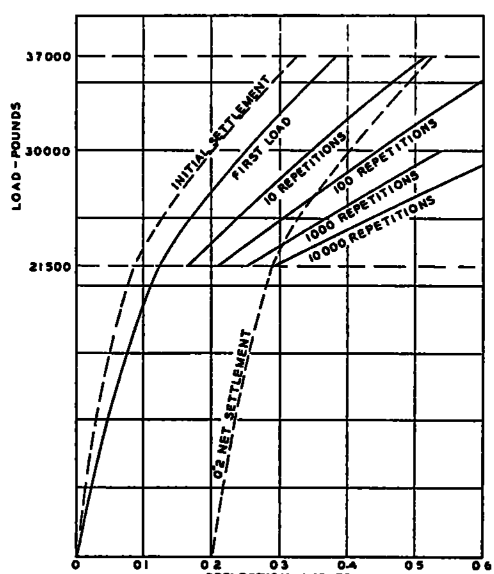

Figure 4. Effect of Repetitions of Load Upon Deflection

Here the design wheel load is assumed to be 37,000 lb. The initial settlement curve is plotted from settlements recorded for the first application of each load increment, and represents initial compaction. The first load application curve is plotted from deflections recorded for the first application of each load increment. Deflection values for 10, 100, 1,000 and 10,000 load repetitions, taken from diagrams similar to Figure 3, are connected by straight lines instead of estimated curves. The 0.2-inch net settlement curve is parallel to the initial settlement curve and represents 0.2-inch settlement, after initial compaction has been obtained. It intersects the repetitional deflection curves at points which may be considered as representing safe loading, except where it exceeds a total of 0.5-inch deflection.

Bearing in mind that airport runways are rarely subjected to static loads repeated over the same identical area, this diagram may be interpreted to indicate a safe design for 37,000 lb. wheel loads on a runway but not on a taxiway. If 10,000 load repetitions are estimated for a taxiway, the same diagram indicates a safe wheel load of about 26,500 lb. over the same tire contact area, with an ultra conservative estimate of 21,500 lb.

When comparing test results from the three trial test sections, it is believed that the best evaluation of relative strength can be obtained by plotting all deflections for a given load from the initial settlement curve taken as zero, as illustrated by the 0.2-in net settlement curve in Figure 4. In this way, the effect of initial compaction is eliminated and any differences due to unequal construction compaction minimized.

LOAD TESTS FOR SUBGRADE BEARING VALUE

The formulas for determining the thickness of trial sections of pavements for supporting heavy loads, require a knowledge of the subgrade bearing value. Obviously the amount of rolling of the subgrade, the weight and rigidity of the overlying surfacing and the subgrade moisture conditions influence the bearing value. Hence, the subgrade bearing value must be determined on the subgrade as it will exist under the pavement and not as it exists at the airport site when in an uncompacted and uncovered condition.

Preparation of Subgrade. The subgrade at the spot or spots selected for test should be prepared as described under "Method of Constructing Test Sections." The upper 6 in. should be scarified and recompacted using a moisture content about two per cent above the standard optimum, if the subgrade material consists of fine grained silts or clays. This procedure will bring the subgrade to approximately the moisture condition desired for making the load tests

Placing Bearing Block. After preparation of the subgrade the spot selected for test should be carefully leveled and the bearing block bedded in place on a thin layer of plaster of paris. A double layer of 1-in. planks should be laid on the subgrade to form a platform about 8 ft. square, centered over the bearing block and having an opening at the center about ½ in. larger in diameter than the bearing block. This platform should be loaded with sand bags so that the surcharge will serve to prevent lateral displacement of the surface of the soil adjacent to the bearing block during test This weighted platform is intended to simulate the vertical restraining influence of the pavement surface

Bearing Blocks. The bearing block should have approximately the same area as the contact area of the tire required for the design wheel load If equipment is not available for applying sufficient load on the large bearing block which may be required, it is suggested that tests be made using three smaller blocks, 16, 20 and 24 in. in diameter

Test Procedure The test should be conducted with repeated loads using the method already described for loading the finished trial pavement sections; and the load necessary to produce a net deflection of 0 2 in., after the required number of repetitions, is taken as the bearing value. If necessary to use the three small bearing blocks instead of one approaching in size the tire contact area, a curve is plotted between the unit load which produces 0.2 in net deflection and the perimeter-area ratio (= 2/radius). Finally, the unit load for the large block may be extrapolated from this curve which will be approximately a straight line with unit loads as ordinates and values for perimeter-area ratio (2/radius of block) as abscissas.

Use of Subgrade Bearing Value Test sections for a runway which in service has relatively few load repetitions in a given spot can be designed with a subgrade bearing value determined at a net deflection of 0 2 in after ten repetitions of load, whereas a taxiway may require the use of a bearing value resulting from a determination at 1,000 or even 10,000 repetitions. A gross deflection of 0.5 in. should not be exceeded for bituminous surfaces and this requirement may possibly govern the bearing value rather than a net deflection of 0.2 in. under repeated loads.

GENERAL CONSIDERATIONS IN THE CONSTRUCTION OF FLIGHT STRIPS AND AIRPLANE RUNWAYS

It is recommended that generally subgrades and embankments be prepared in accordance with the A.A.S H.O. standard specifications for materials for embankments and subgrades (Designation M 57 – 42) which utilizes data furnished by the Standard A.A.S.H.O. and A.S T.M compaction tests.

As a precaution against detrimental swell of the compacted soil, the upper layer (at least 1 ft.) should be comapcted at a moisture content about two per cent above the optimum.[10] For embankments up to about 50 ft. high, the remainder should be placed at not less than 95 per cent standard density. Embankments exceeding 50 ft high should be studied as special problems in soil mechanics and constructed by procedures selected to suit individual cases.

The subgrade should be inspected to insure that the specified compaction is obtained A soft subgrade may affect adversely both the subbase and the base course Lateral drainage ditches should be kept open during construction so that water is not trapped in the subgrade. If difficulty is encountered in drying out the subgrade, some insulation course should be used either to take up the excess moisture or blanket the soft undersoil Stone screenings, sand, and in emergency even hay and straw may be used for this purpose and will provide firm bearing even during rain periods

Base courses should be compacted to the designed density. Stabilization procedures requiring excess water for manipulation purposes should not be employed in areas subject to heavy or continuous rainfall In case of unexpected wet weather, expediency may dictate change of design to the use of granular material containing the minimum

[10] A S T M. Tentative Method of Test for Moisture-Density Relations of Soils, D698 – 42 T A A S H O , Standard Laboratory Method of Test for the Compaction and Density of Soil, T 99 – 38.

amount passing the No. 200 sieve, as designated in the standard specifications[11] for base course materials.

Thorough mixing of stabilized base course materials is an essential requirement. Clay added in correct amounts but not properly dispersed through the granular materials may be as detrimental as too much clay. Use of a mixing plant is recommended to facilitate the production of good mixtures with the specified optimum moisture content

[11] A.A.S.H O. Standard Specifications for Materials for Stabilized Base Course, M 56 - 42. A S T M. Tentative Specifications for Materials for Stabilized Base Course, D 556 - 40 T. Highway Research Board, Wartime Problems No. 5, Granular Stabilized Roads.

Rolling should be continued until adequate compaction of base courses is attained. This is necessary in order that the proper density can be obtained in the bituminous wearing course. Frequent tests should be made to see that the correct density in all courses is being secured. Placement of the material in several layers will aid in securing this density When bituminous wearing courses are placed in layers by mechanical finishers joints between adjacent strips of one layer should overlap joints in the layer beneath. In order to produce tight longitudinal joints between adjacent strips one man should be detailed to place extra needed mixture in any open or low area prior to initial rolling so that a uniform density is produced throughout.

DISCUSSION ON THICKNESS OF FLIGHT STRIPS AND AIRPORT RUNWAYS

MR. M D CATTON, *Portland Cement Association:* As mentioned by Mr. Benkelman in his formal presentation of the report of the Committee on Flexible Pavement Design, "Methods of Designing Thickness of Flight Strips and Airport Runways for Wheel Loads Exceeding 10,000 Lb.," the Committee was not in common agreement on some basic points influencing design The Committee worked diligently for several months on this report, during which time all available data were carefully studied and analyzed Even though common agreement could not be obtained on all points for a wartime bulletin, it was agreed that " it is necessary to build as best we may in the light of highway experience, research and theoretical considerations" and to present a report for consideration

The report describes three design methods

1 That used by the Office of Chief of Engineers, U S Army

2. That used by the Bureau of Yards & Docks, U S Navy, and

3 One proposed by the Committee

A large number of airports have been built using methods 1 and 2, which are supplying experience records However, the third method proposed by the Committee, does not have an extended experience background, which leaves several points to be verified by tests, research and experience

As stated in the report "The success of the trial section method of design (proposed by the Committee) depends upon correct evaluation of the results of the load bearing test." My comments refer particularly to the interpretation and evaluation of the examples of the load bearing tests given in the report.

The methods or procedures for making the test have many desirable features However, some of the recommended interpretations require more background, in my judgment, than is available at present For example, it is assumed (1) that the settlement produced by initial test loadings is confined largely to additional compaction in the base and subbase; and (2) that the settlement curve developed by four load repetitions may be used to develop settlement for as many as 10,000 repetitions of load or more I do not believe that either of these assumptions is necessarily true

Some loading data that I have seen show that initial settlement or deformation in the base is actually a measurement of incipient base failure In these instances, at least, settlement from four load repetitions could not be projected to indicate settlement for a large number of loadings Other test data show the same total static load deformation before and after 2000+ trips of a 33,000-lb. wheel load, but additional static load deformation after 5,000+ loadings. These loading tests indicate that it is most difficult to predict a constant, orderly manner in which settlement and deformation data can be projected from a few loadings to any particular number of subsequent loadings

As indicated above, a shortcoming in the procedure is that it does not permit differentiation between deformation in the subgrade, in the base and in the surfacing. In any case, any deformations due to consolidation of the subbase and base materials will vary with construction control on each job and must be segregated from deformations in other elements of the pavement structure to permit proper design.

I think another instance of misinterpretation of data exists where the statement is made that ... this diagram (Fig 4) may be interpreted to indicate a safe design for 37,000-lb. wheel loads on a runway ... The fact that a total deflection of more than 0 5 in. is indicated after only 10 repetitions of load would lead me to speculate that rupture and failure would result from a few more loadings and that the diagram indicates the design is not safe for a 37,000-lb wheel load.

In determining permissible deformations on flexible pavements in place, it is desirable to know the permissible deformations of each element in the structure with the lowest permissible deformation governing design The subgrade will have a certain permissible maximum deformation before failure, the base course material itself will probably have an entirely different permissible deformation and the bituminous surface a still different permissible deformation. It is my judgment that in many cases permissible maximum deformations or deflections will be governed by the subgrade itself, and that in these cases the deformations or deflections will be very much less than the permissible deflections for either the base material or the surfacing material.

The suggested test procedure and analysis of data contains additional comments on settlement, compaction, deflections, etc., that might be discussed in some detail. However, most of them tie back to a determination of critical deflections. Test data obtained on field installations and published by Col. James H. Stratton, Middlebrooks, Porter and others[1] point up rather strongly that critical deflections may be of the order of less than 0.1 in. rather than 0.2 in, or the maximum 0.5 in. contained in this report. Also, that plate loading tests may be entirely indeterminate and without basis for interpretation for design purposes.

While the testing procedure contained in the committee report may be used to determine deflection data, it is believed that until such time that considerable data have been obtained for study and field performance records established, it is quite essential to be most conservative in establishing permissible deflections in general terms.

[1] "Military Airfields, A Symposium. Construction and Design Problems" by James H Stratton, M. Am. Soc. C. E., *Proceedings*, Am. Soc C. E., January, 1944 "Accelerated Traffic Tests on Flexible Type Pavements" by T. A. Middlebrooks and R M. Haines, Highway Research Board *Proceedings*, Vol. 23, 1943. "Foundations for Flexible Pavements" by O J. Porter, and "Soil Tests for Design of Runway Pavements" by T. A. Middlebrooks and G. E. Bertram, Highway Research Board *Proceedings*, Vol. 22, 1942. "Field Investigation for Flexible Pavement Design" by T. A. Middlebrooks and G. E. Bertram, Highway Research Board *Proceedings*, Vol. 21, 1941.