RESULTS OF ACCELERATED TRAFFIC TESTS OF RUNWAY PAVEMENTS

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SYNOPSIS

Accelerated traffic tests have been conducted on five special test sections and on runways at eight existing airfields. Data are also given on service behavior at airfields under airplane wheel loads

The tests have furnished data on: required thicknesses of base and pavement; effects on thickness of various base materials; quality of base material required just beneath the surface course, and on the action of semi-rigid bases. Large earth-moving machines were used to apply loads from 15,000 to 50,000 lbs. In some cases, the pavement deflections under load were measured and the progressive deformations were recorded in all tests

General conclusions resulting from the test are: that the California Bearing Ratio test has proved to be practical for evaluating soils and is still considered the best method of design to protect against shear deformation, the thickness curves now used by the Engineer Department are close enough for practical purposes; high quality base material (CBR at least 80) is generally required beneath the pavement course; the use of low quality base material in the lower layers of the base in place of 80 percent CBR material does not influence the total thickness required over the subgrade, if the CBR value satisfies the design curves; high construction compaction of cohesionless subgrades is necessary, it is extremely important to compact or drain saturated subgrades of cohesionless fine sands or silts.

The accelerated traffic tests on existing runways confirmed in general the tentative design criteria used by the Department. A comprehensive survey of failures resulting from traffic at airfields shows that most of the failures have been produced by planes having gross loads in excess of the carrying-capacity of the pavements as rated by the present tentative requirements.

Previous papers presented to the Highway Research Board have given the background of the investigations conducted by the U. S. Corps of Engineers to develop methods of design for flexible airfield pavements. The 1941 paper dealt primarily with field-bearing tests[1] and the 1942 paper dealt with the tentative method of designing flexible and concrete pavements, as adopted by the Engineer Department.[2] As was pointed out in the 1942 paper, it was found that the only means of obtaining full information on the actual load-carrying capacity of pavements and tying the data into the adopted method of design was by conducting accelerated traffic tests jointly with field-bearing and other tests. At last year's meeting of the Highway Research Board, Mr. O. J. Porter[3] gave a brief summary of the Stockton accelerated traffic tests, which was one of the earlier tests employed to determine if the extrapolated design curves, for the California method of design, which had been tentatively adopted by the Department, were sufficiently close to justify their presentation to the field. This paper gives a brief summary of the accelerated traffic tests conducted by the Department on special test sections and actual airfields. In addition, data are included on the service behaviors of airfields under airplane wheel loads. There will be included also the results of field-bearing tests conducted in connection with accelerated traffic tests.

The need for such investigations to develop a method for the design of flexible airfield pavements is recognized by engineers fully acquainted with the problems. Airfield pave-

[1] T. A. Middlebrooks & G. E. Bertram, "Field Investigations for Flexible Pavement Design," *Proceedings*, Highway Research Board, Vol 21, p. 137 (1941)

[2] T. A Middlebrooks & G E Bertram, "Soil Tests for Design of Runway Pavements," *Proceedings*, Highway Research Board, Vol. 22, p. 144 (1942).

[3] O. J Porter, "Foundations for Flexible Pavements," *Proceedings*, Highway Research Board, Vol. 22, p. 100 (1942).

ments must be designed to withstand traffic of planes weighing as much as 120,000 lb. (at present), which means wheel loads of 60,000 lb. In addition to the static load, the design must be satisfactory to withstand vibration forces caused by the warming up of the motors Pavements designed similar to those for highways might be satisfactory for infrequent use or limited use by these heavy airplanes, however, the pavement designed and constructed for the Army Air Forces must carry all of the traffic that can be accommodated at an airfield, and it is not economical or safe to assume that the traffic will be very limited. The Army has a large number of fields which have over 300 operations a day and in some cases as high as 700 operations a day of planes weighing over 45,000 lb It is roughly estimated that 300 operations a day will give approximately 2,000 coverages (stress repetitions) on runways and may exceed 15,000 coverages on the main taxiways per year At many of these fields, lighter weight planes also operate in great numbers The number of operations at a field used only by planes weighing less than 30,000 lb may be in the thousands

TRAFFIC TESTS—GENERAL

Purpose Accelerated traffic tests have been conducted on five special test sections and eight existing fields for the purpose of obtaining data to develop design criteria The tests have furnished data on

(1) The required thickness of base and pavement over a subgrade

(2) The effect of type of base material on required thickness

(3) The required quality of base material immediately beneath the surface course

(4) The action of semi-rigid bases

Equipment—Wheel Loads The wheel loads used in the traffic tests have ranged from 15,000 to 50,000 lb The equipment consisted of rubber-tired earth moving equipment such as large scrapers—Euclids, Tournapulls, etc Figure 1 shows a 32-cu -yd LeTourneau Tournapull which was used in some of the tests to produce wheel loads of 37,000 and 50,000 lb

Tracking In the first accelerated test, traffic was confined to one track However, the later tests were conducted with the wheel loads spread over a width approximately three times the width of the tire It is now believed that tests should be conducted with even a wider spread, since it is apparent that the narrow traffic lane introduces various complications The amount of traffic was limited in all test sections to about 5,000 coverages. Although this does not represent the maximum coverages expected on an airfield, it was considered the practical upper limit which could be employed in connection with the accelerated traffic tests,—5,000 coverages result in 15,000 single wheel passes of the equipment in the test lane

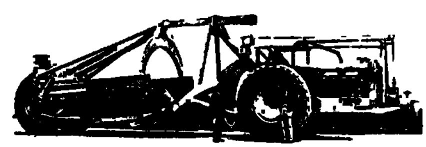

Figure 1. Accelerated Traffic Test Equipment 37,000 to 50,000 lbs. Wheel Load

Tests Since the main purpose of the traffic tests was to develop further the design curves, the California bearing ratio test was the principal one used However, in almost all cases, a thorough investigation was made which included general classification tests, plate bearing tests, triaxial, and in some cases consolidation tests In general, the plate bearing tests were conducted for only one or two cycles. Although, in a few special cases the cycles were carried up to 60

Deflection and Earth Pressure Measurement. In two of the major test sections, Stockton and Barksdale, the dynamic and static deflections were measured with California highway gages. Deflections were obtained on the surface and on the subgrade, and in addition in all cases level readings were taken across the section periodically, in order to obtain the progressive permanent deformation At Barksdale, earth pressure readings were taken to determine the pressure distribution on the subgrade.

STOCKTON TEST SECTION

Since the Stockton test results have been published, and a summary presented in a paper by O J. Porter at the last annual meeting,[3] it is proposed to give only the general conclusions from these tests This accelerated traffic test, which was one of the first conducted, confirmed the requirement of exceedingly thick pavements over clay soils and for all practical purposes checked the extrapolated design curves The CBR value of the base course material was approximately 80 per cent and the subgrade varied from 3 to 6, averaging about 5. The thickness of 32–38 in. proved satisfactory for the 40,000-lb. wheel load and the thickness of 25–30 inches was satisfactory for the 25,000-lb. wheel load.

BARKSDALE TEST SECTION

The subgrade at the Barksdale test section was a black plastic clay with a liquid limit of 45, a plasticity index of 28, and a CBR, as compacted, of about 6 per cent. Figure 2 shows profiles of the sections which were tested with a 50,000-lb. wheel load Several types of base course materials were used and surfaced with 3 in. of asphaltic concrete It will be noted from the figure that there are four items—

Item 1 starts with the limestone-sand mixture directly under the pavement and grades down in quality to the subgrade

Item 2 is the same as Item 1, except that the high-bearing limestone-sand mixture was omitted.

Item 5 has the entire base of high-bearing limestone-sand mixture.

Item 7 is soil-cement.

Similar sections, except relatively thinner, were constructed and tested with a 20,000-lb. wheel load, except for Item 7 (soil-cement) which was the same for both tracks. Figure 3 shows the general view of the test track.

Wheel loads of 50,000 and 20,000 lb. were operated over the respective pavements, spreading the tracks over a width equal to three times the tire width. Traffic was continued until failure of the pavement or until a maximum of 5,000 coverages was obtained over the test lane. Figure 4 shows the condition of the pavement of Items 1 and 2 after traffic. The base material completely failed in Items 1 and 2 of the 20,000-lb. wheel track, and in Item 2 of the 50,000-lb wheel track. In the thinner portions of these items, some subgrade failure occurred. The base did not fail appreciably in the thick portion of Item 1 on the 50,000-lb track, due probably to the greater CBR of the sandy silt A study of cross sections and deflection measurements on Item 1 shows that a total thickness of about 32 in. was required over the subgrade to prevent distressing of the subgrade

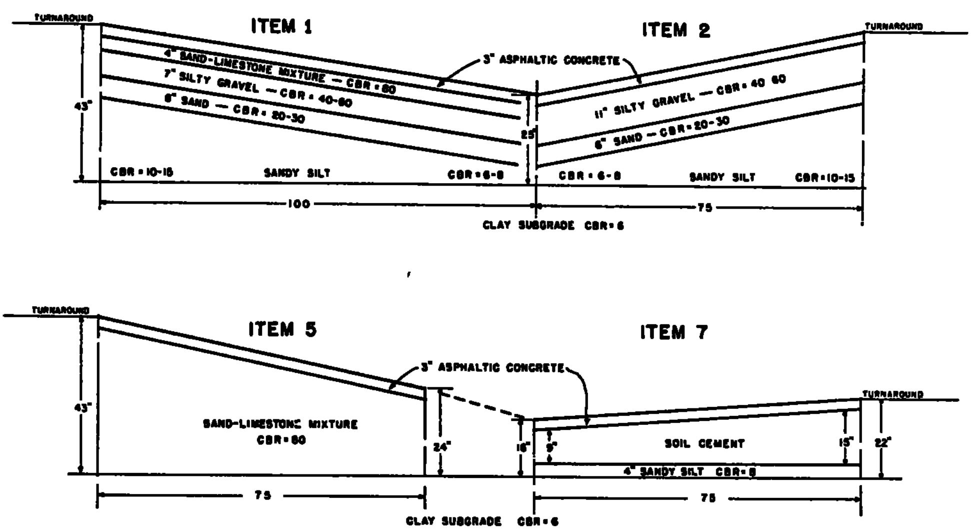

Figure 2. Barksdale Test Section

Figure 5 shows the condition of the pavements of Items 5 and 7 after traffic. The test showed that total thicknesses of 30 in for the 50,000-lb wheel load and 20 in. for the 20,000-lb wheel load were required to protect satisfactorily the subgrade with the base (limestone-sand mixture) constructed as in Item 5. Since these required thicknesses are practically equal to the required thickness shown by tests on Item 1 (composite base

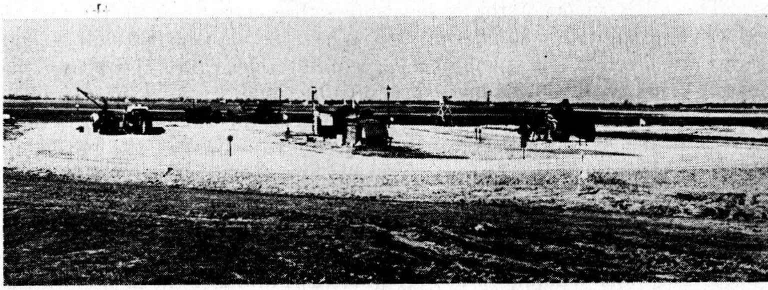

Figure 3. Barksdale Test Track

materials), the test indicates that the type of base material does not appreciably influence the total thickness required over the subgrade provided the materials are otherwise satisfactory and do not have appreciable flexural strength.

Item 7, the soil-cement section, was failed completely by the 50,000-lb. wheel load in a few hundred coverages. The 20,000-lb. track failed in the thin sections, with the thick end being satisfactory for the 5,000 coverages. It was concluded that total thickness of 20 in., including asphaltic concrete, soil-cement, and sandy-silt base was satisfactory to protect the subgrade. With due consideration being given to the low CBR value of sandy silt, it appears that this soil-cement base and the limestone base were comparable in load-carrying capacity. However, attention is directed to the fact that the soil-cement had a fairly low compressive strength.

Two other conclusions made as a result of the test are: (a) High quality bearing material (CBR greater than 80 per cent) is required immediately under the asphaltic concrete when the foundation soils are plastic, and (b) base materials must be highly compacted. The additional consolidation, which occurred as a result of the 50,000-lb. wheel load, in the base materials, was one of the most important side features of the test. Even in the high bearing limestone-sand mixture, considerable compaction (2 to 3 in.) occurred in the traffic lane, although this material had been compacted to densities equal to 95 to 100 per cent of the Modified A.A.S.H.O. compaction test. It was concluded that this material at the densities obtained was unsatisfactory where evenness of the pavement was an essential feature. Compaction also occurred in all other base

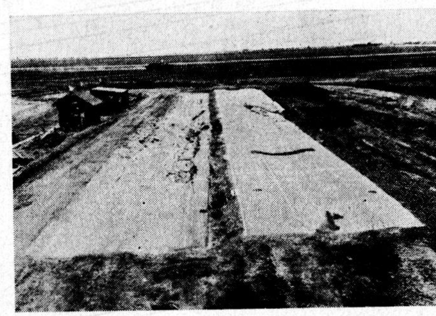

Figure 4. Barksdale, Pavements of Items 1 and 2 after Traffic, 1000 Coverages

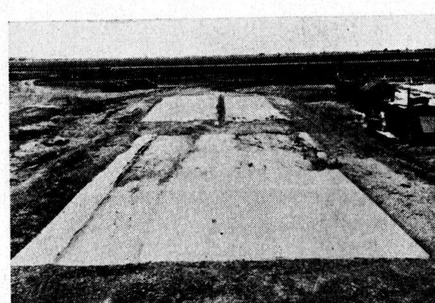

Figure 5. Barksdale, Pavements of Items 5 and 7 after Traffic, 1000 Coverages

course materials, including the sandy-silt which was placed directly over the subgrade.

LANGLEY TEST SECTION

It was at the Langley test section location that an earlier test section was constructed for the primary purpose of conducting field-bearing tests on the surface of different types of bases, and this section was subjected to traffic in order to obtain a rough check on the static method of testing. These results were referred to in the 1942 paper[2] which showed definitely that the critical deflection of the pavement and subgrades involved was less than 0 15-in. where failure occurred, and it would probably have to have been lower than 0 1-in. to obtain a satisfactory pavement. In order to obtain further information on this type of subgrade (silty sand), another test section was constructed having crushed stone base thicknesses varying from 9 to 21 in., beneath a 3-in. asphaltic concrete surface. The sandy-silt subgrade was rolled with a smooth roller before placing the water-bound macadam. The subgrade soil had a plasticity index of 4 and a CBR value of 15 per cent prior to traffic. The test section was first subjected to a wheel load of 20,000 lb. After a few coverages, the pavement started to spring (weave) appreciably over the entire section, and after a few hundred coverages it reached a maximum of 2 in. in the thin portion (12 in.). It was expected that rupture would occur; however, there was no indication of surface cracking of the asphaltic concrete and the section tightened up so that no weaving occurred after 2600 coverages. A total of 6,700 coverages was made; the final settlement was 2 in. at the thick end and 4 in. at the thin end. Since the 20,000-lb. wheel load did not rupture the pavement, a 50,000-lb wheel load was obtained and the test continued on a section which was outside the influence of the 20,000-lb. wheel load traffic lane. The excessive springing was also noted under the 50,000-lb wheel load after a few passes, and failure resulted immediately from the thin end to a thickness of 18 in. and progressed to a thickness of approximately 23 in., after which the pavement functioned satisfactorily. The traffic compacted the base and subgrade at the 24-in. thickness to produce about 5 in. of deformation.

This test clearly shows what may happen if pavements are constructed on relatively loose, saturated, cohesionless silts or fine sands The excessive springing was undoubtedly due to the build-up of excess hydrostatic pressure in the voids of the sand due to the consolidation resulting from heavy wheel loads. In the case of the 20,000-lb. wheel load, this excess hydro-static pressure was released before the failure occurred. However, in the case of the 50,000-lb. wheel load, failure of the pavement resulted before the pressure was released. To prevent subgrade failure due to this condition, subgrade soils of this type should be compacted, in the high stress zone (upper few feet), to a density equal to or above the critical density. Drainage should also be provided where necessary to prevent saturation.

EGLIN TEST SECTION

The purpose of the Eglin test section was to determine the following:

a. Base thickness over clean sand subgrade.
b. Quality of the base.
c. Pavement thickness.
d. Action of sand asphalt.

The sections were placed on a clean, uniform fine to medium sand subgrade having a compacted bearing ratio of approximately 35 per cent. Surface courses of 1½ in. and 3 in were placed over the various bases. The base thickness varied from approximately 3 to 11 in. and three types of base materials were employed, varying from low to high quality (CBR 50–80). One turnaround consisted of a sand asphalt portion of an existing runway.

Separate sections were subjected to 15,000, 37,000, and 50,000-lb. wheel loads. Traffic was confined to lanes three times as wide as the tire width for each load, and was continued until a maximum of 5,000 coverages was obtained. No shear failure occurred in the subgrade and all base materials employed proved satisfactory.

The importance of maximum compaction of cohesionless soils during construction to prevent detrimental compaction by traffic is further emphasized by this test. The test section and the 6 in. of sand asphalt turnaround settled, due to traffic compaction by wheel loads of 37,000 and 50,000 lb., as much as 4 in. The traffic of the 15,000-lb. wheel load caused settlement of about 2 in. Density tests indicated that appreciable compaction by the heavier wheel loads extended to a depth of 4 ft. Comparison of the results of this test and the results of tests conducted in plastic subgrade areas show that the thickness and quality of the base over clean sand subgrade may be less than when the subgrade is plastic. The minimum base requirements given in the appendix of the 1942 paper[2] appears adequate when the subgrade is clean sand Throughout the test, there was no difference in the behavior of sections with 1½ in. and 3 in. of asphaltic concrete wearing course. However, since the pavement was not subjected to the shearing forces produced by airplanes, weathering and aging, as in the case of an actual airfield pavement, it is debatable if conclusions as to the proper wearing course thickness should be drawn from the test results The 6-in sand asphalt pavement forming the turnaround behaved entirely satisfactorily, except for settlement due to traffic compaction of the subgrade.

TABLE 1
ACCELERATED TRAFFIC TESTS ON EXISTING PAVEMENTS

Field No.	Surface	Base[a]	Subgrade[a]	Results
1	5 in. A C	9-in Clayey Sand GF, A2, LL 30, PI 11, Fines 30, Wt 115, WC 14, CBR 25	Silty Clay CH, A6-7, LL 64, PI 38, Fines 75, Wt 97, WC 30, CBR 14.	No failure by 15,000-lb wheel load in 4000 coverages Failure in 200 coverages in limited area where moisture in base was about 2 per cent greater
2	2 in A C	10 in Gravelly Sand GP, A3, LL 27, PI 5, Fines 10, Wt 115, WC 6, CBR 40	Silty Clay CL, A6-7, LL 45, PI 25, Fines 95, Wt 100, WC 25, CBR 5	Weaved immediately under 15,000-lb wheel load Failed completely at 500 coverages. Subgrade failure
3	3-in Bit.	9-in Sand Asphalt	Silty Sand, Uncompacted SF, A3, N P, Fines 21, Wt before test 110, Wt after test 120, WC 6, CBR after test 42	2-4½-in settlement due to compaction by 40,000-lb wheel load in 600 coverages. No shear failure
4	2-in Bit.	Top 4-in Gravelly Sand GF, LL 35, PI 18, wt 109, WC 13, CBR 40 Lower 8-in Clayey Sand, SF, A5, LL 30, PI 15, wt 101-110, WC 30-36, CBR 15	Clayey Sand, SF, A5, LL 30, PI 10, Wt 114, WC 30, CBR 18	No failure by 20,000-lb wheel load in 1500 coverages Failed by 50,000-lb wheel load in a few coverages Base failure
5	6-in Soil-Cement	10-in Clayey Sand SF, A2, LL 28, PI 15, Fines 25, Wt 114, WC 12, CBR 10-20	Clay CH, A7, LL 85, PI 55, Fines 100, Wt 85, WC 32, CBR 3	Edges & joints failed by 12,500-lb wheel load in 700 coverages Entire area failed by 20,000-lb wheel load in 600 coverages. Base failure
6	1½-in A C	6-in Sand Asphalt	Red Clay CL, A6, LL 41, PI 18, Fines 85, WC 23, CBR 10	Pronounced weaving by 15,000-lb wheel load after 100 coverages. Failure at 300 coverages
7	1½-in A C	6-in Soil-cement	Red Clay CL, A6, LL 41, PI 18, Fines 85, WC 23, CBR 10	Failure at joints by 15,000-lb. wheel load at 150 coverages Weaving in entire area after 400 coverages Failure of entire area at 1500 coverages
8	4-in A C	12-in Clayey Gravel GP, A1, LL 22, PI 10, Fines 9, Wt 120, WC 4, CBR 20-30	Clay, CL, A7, LL 45, PI 20, Fines 75, Wt 98, WC 21	Failure started by 15,000-lb wheel load after 100 coverages Base and surface failure

[a] GF, etc —Casagrande Classification, A2, etc —PRA Classification, LL—Liquid Limit in per cent, PI—Plastic Limit in per cent, Fines—per cent passing No 200 sieve, Wt—Dry weight in lb. per cu ft, WC—Water Content in per cent of dry weight, CBR California Bearing Ratio in per cent for test conditions

TRAFFIC TESTS ON EXISTING FIELDS

The results of accelerated traffic tests on existing airfield pavements are shown in Table 1 Some of these tests were conducted during the initial program of investigation and some were made to obtain data on specific pavements. To correlate the results of such tests with design curves, consideration must be given to several factors including the number of coverages used in the test in comparison with the effect of a greater number of coverages The results in general confirm the tentative design criteria used by the Department Since the fields are of military importance, their names and locations cannot be given at this time.

PAVEMENT FAILURES

Recently, a survey has been made of pavements at all military airfields in this country, to obtain brief descriptions and causes of failure resulting from actual traffic Table 2 shows some of the failures that have occurred due to insufficient base thickness At locations where the conditions appear warranted, complete investigations are being conducted to obtain specific data that can be used to develop design criteria. Most of these pavement failures have been produced by airplanes with gross loads greatly in excess of the design loading. Many of the pavements were designed and constructed for pre-war commercial traffic.

TABLE 2

PAVEMENT FAILURES AT EXISTING AIRFIELDS DUE TO INSUFFICIENT BASE THICKNESS

Section of U S	Pavement	Surface	Base[a]	Subgrade[a]	Approx Traffic Causing Subgrade		
					Period	Operation	Plane Wt (lb.)
North	Runway	3-in A.C.	15-in -18-in Gravel GW, A3, CBR 80+	Gravelly Sandy Silt SF, A4, CBR 10±	May to Aug.	2000 1200	60,000 40,000
North	Taxiway	3½-in A C	6-in -12-in Gravel GW, A3, Fines 3%, CBR 80+	Silty Clay CBR 8-12	6 mo, Spring and Summer	1000 1000	60,000 40,000
Middle	Runway & Taxiway	1½-in. A C	6-in. Slag	Silt and Clay LL 38, PI 22, CBR 4-15	One Summer	Intensive Few 1	40,000 55,000 B-17 broke thru Twy. while rev-ing motors
Middle	Runway	2-in. A.C.	4-in Slag, 6-in. Gravel GF, A2, LL 18, PI 5, Fines 20% CBR 40 to 60	Silt and Clay ML-CL, A4-A6, LL 25-35, PI 5-14, Fines 50-80 per cent, CBR 4-35		7200	8,000-15,000-lb Trucks
Middle	Apron	5½-in. A C	12-in Gravel	Sandy Clay CBR 3-8	Summer		47,000-65,000
South	Taxiway	2-in. A.C	8-in Silty Gravel	Clay, A6	May to Sept	75,000	5,000-30,000
South	Taxiway	1½-in. A C	6-in Silty Gravel	Clay, CL, A7, LL60, PI35, CBR 8	1 month	100	40,000-55,000
South	Taxiway	4-in A C	9-in Gravel, CBR 80	Clayey Silt, CBR 6-12	Few months		40,000-50,000
South	Runway	2-in A C	10-in Bit Stabilized Sandy Gravel	Clayey Silt ML, A4, LL35, PI 13, CBR 8-11	Few months	Intensive	40,000-55,000
South	Apron & Taxiway	2-in A C	8-in Caliche LL 30, PI 4, fines 15, CBR 80+	Silty Clay CL, A7, LL 35, PI 15, CBR 8-15	One Summer		20,000-50,000

[a] GF, etc —Casagrande Classification, A2, etc —PRA Classification, LL—Liquid Limit in per cent, PI—Plastic Limit in per cent, Fines—per cent passing No 200 sieve, WC—Water content in per cent of dry weight, CBR—California Bearing Ratio in per cent

PLATE BEARING TESTS

The results of plate bearing tests conducted in connection with most of the traffic tests are too voluminous to discuss in detail in this paper Tests were conducted on the subgrade, base, and pavement surface, using various sized plates and in some cases numerous repetitions The results of tests conducted on pavement surfaces are shown on Figure 6 The results have been adjusted for a bearing plate size equal to the tire imprint area of the wheel used in the traffic tests. The adjustments were made assuming that for any deflection the load intensity is inversely proportional to the diameter of the plate, an assumption which appears reasonably valid according to test results. The two major conclusions which can be drawn from these test data are:

1. The allowable plate deflections which would indicate a satisfactory pavement are variable and depend upon many factors

2 The allowable plate deflection varies with the wheel load Note that a critical deflection of about 0.05-in. for 20,000-lb wheel load would be comparable to 0.15-in. at 45,000-lb wheel load. These deflections include deformation in the surface and base courses.

GENERAL CONCLUSIONS

1. The problem of designing flexible pavements can be divided into two parts; the first requirement,—to prevent shear deformation—is by far the most important, since if the pave-

ment fails due to excessive shear deformation in the base or subgrade a major repair job is necessary. The second requirement,—to prevent excessive traffic compaction—is also very important, and is more critical than generally assumed in the past.

2. At the present time, methods similar to the California bearing ratio method are still considered the best methods of design, to protect against shear deformation. This method, although it needs further refinement, has proved to be a practicable and effective method

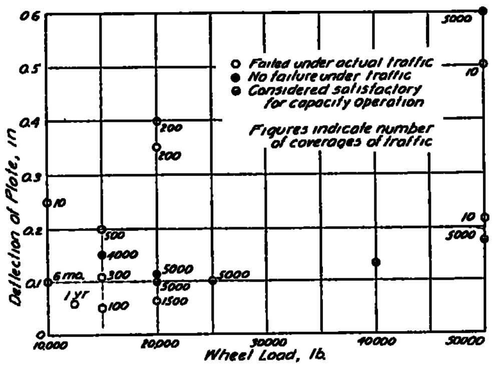

Figure 6. Plate Bearing Test Data

of obtaining a relative evaluation of widely different types of soils.

3. The thickness curves now in use by the Engineer Department are considered sufficiently close for all practical purposes; however, there is no doubt that further modification will be required after the voluminous data now available have been fully analyzed, and further experience on actual airfields is obtained.

4. High quality base material with a CBR of at least 80 per cent is generally required immediately underneath the paving course. However, if the subgrade is a clean granular material, a somewhat lower quality base material may be employed.

5. The test results to date indicate that the type of base material does not influence the total thickness required over the subgrade, provided the CBR value of the material at any given depth satisfies the design curves. However, before making definite conclusions, tests should be conducted to compare the behavior of crushed stone bases (full depth) with lower type bases.

6. Data concerning the action of semi-rigid bases was inconclusive. The low compressive strength soil-cement base at Barksdale did not show any advantage over the limestone base. The Fargo, North Dakota test and actual traffic on a good grade of soil-cement indicated that there was an advantage in this semi-rigid base, provided the joint weaknesses due to non-uniform construction and lack of transfer devices could be eliminated.

7. It can be definitely concluded from these tests that high construction compaction of cohesionless subgrades and bases is very essential, if flexible pavements are to be used for the heavier airplanes without excessive settlement due to traffic compaction. Greater compaction of all subgrades and bases than can be obtained economically with modern equipment will probably be necessary. Compaction requirement probably will have to be raised above the Modified AASHO requirements adopted by the Department.

8 It is extremely important to compact or drain saturated subgrades if composed of cohesionless fine sands or silts, to prevent a "quick" condition which will develop under traffic. A "quick" subgrade is extremely hazardous and will lead to serious breakthroughs.