THE INVESTIGATION OF ROAD FOUNDATION FAILURES

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SUMMARY.

In recent years numerous investigations of road foundation failures have been undertaken by the Road Research Laboratory. The primary object is to reveal the causes of failure, and thus to obtain information leading to improved methods, of design, but they are, of course, of immediate assistance to the road engineer responsible for the maintenance of the roads.

The proper understanding of the causes of failure is rendered more difficult because of the absence of information as to the state of the failed area before failure set in. To overcome this, as far as practicable, a method of comparing conditions at neighbouring sound and defective areas has been employed.

At selected sites, trenches about 3 ft. (1m.) wide are cut though the road construction to expose the subgrade. The soil type and moisture distribution in the subgrade is determined and the level of the watertable located if it is within 8 ft. (2.4 m.) of the surface. Soil density measurements are made in the top 18 inches (50 cm.), of the subgrade and values of relative compaction tests. In the case of clay soils, the unconfined compression test is used to determine the variation of the shear strength of the soil with depth. California bearing ratio tests are made on undisturbed samples of the subgrade and at each site plate-bearing tests are made on the exposed subgrade and the modulus of subgrade reaction ("K") measured. The field work is carried out by a small team of assistants using a mobile laboratory stationed at the site during the investigation.

The application of the technique is illustrated by three recent road foundation failure investigations.

INTRODUCTION

This paper describes methods developed by the Road Research Laboratory for examining road failures and gives examples of their application to the study of the causes of

a) cracking and disintegration of portions of a concrete road
b) settlement and disintegration of a section of a bituminous road
c) differential movements between slabs of a concrete road.

Such investigations of failure in the foundation of a road help the road engineer to decide on the best methods of repair and give the research worker information of value in his studies of pavement design. In addition the investigations sometimes reveal new problems of interest both to the research worker and the maintenance engineer.

One of the main difficulties that has been encountered in investigating causes of road failures is the absence generally of information relating to the subgrade soil conditions at the time when the road was constructed. This difficulty has been partly overcome by the procedure adopted by the Road Research Laboratory in which a comparison is made of the condition both of the subgrade and the construction at neighbouring failed and sound sections of road. This procedure has been found in practice to be valuable in determining the various factors responsible for the road defects.

The main constructional layers of a road, namely, the surfacing, base, sub-base and subgrade are shown diagrammatically in Fig. 1.

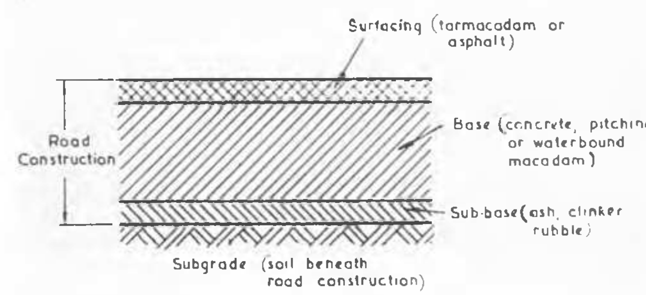


Diagram Showing Constructional Layers of a Road.

FIG.1

PROCEDURE EMPLOYED IN THE INVESTIGATIONS

As mentioned above two areas are selected; one which has failed and a neighbouring one which is sound. In selecting failed areas, for investigation, care has to be exercised to choose sites where little further deterioration is likely to have occurred in the subgrade subsequent to the initial failure due to the entry of water through unsealed road surface cracks. Trenches, about 3 feet (1 m) wide, are cut through the road construction to expose the subgrade at these sites. A half width of the carriageway is examined at a time in order that the road may be kept open to traffic.

A close examination is made of the road construction at each site and measurements are made so that an accurate cross-section of the actual road construction may be drawn. In the case of concrete roads the position and quantity of any reinforcement is noted and cores may be cut for strength tests.

The following tests are usually carried out on the subgrade soil at each site.

Soil type.

Boreholes are sunk in the top 4 ft. of subgrade using a 4-inch (10 cm) diameter post-hole auger, and representative samples (each weighing approximately 1 lb. (0.5 kilogram), are taken of each soil type encountered. These samples are sealed up in tins and removed to the laboratory for subsequent examination at the conclusions of the field work. Mechanical analysis and index tests are carried out on selected samples, the remainder being retained for any possible future tests.

Moisture conditions.

The moisture distribution in the subgrade is found by sinking boreholes about 4 ft.(1.2 m) deep at 1 to 2 ft. (0.3 to 0.6 m) intervals across the road and taking samples of soil at from 1 to 6 inches (2.5 to 15 cm) intervals in each of the boreholes for moisture content determinations. By plotting the variation in moisture content with depth, a diagram can be constructed showing the distribution of moisture in the subgrade across the road. At each site, one borehole is sunk to locate the water-table if the latter should be within 8 feet (2.4 m) of the surface.

Dry Soil Density.

Measurements are made of the dry soil density in the top 18 inches (50 cm) of subgrade either using the core-cutter method 1) or the sand-replacement method 1) depending upon the nature of the soil. A laboratory compaction test (A.A.S.H.O. T 99-38) is carried out on samples of the subgrade soil enabling the relative compaction of the subgrade to be found.

Shear strength.

When the subgrade consists of a clay soil reasonably free from stones, the variation in the shear strength of the soil with depth is found, using the portable unconfined compression apparatus described by Cooling and Golder 2). The assumption is made that the shear strength of the soil is equal to half the compressive strength.

The shear strength-depth profiles are used in the Glossop and Golder method 3) of determining the required pavement thickness. This method assumes that the shear strength of the soil is the main criterion of design and that the shear stress set up in the subgrade by the maximum permissible wheel load should always be less than the shear strength of the soil. The road construction and the subgrade soil are assumed to behave as a homogeneous elastic isotropic medium and the Boussinesq equation is used in the determination of the stress distribution. The Glossop and Golder design method employs an empirical shear stress distribution, obtained by dividing the maximum vertical stress by π . In the analysis of the results of failure investigations the shear stress distribution as given by Boussinesq has been employed as well as the empirical shear stress distribution. The assumption is made that the shear strength of the soil is equal to half the compressive strength.

California Bearing Ratio.

When possible, a number of undisturbed samples of soil are obtained, generally from the top foot (0.3 m) of subgrade at each site and stored in air-tight containers. The California bearing ratio test is carried out in the laboratory on these specimens both at their natural moisture content and after soaking for 4 days. When it is not possible to obtain undisturbed samples, remoulded specimens compacted to the field density, are tested.

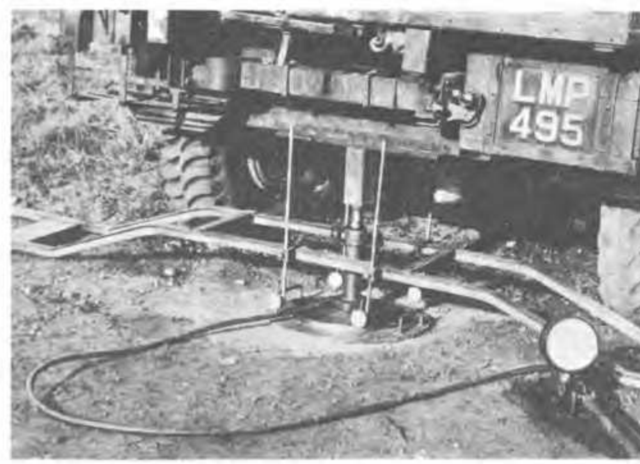
The results of the California bearing ratio tests are used in conjunction with the design curves given by Porter 4) in the estimation of the pavement thickness.

Plate bearing tests.

At each site several load-deflection measurements are made on the surface of the subgrade and also on the sub-base if one be included in the construction. The apparatus used is shown in Figs. 2 and 3. An 18 in. (46 cm) diameter plate is often employed, as this size

Equipment used in the Investigations to Measure the Bearing Value of the Soil.

FIG.2



Close-up of the Plate Bearing Test Apparatus.

FIG.3

Interior of Mobile Laboratory.

FIG.4

is found more convenient to use and is thought to reproduce more closely the state of stress produced by the normal road vehicle than the 30 in. (76 cm) diameter plate sometimes specified. The load-deflection measurements enable values of the modulus of subgrade reaction ("K" lb/sq.in./in.) to be found.

The field work is carried out by an officer aided by two or three assistants. A mobile laboratory is stationed at the site during the investigation, and if desired, all the soil tests can be carried out in the field. The mobile laboratory used in the investigations is shown in Figs 2 and 4.

APPLICATION OF THE TECHNIQUE

To illustrate the employment of the technique in practice, three recent road failure investigations will be described. In each case it was found that the defects were due to several different factors.

A. AN INVESTIGATION OF THE CAUSES OF CRACKING AND DISINTEGRATION OF PORTIONS OF A CONCRETE ROAD

The road at the site of the investigation was constructed in 1924 and consisted of a 24 ft. (7.3 m) wide singly-reinforced concrete carriageway with no central longitudinal expansion joint. Apart from the formation of a longitudinal crack along the crown of the carriageway, the road carried normal traffic satisfactorily until 1944 when unusually heavy traffic caused the rapid deterioration of many of the slabs (see Figs 5 and 6).

The concrete and subgrade were examined in accordance with the usual practice at two sites, site 1 where severe cracking had occurred and site 2 where there was only slight cracking of the slabs.

At site 1, there was 5-6 in. (13-15 cm) of concrete (the bottom 3 in. (7.6 cm) being badly honey-combed) and about 3 in. (7.6 cm) of sub-base, while at site 2 there was 7 in. (18 cm) of better quality concrete and 7 in. (18 cm) of sub-base. The subgrade soil was a heavy clay, the grading curves for samples of soil from different depths together with the results of the index tests are given in Fig. 7. The average moisture content of the top 2 ft. (0.6 m) of subgrade was 44 per cent at site 1 and 38 per cent at site 2, the difference being probably due to the entry of surface water through the cracks in the concrete at site 1.

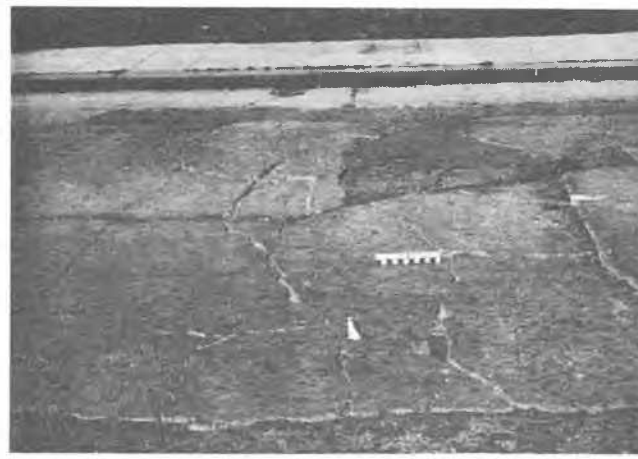
The results of plate-bearing tests, in this instance using a 30-in. diameter plate, are given in Table 1. It will be seen that the subgrade had a much higher bearing value at site 2 than at site 1 where failure had occurred.

Figs. 8 and 9 show strength/depth profiles for the subgrade at the two sitts, together with theoretical curves showing the variation with depth of the maximum vertical stress π and the maximum shear stress for a 12000 lb (5450 kg.) wheel load. The thickness of base and surfacing required by the Glossop and Golder method of design 3) and its modification using the maximum shear stress criterion for the subgrade at the time of the investigation are given in Table 2, together with the actual thickness of road at the two sites. It will be seen that both methods of design require greater thicknesses of construction at site 1 than that provided.

The 12000 lb. (5450 kg) wheel load used in the calculation is probably very rarely encountered in practice but when used with the above design methods it has been found to give results in closer agreement with practice than the 9000 lb. (4080 kg) wheel load which is the present legal limit in Great Britain (4 tons).

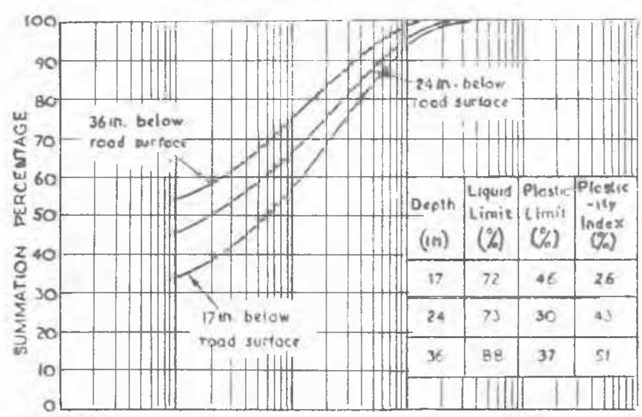
Area of Cracking and Settlement of a Concrete Road.

FIG.5



Severe Cracking and Disintegration of Slabs of Concrete Road.

FIG.6



Depth (in)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
17	72	46	26
24	73	30	43
36	88	37	51

Grading Curves and Results of Index Tests for Subgrade Soil beneath Cracked and Disintegrated Slabs.

FIG.7

It is possible that the assumption of a larger wheel load than occurs in practice may in effect be equivalent to taking account of such factors as impact and load repetition.

The conclusions arrived at from the investigation were (a) that the defective areas on the road developed as a result of insufficient thickness of concrete and sub-base to carry the very heavy traffic, and (b) that a total thickness of base and surfacing of 16 in. would have been adequate to prevent the occurrence of any serious defects. The continuous crack along the crown of the road would have been avoided by the use of a central longitudinal joint.

TABLE 1

VALUES OF "K" OBTAINED BY PLATE BEARING TESTS FOR SITES INVESTIGATED

Location of Test	Plate Bearing Values "K" (lb./sq.in./in.)			
	Site 1 (Extensive Cracking)		Site 2 (Slight Cracking)	
	On Sub-base Over sub-grade	On subgrade (Sub-base removed)	On Sub-base Over sub-grade	On subgrade (Sub-base removed)
East half of road	101	98	179	130
West half of road	87	58	173	146
Average	94	78	176	138

TABLE 2

THICKNESS OF ROAD CONSTRUCTION AT SITES INVESTIGATED WITH THEORETICAL VALUES GIVEN BY THE GLOSSOP AND GOLDER (3) AND THE MAXIMUM SHEAR STRESS METHOD OF DESIGN

Site Investigated	Actual Thickness of road construction (in.)	Thickness given by Glossop and Golder Method (in.)	Thickness given by Max. Shear Stress Method (in.)
Site 1 (Extensive Cracking)	9 (22.9 cm.)	12 (30.5 cm.)	16 (40.6 cm)
Site 2 (Slight Cracking)	14 (35.5 cm)	11 (27.9 cm)	15 (38.1 cm)

B. AN INVESTIGATION OF THE CAUSES OF SETTLEMENT AND DISINTEGRATION ON A SECTION OF A BITUMINOUS SURFACED ROAD

A 24 ft. wide bituminous surfaced road had shown severe settlement accompanied in some places by disintegration especially along the crown and northern side of the road (see Figs 10 and 11). This section of road had been a source of trouble for a considerable period of time and approximately £8000 had been spent on maintenance over a period of 8 years prior to the investigation.

The cross-section of the road (Fig. 12) showed a considerable variation in the thickness of construction from about 30 in. (76 cm) along the kerbs to about 10 in. (25 cm) along the crown. A 9-in. (23 cm) open-jointed drain with rubble surround was located on the northern side of the road at a depth of about 3 ft. (1 m).

The subgrade soil consisted of a rather silty clay, the clay content (material finer than 0.002 mm) increasing with depth. Grading curves for samples of the soil from different depths are shown in Fig. 13, together with the results of index tests. As seen from Fig 12 the top 2 ft. (0.6 m) of subgrade was on an average slightly wetter than the mean plastic limit.

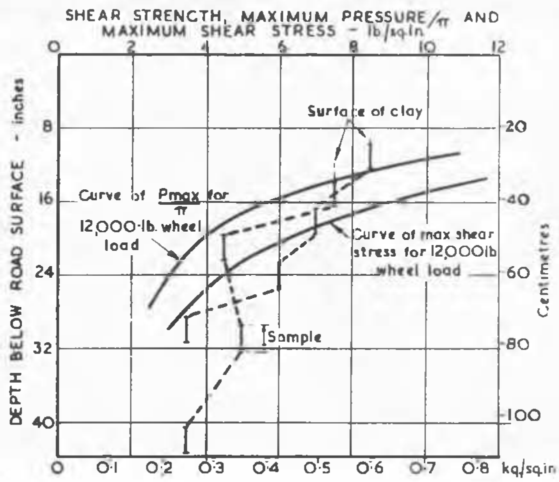
The variation in shear strength of the soil under the centre of the road and the theoretical shear stress curves for a 12000 lb (5450 kg.) wheel load are given in Fig. 14. These show that on the basis of the maximum shear stress criterion there was insufficient thickness of construction along the centre of the road.

The results of C.B.R. tests made on undisturbed samples of soil are given in Table 3.

TABLE 3

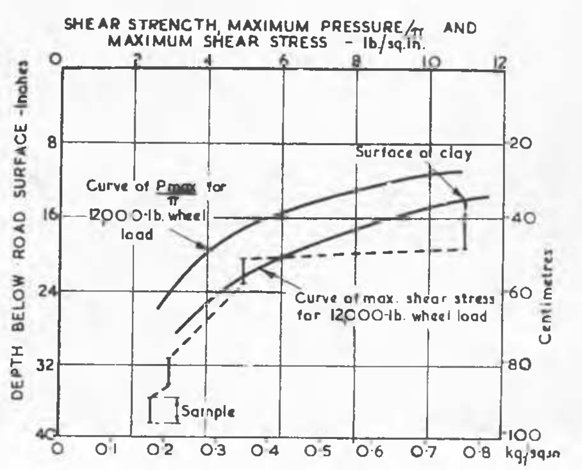
RESULTS OF C.B.R. TESTS ON UNDISTURBED SAMPLES

Description	Average Moisture Content (%)	Average C.B.R. (%)
Unsoaked specimens	28	4
Soaked specimens	34	2



Shear Strength-Depth Profiles for Clay Subgrade at Site 1 with Curves of Maximum Pressure/π and Maximum Shear Stress for a 12.000 Wheel Load.

FIG.8



Shear Strength-Depth Profile for Clay Subgrade at Site 2 with Curves of Maximum Pressure/π and Maximum Shear Stress for a 12.000 Wheel Load.

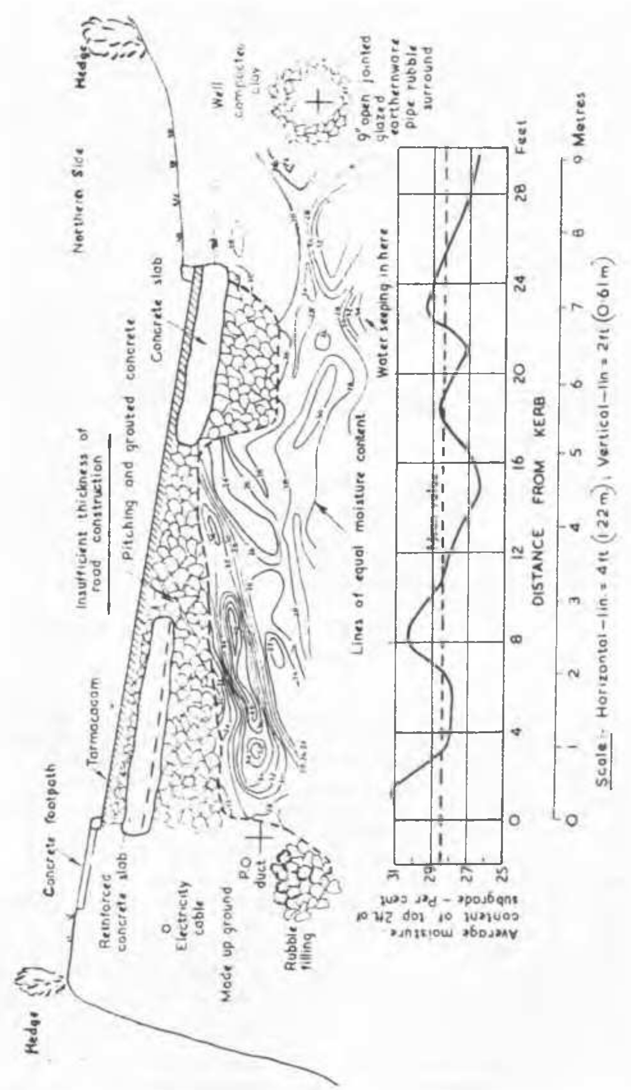
FIG.9

General View of Bituminous Surfaced Road which had Developed Areas of Settlement and Disintegration.

FIG.10

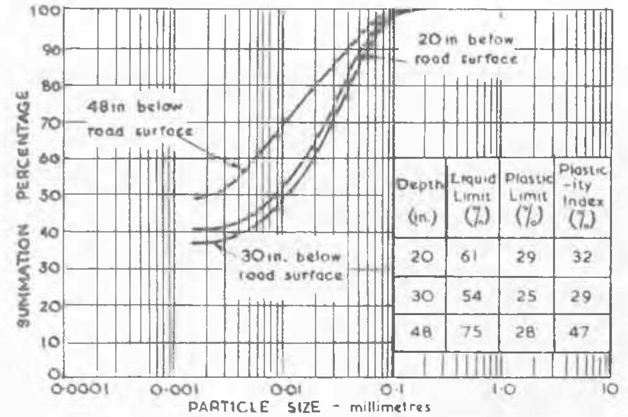
Close-up View of Area of Settlement and Disintegration along the Crown of the Road.

FIG.11



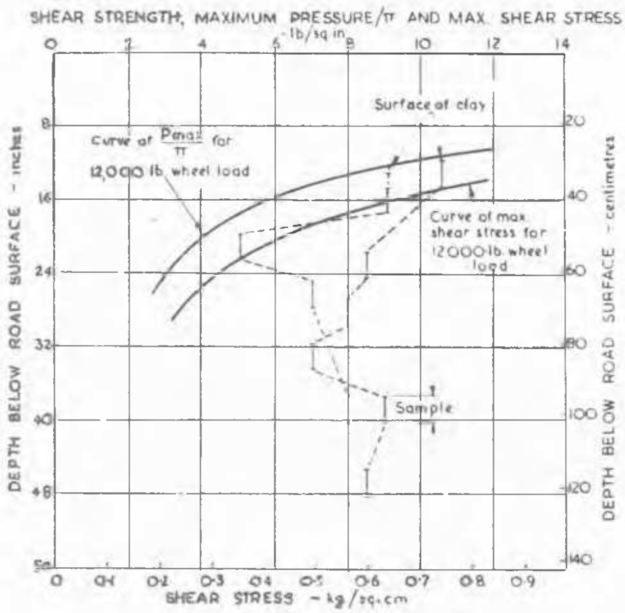
Cross Section of Bituminous Surfaced Road at Site Investigated Showing Construction of Road and the Moiture Distribution in the Clay Subgrade.

FIG.12



Grading Curves and Results of Index Tests for the Subgrade Soil.

FIG.13



Shear Strength-Depth Profiles in the Clay Subgrade with Curves of Theoretical Shear Stress Distribution due to a 12.000- Wheel Load.

FIG.14

For a 12000 lb. (5450 kg.) wheel load, the C.B.R. design charts 4) indicate a thickness of construction of about 25 inches (64 cm) which supports the conclusion that there was an insufficient thickness of construction along the centre of the road.

During an examination of the subgrade it was noticed that water was seeping into a bore-hole near the northern edge of the road (see Fig. 12), indicating that the 9-in. drain on the northern side of the road was not intercepting all the surface and gravitational sub-soil water running off the high ground on that side. This seepage of water into the subgrade was probably a contributary cause of the trouble experienced along the northern edge of the road. For more efficient operation the 9-in. drain should have been located deeper and the drain trench backfilled to ground level with permeable material so as to trap surface run-off.

Differential Movements between Slabs of a Concrete Road.

FIG.15

Close-up View of Differential Movement. Note Approximately 2-in. (5 cm.) Displacement.

FIG.16

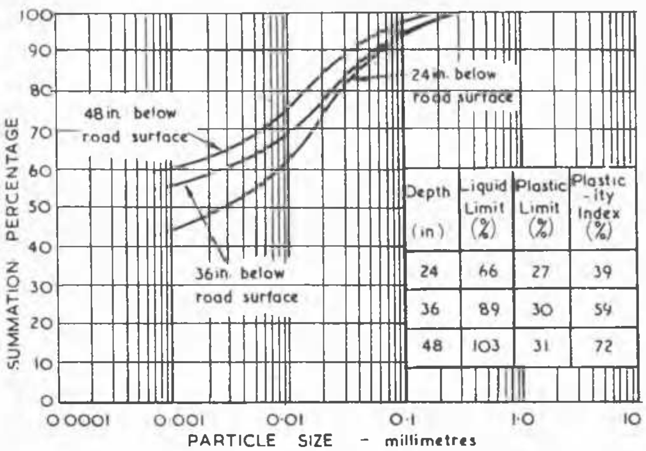
The main factors contributing to the failure were, therefore, an insufficient thickness of construction along the crown of the road and an inefficient intercepting drainage system.

C. AN INVESTIGATION OF DIFFERENTIAL MOVEMENTS BETWEEN SLABS OF A CONCRETE ROAD

The subject of the investigation consisted of a 20 ft. (6.1 m) wide concrete carriageway with a central tongued longitudinal joint laid on an existing tarmacadam road. Differential movements had occurred along the longitudinal joint at intervals over a length of about 900 ft. (275 m) of the road, the slabs being up to 2 in. (5 cm) lower on one side than on the other. (see Figs. 15 and 16).

The subgrade consisted of a heavy clay, highly susceptible to volume changes, in which the percentage of material finer than 0.002 mm increased with depth. Grading curves and results of the index tests for samples of the soil taken from different depths are given in Fig. 17.

The distribution of moisture in the subgrade at one of the sites selected for inves-



Grading Curves and Results of Index Tests of Soil from Subgrade of Concrete Road which had developed Serious Differential Movements between Slabs

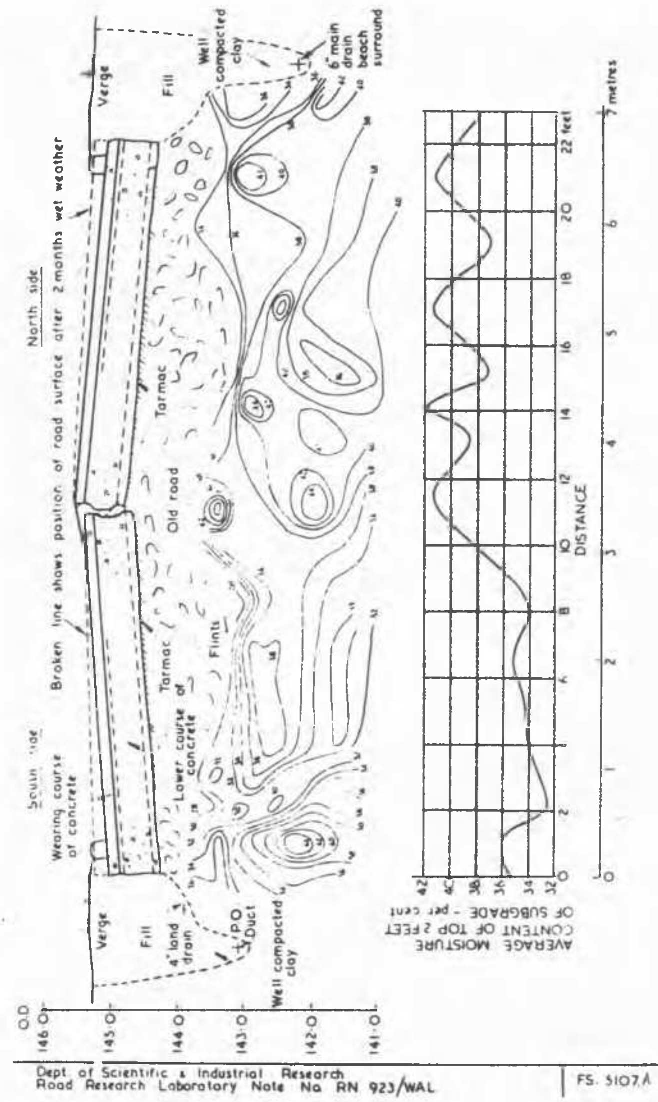
FIG.17

tigation is shown in Fig. 18. The average moisture content of the top 2 ft. (0.6 m) of subgrade was 5 per cent less under the lower half of the road (south side) than under the other side. This difference in moisture content of the subgrade would be sufficient to account for the differential movement of the two halves of the road, assuming reasonably uniform moisture conditions when the slabs were laid.

Further evidence to support the conclusion that volume changes in the clay subgrade were the cause of the differential movements was the fact that at a site where no slab movements had taken place, no difference was found in the average moisture content of the two halves of the subgrade. In addition, when the road was revisited after two months of wet weather, the edges of the road were found to have risen as much as 2 inches (5 cm), as shown in Fig. 18.

The precise cause of the moisture movements and associated volume changes in the subgrade is not quite clear but it is possible that they were in some way connected with a large number of trees which grew on the south side of the road and which were cut down after the concrete road was constructed.

The possibility that the differential movements might be due to traffic loads is discounted bythe extremely large thickness of construction of the road. As shown in Fig. 18, this amounted to about 21 inches (53 cm); the thicknesses required by the C.B.R. 4) and the Glossop and Golder 3) method of design for a 12000 lb. (5450 kg.) wheel load was 18.5 in. (47 cm) and 17 in. (43 cm) respectively.



Moisture Distribution in Subgrade unaer Displaced Slabs. Note Higher Avereage Moisture Content under North Half of Road.

FIG.18

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