overtax the imagination to conclude that such designs are totally inadequate for a 37-kip wheel load for the conditions at Lockbourne. Figure 8 shows the development of crack patterns for five designs in the south tangent of Lockbourne No. 1. This illustrates the clear definition of results, and demonstrates the wide performance difference that can be expected from adequate and slightly inferior designs.

To enable the reader to make elementary comparisons a summary of average physical properties of the materials involved is offered in Table 3.

CONCLUSIONS

It is becoming increasingly clear that the designs for concrete airfield pavements resulting from the more commonly accepted methods of analysis are optimistic. In general it can be predicted that there must be revision of the basis of design which, for heavy aircraft, will require greater added strength of pavement.

ACKNOWLEDGMENTS

The tests at Godman Field were conducted by the forces of the U. S. Engineer Office, Louisville, Kentucky. Although the tests at Northern Field were conducted by the laboratory staff, the force of the U. S. Engineer Office, Nashville, Tennessee helped in many respects. The Material Division (now the Air Technical Command) of the Army Air Forces has lent equipment and personnel, and rendered many services. Credit is due the staff of the Cincinnati Testing Laboratory and the Ohio River Division for having done the rest of the work. This work was done under and by the authority of the Office, Chief of Engineers.

AIRFIELD PAVEMENT EVALUATION

By Messrs. H. J. Lichtefeld, *Engineer, Runways Section* and R. M. Haines[1], *Soils Engineer for Military Construction, Office of Chief of Engineers, U. S. Army*

SYNOPSIS

The Office, Chief of Engineers initiated the Airfield Evaluation Program for military airfields in August 1943 after numerous requests had been received from various commands of the Army Air Forces to determine if airfields would withstand the traffic of specific aircraft to assist in the reallocation of stations brought about by planned increases in training programs.

The evaluation program was considered to be an engineering study to determine the carrying capacity of the pavement as constructed. It encompassed field surveys and investigations in conformance with instructions issued by the Office, Chief of Engineers and consisted chiefly of tests on subgrade, base, and surfaces for both flexible and rigid type pavements. For bituminous pavements, the California Bearing Ratio (CBR) test was performed on undisturbed samples of the subgrade and base; in some instances the tests were made on the material in place. Such tests were made after the removal of the surface course from selected locations on the runway, taxiway, and apron facility. Extraction, gradation, and density tests were made on the surface course. Sections of the portland cement concrete pavement were removed and flexural strength determined by the third point loading method on beams cut therefrom. Plate bearing tests, using a 30-in. diameter plate, were made on subgrade materials. Sieve analyses, densities, and moisture contents of the subgrade and base materials were determined at the selected locations.

Conferences with Army Air Forces determined the desirability of interpreting the data and expressing the results so as to indicate a field evaluation and runway evaluation in terms of capacity operation and limited operation. The data and results of the tests obtained from the survey were applied to the principles in Chapter XX of the Engineering Manual for arriving at the load carrying capacities.

The Army Air Forces have been furnished the necessary information. Copies of the reports are on file at the three departmental laboratories and will constitute a valuable source of information for study in developing new features of design.

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HISTORY

The design and construction of military airfields in this country have been largely done by the Corps of Engineers. In the early stages of the national defense program the Army Air Forces requested many airfields for training purposes involving lightweight aircraft. Later, construction directives for other airfields contemplated heavy wheel loads which were beyond the comprehension of the layman, and in many cases the engineers themselves. To withstand the increased stresses and magnitude of traffic produced by military airplanes, the design and construction of pavements revealed a hiatus which was difficult to bridge because experience of paving engineers was not and still is not fully in accord with the problem at hand. As one engineer remarked on the contemplated design of pavements for 150,000-lb. wheel load . . . "That represents a lot of wheel." Trends in aircraft design and development of plane characteristics influenced airfield design and ultimate use.

It is well known, that the urgency to complete construction immediately preceding and following the early days of December 1941 was critical and in many cases caution was thrown to the wind. An example of construction of a major airfield which was contrary to all basic engineering practices employed in peacetime construction is taken from a report submitted to Office, Chief of Engineers: "Concrete was placed under very adverse weather conditions with temperatures reaching a minimum of 16 deg. F. during the night shift; dust storms occasionally covered freshly placed concrete; frozen aggregates, near-freezing water, and lack of proper protection of freshly placed concrete, all entered into the picture." The above and similar conditions of varying degree presented problems that required more than careful judgment to properly analyze the worth of the completed project. It is conceivable that some detrimental effects would not be readily apparent and would disrupt the continuity of anticipated results by rapid development of latent reactions.

From the foregoing it is understandable why in mid 1943 the Office, Chief of Engineers, District and Division Offices, had received numerous requests from various commands of the Army Air Forces for immediate surveys of airfield installations to determine if they would withstand the load of specific aircraft. In some instances the designs were considered adequate for the intended load; on the other hand some fields were considered capable of carrying greater loads while many had less capacity than that for which they were designed.

To meet these requests, brought forward by planned increases in training programs which frequently resulted in re-allocation of stations, and to provide additional data for construction of facilities for heavy bombardment airplanes, the Office, Chief of Engineers initiated the Airfield Pavement Evaluation Program in August 1943. This program was considered to be an engineering study to present an actual evaluation of the carrying capacity of the pavement as constructed. The program included field surveys and investigations in conformance with instructions and consisted chiefly of tests on subgrade, base, and surfaces for both flexible and rigid type pavements.

DEFINITION OF TERMS

In establishing the criteria for airfield pavement evaluation, the general policy of the Department was similar to the policy used in establishing the criteria for design presented in Chapter XX of the Engineering Manual.[2] The problem of establishing these criteria was discussed with personnel of Headquarters, Army Air Forces. For the pavement evaluation to be of a definite value, it had to be conducted according to standard practice and uniform procedure. Approximately 50 engineer districts participated in this program. Conferences with the Army Air Forces determined the desirability of expressing the results of the survey so as to indicate field evaluation and runway evaluation in terms of capacity and limited operation. Complete agreement was reached on the following definitions and sent to field personnel to avoid confusion:

Field Evaluation. The gross plane weight, specified for the overall field evaluation of capacity and limited operation, that may be operated at the field without any hindrance due to excessive maintenance or reconstruction of any pavement. (In many cases, apron or taxiway pavements control this over-all field evaluation.)

Runway Evaluation. The gross plane weight, specified for the runway evaluation of

[2] Engineering Manual, Chapter XX, War Department, Office of the Chief of Engineers.

capacity and limited operation, that may be operated on any runway without hindrance due to excessive maintenance or reconstruction except possibly at the end of runways. The evaluation will be governed by the carrying capacity of the controlling runway selected according to both operational and carrying capacity features. If planes specified for the runway evaluation are operated at the field and the runway evaluation is greater than the field evaluation, excessive maintenance or reconstruction of some pavements other than runways should be expected.

Capacity Operation. Capacity operation is defined as the maximum traffic that can possibly operate on an airfield for a period of approximately 20 years. The daily operation may be assumed as varying from 100 for the very heavy airplanes to 1,500 for very lightweight planes.

Limited Operation. Limited operation is defined as a few operations a day for a period of approximately 20 years (about 10 per cent of capacity operation) or as the maximum traffic that can possibly operate for a period of 2 to 4 years. However, the use of a pavement rated for limited operation by the maximum traffic that can possibly operate for a period of 2 to 4 years may entail greater yearly maintenance than would a field rated for capacity operation.

The criteria expressed or implied by the foregoing definitions, and interpretation of the results obtained were applicable for airfields in light of military aircraft; and were not intended for nor applicable to standards adopted for commercial or civil traffic. It precluded all reconstruction and maintenance other than normal for the usual life of the pavement. It was readily understood that it was impossible to determine an evaluation which necessitated a certain amount of reconstruction or excessive maintenance thereby permitting delays and non-use periods of operation.

It frequently happened that a study of the traffic distribution at a station indicated that necessary traffic on such pavements would, in many cases, justify the selection of the controlling field pavement. The general intent of the field evaluation was to indicate that the evaluation of a taxiway or apron system was either equal or not equal to the evaluation of the runway system. Where the runway evaluation was used for the field, excessive maintenance would be required if the field evaluation was lower. Weak sections of pavements of limited area were not considered as controlling the over-all evaluation of the field since it would be more economical to accept excessive maintenance or reconstruction on the limited area rather than penalize the majority of pavements. The evaluation terms did not include occasional or emergency landing. It was understood that the evaluation of a pavement for a specified load did not preclude the infrequent operation of a considerably higher load. However, it did not mean that such pavements were satisfactory or adequate for capacity or limited operation of such weight.

SELECTION AND EXTENT OF EXPLORATIONS

The extent of exploration and testing was dependent upon many factors. Determining the controlling pavements was of major importance. Such pavements were defined as those with the least carrying capacity, modified by windrose and airplane weight limitations, and eliminating from consideration for controlling pavements the obsolete, remote, auxiliary, or emergency pavements. To determine the controlling pavement or sections of pavement, the study included a review of all records and data, a review of existing construction methods and all data obtained from explorations and tests made for design, and a complete soil survey of subgrade conditions if other data were not available. The latter was accomplished by a series of auger holes at approximately 500-ft. intervals along the shoulder of the runway. Information from these sources helped to determine the limits of probable controlling pavement section as well as the preliminary test locations. At some fields, sufficient data were available from design analyses and construction records to indicate areas of uniform conditions, in which event inspection of existing conditions and necessary tests were made to check the validity of assumptions made. In instances where no records were available or were obscure, the number of explorations was increased in order to determine representative areas of uniform conditions. Usually three locations on a runway were considered the minimum for testing purposes. The number varied dependent upon conditions enumerated above, or the amount of valid data available.

DATA REQUIRED FOR EVALUATION OF FLEXIBLE PAVEMENTS

Instructions were forwarded to all Division and District Offices that flexible pavements were to be evaluated on the basis of the California Bearing Ratio test or accelerated traffic tests; and such traffic tests were to be conducted only after prior approval of Office, Chief of Engineers. The latter method was employed in one instance only and will be discussed later. The principal features in developing necessary data consisted of the determination of:

(1) Subgrade strength as measured by the CBR value.

(2) Base thickness plus quality of the base course as measured by the CBR test and similar application of the foregoing to sub-base material where present.

(3) Pavement thickness and quality.

To determine and develop the data, tests were required on the subgrade, base, and pavement courses. At each test location where pavement was removed, CBR tests were made on the subgrade and base materials. In addition to this, tests were made to determine grain size distribution, soil constants, classification in accordance with Casagrande and U. S. Public Roads Administration methods, moisture and density in situ, and optimum values of moisture and density; also extraction, gradation, and density tests on the compacted bituminous mixtures. Minor variations in test procedures were evident for determinations of silt and clay content, in-place densities, etc., but in the main they conformed to standard methods for certain areas and were not considered of major importance.

The CBR test[3] served to determine the value of the subgrade and base course. Modification of previous CBR procedure had been made: to compact all specimens in a 6-in. mold, to apply penetration surcharge weights on all soils equal to soaking surcharge weights, and to establish the critical moisture-density relationship to give the CBR characteristics within the range of expected field control. Depending upon the type and the limitations of the physical characteristics of the materials, one of the applicable CBR test methods was employed: undisturbed, in-place, and remolded.

When conditions of moisture and density were not present, such as are expected to develop after the pavement has been in service for a number of years, undisturbed samples of cohesive soils were taken for the penetration test. In Figure 1, is shown the method for obtaining undisturbed samples. This was generally applicable to cohesive soils and had limited usage for coarse granular material. After removal of the pavement and base, the subgrade material was excavated and trimmed away so as to form a pedestal (or as many as considered necessary) 6-in. in diameter and 7-in. high. Usually duplicate samples were taken and in some instances samples were taken in triplicate. A mold, made of 20 gage galvanized iron in the shape of a draw bend, 8-in. in diameter and 8-in. high was placed over the pedestal and filled with molten parrafin wax. After the wax had hardened and cooled, the pedestal was severed at the bottom. The sample was then inverted and sufficient material removed from the mold to permit covering the exposed soil with approximately 1-in. of wax. Such samples were placed in padded boxes and delivered to the laboratory. The top surface of the wax was removed and the normal CBR test procedure was followed.

Figure 1. Undisturbed Sampling for CBR Test

The in-place CBR method was employed for those soils that were at or near saturation and no further compaction was anticipated, as in the case of most cohesive soils; the method was also applicable to non-cohesive soils fully compacted. Figure 2 shows the

[3] Proceedings, Highway Research Board, Vol. 22 (1942) Appendix B, page 162.

apparatus that has been successfully used by many District Offices. This apparatus was developed by the U. S. Waterways Experiment Station and is believed superior in operation to the hydraulic jack method; at least field experiences indicated more reliable results. The apparatus for in-place tests is attached to the rear of a truck which furnished the reaction for the penetration test and it is moved directly over the location to be tested.

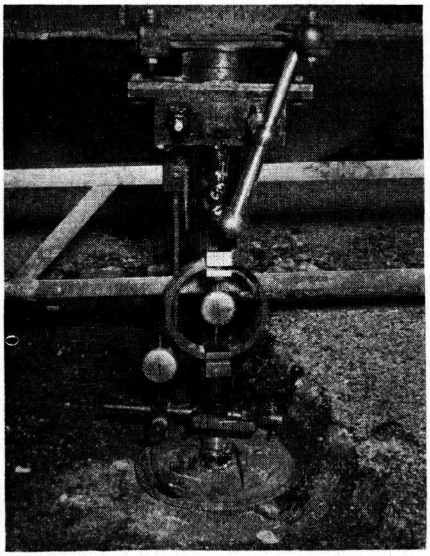

Figure 2. Apparatus for In-Place CBR Test

Essentially the machine consists of a gear box for varying the speed of the piston; a proving ring with an Ames dial calibrated to 0.0001 in. which measures the magnitude of load applied; an adjustable penetrating piston with clamp for holding the penetration gage which is an Ames dial reading to 0.0001 in.; a 12-in. diameter base ring and necessary surcharge weights. Extreme care is necessary in the manipulation of the apparatus to obtain uniform bearing with the piston. The calibration of the proving ring is checked periodically in the laboratory. Usually a slab, 2 ft. by 3 ft., is removed and this area permits two or three check tests to be made for each location.

Remolded samples were used on cohesionless soils which were expected to compact to a higher degree under action of traffic. The laboratory method with modifications referenced above was used.

APPLICATION OF DATA FOR FLEXIBLE PAVEMENTS

Selection of representative subgrade (CBR) value, which usually controlled the carrying capacities of the pavement, was not always a simple or routine task. It required complete and intimate knowledge of the test results as referenced to soil types and in-place conditions. For variations in soil type, the lowest bearing material was considered the controlling type for evaluation except for local areas of small extent. It frequently happened that values of the runways would differ; or a major portion of a runway would vary from the remaining section. No attempt was made to evaluate the pavements on the basis of each individual test result.

The adopted value, representative of the bearing power of the subgrade was applied to the tentative design curves, and the applicable wheel load corresponding to the combined thickness of base and pavement over the subgrade was determined in accordance with established criteria in the Engineering-Manual. An interpretation of these criteria is as follows:

(1) *Pavement Thickness.* The limitation of the carrying capacity of the pavement due to thickness was a 15,000-lb. wheel load for 1½-in. pavement, and for a 37,000-lb. wheel load the thickness was not less than 3 in. In general a 3-in. surface course was considered satisfactory also for a 60,000-lb. wheel load; however, specific cases necessitated variations because of the quality and type of wearing course. A straight line interpolation between values was permitted.

(2) *Quality and Thickness of Base Course.* The minimum allowable base course thickness was 6 in. for both capacity and limited operations, and the rating was established for the CBR value as follows:

Gross Weight of Planes lb.	Minimum CBR
30,000	50
74,000	65
120,000	80

Interpolation of these values, if needed, was permitted. Base courses of less than 6 in.

and a CBR of less than 50 per cent became a matter of judgment in view of traffic performance experience.

(3) *Total Thickness for Limited Operation.* When rating for limited operation is obtained from the design curves, the total thickness of cover above subgrade is assumed to be 25 per cent greater. This is the reverse of the Engineering Manual method which allows 20 per cent decrease in total thickness for limited operation.

The evaluation curves (Fig. 3) for flexible pavements were developed from the basic curves in the Engineering Manual and they served as a ready aide for determining the carrying capacity of the pavements. The total thickness over subgrade for capacity operation is noted on the lower portion of the sheet while thickness for limited operation is shown on the upper portion. Assume a total thickness of 12 in. and a subgrade CBR value of 15; follow the vertical line corresponding to 12-in. thickness until it intersects the CBR value of 15. This corresponds to a gross load of 55,000 lb. (left side of chart) for runway value and 44,000 lb. (right side of chart) for taxiways and aprons, etc. Similar procedure is followed for the limited operation value from thicknesses shown on the uppermost portion of the chart except that no reduction is applied for increased stresses in taxiways, aprons, etc.

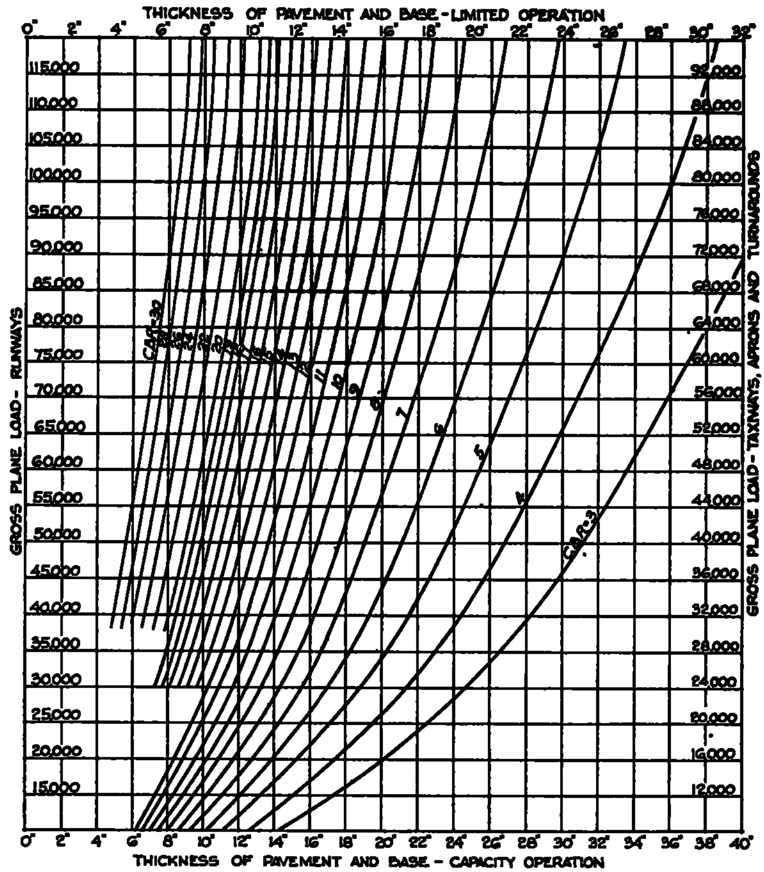

Figure 3. Evaluation Curves for Flexible Pavements, California Bearing Ratio Method

DATA REQUIRED FOR EVALUATION OF CONCRETE PAVEMENTS

The design curves in Chapter XX were used for evaluation of concrete pavements which embodies the relationship between load, soil modulus, and thickness of concrete for specific quality. Hence, the principle features for evaluating the pavements consisted of determining:

(1) Concrete strength from which the working stress is determined.

(2) Subgrade strength expressed as modulus of subgrade reaction, k.

(3) Thickness of pavement.

To determine the flexural strength of concrete in the existing pavements, portions of the slab were removed and cut to proper size and tested by the A.S.T.M. test C-78-39. The depth of the beam represented the full depth of the slab. For beams greater than 6 in. in depth, the span was changed. The width of the beam was equal to or greater than the depth. All beams were tested in an upright position with the top up and soaked 24 hours prior to testing. Not less than five beams were tested from any one area to obtain the average flexural strength. It was necessary to remove slabs from more than one location in order to arrive at the lowest representative flexural strength. As in the case of the flexible pavements, the number of locations from which beams were cut was determined by construction details, time of placement, and type of aggregates, etc.

The recommendation to remove portions of the pavement brought protests from the field forces with many statements of impossibility and impracticability. This adverse criticism proved to be unfounded and all obstacles were easily overcome. After much discussion, the procedure for removing the slabs from the pavement revolved around the following: use of 40-in. core drill, use of jack hammer and drilling around edges of a desired area (approximately 6 ft. square), and use of an electrically driven saw with special carborundum wheels for blades. Figures 4 and 5 show the saw in operation and the slab removed from the test location. Figures 6 and 7 show the 40-in. shot bit ready for drilling and the removed concrete disc after sawing to obtain specimens for beam tests. If the first two methods were used, the beams were usually sawed from the removed slab by some marble company. In some instances the rough underside was ground smooth by a 4-in. carborundum wheel at three points to provide uniform bearing on the base supporting blocks and to permit accurate measurements at the broken section. The method most generally used consisted of capping the underside with capping materials to provide a uniform bearing surface.

It was not considered necessary to prepare test beam from all concrete pavements at an airfield constructed under similar conditions if sufficient data were available to estimate the flexural strength by comparing the data with that obtained from pavements actually tested for flexural strength. Some Districts established the relationship between flexural strength (for a limited number of locations) and compression tests on cores and modified cubes obtained from the beams of the removed section. The resultant ratio was applied to the results on cores removed from other areas to estimate the flexural strength for those areas. This procedure was approved to reduce the number of test locations where pos-

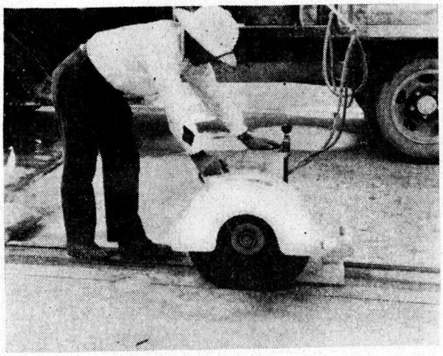

Figure 4. Electrically Driven Saw with Carborundum Blades

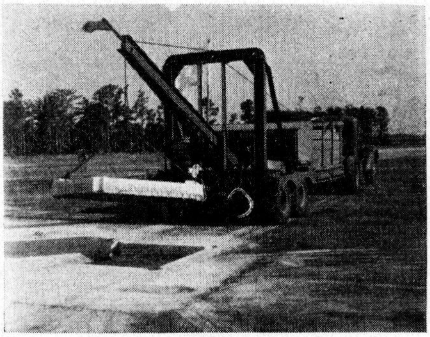

Figure 5. Lifting Cut Slab from Pavement

sible, but in no instance were all tests abandoned and results estimated wholly on a correlation.

The design factors (1.75 and 1.4) established in the Engineering Manual for the design of concrete pavements were based on a flexural strength of concrete at 28 days, and these design factors were used to determine the working stress. Since normal concrete shows a progressive increase in strength up to 3 years which represents approximate ultimate strength, the attained strength at any age was reduced by factors given in Table 1 to arrive at a working stress.

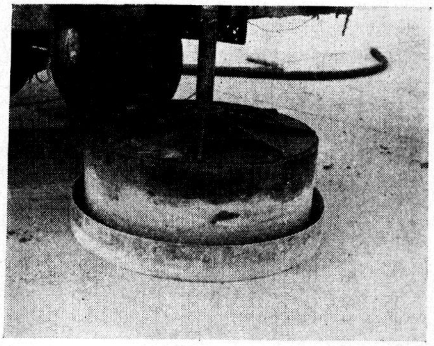

Figure 6. Forty-Inch Shot Bit Ready to Drill

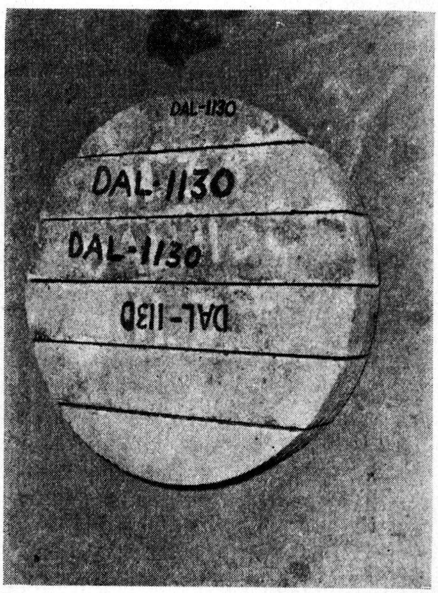

Figure 7. Surface of Concrete Disc after Sawing to Obtain Specimens for Beam Tests.

At ages other than those shown in Table 1 direct interpolation was considered sufficiently accurate to obtain the factors. The factors were taken from available data and were based on concrete composed of standard cements and aggregates passing the standard specifications. For cements other than noted above or if sub-standard aggregates were used, a study was made of available strength-age data to determine factors to be used for the various

TABLE 1

Age at time of test	Factor	
	Capacity operation	Limited operation
28 days	1.75	1.4
90 days	2.1	1.7
3 years or more (approx. ultimate)	2.3	1.8

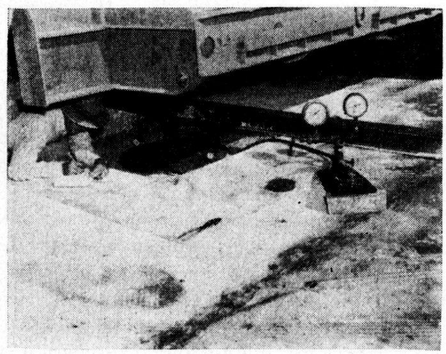

Figure 8. Assembly for Plate Bearing Test

combinations of components peculiar to a certain locality. In instances where little or no increase in strength from the 28 day strength was apparent, the higher factor was used.

The plate bearing test to determine modulus of soil reaction, k_u, was performed after the removal of the concrete slab and special care was exercised to minimize disturbance of the subgrade. In the event of delay in the test, the subgrade area was protected to maintain the present moisture condition. The assembly of apparatus for plate bearing test is shown in Figure 8. The base plate consists of a 30-in. steel plate. Prior to placing of the base plate, the surface of subgrade was made as smooth as possible and a layer of fine sand was placed thereon to produce uniform bearing. To avoid eccentricity of loading, a ball and socket joint was used between the jack and the reaction for the load. The load usually consisted of a loaded trailer. A hydraulic jack with pressure gage was used to record the applied load and movement of plate was measured, in most instances, by three Ames dials placed at 120 deg. intervals. Three dials were considered necessary to minimize the effect of any warping or hinge action of the plates. Loads were applied in increments of 5 p.s.i. and each load was maintained at full value until movement of plate had ceased or until it was less than 0.002 in. per min. The time interval varied from 2 min. upward depending upon the magnitude of load and soil characteristics. A plot of load vs. deformation was made and the critical value was taken as the load required to produce a 0.05-in. deformation.

Since the modulus of soil reaction, k_u, was determined on the subgrades at or near optimum moisture content, it was necessary to reduce this value for conditions of moisture that would be comparable to those that would develop under the pavement. A reduction was not considered necessary for most cohesionless sand subgrades as they were believed to be not effected by saturation. For those soils susceptible to increased moisture resulting in a lower supporting value and in the absence of a more suitable method, the results of the consolidation tests were applied to determine the reduction of k_u. It was assumed that the ratio of loads to produce the same deformation in the two consolidation tests (one at field conditions and one saturated) was approximately equal to the ratio of the loads required to produce same deformation for an unsaturated and saturated subgrade. Therefore, the reduction was in accordance with the formula:

$$k = p_s/p \times k_u$$

in which k = modulus of soil reaction for saturated subgrade

k_u = modulus of soil reaction from field tests

p = load intensity used to determine k_u

p_s = load intensity required in consolidation test on saturated specimen

Thickness of concrete pavement section was determined from cores drilled from the pavement and supplemented with measurements at locations from which the slabs were removed. In most instances the design pavement thickness was used unless the actual thickness varied by more than one-quarter inch from the design thickness.

APPLICATION OF DATA FOR CONCRETE PAVEMENTS

As in the case of flexible pavements, careful consideration was given to the selection of values. For variations in soil type, the lowest representative k values were used. In general, the average flexural strength of concrete for similar construction was used. An example of careful judgment in the application of results from tests on concrete is taken from one report. At this airfield ten test locations were selected from the runways and taxiways. Results of tests from five locations on the runways showed close harmony and averaged 773 p.s.i. at 18 months attained age; on the other hand five locations on the taxiways averaged 524 p.s.i. Examination of all records indicated identical aggregates and cement from one source were employed by the contractor and that no appreciable variation existed in placement technique. Further review of available data indicated that the taxiways were placed under unfavorable temperatures and that freezing weather permanently damaged the concrete. Selection of the lower value in lieu of the average determined that the taxiway system was the controlling pavement.

The adopted values representative of the subgrade bearing value, working stress of concrete, and thickness of pavement were applied to the tentative design curves and the applicable load determined. The nomograph, Figure 9, has been very useful. It is a very compact form of the curves in the Engineering Manual and eliminates much interpolating. The intersection of lines representing appropriate slab thickness and k values (right side of chart) forms one reference point; the other point is the adopted working stress value (left hand margin). The wheel load is determined by aligning these two points with a straightedge and noting the intersection of the straightedge with the slab thickness (center portion of chart). The corresponding wheel load is the result.

FACTORS AFFECTING THE EVALUATION

Performance or service behavior of pavements that exhibited distress under present traffic offered a "ceiling" value not to be exceeded.

Available information indicated that several features of design would change for the very heavy wheel, hence values greater than those obtained from the present design curves were noted as the maximum value plus.

values rather than a specific or definite value. Usually a value of 50,000 lb. may be considered to represent a range of 35,000 to 65,000 lb.

It is to be noted that while the CBR method of design was expected to insure against shear deformation or lateral displacement, it was not calculated to prevent consolidation due to traffic. Permissible settlement due to traffic was not definitely established.

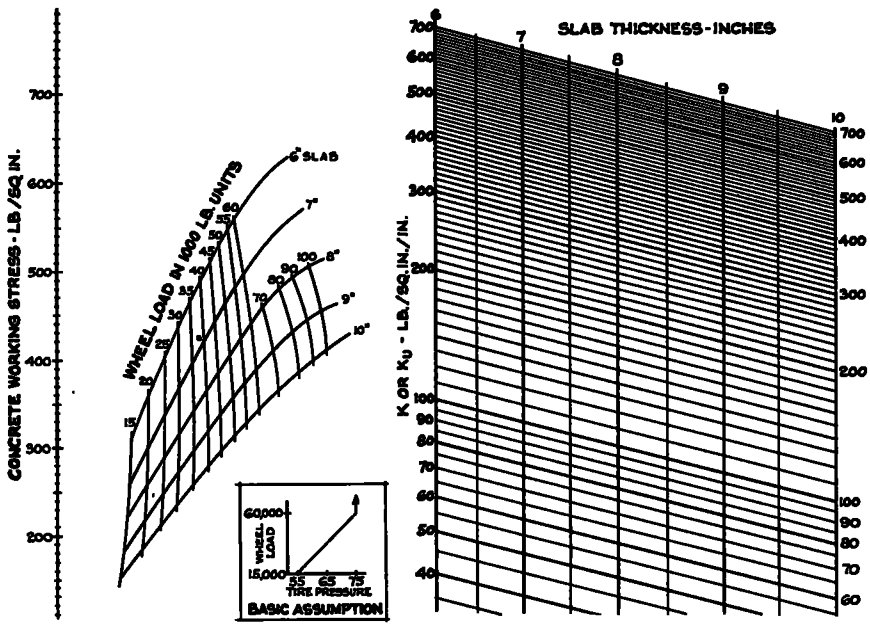

Figure 9. Nomograph for Design or Evaluation of Concrete Slabs at Airfields

In instances where field layout was such that runways were used as taxiways, a reduction of 25 per cent of the carrying capacity was applied because of the increased stress due to vibration of slow moving planes. This criterion is applied to taxiways, aprons, turnarounds, and warm-up pads. It is applied in the case of capacity operation and not for limited operation.

Interpretation of the assigned values have caused considerable comment. It can not be assumed that the thickness required by design curves are valid within 20 per cent. Since a 25 per cent increase in thickness will generally increase the carrying capacity by 75 per cent, it is readily understandable that the evaluation values represent a probable range of

Sub-standard base materials with excess thickness of bituminous surfacing presented conditions that were not applicable to established criteria. Ratings were applied almost wholly on the quality of construction, observation, and experience.

The rated capacities represent values which probably will prevail after the moisture contents of the subgrade have reached values expected in a period. The time following construction for the moisture to increase to these expected values varies greatly and in some cases the expected values may never be reached. Until the assumed moisture contents are reached, the actual capacity of the pavement is greater than rated.

Possible frost susceptible soils were given consideration and a reduction in carrying capacity was made where conditions warranted. For concrete pavements where a nonfrost-heaving base course did not extend to a depth of at least 50 per cent of the average frost penetration, a reduction in the bearing value of the subgrade was made. Tentative criteria for flexible pavements to insure stability required combined thickness of pavement and nonfrost action base material equal to the average depth of frost penetration except that the maximum thickness should not exceed the following for the gross loads listed:

Gross Loads lb.	Thickness in.
120,000	40
74,000	30
30,000	20

It is to be noted that the above values approximate thicknesses for a fictitious CBR value of 4. Investigations are now under way to establish criteria for designing pavements in areas subject to frost. The Boston District conducted a limited amount of traffic testing[4] in connection with the evaluation program.

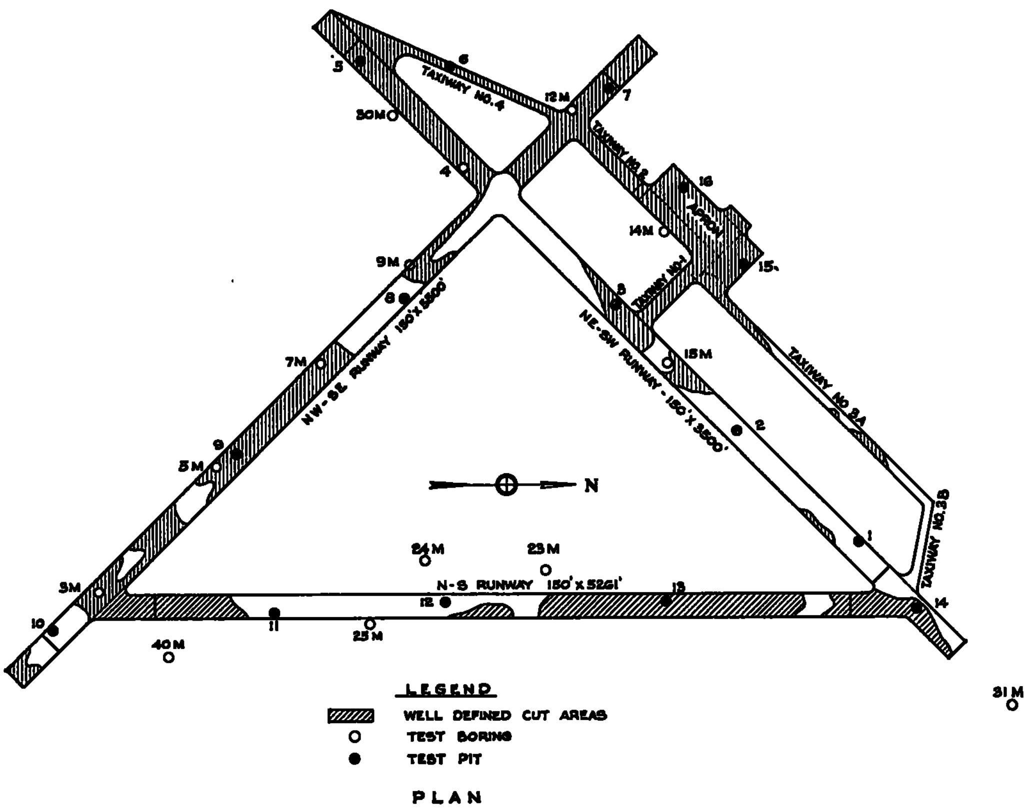

Figure 10. Airfield Pavement Evaluation. Subgrade Data and Test Locations

REPORTING

The Airfield Pavement Evaluation Reports comprise a summary of all important features for only pavement installation. In addition to a compilation of all test results and values derived therefrom, the report contains a general description of the field, construction, traffic, and maintenance history, a description of all field and laboratory tests, and typical sections of pavement areas. Appendices to the report include (1) a key map showing location of all test sites (Figure 10), (2) a historical record and data sheet (Table 2) on

[4] See page 79 of this volume.

TABLE 2

TYPICAL HISTORICAL RECORD AND DATA SHEET FOR AIRFIELD PAVEMENT EVALUATION PROGRAM

	Paved Areas			Subgrade		Base					Surface			Gross Plane Wgt.			
Identification	Length, feet	Width, feet	Area, sq. yds.	Classification Cassagrande	"C B R" or "K"	Type	Thickness, inches	"CB R" or "K"	When Built	Concrete Working Stress	Type	Thickness, inches	When Built	Capacity	Limited	Present Condition	Construction Agency
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
NE-SW Runway.........	5,500	150	77,520 (b)	CL, CH	5	Crushed stone	14	80+	1942		Asphaltic concrete	3	1942	25,000	40,000	Good	U.S.E.D.
NW-SE Runway.........	5,500	150	81,670 (b)	CL, CH	4	" "	13	80+	1942		" "	3	1942	15,000 (a)*	25,000	"	U.S.E.D.
N-S Runway.	5,261	150	74,150 (b)	CH	7	" "	16	80+	1942		" "	3	1942	40,000 (a)	95,000	"	U.S.E.D.
Taxiway No. 1	425	100.	4,720	CL	4	" "	13	80+	1942			3	1942	15,000 (a)	25,000	"	U.S.E.D.
Taxiway No. 2	525	100	5,830	CL	4	" "	13	80+	1942		" "	3	1942	15,000 (a)	25,000	"	U.S.E.D.
Taxiway No. 3 B.........	529	50	2,940	CL	4	" "	13	80+	1942		" "	3	1942	15,000 (a)	25,000	"	U.S.E.D.
Taxiway No. 4	1,497	50	8,310	CL, CH	4	" "	13	80+	1942		" "	3	1942	15,000 (a)	25,000	Surface uneven	U.S.E.D.
Taxiway No. 3 A..........	1,820	50	10,110	CL, CH		" "	6	160	1942	248 (1) 321 (2)	Concrete 8"-6"-8"	6	1942	20,000**	38,000	Some transverse cracks —few corner cracks	U.S.E.D.
Apron Original..........			20,000	CL, CH		" "	6	160	1942	248 (1) 321 (2)	" "	6	1942	20,000**	38,000	" "	U.S.E.D.
All Runway Turn-Arounds.....	2,261	150	37,680	CL, CH		" "	6	160	1942	248 (1) 321 (2)	" "	6	1942	20,000**	38,000	" "	U.S.E.D.
Apron Addition.........			8,000	CL		" "	6	160	1944	328 (1) 411 (2)	Concrete 10½"-7"-10½"	7	1944	45,000	75,000	Good	U.S.E.D.

* Controlling Pavement—Runway and Field Evaluation.

** Service record of coarse aggregate used in this pavement indicates that excessive maintenance, due to conditions other than traffic, may be expected after a ten (10) year period.

Traffic History. Traffic during the period November 1942 to December 1943 consisted principally of B-25 and B-26 type aircraft. Traffic during the period December 1943 to December 1944 consisted principally of C-47 type aircraft. Landing and take-off (1 cycle) traffic is estimated to have varied from 20 per day, for the heavier craft to approximately 600 per day for the light planes. Traffic distribution on the runways during this period is estimated to have been as follows: N-S, 15%; NE-SW, 70%; NW-SE, 15%.

(1) Working Stress—Capacity Operation.

(2) Working Stress—Limited Operation.

General Notes. The condition of all airfield pavements is generally good. Taxiway No. 4 developed minor depressions during the first year of operation, but this condition has been corrected with bituminous patching material.

Lengths of runways are measured on the center-line from end of pavement to end of pavement, including intersections with other pavements. Lengths of taxiways are measured on the center-line from edge of runway to edge of runway or apron. The sum of the pavement unit areas given in Column 4 does not represent the actual total pavement area, due to the method of measuring runway lengths.

All thicknesses given for flexible pavement are mean measured thicknesses. All thicknesses given for concrete pavement are core measurements.

Areas which have not been directly tested have been assigned evaluations equal to similar, concurrently constructed pavements.

(a) Evaluations of all taxiways, aprons, and other pavements used for taxiing and warm-up of planes have been reduced by 20% to compensate for overloads due to this type of operation.

(b) Area of asphaltic concrete pavement only, runway turnarounds not included.

Flexural strength for each concrete section determined from 8 beam tests made on each section of pavement removed.

which are shown the length, width, and area of all pavements; subgrade and base course classification and respective bearing values; type and thickness of surface; date built; condition of pavement; and any unusual feature that is mentioned in note form, and (3) a layout map showing the value of each and every portion of the airfield system by appropriate color scheme to correspond to a legend indicating the assigned values. Addenda are issued to maintain the reports current for new construction that is completed or for changes in the physical characteristics of the airfield that vary the evaluation value.

Approximately 600 evaluation reports have been reviewed by the Office, Chief of Engineers. Review of each report is accomplished and concurrence with findings reported therein is made prior to forwarding to the Army Air Forces. The findings have aided the Army Air Forces in making a reallocation of airfields. The volume of work did not permit a detailed engineering review of the reports; however, copies of all reports are on file at the three departmental laboratories where detailed studies are being made that may result in the refinement and development of new features of design.

ACCELERATED TRAFFIC TEST AT LANGLEY FIELD, VIRGINIA

By D. D. Leslie and R. M. Haines[1]

U. S. Engineer Department

SYNOPSIS

An accelerated traffic test was conducted on a specially constructed flexible pavement test track. The purpose of the test was to study the behavior of base and pavements of various thicknesses placed on a low plastic subgrade when subjected to traffic with wheel loads of 20,000 and 50,000 lb. and to obtain data necessary for development of design curves for the California method of design of flexible pavement. The test section was 200 ft. long exclusive of ramps and turnarounds and consisted of high quality asphaltic concrete and a macadam base with total thickness varying from 12 to 24 in. The subgrade was a heterogeneous sandy silty soil, deposited previously by hydraulic fill methods. The ground water table was near the surface of the subgrade. Two lanes, each 6 ft. wide, in the test track were subjected to traffic of a 20,000-lb. wheel load until 6,667 coverages had been completed. After the 20,000-lb. wheel load test was completed, two additional lanes were subjected to the traffic of a 50,000-lb. wheel load for 2,733 coverages. One of these test lanes was in the area previously traversed by the 20,000-lb. wheel load.

The test data and observations of the action of the section show that the occurrence of hydrostatic excess pressure in the subgrade pore water (commonly observed as a "quick condition") greatly affected the behavior of the test section. Although the pavement did not crack under the traffic of the 20,000-lb. wheel load, springing of the pavement up to 2 in. occurred at the thin end. The section completely failed up to a thickness of 22 in. under the traffic of a 50,000-lb. wheel load. The results of the test clearly emphasize the need for subgrade compaction or ample thickness of base over saturated, fairly low density, fine sands and silts that may become "quick" during airplane traffic.

A brief summary of the accelerated traffic tests conducted by the U. S. Corps of Engineers on special test sections and on existing airfield pavements has been presented to the Highway Research Board (1).[2] Other papers (2), (3), (4), (5), (6), (7) have given the back-

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[2] Numbers in parentheses refer to the list of references at the end of the paper.