6. In specifying degree of density more attention needs to be given to the strength of the compacted mixture At present the maximum density produced by the A.S.T.M. or A.A.S.H.O. test methods is more or less accepted as being sufficient to produce adequate strength. Actually the strength, at this density and corresponding optimum moisture varies greatly among soils of different types. Eventually, we should use some strength index test as the criterion for design. Another factor that needs attention in connection with moisture density relationships is the percentage of air-voids at maximum density and optimum moisture. Laboratory tests indicate that unless the air-voids are low at optimum conditions the compacted sample will take up water Therefore, in addition to designing for strength we should also design for permanence by restricting the water capacity of the compacted mixtures

7. Methods need to be developed for the determination of density in the laboratory so that field tests can be correctly correlated with them

8 Both the contractors and the field inspection personnel need to know more about the basic principles of soil compaction

9 The possibility of damage by frost action should be given more attention. However, it should be pointed out that a great many compacted soil mixtures will withstand frost action even under very adverse water conditions.

FLEXIBLE PAVEMENT TEST SECTION FOR 300,000-LB. AIRPLANES, STOCKTON, CALIFORNIA

By Ralph A. Freeman, *Senior Engineer* and O J. Porter,[1] *Consulting Engineer Pacific Division, Corps of Engineers*

SYNOPSIS

A special test section has been constructed at Stockton Army Airfield by the Corps of Engineers to obtain data for the establishment of flexible pavement design criteria for 300,000-lb airplanes, using the California Bearing Ratio method

The test section proper is a paved area 70 ft wide and 650 ft long which is divided into 23 different items Each item is of a different design having total thicknesses varying from 40 to 66 in over a weak clay subgrade (CBR 8 per cent ±), from 22 to 37 in over a medium strength clay loam subgrade (CBR 24 per cent ±) and from 7 to 22 in over a strong sand subgrade (CBR 50 per cent ±). A high quality asphaltic concrete pavement varying from 2 to 16 in. in thickness and a crushed rock base (CBR 100 per cent +) varying from 0 to 19 in in thickness, are being tested

Data are being obtained on the relative behavior of these subgrades when protected by different thicknesses of pavement, or by combinations of various thicknesses of pavement and foundation materials, and subjected to the accelerated traffic of a heavily loaded 110-in. diameter airplane tire.

Accelerated traffic of this huge tire mounted in a mammoth testing rig of unique design and loaded to 150,000 lb has been uniformly distributed over a 20-ft. wide traffic lane in each item Because of the trend towards heavier airplane loads the wheel load will be increased to 200,000 lb or more, if feasible, and traffic continued over all items until failure, or until 2,000 coverages (repetitions of load) have been completed

[1] Staff Materials and Research Engineer, State of California Division of Highways

Deflections and pressures under both static and moving wheel loads varying from 31,000 lb. to 200,000 lb. or more, are being measured with electrical gauges and pressure cells Pressures are measured at various depths in the foundation The deflections and deformations are recorded for the top of the pavement, the top of the subgrade and at intermediate points between the base and subgrade.

The paper is a description of the procedures and methods used in testing It establishes for record the basis for future presentation and discussion of results

As a result of publicity during the past year or more, the discussion of land-based airplanes weighing 150 tons has become fairly common. Among paving engineers and consultants of the Corps of Engineers, this discussion has centered on the landing gear to be used, since the type selected would greatly affect the pavement design requirements for 300,000-lb. airplanes.

In the summer of 1944, Army Air Forces advised the Chief of Engineers that airplane designers had selected landing gear assemblies using a single, 110-in diameter tire under each wing to support one-half of the major portion of the weight of the 300,000-lb B-36 Bomber, or C-99 transport. Therefore, it became imperative to expand and accelerate the preliminary studies previously initiated to determine the flexible pavement design criteria for 150,000-lb wheel loads Accordingly, careful consideration was given to the data required to establish comprehensive and adequate criteria and to the means to be used in obtaining the information

Accelerated traffic tests previously conducted by the Engineer Department had proven to be most satisfactory in verifying the tentative flexible pavement design curves for airplane wheel loads up to 60,000-lb shown in Figure 1.[2] Consequently, it was decided to test with the accelerated traffic of an airplane tire loaded to 150,000 lb or more, a specially constructed section in which were embodied the major design variables

The purpose of this accelerated traffic test is to furnish the information required for the adequate and economical design of flexible pavements using the California Bearing Ratio (CBR) method as modified and adapted to airfield pavements by the Corps of Engineers The test results will be used to establish the position of the 150,000-lb wheel load design curve on the chart shown in Figure 1

[2] Chapter XX OCE, Engineering Manual, Design of Runways, Aprons & Taxiways in Army Air Force Stations.

The contact areas and pressures, for the wheel loads shown on the design curves, and for the loaded B-36, bomber tire are shown in Figure 2, in terms of the diameters and heights of columns of concrete having equivalent weights and end areas For comparison, similar columns of concrete representing 5,000-lb. loads on high contact pressure truck tires and the 2,000-lb. wheel load of a light training plane have been added

The magnitude of the load on a single tire to be carried by an airfield pavement during landing, taxiing and taking off of a 300,000-lb. airplane is difficult to visualize This enormous load is comparable to that of a large locomotive and the weight carried by one tire can be represented by a column of concrete over 3½ ft in diameter and about 100 ft in height (Fig 3) The effect of the great weight, mounted on a tire and bouncing over the pavements stirs the imagination of pavement engineers, but the problems involved cannot be solved from past experience Figures 2 and 3 also graphically illustrate the rapid increase in standard airplane wheel loads during the last decade, and the enormous increase in load which some airfield pavements must now be designed to carry Even heavier loads are now contemplated by airplane designers Because of this trend the wheel load for the traffic test will be increased to 200,000 lb or more, if feasible, with contact pressures ranging between 130 and 150 p s i

Stockton Army Air Field was selected as the site for this test section because

1 Preliminary explorations made in 1945 revealed that the moisture content of the native adobe clay subgrade beneath a portion of the flexible pavement on one of the existing runways had become equalized to depths of 4 to 6 ft This pavement which is approximately 18 in in total thickness was constructed in the summer of 1941 during favorable weather, permitting control of subgrade moisture contents within a range of 16 to 18 per cent of the dry weight of the soil After a period of 4 years this moisture content

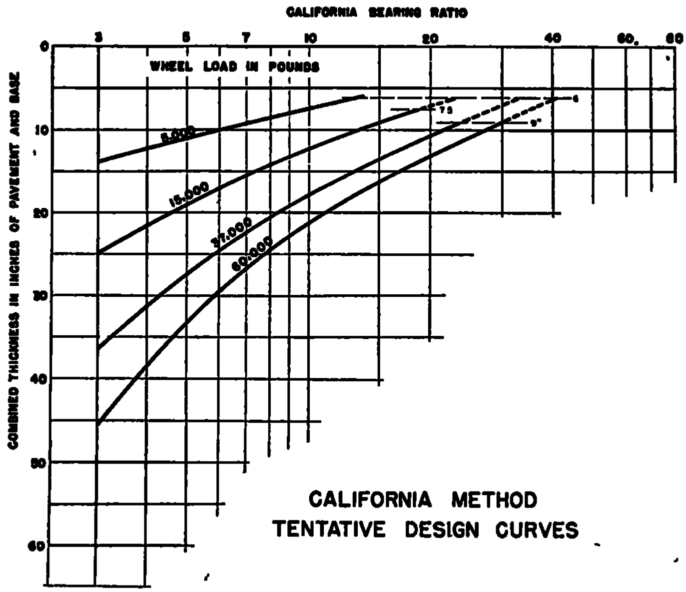

Figure 1. These design curves have been checked by previous accelerated traffic tests and are now accepted as standard design criteria by the Corps of Engineers.

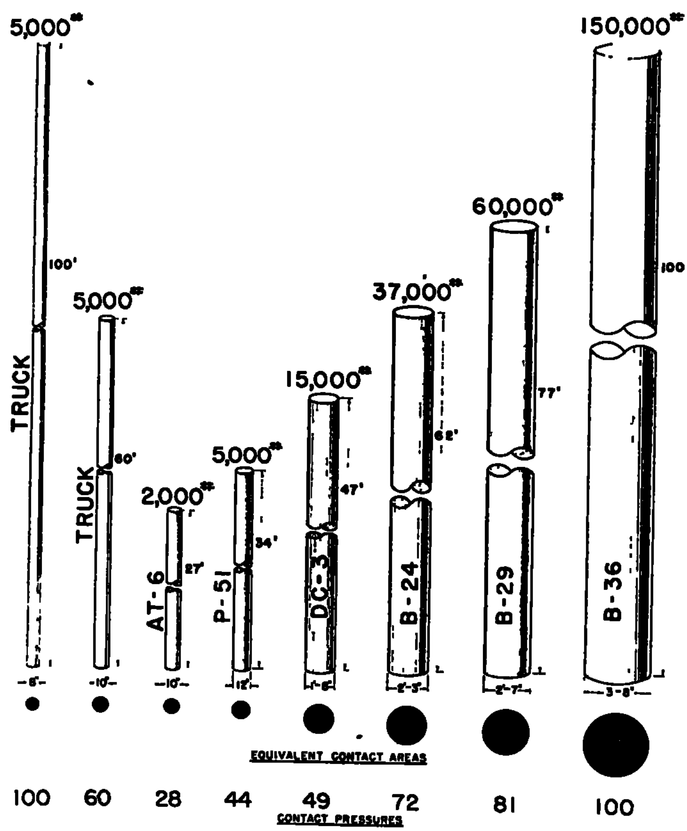

Figure 2. Wheel Loads of Aeroplanes and Trucks. Shown as columns of concrete having same diameters as circles representing actual contact areas of loaded tires.

had increased to about 27 per cent. Field CBR tests showed "in place" values ranging from 4 to 9 per cent.

2. Investigation of available borrow pits and commercial sources indicated that soils and materials having the desired characteristics could be obtained within a reasonable distance of the site.

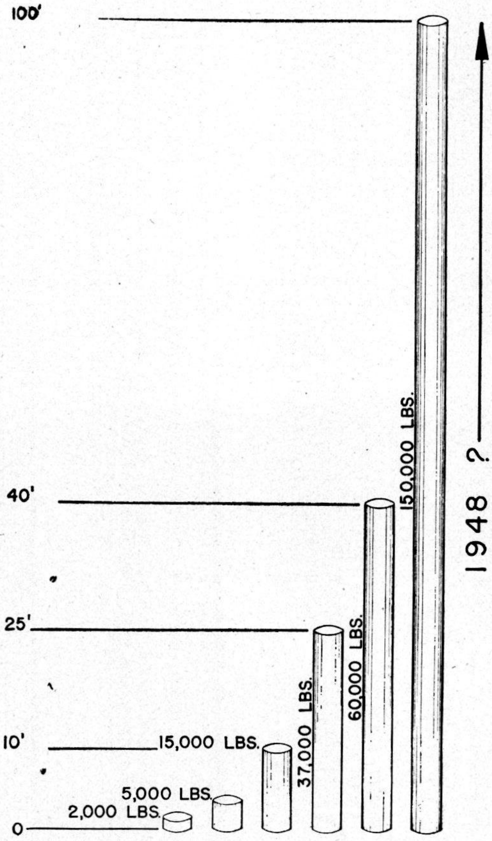

Figure 3. Wheel Loads as Columns of Concrete 3 ft.-8 in. in Diameter.

3. Test data can be correlated with that obtained during the original accelerated traffic test,[3, 4] conducted by the Corps of Engineers at this airfield in April 1942 to verify the tentative design curves for lighter wheel loads. The location selected for the test section is shown in the aerial photograph, Figure 4.

4. The data obtained can also be correlated with exhaustive studies[5] of the adobe clay from this airfield made by the Flexible Pavement Laboratory, U. S. Waterways Experiment Station.

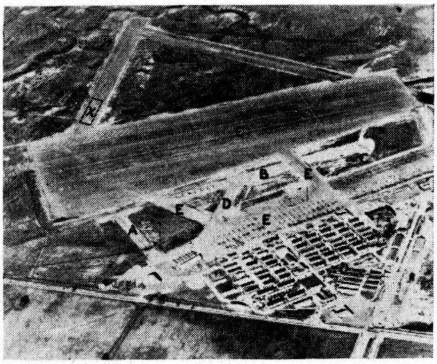

Figure 4. The X in the rectangular box locates the site of the 300,000-lb. test section. The photograph was taken prior to construction of the first Stockton test section, which was located at "D". The pavements at A, B, and C, are 6 in. of emulsion stabilized sand which failed in 1941 under light trainer planes. New pavements were constructed at E and X in 1941-42.

REVIEW OF INVESTIGATION

Instructions for this investigation issued by the Chief of Engineers required the construction and testing of special sections designed to provide information regarding the performance under traffic of approximately (a) A 6-percent ± CBR clay subgrade and a 20-percent ± clay loam subgrade, when protected by various total thicknesses of pavement base and gravelly sand sub-base, and (b) A 50-percent ± CBR clean gravelly sand subgrade when protected by various thicknesses of pavement, and pavement and base.

In view of the magnitude of the load, high quality asphaltic concrete pavement and crushed rock base material (CBR 100-percent +) were specified.

[3] Report on Stockton Runway Test Section, published by U. S. Engineer Office, Sacramento District.

[4] *Proceedings*, Highway Research Board, Vol. 22, 1942, "Foundations for Flexible Pavement," O. J. Porter.

[5] Technical Memorandum No. 213-1, "The CBR Test as applied to the Design of Flexible Pavements for Airports," published by the Corps of Engineers.

Materials meeting these requirements were selected from the results of numerous laboratory tests on specimens obtained from several borrow pits and various commercial sources.

A test section 650 ft long and 70 ft. wide, containing 23 individually designed items using different combinations and thicknesses of the selected materials has been constructed on the adobe clay subgrade after removal of a portion of an existing runway pavement These items include those in the turning areas

Field CBR tests were used to determine the bearing value of the undisturbed adobe clay subgrade and to control the processing and placing of adobe clay fill and the clay loam material Laboratory CBR tests on specimens remolded at field moisture content and density controlled the processing and placing of the gravelly sand and crushed rock base Standard Hubbard-Field stability tests, sieve analyses, and density measurements were used to control the mix design and the placing of the asphaltic concrete pavement.

A 200-ton capacity pneumatic roller designed by the Pacific Division was used in compacting the foundation materials in an attempt to reduce to the minimum further consolidation under the heavy wheel-load traffic.

After completion of the foundation and base, tests similar to those used for construction control were made on the various subgrade soils and foundation materials The results of these tests indicated "in place" CBR values for the sections as constructed of about 7 per cent for the adobe clay, 18 per cent for the clay loam, and 50 per cent for the gravelly sand.

Provisions are made for determining the extent and type of deformation due to traffic of the surface of each type of material, and for measuring the settlement or rutting of the pavement during traffic. Vertical movements under both static and moving wheel loads are measured at four to six points in each of the sections or items and recorded on photographic film using electrical deflection gauges and oscillograph equipment Progressive measurements of the magnitude of deflection and the rate of settlement during traffic detect any tendency of the foundation or pavement to become stronger or weaker due to either repetitions of load or changes in temperature

Traffic of the 110-in. diameter tire, mounted in a mammoth testing rig of unique design and loaded to 150,000 lb., has been uniformly distributed over a 20-ft wide traffic lane in each item. This traffic was initiated in September 1945 and continued intermittently until November 1945 when 262 coverages, or load repetitions had been completed over each portion of the traffic lane.

It was originally contemplated that this traffic would continue until failure or until 2,000 coverages had been completed However, it was found that both deflections and rate of settlement of the adobe clay and clay loam subgrades had decreased as traffic progressed and the weather became cooler. It was also found that a daily change in temperature from 80 F to 50 F stiffened the asphaltic concrete pavement and reduced deflections by as much as 30 per cent

Consequently, it was decided to explore and test the adobe clay and clay loam subgrades. These tests revealed that the clay had stiffened sufficiently to increase its CBR to an average value of 8 per cent Density measurements and laboratory tests indicated that this stiffening was due to the decrease in temperature and not to consolidation of this subgrade under traffic

Similar investigations showed that during this traffic period the clay loam subgrade had increased in CBR value from about 18 per cent to 24 per cent Density measurements indicated that the subgrade had consolidated 2 to 4 lb per cu ft during traffic, which would account for at least a portion of the increased strength The possibility of developing even a somewhat higher "in place" CBR value with additional traffic appears likely

As a result of these findings, resumption of traffic has been postponed until the summer of 1946 when higher temperatures will prevail The load on the single tire is to be increased to 200,000 lb and contact pressures to about 150 p s i Traffic of this heavier wheel load will continue until failure or until 2,000 coverages have been completed To further increase the severity of the test and to insure completion of traffic during the coming summer and fall months the width of the traffic lane has been reduced to 12 ft

The observed behavior of the pavement in the various items is to be correlated with laboratory and field CBR tests made on the soils and foundations materials immediately after failure, or subsequent to completion of traffic. The data obtained will be analyzed and correlated with design curves for lighter wheel loads for the purpose of developing an empirical design curve for the 150,000-lb. wheel load

Electrical measurements of deflections of the pavement, base and subgrade soils under both static and moving wheel loads of 36,000, 100,000 and 150,000 lb were recorded prior to and subsequent to completion of the 262

also to be made using two sets of 56-in diameter tires mounted in tandem, inflated to pressure of about 170 p s i. and loaded to 150,000 lb as it is now anticipated that this type of wheel assembly may be used in the future on some of the heavier airplanes

Triaxial shear tests are to be made on the foundation materials and pavements subsequent to traffic Modified static load bearing tests using the 150,000-lb load on the 110-in. tire, in lieu of the standard 30-in diameter steel plate, have been completed

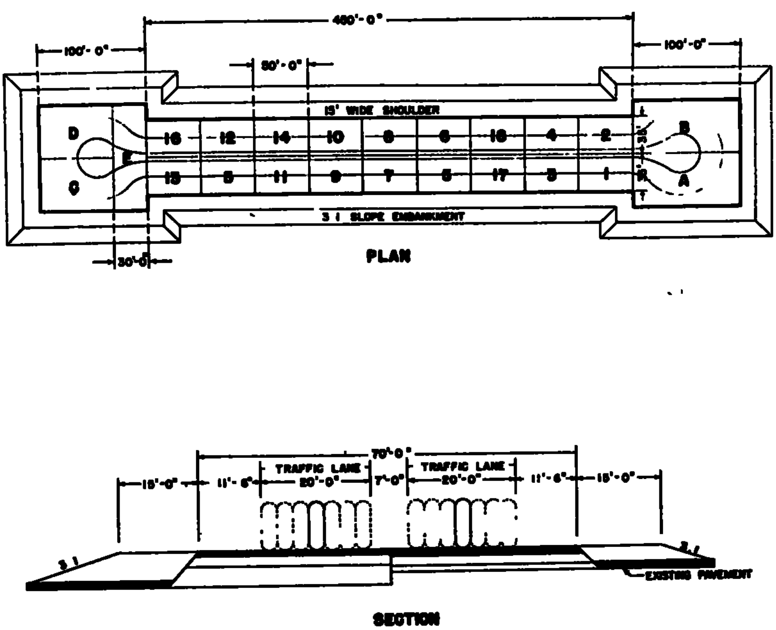

Figure 5. Layout Plan of Test Track

coverages of the 150,000-lb load The latter readings, which were made during cool weather, will be repeated with similar measurements for the 200,000-lb. wheel load being made when traffic is resumed

Deflection measurements for the 150,000-lb wheel load were also made at the end of 60 coverages Deflections under the moving wheel load of 200,000 lb will be made at the end of 100, 300, 1000, and 2000 coverages

The distribution of stresses in the pavement foundation under moving and static wheel loads of 100,000, 150,000, and 200,000 lb are measured in selected items, using electrical pressure cells installed at various depths in the base and subgrade

Deflections and pressure measurements are

The additional data obtained from these supplemental tests will be used in interpreting test results and in the general development of flexible pavement design criteria. The pressure and deflection measurements will provide data for theoretical analyses of the stress strain characteristics of the materials, and the distribution of pressure in layered foundations

TEST SECTION

Layout

The test section is an asphaltic concrete paved embankment constructed after removal of a portion of an existing runway pavement The paved area includes a test track 70 ft wide and 450 ft long, with 100 ft square maneuver areas at each end This test track is divided into 18 items or sections, 50 ft long and 35 ft wide, each of a different design. The items are identified by numbers and their surface dimensions and relative location in the test section are shown on the plan in Figure 5 The cross section on this effort required to pull the heavily loaded testing rig at speeds of 4 to 5 miles per hour.

The 15-ft wide shoulders and 3 to 1 embankment slopes afford ample support for the pavement and foundation and protect the subgrade and base materials from absorption of moisture from the sides

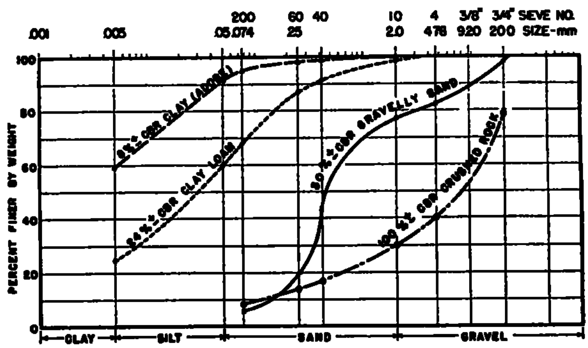

Figure 6. Typical Mechanical Analysis Curves for Foundation Materials

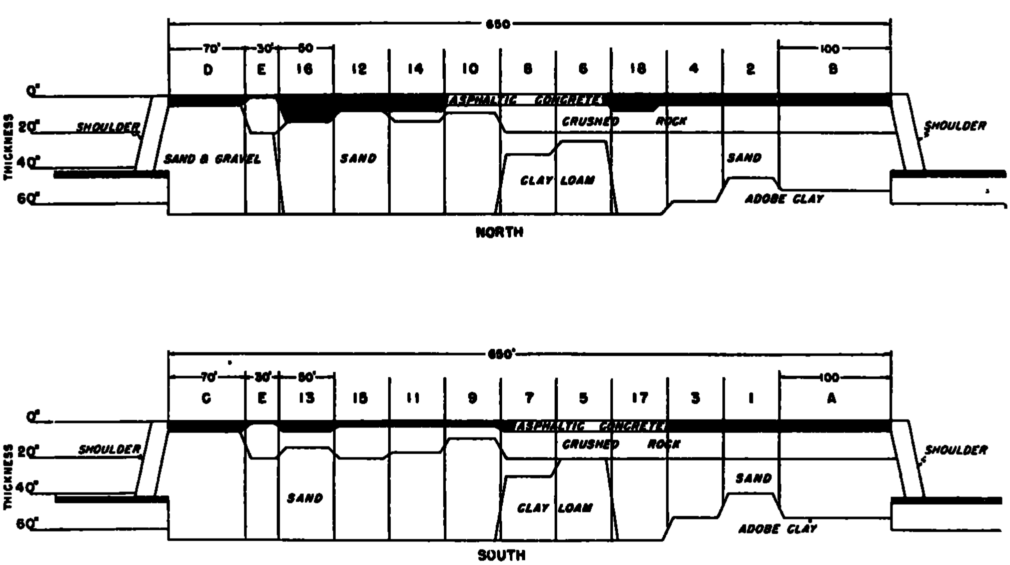

Figure 7. Profiles Along Traffic Lanes

figure also shows the maximum range in thickness of the various items and other general features of the test track

The pavement and oiled shoulders form a crown section with 1½ per cent transverse slopes to insure adequate surface drainage Longitudinal grades vary from level to 0 33 per cent reducing to the minimum the tractive

Design of Items

Three groups of items, containing different combinations and thicknesses of the materials selected for testing, have been designed to accomplish one or more of the major objectives of this investigation Typical mechanical analysis curves of the clay loam, gravelly sand

and crushed rock used in construction of the 18 test track items and, of the native adobe clay subgrade soil, are given in Figure 6 The various soils classifications and physical characteristics of these materials are given in Table 1 The approximate CBR values reflect the effects of traffic and temperature as of November 1945 For simplicity the gravelly sand is identified hereafter as sand in both the discussion and accompanying figures The grouping of the 18 test track items, the arrangement of all items in the test section, and the relative thicknesses of the different materials and pavement used in their design, are indicated on the profiles in Figure 7 The five items in the two maneuver areas are

TABLE 1

Soils Classification			Atterberg Limits			Sp Gr	Approx in place CBR
B of S	Casagrande	PRA	L L	P. L	P I		
Clay (Adobe)	CH	A 7	52	19	33	2 73	8% ±
Clay Loam	CL	A 4	29	18	11	2 73	24% ±
Gravelly Sand	SP	A 3	24		N P	2 78	50% ±
Crushed Rock	GW	A 3	16		N P	2 90	100% +

treated as a separate group since they are designed to provide limited comparative data on special materials under varied traffic conditions

Details of the different mixes used in the design of the asphaltic concrete pavement are given in Table 2 The thicknesses of the wearing courses are varied from 1½ in to 2½ in , and of the binder course from 2 in. to 4 in to obtain total pavement thicknesses of 2, 4, 7, 10 and 16 in

The transitions between different thicknesses of layers of the same material in adjacent items, shown in Figure 7, extend 5 ft. into each item The purpose of these 10-ft transition sections is to reduce to the minimum the possibility of failure along the end of one item affecting the behavior of an adjacent stronger item The remaining relatively large area of uniform design will permit detailed correlation of the behavior of the pavement under traffic with the results of "in place" CBR tests made on foundation materials after traffic

The three groups into which the 18 test track items have been segregated and the group of five items in the maneuver areas will be discussed separately. To facilitate this discussion these groups are presented schematically in the accompanying figures.

Weak Subgrade Soil (CBR 8 per cent ±). The five items shown in Figure 8 will provide data on the relative behavior of the adobe clay subgrade when protected by total thicknesses of pavement, base, and subbase varying from 40 in to 66 in Total thicknesses of

TABLE 2
ASPHALTIC CONCRETE MIX DESIGNS
Low Dust Content Mix (Item A only)

Screen Size	Percentage Passing Screens (Square Openings)	
	For Binder Course	For Wearing Course
1½-in	100	
1-in	70–90	100
¾-in	52–75	95–100
⅜-in	32–52	64–80
No 4	22–36	40–55
No 10	16–26	23–33
No 40	7–13	12–22
No 80	3–8	7–16
No 200	1–4	1–5
Bitumen (% by wt)	4½–5½	5–6½

Standard Dense Mix

Screen Size	Percentage Passing Screens (Square Openings)			
	Binder Course		Wearing Course	
	2 in – 2½ in	3 in to 4 in	1½ in to 2 in	2½ in
2-in		100		
1½-in		76–100		
1-in		64–75		100
¾-in	100		100	85–100
½-in	76–100	48–63	86–100	73–88
⅜-in	58–71			
No 4	35–54	30–48	55–67	46–60
No 10	24–42	20–37	40–54	32–47
No 40	10–23	10–21	22–31	16–26
No 80	6–15	6–13	12–20	10–18
No 200	3–8	3–7	4–8	4–8
Bitumen (% by wt)	3 5–5 5	3 5–5.5	5–6	5–6

40, 46, 52, 59, and 66 in. have been obtained by varying the thickness of sand base in each item. The 7-in pavement and 15 inches of crushed rock are considered ample reinforcement over the sand, thus confining any determinental movement which develops under traffic to the clay adobe subgrade.

Medium Strength of Subgrade Soil (CBR 24 per cent ±) The four items shown in Figure 9 with total thicknesses of pavement base and subbase varying from 22 to 37 inches will provide similar data on the clay loam subgrade As in the preceding group, the thickness of sand base has been varied to give total thicknesses of 22, 27, 32 and 37 inches. To make certain that no detrimental movement of the weaker adobe clay subsoil will develop under traffic, all items have a total thickness of 66 inches, thereby restricting the comparison of their behavior to a study of the clay loam subgrade.

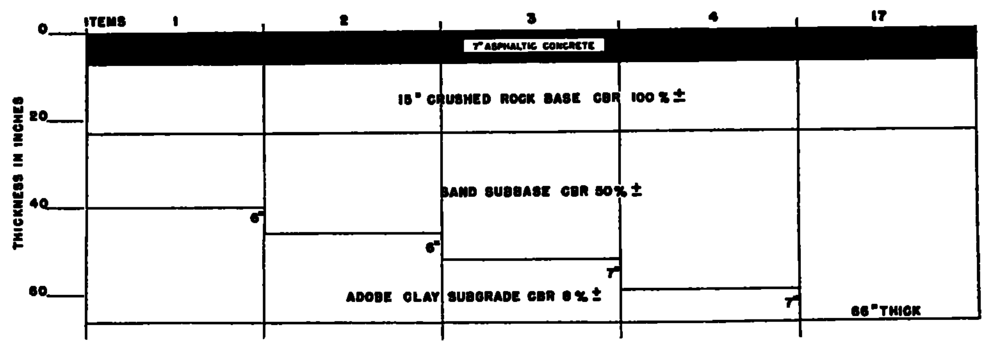

Figure 8. Design for Weak Subgrade

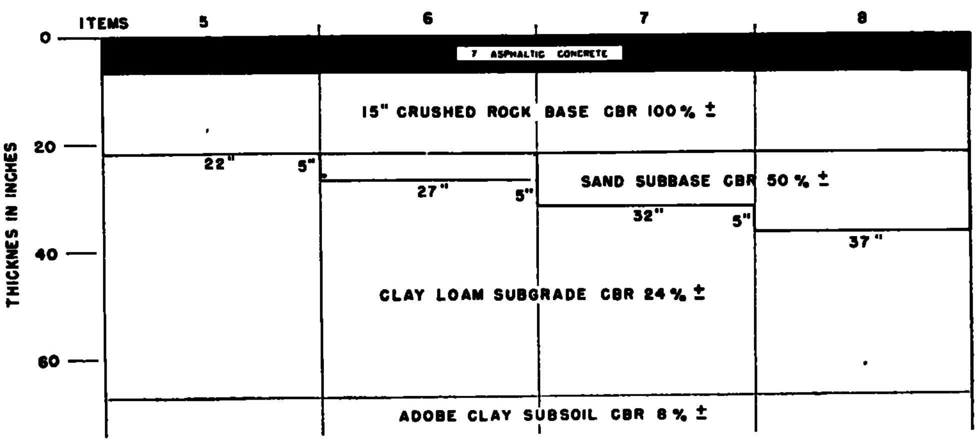

Figure 9. Design for Medium Strength Subgrade

Strong Subgrade or Subbase Study (CBR 50 per cent ±). The ten items grouped in Figure 10 are designed to provide data on the relative behavior under traffic of different thicknesses of pavement and of various combinations of asphaltic concrete pavement and crushed rock base when supported by an adequate depth of highly compacted sand subgrade or adequate thickness of dense sand subbase. The 16 inches of asphaltic concrete pavement in Item 16 is believed to be a much greater thickness of reinforcement than necessary, but it will furnish information for comparison with conventional designs of similar total thickness of asphalt concrete and base course.

Miscellaneous Data. The turning areas are divided into five different items each designed to obtain a limited amount of data for correlation with the behavior of adjacent items and of similarly designed items in the test track. No provision is made for deflections or pressure measurements. Details of these items are shown on Figure 11.

Items A and B are similar in design to Item 2 (7 inches of dense graded pavement, 15 inches of base and 31 inches of sand subbase), except that the asphaltic concrete surfacing in Item A is a low dust content mix. It is anticipated that data will be obtained on the relative behavior of the two different types of asphaltic concrete pavement under the turning action of the heavily loaded large contact area tire. Also data on the respective resistance of the two types of pavement to cracking due to deflections or differential settlement may be obtained served The behavior of the 6-in. asphaltic concrete pavement in Item C can also be partially correlated with the behavior of the 10-in. and 16-in pavements in Items 12 and 16.

Item E, which was added after final plans had been prepared and construction initiated,

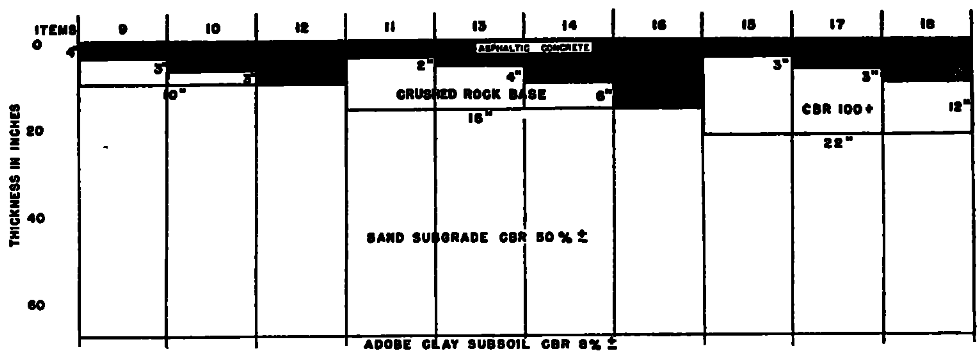

Figure 10. Design for Strong Sand Subgrade

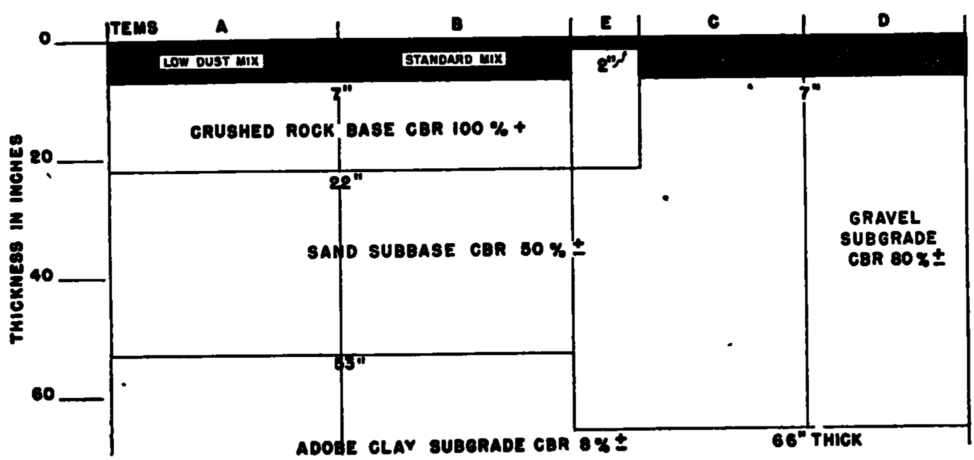

Figure 11. Maneuver Areas—Miscellaneous Data

Items C and D have 7 inches of the dense well-graded asphaltic concrete placed on two different types of granular foundation materials Total thickness of each item is 66 inches Item C has 59 inches of highly compacted 50 per cent ± CBR sand. Item D has 59 inches of a highly compacted sand and gravel material graded to represent a typical pit run material having a CBR of 80 per cent or better The relative behavior of these two types of bases under traffic is to be observed

consists of 2 inches of the standard dense well-graded asphaltic concrete and 20 inches of crushed rock base on 45 inches of granular base. Every effort is being made to confine the traffic in this item to the traffic lanes, in order that the behavior of the thin pavement under controlled traffic can be correlated with the behavior of the thicker pavements in Items 15, 17, and 18, which have the same total thickness of pavement and base.

TESTING RIG

The testing rig is a mammoth piece of equipment especially designed by the Corps of Engineers for testing both existing airfield pavement and special test sections with accelerated traffic of airplane tires carrying loads representing weights of the airplanes. Provisions are made for mounting the single B-24 tire and gear, the dual tired B-29 assembly and the 110-in. diameter B-36 tire and wheel, and for loading these tires to 37,000, 60,000 and 150,000 lb., respectively. The B-36 wheel is equipped with air brakes so that the effect of dead wheel landings and locked wheel turns, both on the tire and on the flexible pavement, may be determined. Consideration is now being given to mounting a multiple tired (dual-tandem) landing gear assembly in the rig to carry loads of 150,000 lb. and greater.

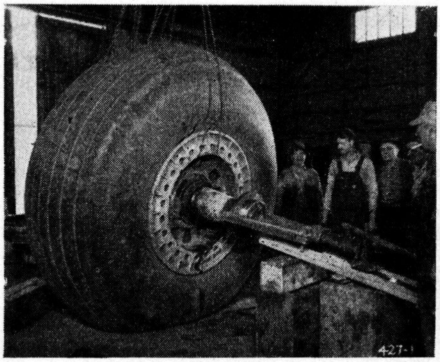

Figure 12. This picture was taken when failure of the magnesium airplane wheel at the end of the first 262 coverages (about 450 miles of travel) required its replacement with a steel wheel. This change increased the weight about 5,000 lb.

The testing rig consists of three units: A load box in which is mounted the testing wheel and tire, a yoke mounted on two 18- by 24-in. tires to balance to load box, and a Super C Tournapull power unit. The load box is divided into three compartments by heavy steel partitions. The tire and wheel are mounted in the center compartment. The two end compartments have sufficient capacity to permit uniform loading of the tire to a total load of 150,000 lb. using pig iron or cast iron weights. By using lead, the load can be increased to 200,000 lb. or more. A pin connection at the front of the load box and greased slides between the load box and yoke permit free vertical movement. Consequently, the weight of the tire assembly and load box are exerted through the tire to the pavement without restriction. Figure 12 shows a photograph of the 110-in. diameter tire and wheel being worked on in the shop.

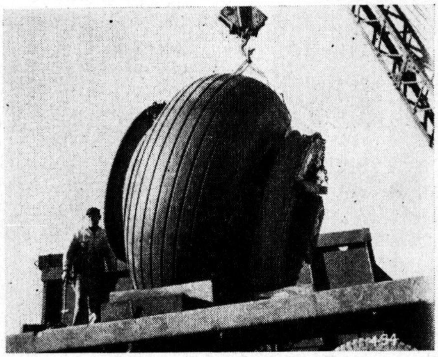

Figure 13. This is a new tire being installed. Failure of the magnesium wheel ruined the casing of the original tire.

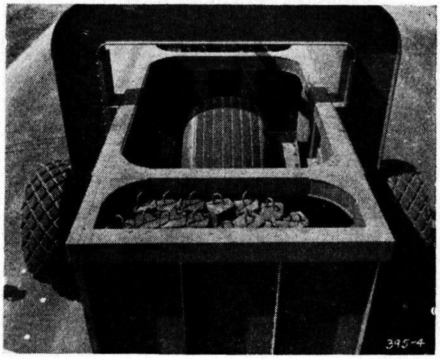

Figure 14. The testing rig loaded to 100,000 lb. Iron bars are added to increase the load to 150,000 lb.

In Figure 13, the tire and wheel, with airbrakes attached, are being mounted in the rig. The width of the inflated tire is 44 inches. Its enormous size is clearly indicated in this photograph.

The tire, weighted load box and yoke are shown assembled in Figure 14. The completely assembled test rig is shown operating on the test track in Figure 15.

Footprints of the tire when loaded to 31,000, 100,000, and 150,000 lb. are shown in Figure 16. The dimensions, contact areas, and contact pressures given in this figure are subject to correction as they may be in error, due to the method used in obtaining the prints.

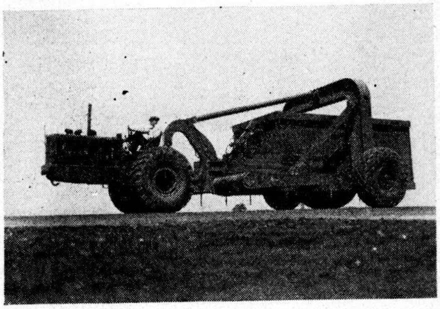

Figure 15

reducing the width of the lane to about 12 ft., the inner track and two outer tracks will be eliminated, decreasing the number of tracks to four. The two inner tracks will cover the electrical pressure and deflection gauges.

The 19- to 20-ft. width of pavement remaining outside of the traffic lanes and the 12- to 13-ft. space between the lanes eliminates any necessity for considering edge effects in interpreting test results.

PRELIMINARY INVESTIGATIONS

Selection of Site. To locate an area where uniform moisture conditions obtained in the adobe clay subgrade beneath the existing runway pavements, about 100 exploration holes were bored to depths of 9 or 10 ft. using the 1-in. Porter sampler. About 80 of these holes were in the area finally selected as the

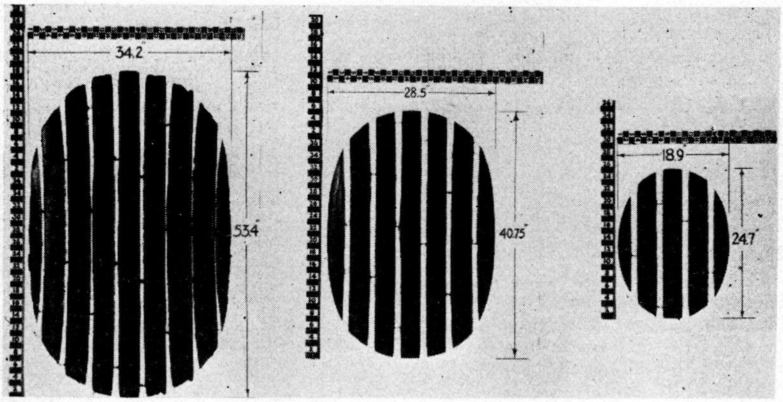

Figure 16. Footprints of 100-in. Diameter Tire for Various Wheel Loads

Wheel Load	**150,000 lb.**	**100,000 lb.**	**31,000 lb.**
Contact Area	**1526 sq. in.**	**988 sq. in.**	**373 sq. in.**
Contact Pressure	**100 lb. per sq. in.**	**101 lb. per sq. in.**	**83 lb. per sq. in.**
Tire Inflation Pressure	**103 lb. per sq. in.**	**98 lb. per sq. in.**	**98 lb. per sq. in.**
Deflection	**$10\frac{1}{2}$ in.**	**$7\frac{1}{4}$ in.**	**None**

Traffic

The uniform distribution of traffic of the 150,000-lb. wheel load over the 20-ft. wide traffic lane shown on the plan and section in Figure 5, and the planned reduction of the width of the lane to about 12 ft., have been discussed.

As indicated on the typical section, seven single passes or tire tracks are required for a complete coverage of the 20-ft. lane. In

site for the test section. Moisture contents and densities were measured, and field CBR tests were made in each 6-in. increment of the adobe clay subgrade to a depth of 6 ft. in test pits at 35 locations in the selected area. Results of these tests indicated that uniform moisture conditions obtained in the subgrade and that "in place" CBR values were within the desired range of 5 to 9 per cent. Undisturbed samples of the native soil were tested in the laboratory for correlation with field CBR test results. Laboratory tests were also made on remolded samples to obtain data required for placing embankment fill having CBR values conforming with the undisturbed clay subgrade

Foundation Materials And Soils

A thorough investigation was made of available borrow pits Specimens from 13 sources of clay loam, and 13 sources of gravelly sand were tested in the laboratory to determine their CBR moisture relationship when compacted to maximum density. The purpose of this investigation was to obtain data for the selection of materials which, when compacted at or near the required moisture content, would have "in place" CBR values that would not be too sensitive to variations in moisture content of 1 to 2 per cent, or to further increases in density due to consolidation under the heavy wheel load traffic

In order to determine the CBR values which probably could be obtained within the limits of moisture content control feasible during construction, and to anticipate the effect of traffic consolidation, special testing methods were employed Specimens from each source were compacted in the 6-in CBR mold at various molding moisture contents, using both 55 and 100 blows of the 10-lb rammer per 1-in. layer Immediately after compaction standard CBR tests were performed on the unsoaked specimens

A clay loam material was selected which the tests indicated would have a CBR ranging from 15 to 20 per cent at moisture contents ranging from 13 to 14 per cent At these moisture contents this material did not show an appreciable increase in density or CBR value for the increased compactive effort

Tests on the selected gravelly sand showed CBR values of 40 per cent for specimens compacted with 55 blows, and of 55 per cent for specimens compacted with 100 blows at moisture contents ranging from 4 to 10 per cent Specimens compacted under a static load of 3,000 lb per sq in showed CBR values of 60 to 80 per cent for moisture contents ranging from 6 to 12 per cent Moisture-density curves were very flat, indicating an optimum moisture content of about 5 per cent and optimum density of about 116 lb per cu. ft. for specimens compacted with 100 blows. Moisture density curves for the 55-blow specimens and the 3,000 lb per sq in static load were almost identical

The 80-percent CBR gravel used in Item D and the 100-percent CBR crushed rock base material were tested when compacted to high density slightly on the dry side of optimum Since the specimens were not soaked, very high CBR values were obtained on both of these materials

It is to be emphasized that the testing procedure used in determining the subgrade soil and foundation requirements for this test section vary materially from the standard methods[6] used for airfield pavement foundation design This procedure permitted analysis for the "in place" conditions

It was recognized that there was a possibility that this testing procedure might not indicate the CBR values ultimately developed in the prototype under traffic This possibility is reflected in the behavior of the clay loam subgrade discussed previously

In these preliminary investigations 683 laboratory CBR tests, 373 field CBR tests, 1100 moisture and 186 density measurements were made.

CONSTRUCTION

The necessity for obtaining substantially uniform CBR values in each material, required a special study of the procedures to be used during construction. Every effort was made to develop methods which would reduce variations in physical characteristics, moisture content, and density to the minimum

To avoid costly removal and replacement of large quantities of materials, a pilot section approximately 20 ft wide and 100 ft long was constructed Different processing methods were tried, from which the method or methods producing the most uniform results with the least amount of effort were selected

The essential problem involved in processing the clay adobe and clay loam soils was to obtain moisture contents within close limits (1 to 2 percent) uniformly throughout all of the material Consequently, the procedure to be used in adding and mixing water in these materials was thoroughly investigated

Adobe Clay Fill

Adobe clay for the embankment fill was obtained from a borrow pit adjacent to the

[6] Chapter XX OCE, Engineering Manual.

test site. Moisture contents of this material ranged from 2 to 6 per cent lower than the laboratory tests had indicated were required to provide the desired "in place" CBR value.

A layer of the clay was spread by carryall on a "mixing table" and sprayed with water in amounts determined necessary by moisture content and field CBR tests. Water trucks equipped with a pump and a 30-ft. spray bar were used in the manner shown in Figure 17.

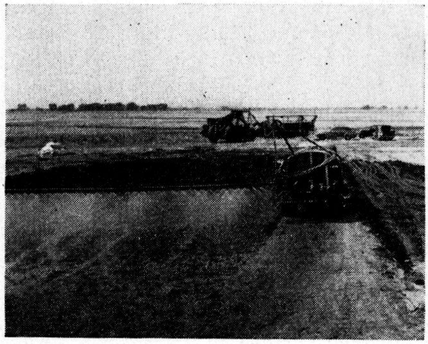

Figure 17. Uniform distribution of water is obtained by standard type lawn sprinkler heads mounted on the 30-ft. spray bar.

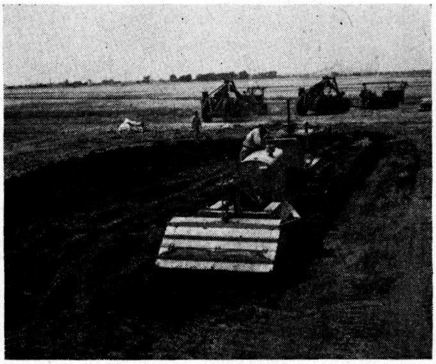

Figure 18

This equipment was also used during construction for moistening the partially completed work to compensate for loss of moisture by evaporation.

In developing the most efficient method of mixing the additional water uniformly throughout the clay mass, many different methods were tried. These included blading, disking, harrowing; working, reworking and rolling with carryalls and bulldozers; and processing in a traveling mixing plant and with a Seaman Pulvi-mixer. Rolling the mixed material with weighted pneumatic tired rollers and steel wheeled rollers proved satisfactory.

The Seaman Pulvi-mixer broke the clay into a mass of small lumps throughout which the moisture was uniformly distributed and produced the best results. This mixture was placed on the grade in thin layers 3- or 5-in. thick and rolled with about five passes of a weighted pneumatic tired roller. The roller tires mashed the lumps and manipulated the

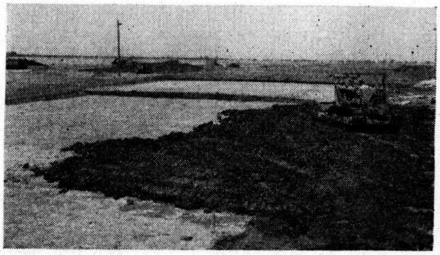

Figure 19. Spreading the clay fill subgrade. The asphalt emulsion sealed natural subgrade has been sprinkled lightly with sand.

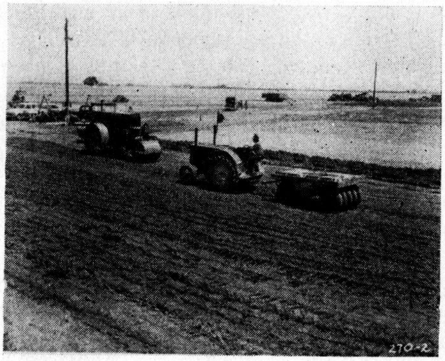

Figure 20

clay into a homogenous and uniform mass. The pneumatic-tired roller, with weights removed, and the steel wheel roller levelled the surface in preparation for placing the next layer of material. The photographs in Figures 18, 19, and 20 show the major steps in this processing procedure.

Clay Loam Subgrade

The clay loam material (24 per cent ± CBR) was obtained from two separate pits located within 10 miles of the airfield and stock-piled on the site. This proved to be a difficult material to process. Due to differences in their characteristics it was necessary to dry and blend the two materials thoroughly by blading, disking, and harrowing, in addition to mixing with the pulvimixer. Several repetitions of this processing were required. After blending, the desired amount of water was added and the material was mixed and placed on the grade in the same manner as the adobe clay.

The CBR value of the clay loam mixture was considerably more critical with respect to variations in moisture content and density than the preliminary laboratory tests had indicated. This made necessary numerous tests and processing operations not originally anticipated.

Sand Subgrade and Subbase

To insure uniformity, materials for the 50 per cent ± CBR sand base were separated on the No. 4 sieve prior to delivery from the pit. These materials were dried and blended by

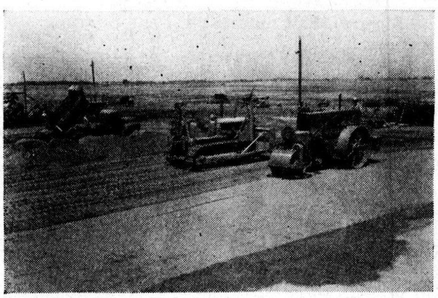

Figure 21

processing in an asphalt plant. Sufficient water was added in the pugmill to provide moisture content slightly dry of optimum after the mixture had been placed and compacted on the grade. The material was delivered in dump trucks and spread in layers 4 to 6 inches thick by an RD-8 bulldozer. High densities were obtained by tracking with the bulldozer and rolling with a 12-ton steel wheel roller, as shown in Figure 21. When sufficient layers had been placed to adequately protect the subgrade from detrimental deformation, additional compaction was obtained by rolling succeeding layers with three to four passes of the empty 200-ton pneumatic roller. The size of this roller is shown by the photograph in Figure 22. Its weight empty is 40 tons. The photograph in Figure 23, showing the 36- by 40-in. carryall tire being prepared for mounting in the roller emphasizes its size. This is the largest carryall tire manufactured to date.

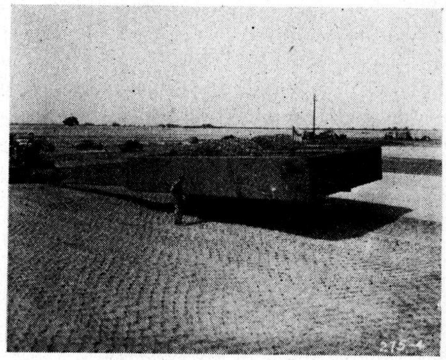

Figure 22. Dual 36- by 40-in. tires are mounted in two separate loadbox units, each 8 ft. wide and 26 ft. long. When used as a roller the units are bolted together. The long tongue is required when beams are inserted to spread the units to 25 ft. and 46 ft. center to center (equivalent to B-29 and B-36 wheel spreads) when the roller is used for testing.

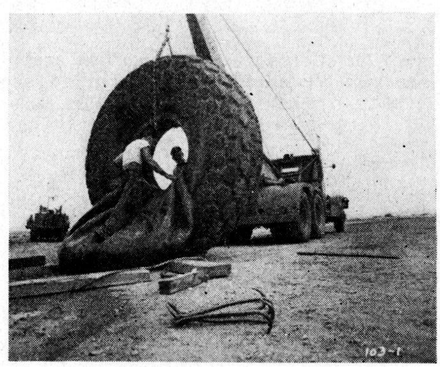

Figure 23

Gravel and Crushed Rock Materials

The materials for both the 100 per cent + CBR crushed rock base and the 80 per cent + CBR gravel were obtained from commercial sources. These materials were separated on the $\frac{3}{4}$-in. and No. 4 sieve, and then batched and mixed in an asphalt plant before being placed on the grade in the same manner as the 50 per cent ± CBR material. Further consolidation was obtained by rolling the finished surfaces with five passes of the 200-ton pneumatic roller loaded to 240,000 lb.

The asphaltic concrete pavement materials consist of crushed granite, crushed river gravel, clean river sand, fine silty sand, limestone dust filler, and 85-100 penetration asphalt. Six mix designs, conforming to the specifications in Table 2 were used. Hubbard-Field tests controlled the design. A 4-bin hot plant and a standard paving and finishing machine were used. Courses varied from about 1½ inches to 4 inches in thickness. Each course was compacted with a 12-ton, 3-wheel roller and finished with an 8-ton tandem. Relative densities of 92 per cent and 95 per cent of theoretical maximum, specified for binder and wearing courses respectively, were obtained. A picture of cores taken from the finished pavement for installation of deflection gauges is shown in Figure 24. After final rolling and finishing to a smooth plane, the top of the natural subgrade, and each processed subgrade and base course was sealed with about 0.3 gal. of asphalt emulsion per square yard. This seal prevented change in moisture content of the subgrade and base courses during placement of the next foundation course.

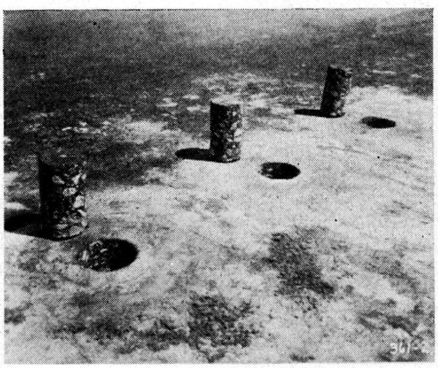

Figure 24. Cores were cut from 9-in. asphaltic concrete pavement using a chilled shot core drill.

During construction elevations at the intersection of grid lines spaced 3 ft. apart were recorded for the emulsion sealed surfaces. By checking against the original surveys the amount of settlement or deformation of these surfaces under traffic can be determined from resurveys made in trenches cut through the pavement to undisturbed subgrade material. The emulsion seal will provide a reference plane for measurements at intermediate points. These resurveys and measurements will be made immediately after failure of any item, and in each unfailed item subsequent to completion of traffic.

The elevation of points set in the finished pavement surface directly above the points surveyed during construction, were recorded prior to the initiation of traffic. These points are resurveyed at intervals during traffic to record any settlement or rutting of the pavement.

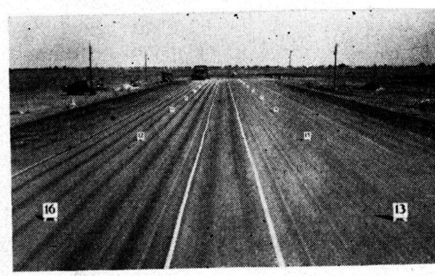

Figure 25. Completed Test Section

A photograph of the completed test section, taken prior to traffic, is shown in Figure 25. The numbered placards placed in the traffic lanes identify the items.

CONSTRUCTION CONTROL AND CHECK TESTS

Field Control, Adobe Clay and Clay Loam Subgrade Soils

The processing and placing of the clay adobe fill and clay loam subgrade soil were controlled by frequent moisture content measurements made both during processing and after placement, and by "in-place" density measurements and field CBR tests on the completed layers. The field CBR test was the controlling test. Materials not meeting design requirements were removed, reprocessed and replaced or, when possible, reprocessed in place. In determining moisture contents, small specimens were "quick dried" in a hot oven. This permitted close control of processing and placing operations as results were available within an hour after sampling. These results were checked constantly against standard tests made on large specimens.

Special field CBR testing equipment, designed to increase the accuracy of results and accelerate evaluation of the placed materials, was used in order to reduce interruptions of processing and placing operations to the minimum. A photograph of this equipment mounted on the rear of a pick-up truck is shown in Figure 26. Hydraulic fluid placed in the accumulator tank is maintained under a pressure of 1,000 to 2,000 p.s.i., using the hydraulic pump mounted on the right rear corner of the truck. A small hand valve controls transmission of the accumulated pressure to the penetration

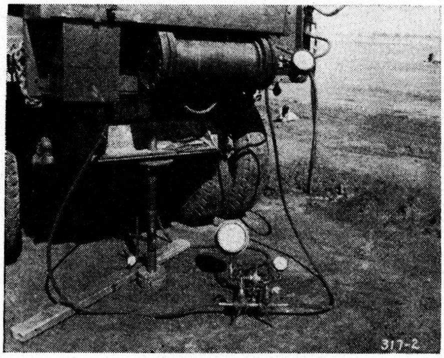

Figure 26. About 1500 field CBR tests have been made up to the present time.

piston. By observation of the Ames dial fastened to the piston, and stop watch control, the required constant rate of penetration of the piston can readily be maintained by the operator, regardless of the consistency of the material being tested. The pressure registered on the gauges mounted between the valve and the piston are recorded for each 0.1 inch of penentration. A helper records these pressures and calculates the CBR values as the test progresses. A spring fastened to the top of the piston returns it to its original position upon completion of the test and release of pressure. The pressure required to extend the piston to seating position is recorded and subtracted from the readings made during the test. The 6-in. diameter split surcharge weights placed around the piston approximate the pressure of the foundation and pavement to be placed on the surface being tested. A maximum surcharge of 30 lb. was specified.

Operation of this equipment proved it to be very advantageous. It is mobile, easily assembled, and produces uniform rate of penetration.

Control of Granular Foundation Materials

Due to the presence of 1-in and 2-in. particles in the sand, gravel and crushed rock materials, evaluation and field control by testing with the field CBR equipment was found impracticable. Consequently, reliance was placed on moisture content and density measurements, supplemented by laboratory CBR tests on remolded specimens taken from the grade.

Asphaltic Concrete Pavement

The usual sieve analyses, bitumen content and density determinations, and Hubbard-Field stability tests were used to control the mixing and placing of the asphaltic concrete pavements.

Scope of Tests

In controlling the placement of the soils and foundation materials 322 laboratory CBR tests, 492 field CBR tests, 580 moisture content and 313 density measurements were made.

Check Tests—Foundation Materials

To determine the effect on CBR values of any consolidation or change in condition of the subgrade soils and foundation materials, 83 test pits were excavated through these materials as construction neared completion, and before the pavement was placed. This procedure was adopted in order to avoid the removal and replacement of excessive amounts of materials in the test areas.

At least two of these test pits were excavated in each item at locations outside of the traffic lane. Moisture and density measurements and field and laboratory CBR tests similar to those used for construction control were made on each material.

The bearing values of the soils and foundation materials prior to traffic, as determined by the results of the CBR tests, will be compared with values determined subsequent to failure or completion of traffic from the results of similar tests.

Figure 27 shows the field CBR equipment

being used to test the subgrade at a depth of about 4 ft. below the surface. The piston is lengthened by inserting thick wall steel tubing machined to size and fitted with threaded connections. True vertical position of the piston is obtained by a ball and socket arrangement and a three point bolt and nut adjustment. Test results correlated well with laboratory tests on undisturbed samples.

In checking the "in place" condition after construction 445 laboratory CBR tests, 580 field CBR tests, 1225 moisture content and 625 density measurements were made.

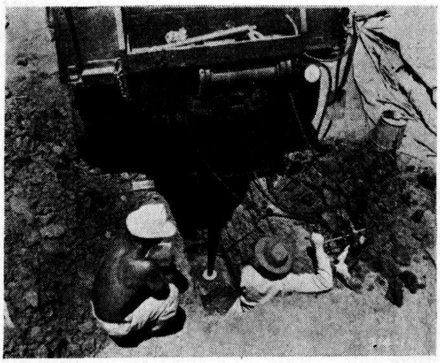

Figure 27

ELECTRICAL DEFLECTION AND PRESSURE GAUGES

Deflection Gauge Installations

Couplings for electrical deflection gauges were installed in duplicate in the surface of the pavement in each of the 18 test track items in such a manner that measurements of the vertical movements at the surfaces of the pavement, subbase, and subgrade could be made at two widely separated points in each item. These measurements are recorded on photographic film mounted on a continuous drive holder in an oscillograph. The plan in Figure 28 shows a typical layout of the deflection gauge installations.

Details of the electrical gauge and oscillograph equipment are given in "Foundations for Flexible Pavements," Appendix B by O. J. Porter, *Proceedings*, Highway Research Board, Vol. 22, 1942, which describes the instrumentation used in the original Stockton traffic test.

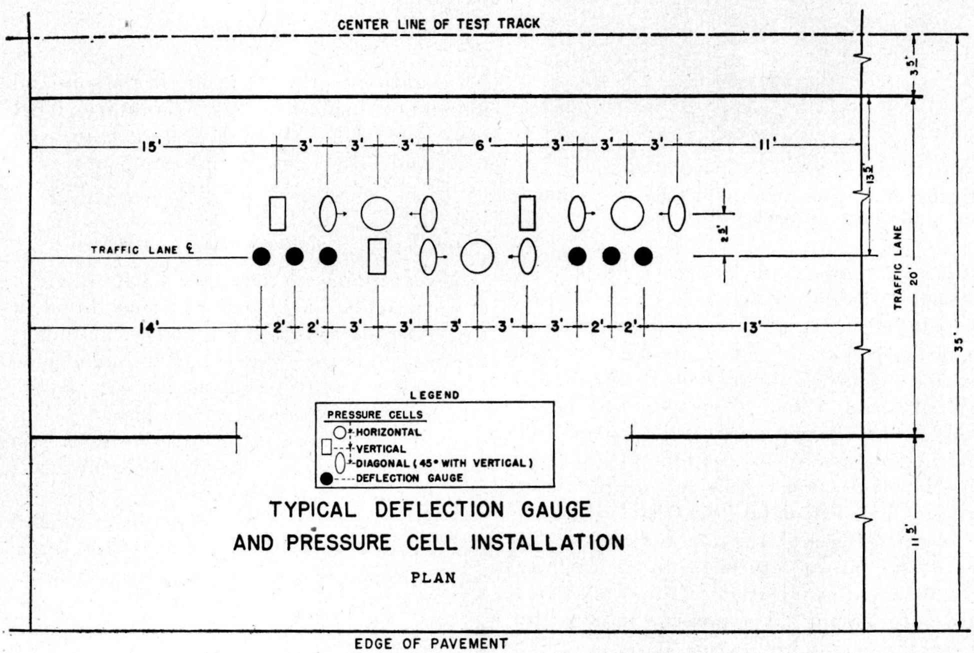

Figure 28

The major departure from the method of

installation previously used is the provision made for measurement of sub-surface reactions using gauges installed in couplings set in the surface of the pavement. This was accomplished by firmly seating redwood blocks 2 inches thick and 8 inches square in the surface of the subgrade and subbase during construction. After completion of the test section, 1-in. holes were drilled from the surface and lined with conduit to protect the reference rod from the effect of movement of the adjacent material under traffic. The ½-in. diameter reference rods were then fastened securely to the wooden blocks by means of wood screws welded to one end of the rods. The total movement of the pavement and foundation was referenced to rods driven to a firm and permanent seating in the subsoil.

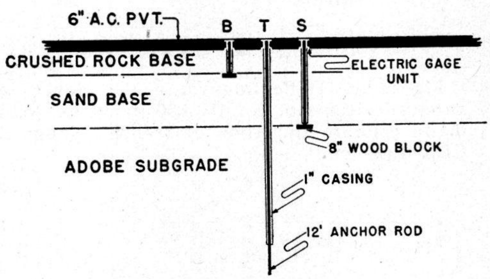

Figure 29. Typical Deflection Installation

Typical details of the deflection gauge installations are shown in Figure 29. The differences between the deflections referenced to the fixed rods and those referenced to the rods fastened to the redwood blocks measure vertical movements at the surfaces in which the blocks are placed. Deflections readings at gauge "B" measure the compression and permanent settlement developed during traffic in the pavement and base. From the readings at gauge "S" similar data are obtained for the pavement, base, and sand subbase combined. Gauge "T" measures the total deflection and deformation or settlement in the entire structure. By subtracting the measurements at "B" from the measurements at "S" the amount of movement in the sand subbase can be determined.

Using the conditions shown in Figure 29 as an example, subtraction of "B" readings from "T" readings gives the amount of vertical movement at the bottom of the crushed rock base or surface of the sand subbase. Similarly, the reaction at the surface of the subgrade is obtained by subtracting the "S" readings from the "T" readings.

The photograph in Figure 30 shows all of the units of a typical deflection gauge installation. The threaded brass core rod is fastened to the reference rod and the gauge installed

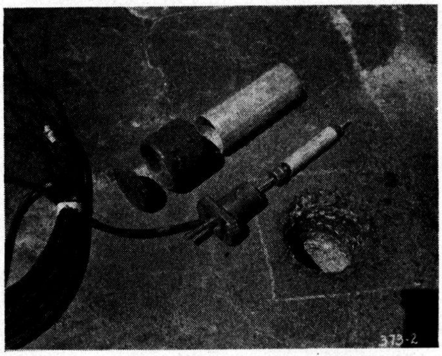

Figure 30

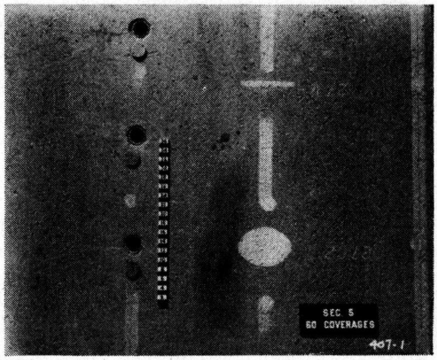

Figure 31. The narrow rectangle and the oval indicating vertical and diagonal cells are painted on the surface directly above the cell.

in the coupling only during the period when electrical measurements are being made. The rubber covered wire is used at that time to connect the gauge with an oscillograph housed in a bus, which permits movement of the equipment to any desired location. Figure 31 shows the couplings cemented in the pavement with caps removed ready for installation of the gauge and core rods.

Deflections under moving wheel loads of 36,000, 100,000 and 150,000 lb. have been made at all deflections gauges. Data have been obtained on the progressive vertical movement of the surfaces of the pavement, base, and subgrade as the load approaches and leaves the coupling when moving in the direction of traffic. Measurements are made with the loaded tire travelling along the track in which the gauges are installed. Similar measurements will be made for the maximum wheel load selected for use in the traffic test, (200,000 lb. or greater).

In items 1, 5, 10, and 17, a deflection pattern was obtained for the 100,000-lb. and 150,000-lb. wheel loads when moving in the direction

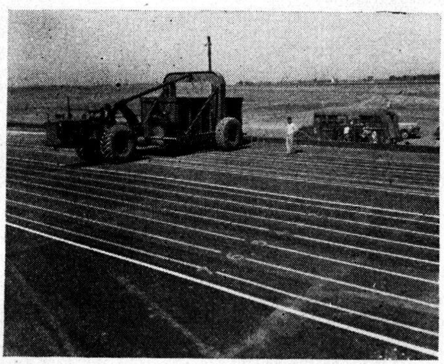

Figure 32

of traffic and also transverse to the direction of the regular traffic. Numerous readings are being made at offset distances sufficiently close to obtain all data required for the preparation of complete deflection contours.

Measurements under static loads of 100,000 lb. and 150,000 lb. were made with the loads centered over each coupling and at each offset point with the major axis of the tire both parallel and normal to the traffic lanes. A photograph showing the exterior of the bus used to house the electrical oscillograph and recording equipment, and the testing rig in a position transverse to the direction of traffic is shown in Figure 32.

Figure 33 shows the effect of the total thickness of pavement, base and subbase on the total deflection at the top of the pavement, the deflections at the top of the sand subbase (bottom of the crushed rock base), and at the top of the subgrade under moving and static loadings of 150,000 lb. Vertical movements in the pavement and base are also shown. These data which have been obtained for the pavements shown in Figure 8, are to be used in the study of the weak clay subgrade.

All measurements were recorded for conditions prior to the initiation of traffic. They have not been corrected for the differences in pavement temperatures due to the time of day or to weather conditions prevailing at the time the various readings were made. Available data indicate that when these temperature corrections are made, even smoother curves will result. The two points shown for each

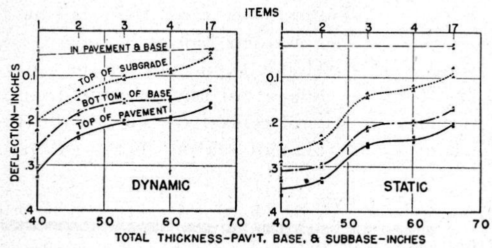

Figure 33. Deflections of weak adobe clay subgrade items under 150,000-lb. wheel loads made prior to initiation of traffic. Subgrade CBR 8 per cent ±.

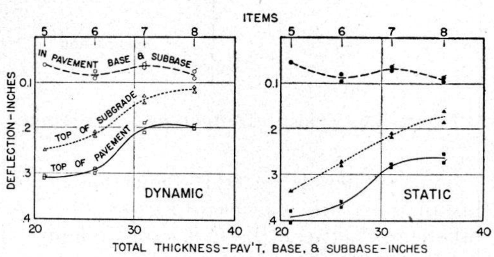

Figure 34. Deflections of medium strength clay loam subgrade items under 150,000-lb. wheel loads made prior to initiation of traffic. Subgrade CBR 24 per cent ±.

condition are measurements made at the duplicate gauges spaced 21 ft. apart as detailed in Figure 28. The closeness of these duplicate readings for such widely spaced points in each item reflects the uniformity obtained in the construction of the foundation.

Similar deflection data are shown in Figure 34 for the medium strength clay loam subgrade pavement designs depicted in Figure 9. Movements at the bottom of the sand subbase were not measured, and the reaction of the pavement, base, and subbase is combined.

It will be noted that deflections at the surfaces of the pavement, base and subbase shown in Figures 33 and 34 are greater for static than for moving (dynamic) loads. This difference in deflection under the two types of loading has been reported and discussed in previous investigations[7]. pressure cells of the type developed by the Waterways Experiment Station were placed at various depths in Items 1, 5, 10, and 17. These cells which are about 1 inch thick and 12 inches in diameter, measure pressures by

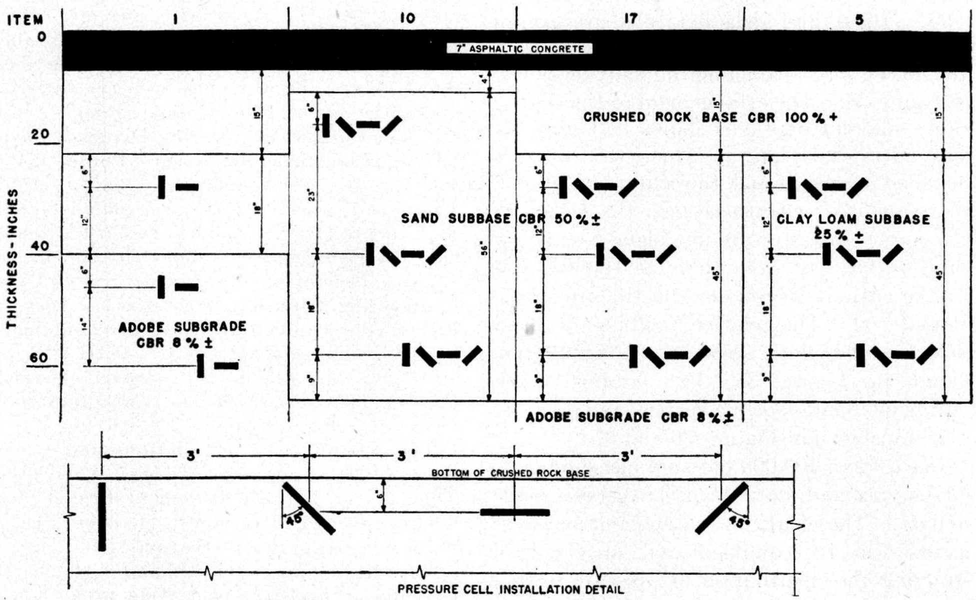

Figure 35. Pressure Cell Installation

Figure 36. Conduit encased connection wire is buried in a trench and extends to face of embankment.

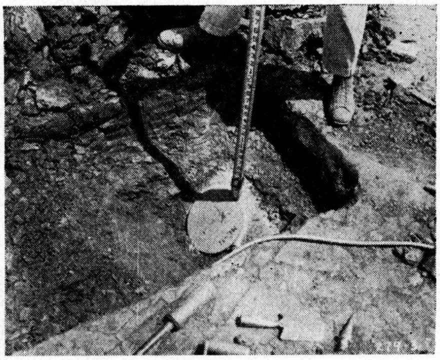

Figure 37

means of SR-4 strain gauges and are described in "Technical Memorandum No. 210-1, Interim Report on Soil Pressure Cell Investigation" dated 15 July 1944, published by the Corps of Engineers. Pressure measurements are made at the time, and at the same offset intervals that deflection measurements are made.

Pressure Cell Installations. To obtain data for determining the distribution of stresses in the subbase materials and subgrade soils,

[7] O. J. Porter, "Foundations for Flexible Pavements," *Proceedings*, Highway Research Board, Vol. 22, 1942.

In Items 5, 10, and 17 the cells are placed in three different positions, horizontal to measure vertical pressures, vertical to measure horizontal pressures, and diagonally at an angle of 45 deg to measure diagonal pressures Diagonal cells were not included in Item 1. The vertical and diagonal cells are placed normal to the regular traffic lanes. All cells are spaced 3 ft apart longitudinally as shown in Figure 28. The arrangement of the cells at three different depths is shown in Figure 35 The horizontal plane in which the cells are installed passes through the center of each cell. Consequently, cells placed near the surface of the base or subgrade are in a plane 6 in. below these surfaces in order that the vertical cells will be entirely surrounded by the same type of material. The relative positions of these cells are shown to scale in the installation detail in Figure 35 Photographs taken during installation of the vertical and diagonal cells are shown in Figures 36 and 37.

In excess of 100,000 pressure measurements for moving and static loads have been made to date These data and subsequent measurements will be compiled and analyzed in studying the distribution of pressure in and the stress-strain characteristics of the base and subgrade under these very heavy wheel loads.

ACKNOWLEDGEMENTS

This investigation is being accomplished in accordance with an Outline of Instruction issued by Office, Chief of Engineers, Colonel L C Urquhart, Chief, Engineering Division, Military Construction Division. The assistance of Mr T B. Pringle and Mr H J. Lichtefeld of the Paving and Railroad Branch, Military Construction Division, has been invaluable The work has been accomplished under the direction of Colonel John C. Low, CE, Chief of the Engineering Division, Pacific Division, and Brigadier General Philip G Bruton, CE, Division Engineer

The test section was constructed by the Sacramento District, Colonel Lester F Rhodes, CE, District Engineer, under the supervision of Mr Henderson E McGee, Asst Chief, Engineering Division, Sacramento District Electrical instrumentations and measurements have been supervised by Mr J. E Barton, aided by Mr. Glenn B. Morgan, Assistant Physical Testing Engineers, California State Division of Highways

The pressure cell installations and studies are under the direction of Mr. Wm. B Turnbull, Chief of the Flexible Pavement Branch, Embankment and Pavement Division, U. S. Waterways Experiment Station.

Mr. O. J Porter, consultant for the Pacific Division is in charge of testing program and preparation of the final report Mr R A. Freeman is head of the Airfields Section, Pacific Division