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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Road Research Laboratory

INVESTIGATION TO STUDY MOISTURE CONDITIONS UNDER ROADS IN KENYA

by

M.P. O'Reilly and F.H.P. Williams

Section:	Tropical (R.S. Millard)
Research Team:	F.H.P. Williams, K. Russam, M.P.O'Reilly, J.S. Tanner, A.B. Baker, B. Odinge, J.A. Okoth, M. Omukhunya

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SUMMARY

The present investigation forms part of the programme of research into moisture conditions, states of compaction and strengths of subgrades under bitumen-surfaced road pavements in tropical areas and was carried out in co-operation with the Road Authority and the Ministry of Works, Kenya. Measurements have been taken over a fifteen-month period at seven sites on roads situated on red clay, black clay, sandy clay and ash and pumice soils.

Moisture conditions

The main rains in 1958 were unusually heavy and were preceded by a wet 1957 so that the investigation commenced in conditions which could be expected to be much wetter than normal. Under the centre of the roads, i.e. about 10 feet from the edge of the pavement, the moisture contents were generally stable. Variations which were found in moisture conditions under the edges of the roads were related to surface run off and drainage conditions over the verge. In general, moisture contents under the road were at or below the plastic limit of the soils and at subgrade level the average was generally less than the optimum moisture content in the B.S. Compaction Test.

Densities of subgrades

The field density measurements indicate that the relative compaction of subgrades was often low. Even at a low state of compaction the subgrades had a high *in situ* strength. The *in situ* strength did not appear to be directly related to density. However, the obtaining of higher field densities in the base and sub-base would help to minimize after-construction troubles caused by compaction by traffic.

Strength of subgrades

Despite the low states of compaction achieved the measured *in situ* values of the California Bearing Ratio (C.B.R.) in general exceeded 10 per cent indicating good or excellent subgrade strengths. The few exceptions were found near the edges of the roads particularly where there were poor drainage conditions and permeable shoulders. The reduction in strength was usually only serious in the outer 2-3 ft of road. With dense well-drained shoulders, advantage can be taken of the general good subgrade strengths.

Design considerations

Although only seven sites were investigated in detail, spot tests were made subsequently on a very large number of other sites in East Africa which supported the results of the detailed investigations and will form the subject of a further note. While there may be exceptional soil conditions which were not covered by either the detailed investigation or the spot tests, the results obtained indicate that under climatic conditions such as occur in Kenya (marked wet and dry seasons) and with no definite water table within ten feet of the surface, the main influence on the strength of the subgrade soils is moisture available from the sides of the road. They further suggest that, given dense and well graded shoulders so that water is shed rapidly away from the road edges, and a road base and surfacing which in combination are sensibly impervious, design thicknesses may safely be based on C.B.R. values obtained from specimens of the subgrade soil, tested at the maximum dry density and at optimum moisture content in the British standard compaction test.

INVESTIGATION TO STUDY MOISTURE CONDITIONS UNDER ROADS IN KENYA

Introduction

The bearing capacity of a road subgrade depends on the soil type, dry density and moisture conditions occurring under the pavement. Soil type is usually predetermined, while the dry density can be measured and in the upper layers of the formation controlled. A knowledge of the most adverse moisture conditions which occur under a pavement is necessary to design an adequate but not excessive road structure.

The present investigation forms part of the programme of research into moisture conditions and the associated strengths under bitumen-surfaced road pavements in tropical areas and was carried out in co-operation with the Road Authority and Ministry of Works, Kenya. Seven sites, covering a range of soil types and rainfall areas were investigated over a complete climatic cycle. Measurements commenced in April 1958 and continued until July 1959, this period including the 1958 and 1959 main rains ("long rains"), and the 1958 secondary rains ("short rains").

Location of sites

The sites investigated were situated in the Kenya Highlands at elevations between 4,900 and 6,900 feet above sea level. Five were within a thirty mile radius of Nairobi and the remaining two in the Rift Valley. (Fig. 1) and Appendix 1.

Sites Nos 1 and 2 on the Limuru "A" Route and Thika-Sagana Road respectively were located on red clay soil in the Kikuyu Reserve. Site No. 1 was on the rising ground which culminates in the Kikuyu Escarpment to the west of Nairobi and Site No. 2 was situated in the rolling country north-east of Thika. Three subsites* giving conditions of cut, fill and level ground were investigated at each site. At Site No. 2 the subsite on fill was sited in a valley where a permanent stream maintained a watertable at a depth of 10 to 11 feet below the road surface.

Site No. 3 was in a typical black clay area on the Embakasi Plains and was on the Nairobi-Mombasa Road near the 12 mile post. Here 2 to 4 feet of black clay overlay decomposing rock and this shallow depth of soil made interpretation of the moisture profiles difficult. A further site was therefore selected on the Ngong Road (Site No. 7) where the black clay was $7\frac{1}{2}$ to 8 feet deep and measurements commenced there in September 1958. Site No. 3 contained two subsites both on level ground while Site No. 7 had one subsite also on level ground.

Site No. 4, the remaining site in the vicinity of Nairobi, was on the Nairobi-Mombasa road at Mile 27 where the road traverses the Kapiti Plains south-east of Athi River. The soil was a sandy clay in the transition between the black clay soils which occur on the plains south of Nairobi and Athi River and the sandy soils below the Mua Hills.

The two sites in the Rift Valley were located in the vicinity of Naivasha and Nakuru on volcanic ash and pumice soils. Site No. 5 was south of Naivasha on the Nairobi-Nakuru Road with Lake Naivasha to the west and Mount Longonot to the south. Site No. 6 was on the Nakuru-Eldoret Road near Mile 8 and was on the high ground to the north-west of the town and the Menengai Crater.

/A

*The annotation of the subsites (a, b, c) was arranged so that the "a" subsite was always nearest Nairobi.

A plan, longitudinal and cross sections of each site are given in Appendices 2 to 8 and Figs. 2 to 8 are general views of the sites and the surrounding countryside.

In selecting the sites care was taken as far as possible to select lengths on deep typical soil profiles so that the results would not be influenced by extraneous drainage conditions. As far as possible lengths were selected with no apparent failures in the surfacing.

Field measurements. General

At each subsite a short length of road was selected and measurements were taken within this area moving progressively away from the initial sampling point. The openings for moisture content measurements were made at monthly intervals and extended as required for C.B.R., dry density determinations and samples for soil suction measurements. (See Appendices 2 to

Moisture content measurements

On the occasion of the monthly samplings three boreholes, located on the verge, 3 feet inwards from the pavement edge and on the road centre-line were sunk to a depth of 6 feet, or to rock, using a 4-inch diameter Jarrett auger. In addition, a trench to subgrade level and extending 4 feet inwards from the pavement edge was excavated. Samples were obtained from the subgrade and road construction layers for moisture content and plasticity determinations. The moisture content data obtained are shown in Fig. 9.

In August/September 1958 lined boreholes to record watertable levels were sunk at each subsite to a depth of 12 feet or until a hard layer was encountered at a lesser depth. With the exception of the Thika-Sagana site on fill, (2c) already referred to, no watertable was located in any of these. On the Ngong road site, water was found to stand in the borehole after rain, but this was subsequently proved to be due to seepage from the surface down the side of the lining.

Density measurements

Two sets of in situ density measurements were made at all sites and subsites. The sand replacement method was used on subgrades and the water displacement method on "murram"* base and sub-base materials using the procedures in B.S. 1377 : 1948.(1) The results of the tests on the subgrades are summarized in Table I and those on the "murram" bases and sub-bases in Table II where they are compared with the results of the laboratory compaction tests.

California Bearing Ratio (C.B.R.) measurements

Three sets of in situ C.B.R. measurements were made at all sub-sites, two sets being carried out during the 1958 and 1959 main rains and the remaining set in October/November 1958 after three months of very dry weather.

Testing was carried out in a trench and for convenience no surcharge weights were used. Individual tests were spaced at 1 ft intervals across the half width of road, commencing 6 in. from the pavement edge. C.B.R. measurements were made on all subgrades and on bases and sub-bases consisting of "murram", "murram" and stone and stone and sand mixtures.

/Tests

*"Murram" a local name in East Africa used to denote a nodular gravel sand clay.

Tests were not carried out on pitched or "quarry run" stone bases. The general set-up and apparatus used are shown in Fig. 10. To eliminate the large travel of the rear springs the lorry was supported on chassis stands during testing. Setting up was facilitated by the use of a rack and pinion jack with a 12 in. travel (Tanganyika Jack) and a steel plate to span the trench. The C.B.R. values are shown in Fig. 11 and the individual C.B.R. results are shown in Appendix 9.

Traffic counts

Traffic counts extending over the 16 hour period from 5 a.m. to 9 p.m. (E.A. Time) were taken on two occasions at each site. The traffic in each half-hourly period was recorded and segregated into light, medium, heavy and public service vehicles. The first three types were classified by their tare weights which were usually displayed on the driver's side of medium and heavy vehicles. Light vehicles had tare weights of less than 3,000 lbs, medium vehicles tare weights between, 3,000 and 7,000 lbs and heavy vehicles tare weights of over 7,000 lbs. The results of the counts are summarized in Table III.

LABORATORY TESTING

Classification tests. Liquid limit

Liquid limit determinations were carried out on air-dry soil or on soil stored at the field moisture content. The samples were conditioned for testing as recommended by Norman[2] and tested according to the procedure in B.S. 1377 : 1948[1] It was found that clay soils needed very thorough and prolonged mixing to ensure that reproducible results were obtained.

Plastic limit

Plastic limit determinations were carried out on soil stored at the field moisture content or on material conditioned for the liquid limit tests. At least six of the samples normally obtained from the three boreholes put down monthly at each subsite were tested. The results were used to trace any variations in soil type as the test was quick and its correlation with the moisture conditions in the soil has been shown to be as reliable as that given by the liquid limit.[3] The variation of the plastic limit with depth and the range of values recorded at each level are shown in Fig. 12.

Plasticity index

The liquid limit and plasticity index of samples tested from the various sites have been plotted on Casagrande Charts (Fig. 13). These show that the soil investigated ranged from clays and silts of low compressibility to similar materials of high compressibility.

Compaction tests

Standard compaction tests[1] were carried out on subgrade material from all subsites. With the soil from Nakuru Site (No. 6) a fresh sample was used for each determination as the large pumice particles in it were easily crushed. This soil was also peculiar for the fact that the dry density/moisture content curve was extremely flat and that values within 1 to $1\frac{1}{2}$ lbs of the maximum dry density could be obtained over a wide range of moisture contents (see Fig. 14). The results of the compaction tests are shown in Table I.

/Specific

Specific Gravity

Specific gravity determinations were carried out on subgrade soil from all subsites using test No. 7A B.S. 1377 : 1948.[1] The values obtained are shown in Table I, and have been used to calculate the air content of the in situ subgrade soil and in the laboratory compaction tests.

Meteorological data

Daily rainfall figures for the period 1st January 1958 to 31st July 1959 have been supplied by the East African Meteorological Department for rainfall stations near the sites being investigated. The monthly and longterm average monthly totals are shown in Fig. 9. In addition, relative humidity, maximum/minimum temperatures, sunshine hours and wind speed data for Ngong Road Site (No. 7) are given in Table IV and average and monthly values for Naivasha and Nakuru Sites (Nos. 5 and 6) are given in Table V.

The rainfall from January to July 1958 varied from $1\frac{1}{2}$ to 2 times the average for these 7 months. This wet period was followed by three dry months at all but the Nakuru Site (No. 6). From November 1958 to July 1959 the rainfall at the sites in the vicinity of Nairobi was below average, while that for Naivasha and Nakuru Sites (Nos. 5 and 6) in the Rift Valley was slightly above average. The 1957 rainfall figures were also in excess of the average annual values for the various sites. The rainfall conditions were thus seasonable for the investigation, the initial measurements being made during and after a wetter than average period, while subsequent measurements were taken in generally drier than average conditions.

RED CLAY SOILS

Limuru "A" Route Site (No. 1)

The present road at this site was constructed in 1949-50. The red clay soil here was at least 12 feet deep and rests on volcanic rock, probably phonolite. The soil was typical of the red clays occurring in humid regions[4] and was a residual latosolic soil with a blocky subangular friable texture. The Casagrande classification was MH and the plastic limit determinations gave lower average values on level ground subsite (c) than on fill (a) and cut (b) subsites.

The permanent watertable was at a depth of 60 feet below the lower end of the site. The general drainage of the road and verges was good. Rainfall data show that the rainfall for 1957 was 140 per cent of the longterm average, for January/July 1958 150 per cent of average, for August/October 1958 20 per cent average and for November 1958/July 1959 70 per cent average.

The moisture content measurements (Fig. 9, a, b and c) showed a seasonal fluctuation in the verge with maximum values coinciding with the main rains. The values for the profiles 3 feet from the pavement edge were less variable and initially the top layers there were slightly wetter than the centreline, but this difference lessened as measurements progressed. A sudden increase in moisture content was recorded on the level ground subsite (c) in July 1959 at depths below 3 feet. This was related to the close proximity of the July profiles to a culvert which probably contained leaking joints since additional boreholes put down both uphill of the culvert and near sampling points used in April/May 1958, showed moisture contents in agreement with the usual values. The moisture content measurements on the top of the base and subgrade showed some seasonal wetting up at the pavement edge but its effect on the strength had disappeared at 3 feet from the edge (Fig. 11, a, b and c).

/The

The subgrade densities on cut and level ground at 7 to 13 inches below the road surface were only 90 per cent of B.S. compaction, while on fill, at similar depths, they were nearly 100 per cent of B.S. compaction. The average air voids were 11 per cent on the embankment and 24 per cent on level ground. The moisture contents were usually less than the optimum moisture contents obtained in the B.S. compaction tests. The standard deviations indicated that the density conditions were uniform[5][6][7] at each subsite for both the subgrade and base, and the average results obtained in individual test series were in good agreement.

The results obtained from in situ C.B.R. tests on the soil 5-9 in. below the road surface indicated a subgrade which may be classified as good.[5] The lowest average for a set of in situ C.B.R. tests on the subgrade across half the width of the road, at a depth of 5-9 in. below the road surface occurred at subsite (a) (fill) in October 1958 and was 19 per cent. In all the 84 measurements only three values were below 15 per cent and none was below 10 per cent. The C.B.R. measurements on the "murram" base were somewhat variable, the average values ranging from 35 per cent to 70 per cent C.B.R.

Site No. 2 Thika-Sagana Road

Construction of this road was completed in February 1957. The red clay soil here was browner in colour than that at Site No. 1. The profile was also shallower and the underlying rock basalt.[8] At the level ground subsite (a) a hard layer prevented augering below 9 feet. On the cut subsite (b) yellow brown clay was sometimes found at a depth of 5 to 6 feet. This soil was damp and plastic and nearby cuttings showed that it was the transition soil lying on the rock. The rock, however, was not encountered in a 12 feet deep borehole. At the fill subsite (c) the brown soil embankment rests on blue alluvial clay.

The red clay soil[4] was a residual latosolic soil with a weak subangular blocky texture such as occurs in sub-humid regions. Although similar to the soil at the Limuru Site (No. 1) it could be differentiated from it by its browner colour and also on the Casagrande chart where it lies on the A-line and was classified as MH-CH. Soil conditions as indicated by plastic limit determinations were similar at all subsites.

Subsite (c) (fill) was located across a clay-bottomed valley in which flowed a permanent stream some 10-11 feet below the road surface. The drainage of the road and verges was good. The rainfall at the site was 135 per cent of average in 1957, and 205 per cent of average for the seven months January/July 1958. In the following three months August/October 1958 the rainfall was 30 per cent of average while from November 1958/July 1959 the figures recorded were just below average.

The moisture profiles obtained in the verge and at 3 feet from the pavement edge exhibited a similar pattern to those at Site No. 1 (Fig. 9, d, e & f.) On the centreline some progressive wetting up occurred initially but the values became more stable in the period September/December 1958 and little change occurred subsequently. This phenomenon was most probably associated with the relatively recent road construction and the attainment of equilibrium conditions under the road. The moisture content measurements on the top of the sub-base and subgrade indicated some seasonal wetting up but its effect on the strength had again disappeared at 3 feet from the edge. (Fig. 11, d, e & f)

The field densities on the subgrade showed similar trends to those at Site No. 1, the relative compactions on the subsites on cut and level ground being 90-95 per cent of B.S. maximum dry density at 12-18 in. below the road surface and the densities on the fill subsite were just slightly below the B.S. maximum dry density at 20-26 in. The standard deviations again indicated uniform density conditions. The average in situ moisture contents obtained in the field density measurements were less than the optimum moisture content obtained in the B.S. compaction tests. Densities

/in

in the "murram" sub-base were more variable than those in the "murram" base material at Site No. 1. There was an appreciable variation between the results obtained on the subsites, the highest results being obtained on the fill subsite.

The in situ C.B.R. values obtained on the subgrade 10-20 in. below the road surface were lower than at Site No. 1. Of the 86 determinations made only 2 were less than 10 per cent C.B.R. but 23 were less than 15 per cent C.B.R. The average C.B.R. of the "murram" sub-base ranged from 14.4 per cent to 41.3 per cent and decreased with depth below the road surface. The softer nature of the "murram" sub-base material made seating easier than at Limuru and the results obtained were not very variable.

Discussion of results

The results indicate that some wetting up of the subgrade was taking place under the centreline of the road at the Thika-Sagana road site for some 22 months after construction was completed. After this period, the moisture content pattern at both sites was similar. At Limuru site (No. 1) and Thika-Sagana site on level ground (No. 2(a)) the values recorded were below the plastic limit while at the latter site on cut and fill, site No. 2(b) and (c), they were generally in the region of the plastic limit. These higher relative values may be related to the shallower depth to the rock surface at the cut subsite (b) which would impede the downward movement of water, while at the fill subsite (c) they would be attributable to the high watertable.

The effect of seasonal wetting on the subgrade strengths at the road edges was evident but the change in design pavement thickness required was not great. The comparison of the in situ C.B.R values and pavement depths with the C.B.R. design curves in Road Note No. 20[9] (Curve D) shows that the road thickness at the Limuru Site (No. 1) had a slight margin in excess of that required by the average in situ C.B.R. values. A few individual results were marginally lower than the required value for the depth of construction found. At site No. 2 pavement thicknesses on cut and level ground were some 4-6 in. in excess of those given by the design curves and on fill it was about 10 in. in excess. A tendency was noticed at both sites for the average C.B.R. values to decrease as the depth to subgrade level increased. The relative compactions in conditions of cut and level ground were low at both sites while those on fill were only slightly less than the B.S. maximum dry density obtained in laboratory tests.

The overall picture was one of fairly dry conditions under the pavement with moisture contents seldom exceeding the plastic limit or the optimum moisture content in the B.S. compaction test. Saturated conditions were never encountered and subgrade strengths were good.

BLACK CLAY SOILS

Site No. 3. Mombasa Road, Mile 12

The road at this site was completed in 1949-50. The black clay soil (black cotton soil) was 2-4 feet deep and rested on phonolite, the top layers of which were decomposed. Some carbonate has accumulated in the region of the boundary between soil and the decomposing rock. The area was a typical black clay area[4] on a plain with impeded drainage and the Casagrande classification of the soil was CH.

Pumpable water was permanently available at a depth of 300 feet at the site. Some water could accumulate and stand in the ditches outside the road verge, but no perched water table was found in the boreholes. The level of a seasonal stream was less than 100 ft below the level of the site. Rainfall data show that the rainfall for 1957 was 170 per cent average, for January/July 1958 175 per cent average, for August/October 1958 15 per cent average and for November 1958/July 1959 85 per cent average.

/The

The moisture content measurements were limited by the shallow depth of soil and were somewhat variable. The verge profiles show seasonal fluctuations with peak values coinciding with the main rains. The values on the profiles 3 feet from the pavement edge were normally wetter than those on the centreline where conditions were reasonably stable but this difference decreased with depth. (Fig. 9, g and h). The moisture content determinations on the top of the subgrade showed much wetting up near the verge (Fig. 11, g and h).

The field densities on the subgrades at 15-24 inches below the surface were close to the B.S. maximum dry density while the average associated moisture contents were well below the optimum moisture contents obtained in the laboratory. The average air voids were about 20 per cent, but the subgrade densities were rather more variable than in the case of the red soils, and the minimum value obtained was 6 per cent.

The in situ C.B.R. test showed variable subgrade strengths. The edge values with the exception of one set of tests were low while the strengths between 5 feet from the pavement edge and the centreline were invariably high. Of the 61 determinations made 8 were below 7 per cent C.B.R. and 15 were below 10 per cent C.B.R. with 12 of the latter occurring within 2 feet 6 in. of the verge. The low C.B.R.s and high moisture contents near the pavement edge appeared to be due largely to the permeable shoulder of "quarry run" stone which facilitated the percolation of run off from the road surface to subgrade level. This conclusion was supported by the C.B.R. tests carried out in April and May 1959. The values recorded at subsite (a) where the verge was fairly impermeable were extremely high even close to the verge and were associated with low subgrade moisture contents. Those recorded at subsite (b) where the verge was very open and porous were very low up to 4 ft 6 in. from the pavement edge. The C.B.R. values recorded immediately under the road surface were reasonably good. Weaker layers were encountered at lower levels, but these were not less than the value required by the C.B.R. design curve.

Site No. 7 - Ngong Road

The present road at this site was reconstructed in 1950. The original road, which was in existence before 1947, had a bitumen surface over approximately 6 in. of "murram" over the black clay. The construction laid over this in 1950 consisted of approximately 4 in. of rather clayey "murram", below 6 in. of "murram" which was surfaced with a multiple bituminous surface dressing. The soil profile was $7\frac{1}{2}$ to 8 feet deep and rested on tuff. The area was a plain with very little fall, though at some distance from the site the ground fell sharply to a river. This is typical of the poorly drained areas in which this type of soil occurs.(4) The soil was again classified as CH but has somewhat higher plasticity values than the soil at site No. 3.

Pumpable water was permanently available at a depth of 200 feet below the site. Some standing water collected in the roadside ditches which were some 8 to 10 feet from the edge of the bitumen surface from March 1959 onwards but no perched water tables were encountered in the boreholes. The normal rainfall at this site is slightly more than at site 3; during the measurements the records of rainfall had a similar relationship to the averages as at site 3.

The moisture content profiles were extremely stable in all locations below 2 feet (Fig. 9, m). The verge profiles showed very slight peaks coinciding with the secondary rains in 1958 and the main rains in 1959 and there was little difference between the moisture content values in the verge and those under the road. The measurements taken on top of the various construction layers and the subgrade showed very little wetting up near the

/pavement

pavement edge. The verges were covered with a layer of compacted "murram" which was virtually impermeable.

The field densities 14-20 in. below the road surface indicated relative compactions similar to those at Mombasa road Mile 12 (site No. 3) while the lower standard deviations indicate more uniform conditions. The associated moisture contents were below the optimum moisture content obtained in the British Standard compaction test. The average air voids content ranged from 16 to 21 per cent, the minimum value recorded being 13 per cent.

The minimum in situ C.B.R. value recorded at subgrade level was 10 per cent (Fig. 11, m). Patches of a greyish, more silty material were generally encountered in the surface of the subgrade immediately below the road structure. Good bearing values were obtained from both the grey and the black clay at subgrade level (Appendix 9 and 10). Slightly lower values were recorded at a greater depth with the black clay, but these were above those required by the C.B.R. design curve.

The C.B.R. tests carried out on the various construction layers gave values of 60-70 per cent C.B.R. under the present road surface. A layer of weak material was encountered above the old road surface in the tests in November 1958 and was probably due to the localized trapping of some water which had penetrated the present surfacing. The strength of the "murram" base beneath the old road surface was excellent and was in excess of 150 per cent C.B.R. The moisture content and in situ C.B.R. measurements show that the shoulders at this site combined sufficient impermeability with adequate crossfall to prevent much run-off from percolating to subgrade level.

Discussion of results

The conditions under the central portion of the pavement at site No. 3 were drier than at site No. 7 and this may reflect the somewhat drier climate in the former area. Conditions in the verge showed much greater fluctuation at site No. 3 and the wetting up that occurred there was probably due to the permeable hard shoulder. At site No. 7 the moisture content profiles were extremely stable and the values in the verge and under the road were similar. Excepting the values caused by the permeable shoulder conditions at site No. 3, the moisture contents at both sites were always less than the plastic limit.

The wetting up at the road edges on site No. 3 already referred to, resulted in a large reduction in subgrade strength along the outer 3 ft of the road. However, these conditions excepted, the subgrade strengths were high. The comparison of the low in situ C.B.R. values at site No. 3 with the C.B.R. design curve (E) in Road Note No. 20[9] indicated that the thickness of construction used generally matched the lowest C.B.R. values found. In situ densities were similar to the B.S. maximum dry density, while air voids were of the order of 20 per cent.

The overall picture was that the general conditions under the pavements were dry, with moisture contents below both the plastic limit and the optimum moisture content of the B.S. laboratory compaction test, and that the subgrade strengths associated with these dry conditions were good. However, when wetting up occurred due to the use of permeable hard shoulders great reductions of strengths at the pavement edge resulted. If the potentially strong subgrade conditions on this type of soil are to be made use of, then the shoulders need to be reasonably impermeable and have sufficient crossfall to facilitate run off from the road surface to the drainage ditches.

/SANDY CLAYS

SANDY CLAYS

Site No. 4 Mombasa Road, Mile 27

Construction of the road at this site was completed late in 1956. The sandy black clay soil here was a transition soil between the black clays of the plains and the sandy soils derived from the weathering of the basement gneissic rocks of the Mua Hills. The soil profile rests on "kankar" (calcrete) deposits which overlie rock and the site was located on the approximate geological boundary between the Kapiti phonolite and the basement gneisses.(10) The Casagrande classification was generally CL although some more plastic soils were encountered near rock on subsite (a) at depths below 4 feet.

This area is semi-arid and the permanent watertable in this area was generally within about 70 feet of the surface. The layer of clay on top of the rock at subsite (a) was wet and plastic on occasions. The rainfall in 1957 was 145 per cent of average, January/July 1958 170 per cent of average, in August/October 1958 no rainfall was recorded and in the concluding period November 1958/July 1959 the rainfall was 70 per cent of average.

The moisture content measurements were somewhat variable due to changing soil types (Fig. 9, i and j). The pattern at subsite (a) was similar to that on the sites on the red and black clays. At depths of 3 to 5 ft there was a progressive wetting up over the period of the measurements. At subsite (b) near the bottom of the incline, conditions were quite wet in the top layers of the subgrade but below this the soil was extremely dry on the centreline. This condition could be explained by the dished transverse profile of the road surface which causes a large proportion of the run-off from the road on the incline to be channelled on to the verge at the bottom of the slope where the more luxuriant roadside vegetation reflects this added supply of moisture. The moisture content values on the construction layers and on top of the subgrade show little verge wetting up on subsite (a). On subsite (b) verge values were often lower than those under the pavement and this probably resulted from roots drying out the soil in the former regions. (Fig. 11, i and j).

The field density determinations generally indicated a relative compaction of 95 per cent B.S. maximum in the subgrade at depths 18-24 in. below the surface. At subsite (b) the densities across the road were variable giving densities in excess of the B.S. maximum dry density at the verge and values down to 85 per cent relative compaction on the centreline. This non-uniform condition was reflected in the high standard deviations recorded. The average moisture content associated with the field density determinations was always less than the optimum moisture content in the laboratory. The air voids contents reflected the wetter conditions at subsite (b), where the average values were 13 per cent with a minimum value of 8 per cent. At subsite (a) the corresponding figures were 18 per cent and 13 per cent respectively.

The in situ C.B.R. measurements showed good subgrade strengths on subsite (a), the lowest average being 12 per cent C.B.R. The wetting up at subsite (b) has reduced these and values of 6-9 per cent C.B.R. were very common under the road. The values obtained on the base and sub-base layers, while variable due to the proportion of crushed stone in these materials, indicated adequate average strengths.

Discussion of results

This site was situated in a semi-arid area and subsite (a) was drier than subsite (b). The soil at subsite (a) was wetter relative to the plastic limit than that at the Mombasa road Mile 12 (site No. 3) which was in a wetter area, and this may be a result of the sandier and more permeable surface soil. At subsite (b) the wet layers immediately under the road structure were contributed to by pecularities of road surface

/drainage.

drainage. The higher moisture contents do not occur below 4 ft and this is probably due to the more plastic layer near the surface preventing downward percolation of water. Even in the wettest condition under the road the moisture content of the soil was only of the order of the plastic limit.

The in situ C.B.R. values indicated fairly good subgrade conditions. The average relative compactions were low and the density varied appreciably across the road. This had been a determining factor in designing the thickness of construction required. Again the average moisture contents at subgrade level were below the optimum moisture contents of the British Standard laboratory compaction test.

In general, conditions at subsite (a) were fairly similar to those at the other sites in the Nairobi area. The moisture contents were below the plastic limit until the more plastic soil overlying the rock was reached. This may indicate an incipient perched watertable. At subsite (b), while subgrade level was wet, conditions became drier with depths, and this might indicate that the impervious layer is at a higher level.

ASH AND PUMICE SOILS

Site No. 5 - Naivasha

The road at this site was constructed in 1944 and the soil consists generally of volcanic debris which were deposited under lacustrine conditions and the soil profile in these conditions is often hundreds of feet deep.(11) The soil was fine grained and had a Portland stone colour, the Casagrande classification being CL-CI. The plastic limit determinations showed fairly uniform soil conditions down to a 6 feet depth.

The permanent watertable in this area was similar to the water level in Lake Naivasha, about 200 feet below the site. The general drainage condition of the road and verges was good. This area is semi-arid and the rainfall in 1957 was 140 per cent of average. The following seven months, January/July 1958, it was 165 per cent of average. The three months August/October had 50 per cent of average and from November 1958 to July 1959, 110 per cent of average was recorded.

The moisture content profiles in the verge exhibit peaks coinciding with the main rains (Fig. 9, k). Wetting and drying were very rapid and trends of moisture content change following the pattern of the main rains were recorded at depths below 4 feet, under the road pavement. Above this level the values found in the profile 3 feet from the pavement edge and on the centreline were similar. The moisture content measurements on the top of the subgrade showed seasonal wetting up at the edge.

The field density determinations gave relative compactions of the order of 90 per cent maximum dry density in the British Standard compaction tests, with low values at the edge on both occasions, while the higher than usual standard deviations also revealed uneven conditions.(6) Average air voids were 18-21 per cent with a minimum value of 14 per cent and the corresponding moisture contents were below the optimum moisture contents in the British Standard compaction tests.

The C.B.R. measurements showed generally good subgrade conditions with the exception of low values where high moisture contents occurred at the edge as mentioned above. (Fig. 11 k). Of the 30 tests carried out only 3 values below 10 per cent C.B.R. were recorded and the average strengths ranged from 15 per cent to 20 per cent C.B.R. The road base here consisted of hand pitched stone 5 to 7 in. deep and was well and tightly packed. There was some deformation of the road surface particularly near the edge which may be attributed to the pitched stone base and the lack of compaction of the subgrade. A deformation of a longer wavelength is also apparent along this stretch of road, which may well be associated with the very low state of compaction in depth of the subgrade soil. The railway line which runs parallel to the road at this point has a history of a high rate of line breakages which has been traced to the low state of compaction of the soil*.

/Site

*Private communication from the Chief Materials Engineer, Ministry of Works, Kenya.

Site No. 6 Nakuru

Construction of the road at this site was completed in 1951. The soil profile several hundreds of feet thick consists of volcanic debris varying from granular pumice of gravel size to fine dust. The dust was black in colour in the upper layers but changed to a brown colour at a depth of about $4\frac{1}{2}$ feet. This brown soil was less permeable than the higher layers and traces of free water were on occasion recorded there after recent rain. Some traces of obsidian were also noticed in the profile. Soil conditions were extremely variable, due no doubt to the method of deposition of the deposits. At this site the original bituminous surfacing had given service for 7 years and resealing was becoming necessary. Severe crazing of the road surface occurred at the site soon after the start of the measurements and the investigation was continued under an unfailed section, 100 yds further along the road.

Pumpable water was available at 750 feet.(12) The drainage of the road and verges was good. This area is sub-humid and the rainfall there in 1957 was 105 per cent average. The following period January/July 1958 it was 160 per cent average, while August/October 1958 and November 1958/ July 1959 had 165 per cent and 115 per cent average respectively.

The moisture content profiles showed considerable fluctuations in moisture contents, but these are thought to be mainly attributable to soil type. The pattern in the verge followed the general pattern of the rains to depths of 6 feet while conditions under the pavement were more stable. The general conditions in the verge were similar to site No. 5 with regard to the plastic limit of the soil (Fig. 9, 1).

The field densities determinations gave a relative compaction of 95 per cent of the maximum dry density given by the British Standard compaction test at depths of 8-15 in. below the road surface. The low standard deviations showed uniform subgrade conditions. The high air voids, 25 per cent, are due largely to the porous nature of the material. The specific gravity of the material was low and as already mentioned a fresh sample was required for each individual point in the moisture/dry density relationship. A typical compaction curve is given in Fig. 14. The curve is very flat, and values within 2 per cent of the maximum density were obtained at moisture contents 10 per cent dry of the optimum.

The in situ C.B.R. tests revealed excellent subgrade strengths, only two of the 31 values recorded being less than 15 per cent C.B.R. The values obtained on the green pumice-like sub-base material were variable, and this is thought to be largely due to difficulties in seating the plunger accurately in this material. (Fig. 11, 1).

Discussion

In general, the moisture conditions under the road at both sites were broadly similar. At these sites the soil conditions were determined by their modes of deposition and the moisture content profiles reflected the variability. During the dry periods conditions in the verge at the Naivasha site (No. 5) were much drier than under the road as also, to a lesser extent, were the upper two feet of the verge of the Nakuru site (No. 6). This did not occur at the sites in the Nairobi area. This difference is probably due to the highly permeable nature of the soils at the Naivasha and Nakuru sites.

At both sites the subgrades were found to have high strengths at soil moisture contents of the order of the plastic limit. The optimum moisture content in the laboratory compaction tests was generally in excess of the field values and the field densities obtained showed low states of relative compaction.

/General

General discussion

In the area under investigation the permanent watertable was generally deep. The only source of moisture available to influence the conditions under the pavement was rainfall which was mainly confined to the two rainy seasons. The precipitation rates were high and the drainage conditions at the sites generally permitted a quick run-off from the road surface and verges. The remaining water which percolated into or was absorbed by the verges caused some edge effects. The results show generally dry conditions under bituminous surfaced roads in this climatic and topographical environment and appear similar to those described in semi-arid areas of Southern Australia.(13) Moisture contents were generally at or below the plastic limit, and at subgrade level the average was generally less than the optimum in the British Standard compaction test.

However, the "edge effects" resulted in greatly reduced subgrade strengths on black clays at the road edge, particularly when this condition was accentuated by permeable hard shoulders (Mombasa road Mile 12, site No. 3) or drainage peculiarities (Mombasa road Mile 27, site No. 4). If shoulders are made of a compacted gravel clay which is relatively impermeable these effects should be limited to very tolerable proportions and the depth of pavements could be based on the general dry conditions with their accompanying good subgrade strengths.

The in situ C.B.R. values recorded reflected the generally dry conditions and individual values less than 10 per cent C.B.R. were rarely found. The low results were, in general, attributable to edge effects as discussed above. At some sites the road construction thicknesses found were of the same order as those recommended in the C.B.R. design curves, Road Note No. 20,(9) for C.B.R. values similar to those measured in situ. With fine grained soils the in situ C.B.R. value is a good approximation to the C.B.R. value determined by laboratory testing, thus the fact that these roads are giving good performance at these points supports the view that these curves are applicable in these conditions. Since the average moisture contents at subgrade level were less than that in the B.S. compaction tests a C.B.R. value which may be used safely in design may be obtained from laboratory specimens compacted and tested at the B.S. maximum density and optimum moisture content.(9) A similar procedure has been used in Nyasaland.(14)

(To permit the attainment of more uniform moisture conditions within the specimens it is suggested that these should be sealed immediately on moulding and allowed to remain overnight before testing.(15))

The field density measurements indicate that the state of compaction of subgrades was often low except on the black clay. The fact that mean densities comparable with the B.S. maximum dry density have been achieved on some of the sites indicates that they could be obtained in practice. In view of the low states of compaction which sometimes occur in the natural soils it would seem desirable that steps should be taken to ensure that the top two feet of the formation is adequately compacted, particularly on level ground and in cut. Relative compactions of 95-100 per cent British Standard should be obtained in the top 12 in. and at least 90 per cent in the second foot. The base and sub-bases should be compacted to 100 per cent British standard compaction to minimise after construction troubles caused by traffic compaction.(16) With the red clays the highest densities were found on the fill subsites where the soil had been excavated and placed in layers. The accompanying in situ strengths as measured by the in situ C.B.R. test were not as high as those measured on the cut and level ground subsites, where the density was lower. This is probably due to the fact that at the latter subsites the original structure, which occurs in this type of soil, had been retained while the soil had compacted over the years from its natural state, often some 70 per cent relative compaction B.S., to its present state.

Conclusions

See Summary.

Acknowledgements

The Road Research Laboratory wishes to thank the Road Authority and the Ministry of Works, Kenya, for their assistance and co-operation in the investigation. The members of the research team wish to thank the members of the above organizations for their helpfulness and assistance - especially those of the Materials Branch, Ministry of Works, with whom they had most contact.

/TABLE I

TABLE I

Summary of field density and laboratory compaction tests on subgrades

Site	Sub-site	Date	Field determinations						Laboratory determinations					
			Average dry density lb/cu.ft	St. deviation lb/cu.ft	Average M.C. %	Average air voids %	Min. air voids %	Number of tests	Max. dry density lb/cu.ft	Optimum M.C. %	Air voids %	Specific gravity	Soil classification	Relative compaction %
1	(a)	19/8/58	77.6	2.4	35.6	11.1	7.0	5	80	35	9.5	-	M_H	97
		12/3/59	79.9	1.8	33.3	11.8	7.8	6	81	36	7.1	2.81	M_H	99
	(b)	[illegible]	[illegible]		[illegible]	[illegible]								

TABLE II

Summary of in situ density tests on murram base and sub-base materials

Site	Subsite	Tests in August, September, and November 1958			Tests in March 1959		
		Average dry density	St. deviation	No. tests	Average dry density	St. deviation	Tests
1	(a)	96.1	2.6	5	97.3	2.1	3
	(b)	95.3	0.8	6	96.4	3.5	5
	(c)	101.3	3.8	7	101.8	3.8	5
2	(a)	101.4	3.5	7	102.8	5.7	6
	(b)	95.0	5.1	6	105.0	3.4	4
	(c)	113.8	3.3	7	115.3	3.9	5
3	(a)	-	-	-	107.9	-	1
	(b)	101.9	6.2	8	-	-	-
7	(a)	112.7(1)	3.4	8	114.4	7.3	5
		128.6(2)	5.4	7	128.5	4.5	5

(1) Murram sub-base at 6 in. below existing road surface.

(2) Murram base under old road surface.

/TABLE III

TABLE II

Summary of in situ density tests on murram base and sub-base materials

Site	Subsite	Tests in August, September, and November 1958			Tests in March 1959		
		Average dry density	St. deviation	No. tests	Average dry density	St. deviation	Tests
1	(a)	96.1	2.6	5	97.3	2.1	3
	(b)	95.3	0.8	6	96.4	3.5	5
	(c)	101.3	3.8	7	101.8	3.8	5
2	(a)	101.4	3.5	7	102.8	5.7	6
	(b)	95.0	5.1	6	105.0	3.4	4
	(c)	113.8	3.3	7	115.3	3.9	5
3	(a)	-	-	-	107.9	-	1
	(b)	101.9	6.2	8	-	-	-
7	(a)	112.7(1)	3.4	8	114.4	7.3	5
		128.6(2)	5.4	7	128.5	4.5	5

(1) Murram sub-base at 6 in. below existing road surface.

(2) Murram base under old road surface.

/TABLE III

TABLE III

16 hour traffic counts

Site No.	Date	Light	Medium	Heavy	Public service vehicles	Total	C.B.R. design classification	Max. traffic flow in ½ hour
1	23/2/59 24/6/59	785 753	88 57	73 60	36 75	982 945	D D	80 77
2	24/2/59 25/6/59	292 305	68 91	88 140	53 58	501 594	D D	25 42
3	25/2/59 26/6/59	454 583	96 107	314 405	27 42	891 1137	D E	54 58
4	26/2/59 29/6/59	180 252	27 48	127 179	18 41	352 533	D D	23 33
5	15/4/59 13/7/59	495 565	46 49	76 73	18 17	635 704	C C	39 40
6	17/4/59 15/7/59	698 562	46 29	67 74	15 11	826 676	C C	49 40
7	27/2/59 30/6/59	1890 1708	130 133	121 120	16 25	2157 1986	D D	171 157

/TABLE IV

TABLE IV

Monthly meteorological data. Ngong Road site (No. 7)

Month	Relative humidity 0600*	Relative humidity 1200*	Sunshine Hrs/day	Wind run Mls/day	Mean temperatures °F Max.	Mean temperatures °F Min.	Remarks
1958 January	82	51	8.8	147	76.2	52.5	0600* G.M.T. is 9 a.m. E.A. time.
February	73	48	8.7	102	78.2	50.6	
March	81	47	8.7	93	78.2	53.2	
April	91	55	7.2	99	76.3	55.3	
May	89	66	5.0	66	73.5	55.6	1200* G.M.T. is 3 p.m. E.A. time.
June	89	63	4.3	53	70.6	52.3	
July	94	70	2.6	38	67.2	50.7	
August	83	56	4.7	41	70.7	48.8	
September	81	45	7.1	61	76.5	47.1	
October	79	41	7.3	85	78.0	53.9	
November	82	47	8.4	127	77.5	55.4	
December	86	59	6.8	130	74.4	54.3	
1959 January	81	46	8.6	143	77.0	53.6	
February	71	39	9.5	125	80.5	51.6	
March	77	43	8.9	102	78.0	53.6	
April	87	59	7.1	83	74.2	57.4	
May	88	60	6.0	70	73.5	56.6	
June	84	52	6.5	56	71.8	50.3	
July	87	54	4.3	57	69.8	47.8	

/TABLE V(a)

TABLE V(a)

Average meteorological data. Naivasha site (No. 5)

Month	Relative humidity		Wind force knots		Mean temperatures °F		Remarks
	0600	1200	0600	1200	Max.	Min.	
January	66	28	3	6	81.9	46.6	
February	66	28	3	6	82.9	46.8	
March	71	34	3	7	81.2	49.7	
April	80	51	3	5	77.2	52.7	
May	82	54	3	7	74.9	52.3	
June	81	51	3	7	73.4	49.8	
July	80	49	3	7	72.5	48.8	
August	79	48	3	8	73.3	49.0	
September	75	43	3	8	76.1	47.9	
October	71	41	3	7	78.0	48.3	
November	75	47	3	6	76.5	48.7	
December	70	40	3	5	78.4	47.6	
Mean	75	43	3	7	77.2	49.0	

TABLE V(b)

Average meteorological data. Nakuru site (No. 6)

Month	Relative humidity		Wind force knots		Mean temperatures °F		Remarks
	0600	1200	0600	1200	Max.	Min.	
January	65	31	3	12	82.8	47.7	
February	64	28	3	13	84.8	48.3	
March	69	33	3	11	84.0	50.0	
April	78	47	3	8	80.0	52.6	
May	80	53	3	8	77.9	52.6	
June	81	49	3	8	76.9	50.6	
July	82	51	3	8	75.4	50.4	
August	81	53	3	8	75.6	50.0	
September	77	45	3	8	78.5	47.9	
October	73	45	3	9	79.3	48.0	
November	75	47	3	9	78.2	48.9	
December	72	40	3	12	79.5	48.7	
Mean	75	43	3	10	79.4	49.6	

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Road Research Laboratory,
July, 1960.
PW.

APPENDIX 1

Site No.	Limuru 'A' Route (1)	Thika-Sagana Road (2)	Mombasa Road Mile 12 (3)	Mombasa Road Mile 27 (4)	Naivasha (5)	Nakuru (6)	Ngong Road (7)
Location	Near Kiambaa village	Mile $33\frac{1}{2}$ from Nairobi	Nairobi-Mombasa Road 12 miles from Nairobi	Nairobi-Mombasa Road 27 miles from Nairobi	Nairobi-Nakuru Road $50\frac{1}{4}$ miles from N'bi	Nakuru-Eldoret Road 8m from Nakuru	$\frac{3}{4}$ miles west of Dagoretti Corner, Nairobi
Ordnance Sheet No.	148/1	135/III	148/IV	162/I	133/IV	118/IV	148/III
Base ...	-	-	-	$1\frac{1}{2}$-9	1-$4\frac{1}{2}$	5-9	12-17
Sub-bases in.	-	-	-	$15\frac{1}{2}$-18	$16\frac{1}{2}$-22	16-22	21-24
							$14\frac{1}{2}$-20
							$14\frac{1}{2}$-20
							17-22
							-
							$2\frac{1}{2}$-$5\frac{1}{2}$
							6-$8\frac{1}{2}$
							$7\frac{1}{2}$-11
							(ii) 1-5 (iii) 5-10 14-$17\frac{1}{2}$

Total	in.	5-9	5-8	5½							

*Note: (i) Base of present road.
(ii) Sub-base of present road.
(iii) Old road structure incl. surface usually 1"-1½".

APPENDIX 1 (Contd)

Second provisional soil map of Kenya

G.H, Gethin-Jones and R.M. Scott

Soil descriptions abstracted from Key

WELL-DRAINED SOILS

Humid regions

5. Dark-red friable clays with deep humic topsoil (latosolic soil). Dark reddish-brown (5YR 3/3) deep, high humic (3-7 per cent carbon) "A" horizon, overlies a dark red (2.5YR 3/6) subangular blocky friable clay. Derived from both volcanic and basement complex rocks and occur on the summits of broad flat-topped ridges, formed mainly by parallel rivers, between 5,000-7,000 ft. Rainfall over 40 in.

6. Dark-red friable clays (latosolic soils). Dusky-red (2.5YR 3/2) high humic (3-5 per cent carbon) "A" horizon, overlies a dark-red (2.5YR 3/6) subangular blocky friable clay. These soils are associated with 5 and occur on the more sloping land.

Sub-Humid regions

7. Red friable clays (latosolic soils). Dark reddish-brown (2. 5YR 3/4) medium humic (1.5 - 3 per cent carbon) "A" horizon overlies a red (2.5YR 4/8) weak subangular blocky friable clay. Derived from both volcanic and basement complex rocks and occur on gently rolling land between 3,000-6,000 ft. Rainfall 25 in.-45 in.

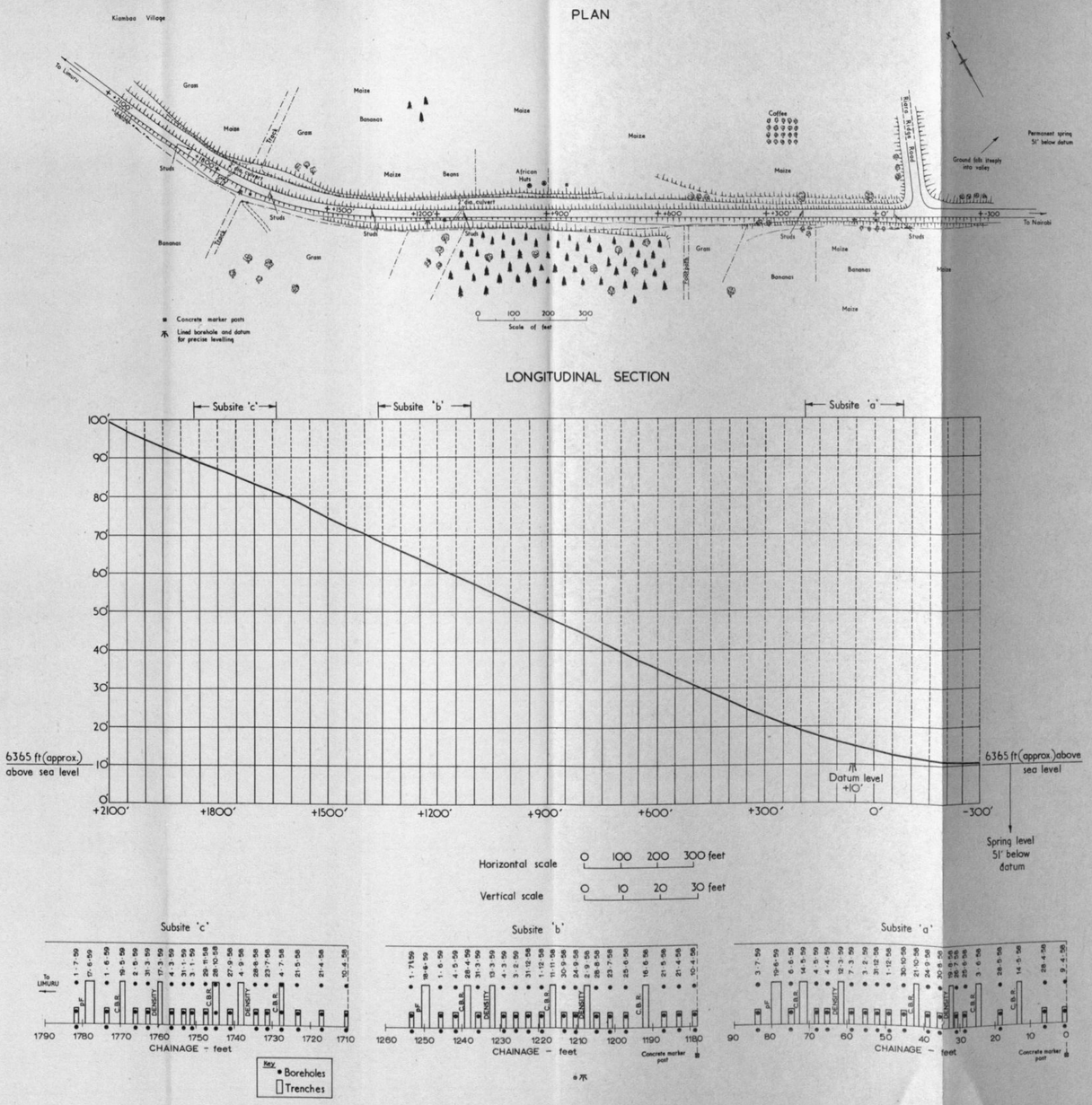
SOILS WITH IMPEDED DRAINAGE

22. Black clays (grumosolic soil). Consist of a range of "Black Cotton" soils and include the calcareous and non-calcareous variants. These are mainly derived from colluvium and occur on plains varying in altitude from sea-level to 7,000 ft. Rainfall 15-45 in.

LITHOSOLS AND REGOSOLS

34. Ash and Pumice soils. These soils show no profile development other than a more humic surface soil. Dark greyish-brown (10YR 4/2) humic (2 per cent carbon) silt loam "A" horizon overlies a brown (10YR 5/3) loose loamy fine sand. Derived from recent unconsolidated volcanic ash on smooth rolling to level land at 2,000-7,000 ft. Rainfall 20-30 in.

App. to RN/3807.

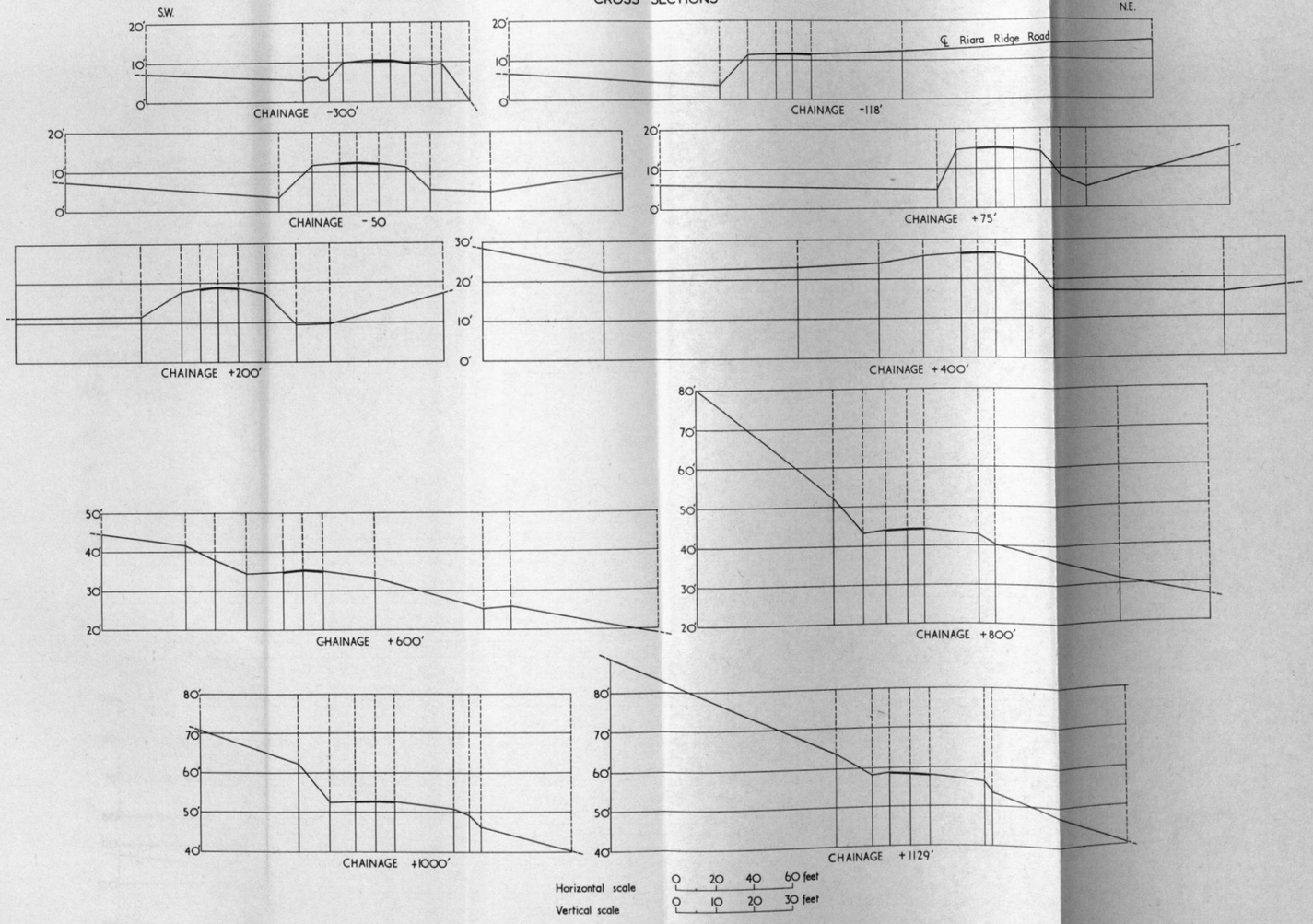


Appendix 2.a. LIMURU 'A' ROUTE

Dept. of Scientific & Industrial Research
Road Research Laboratory Note No. RN.3807/MPO'R. FHPW

FS. 15992

CROSS SECTIONS

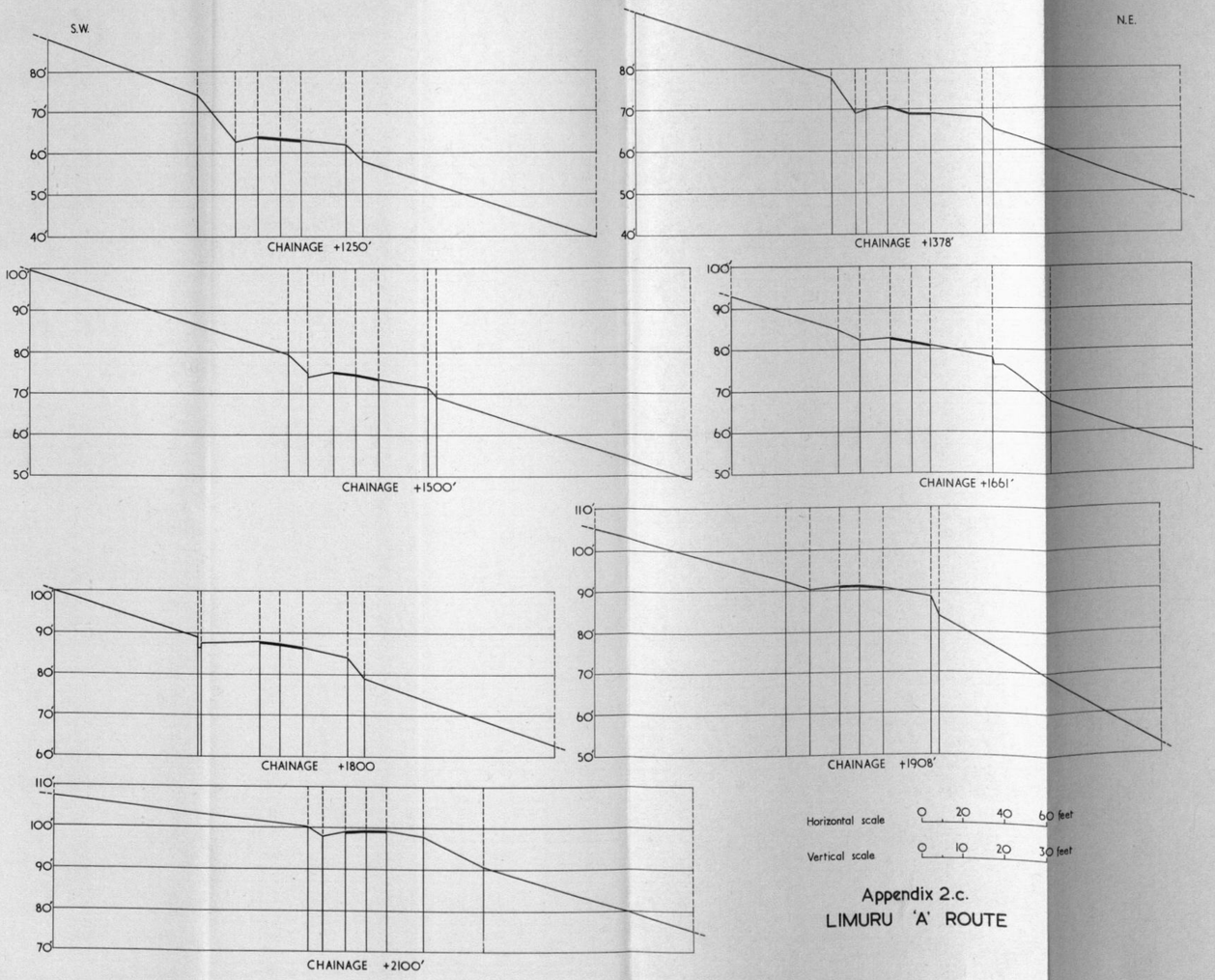


Appendix 2.b. LIMURU A ROUTE

Dept. of Scientific & Industrial Research
Road Research Laboratory Note No. RN/8807/MPO'R. FHPW

F.S.15993

CROSS SECTIONS



Horizontal scale 0 20 40 60 feet

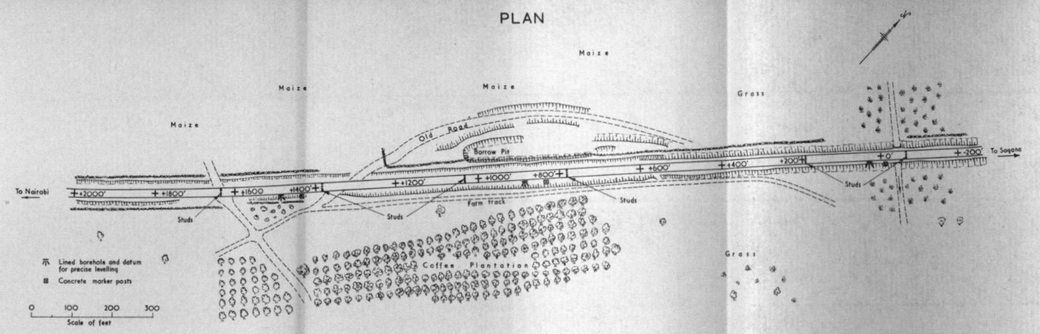
Vertical scale 0 10 20 30 feet

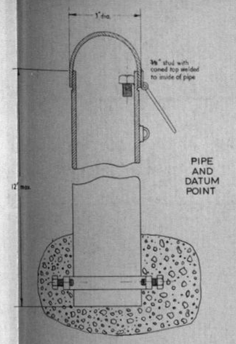
Appendix 2.c.
LIMURU 'A' ROUTE

Dept. of Scientific & Industrial Research
Road Research Laboratory Note No. RN.3807/MPO'R., FHPW

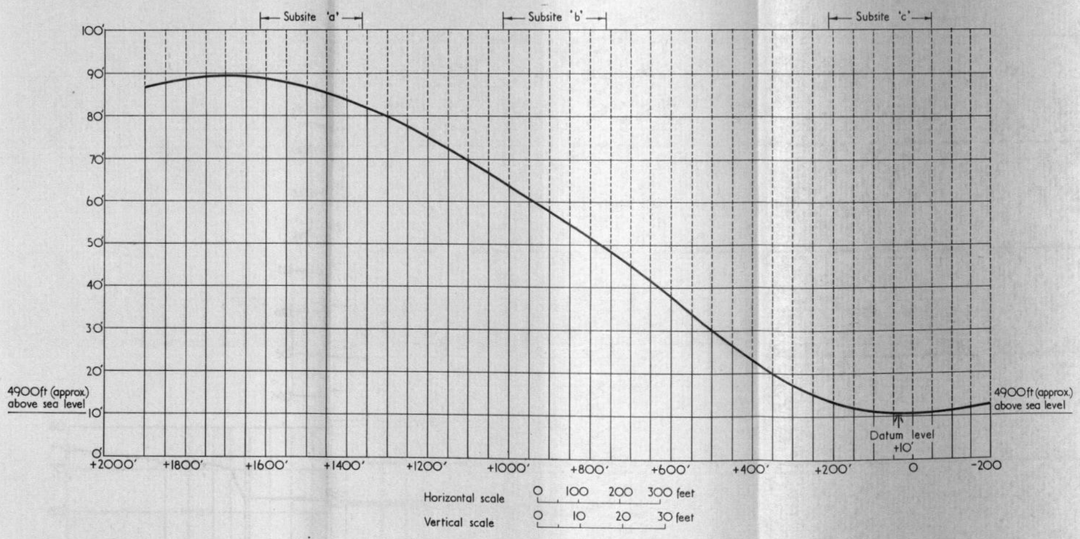
FS.19914

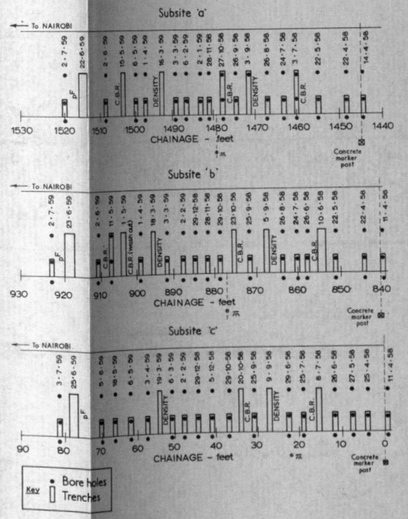
PLAN





LONGITUDINAL SECTION





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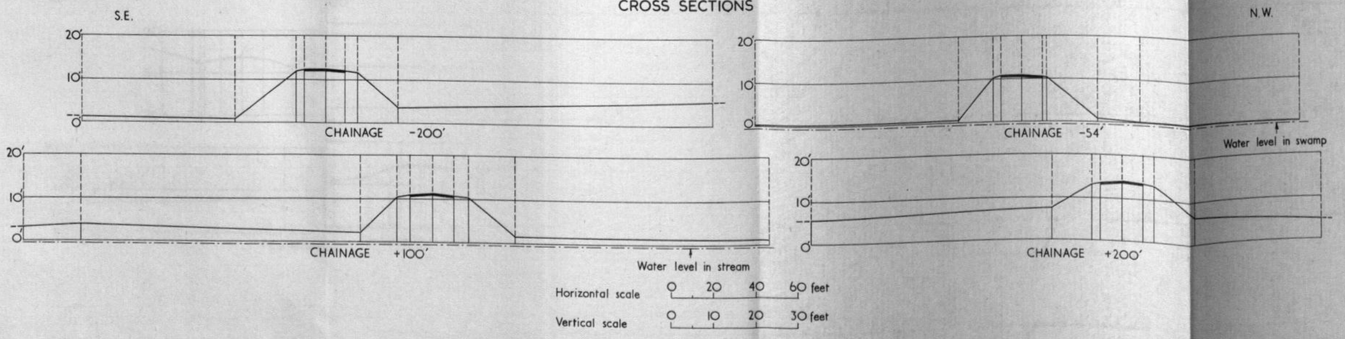

Appendix 3.a. THIKA - SAGANA ROAD

Dept. of Scientific & Industrial Research
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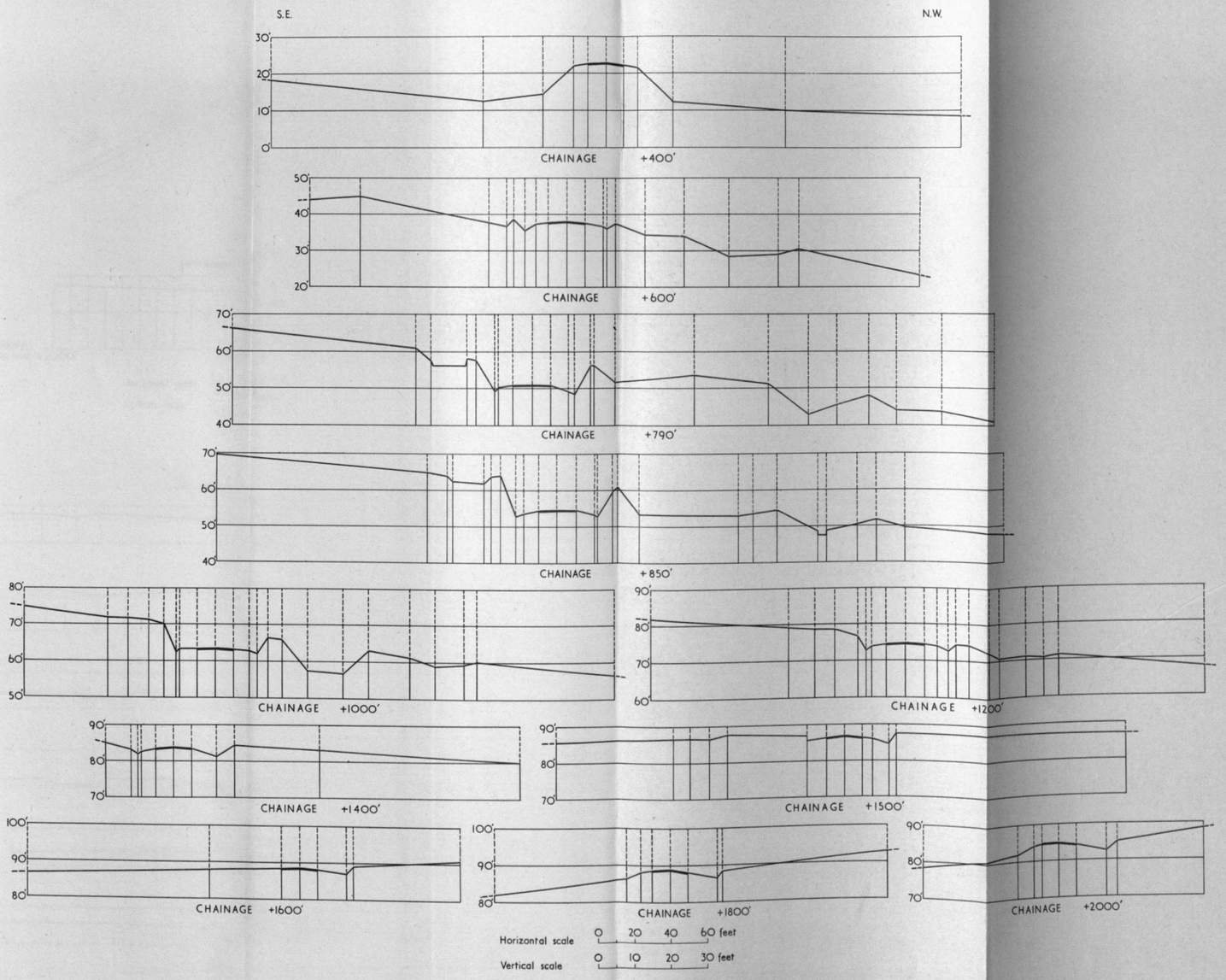
CROSS SECTIONS

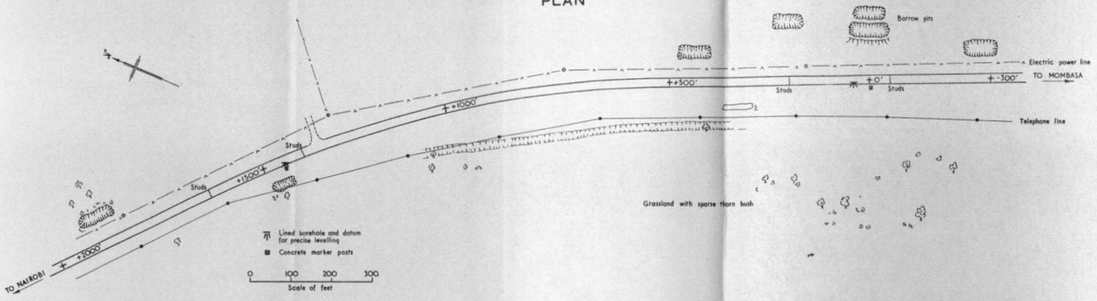


Appendix 3.b. THIKA – SAGANA ROAD

Dept. of Scientific & Industrial Research
Road Research Laboratory Note No. RN.3807/MPO.R.,FHPW

F.S.15991

PLAN



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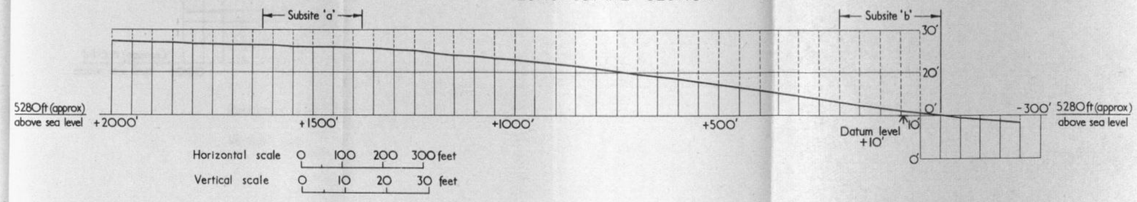

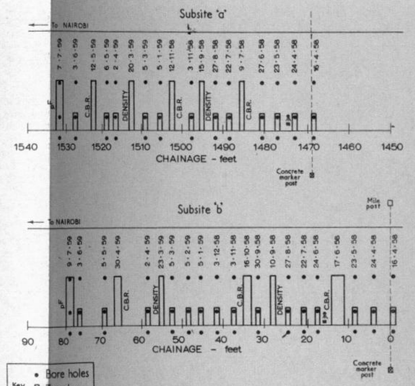

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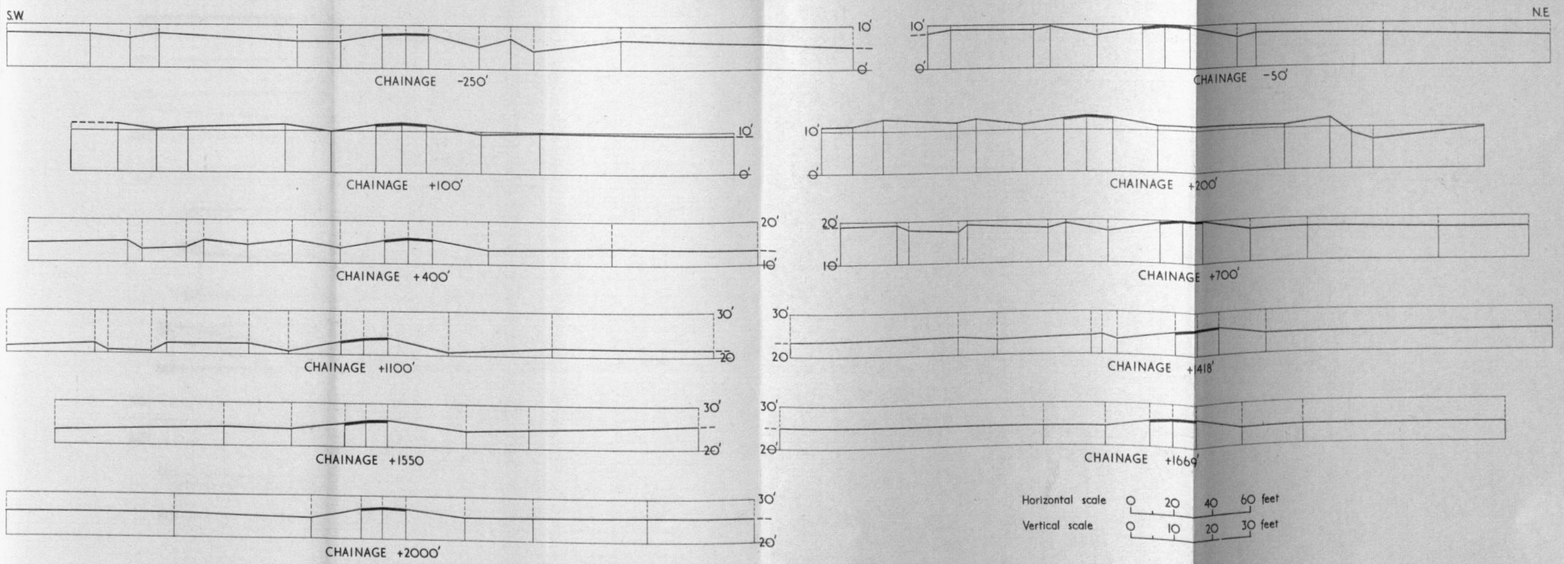
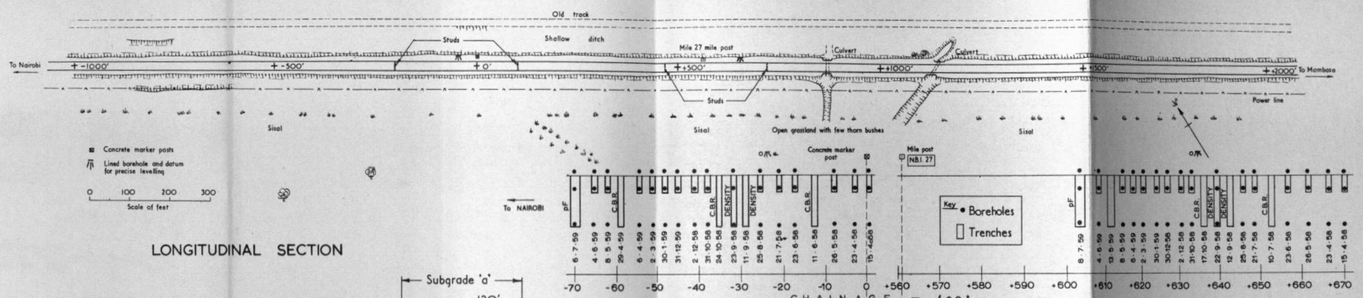


Appendix 4. MOMBASA ROAD MILE 12

ntific & Industrial Research
rch Laboratory Note No. RN.3807 / MPO'R. PHPW
FS.15999

PLAN



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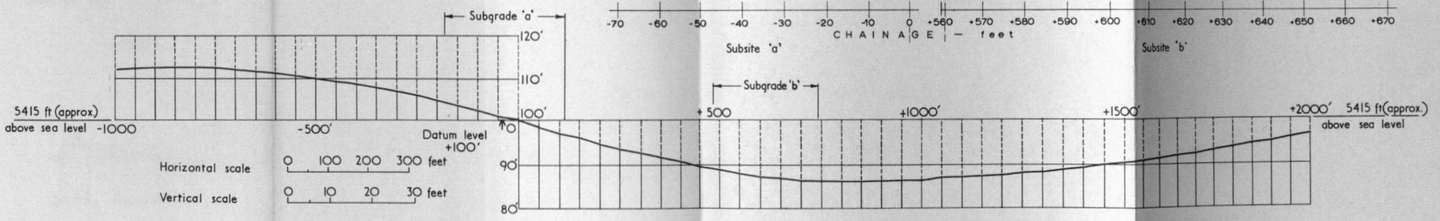

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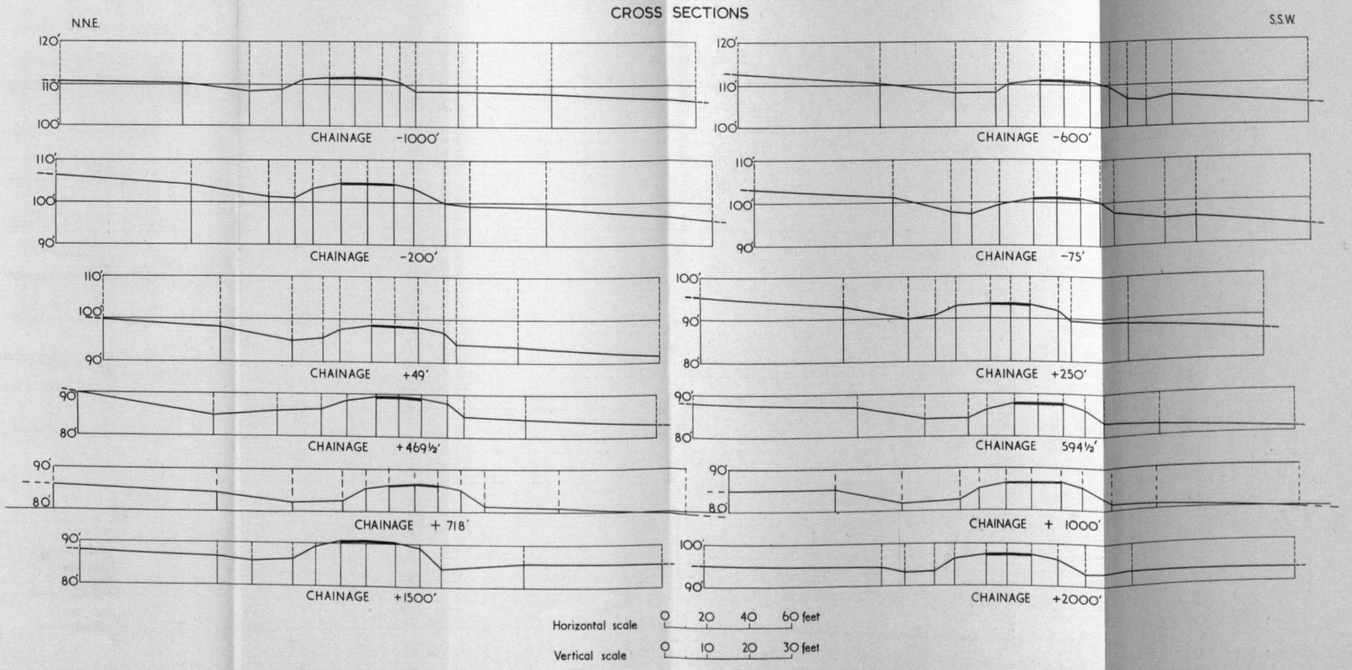
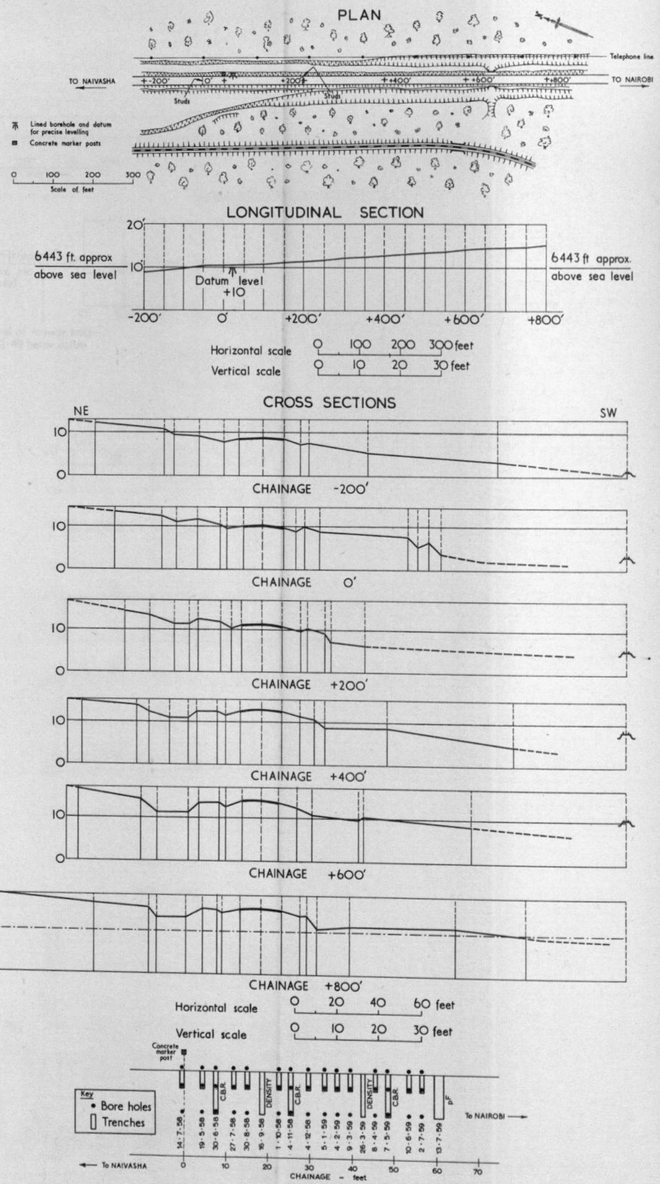
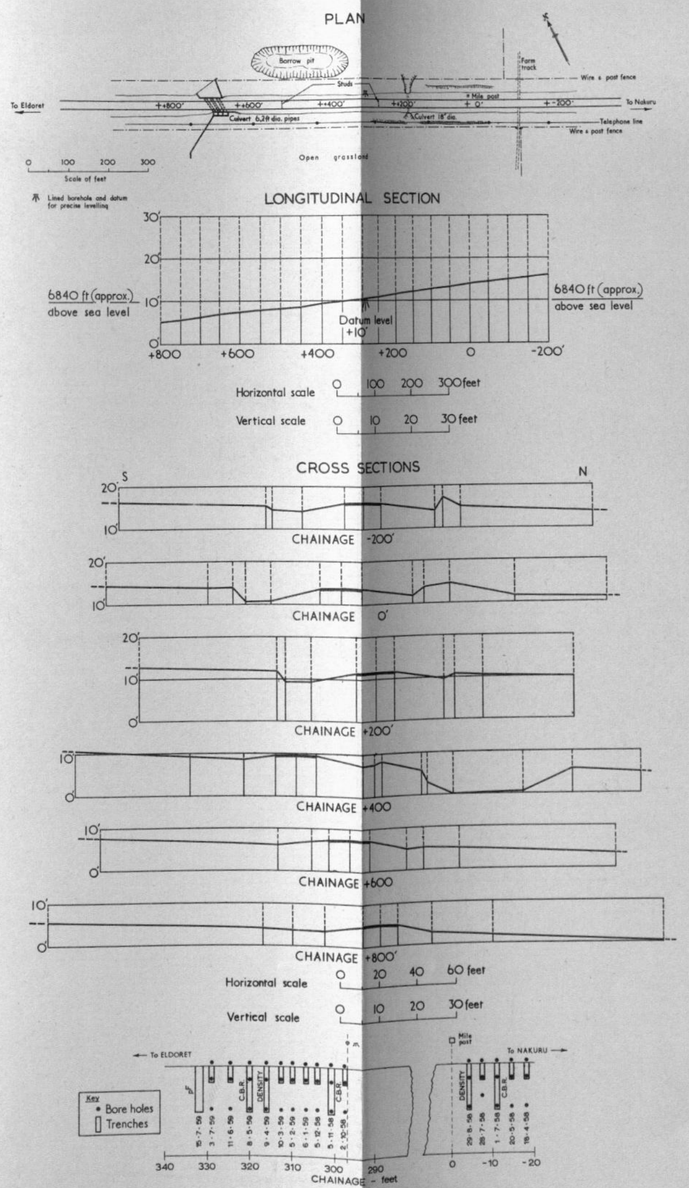


Appendix 5. MOMBASA ROAD MILE 27

Dept. of Scientific & Industrial Research
Road Research Laboratory Note No. RN.3807/MPO'R. FHPW



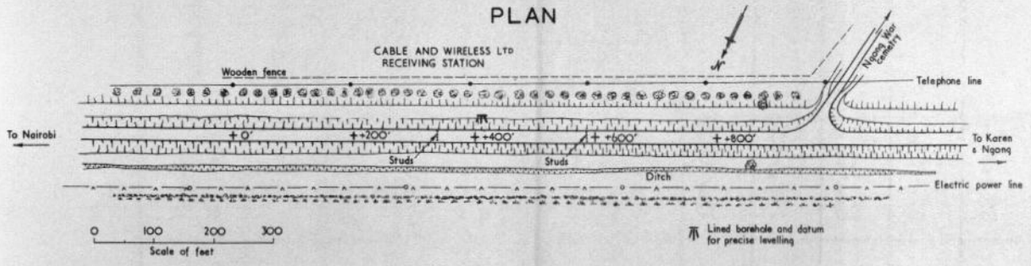
Appendix 6 NAIVASHA



Appendix 7 NAKURU

Dept. of Scientific & Industrial Research
Road Research Laboratory Note No. RN.3807/MPO'R., FHPW

PLAN



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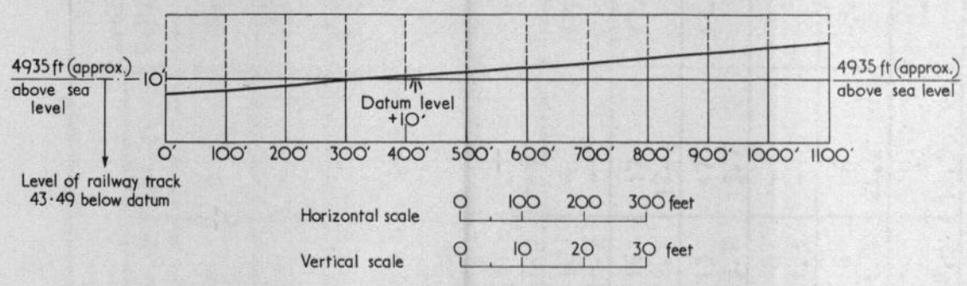

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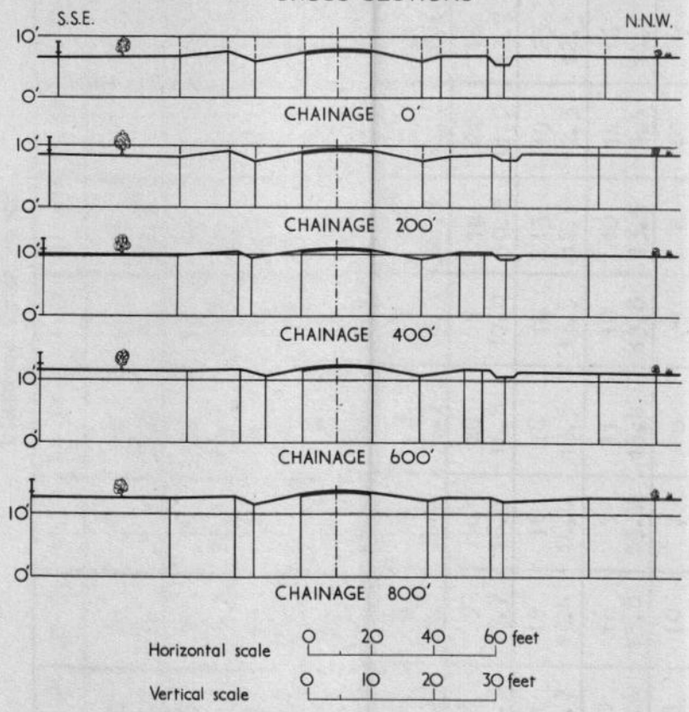

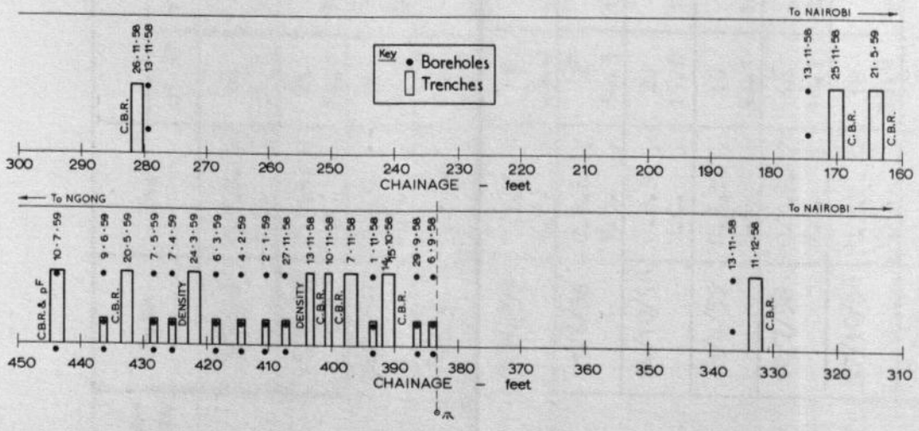

Appendix 8. NGONG ROAD

Dept. of Scientific & Industrial Research
Road Research Laboratory Note No. RN.3807/MPO'R, FHPW

APPENDIX 9

In situ C.B.R. tests on subgrades

Site No.	Sub-site	Date	Test	Distance from verge 0' 6"	1' 6"	2' 6"	3' 6"	4' 6"	5' 6"	6' 6"	7' 6"	8' 6"	9' 6"	10' 6"	Average C.B.R. %	Depth of test	Remarks
1.	a.	3/6/58	C.B.R. %	18	20	28	25	30	-	25	-	-	-	-	24.3	7"	*After heavy shower.
			M.C. %	35.2	38.8	37.5	37.4	37.5	-	40.9*							
		21/10/58	C.B.R. %	24	26	30	31	36	18	27	27	24	-	-	27.0	6½"-7½"	
			M.C. %	34.9	32.9	37.6	37.4	36.0	36.7	35.6	36.7	36.7					
		14/5/59	C.B.R. %	14	17	18	23	24	21	17	17	21	-	-	19.1	7"-9"	
			M.C. %	38.0	36.5	33.5	37.2	36.8	35.4	36.0	37.0	34.2	-	-			
	b.	16/6/58	C.B.R. %	22	17	25	22	31	25	32	23	24	10	-	23.1	8"-9"	
			M.C. %	40.3	40.2	41.7	41.3	39.4	38.4	36.2	30.1	35.6	39.2				
		11/11/58	C.B.R. %	31	22	37	32	23	43	40	23	31	20	-	30.2	5½"-8"	
			M.C. %	38.2	39.3	39.2	37.4	37.4	29.8	29.9	37.0	32.9	33.6				
		28/4/59	C.B.R. %	26	29	30	28	35	15	19	21	18	23	-	24.4	5"-7½"	
			M.C. %	38.7	37.4	38.4	32.8	37.1	29.5	30.8	37.7	35.0	35.0				
	c.	4/7/58	C.B.R. %	13	24	21	26	24	45	44	39	35	37	-	30.8	5½"-6½"	
			M.C. %	34.9	30.9	33.4	27.2	26.5	26.5	27.6	27.5	27.4	29.3				
		28/10/58	C.B.R. %	37	28	35	31	38	35	30	29	43	35	-	34.1	5"-7"	
			M.C. %	30.0	30.8	27.9	27.9	26.3	25.2	27.1	28.4	27.8	28.7				
		19/5/58	C.B.R. %	46	35	34	28	28	17	36	29	35	35	-	32.7	7"-8"	
			M.C. %	30.4	30.8	27.0	30.3	28.7	30.2	28.5	28.7	29.4	27.2				
2.	a.	3/7/58	C.B.R. %	17	16	24	21	16	23	23	27	36	30	-	23.3	12"-14"	
			M.C. %	29.0	29.1	27.7	27.4	28.0	26.7	25.2	24.1	23.1	23.0	-			
		27/10/58	C.B.R. %	18	20	18	19	19	25	27	28	32	25	-	23.1	10"-16"	
			M.C. %	29.2	29.1	28.3	27.7	27.3	26.2	25.1	25.0	24.1	23.8	-			
		15/5/59	C.B.R. %	10	11	16	16	17	24	23	33	25	15	-	19.0	12½"-16"	
			M.C. %	31.0	29.8	29.1	28.9	27.4	26.7	26.2	26.3	25.9	26.4	-			
	b.	10/6/58	C.B.R. %	9	10	11	12	16	9*	-	-	-	-	-	11.2	12"	*Doubtful
			M.C. %	37.1	35.3	34.9	33.7	32.8	34.7	-	-	-	-				
		23/10/58	C.B.R. %	14	11	15	15	18	16	14	12	14	12	-	14.1	13"-15"	
			M.C. %	34.2	33.5	32.3	31.4	30.4	30.2	30.9	31.7	31.0	32.0				
		11/5/59	C.B.R. %	17	19	17	18	24	18	18	17	21	19	-	18.8	13"-14½"	
			M.C. %	32.8	32.2	33.0	31.2	31.4	30.1	31.7	31.2	31.3	32.0				
	c.	8/7/58	C.B.R. %	16	22	17	10	15	17	21	18	23	24	-	18.3	20"	
			M.C. %	31.8	28.3	30.0	32.3	31.6	30.6	29.1	29.2	28.5	28.4				
		20/10/58	C.B.R. %	19	21	19	16	-	10	11	13	13	20	-	15.8	17¼"-20¾"	
			M.C. %	31.9	31.2	28.9	29.1	-	32.9	31.5	30.5	30.0	30.2				
		18/5/59	C.B.R. %	17	15	20	10	12	12	19	11	19	14	-	14.9	18½"-20"	
			M.C. %	29.8	31.2	30.9	31.4	33.8	31.6	30.0	30.3	30.3	30.2				
3	a.	9/7/58	C.B.R. %	5	8	9	12	8	16	21	22	28	35	-	16.4	15½"-16"	
			M.C. %	39.9	37.6	38.4	31.2	31.8	28.3	24.0	23.9	25.4	26.1				
		12/11/58	C.B.R. %	7	16	10	19	31	20	23	15	26	22	35	20.4	15½"-17¾"	
			M.C. %	37.5	35.8	34.5	31.2	26.0	24.9	19.3	22.9	24.2	24.8	22.4			
		12/5/59	C.B.R. %	18	17	18	24	31	32	35	43	42	41	51	32.0	15½"-17"	
			M.C. %	31.8	32.8	30.3	25.5	26.5	25.5	23.9	23.5	23.0	23.1	23.9			
	b.	17/6/58	C.B.R. %	3	4	9	10	12	17	21	-	-	-	-	10.9	18"	
			M.C. %	41.5	39.4	38.1	33.3	29.0	25.4	21.8	-	-	-	-			
		16/10/58	C.B.R. %	6	5	10	11	14	19	21	34	23	27	30	18.2	19"-21"	
			M.C. %	36.0	38.7	34.8	33.1	28.6	26.8	22.4	22.1	21.3	21.1	21.3			
		30/4/59	C.B.R. %	3	4	4	6	9	12	18*	23	25	20	27	13.7	19"-22"	*Stone under plunger
			M.C. %	42.2	41.0	39.5	36.8	34.7	28.8	27.9	24.0	22.1	21.9	22.6			
4	a.	11/6/58	C.B.R. %	2*	8	9	14	20	9	14	22	16	10	-	12.4	18"-24"	*Doubtful
			M.C. %	14.3	17.3	19.7	16.3	16.8	17.0	10.8	11.0	12.7	16.7	-			
		24/10/58	C.B.R. %	20	21	19	16	18	14	13	19	23	16	17	17.8	18"-20½"	
			M.C. %	15.2	11.7	17.4	14.0	13.5	13.5	12.1	12.3	12.3	12.1	12.4			
		29/4/59	C.B.R. %	16	20	16	9	11	10	10	14	16	13	17	13.8	18½"-22"	
			M.C. %	14.1	14.6	15.8	15.7	15.2	13.8	13.5	13.3	14.1	13.7	13.7			
	b.	10/7/58	C.B.R. %	16	8	10	7	8	9	8	10	9	8	-	9.3	23"-24"	
			M.C. %	16.1	22.8	22.7	23.5	20.6	21.2	20.7	21.0	22.0	21.3	-			
		17/10/58	C.B.R. %	18	9	13	8	9	6	7	8	9	6	6	9.0	21"-22"	
			M.C. %	14.9	22.1	20.4	21.3	18.9	19.1	20.5	19.7	19.9	21.2	21.2			
		13/5/59	C.B.R. %	17	10	9	7	8	7	10	9	8	7	5	8.8	22"-23½"	
			M.C. %	18.0	20.6	21.8	21.0	20.3	21.7	20.9	21.4	19.9	22.5	19.9			

/APPENDIX 9 (Contd)

APPENDIX 9 (contd)

Site No.	Sub-site	Date	Test	Distance from verge 0' 6"	1' 6"	2' 6"	3' 6"	4' 6"	5' 6"	6' 6"	7' 6"	8' 6"	9' 6"	10'6"	Ag. CBR %	Depth of test	Remarks
5.	a.	30/ 6/58	CBR % M.C %	18 28.4	32 29.5	21 26.6	16 28.3	19 30.3	17 31.2	24 28.8	27 28.0	13 29.9	16 28.4	- -	20.3	6"	
		4/11/58	CBR % M.C %	13 25.8	17 32.1	26 28.6	14 29.9	17 28.4	9 30.4	12 30.2	17 26.6	14 29.0	12 28.8	- -	15.1	$6\frac{1}{4}$"-$7\frac{1}{2}$"	
		7/ 5/59	CBR % M.C %	6* 31.8	9 29.6	11 31.7	13 31.6	17 29.9	26 28.6	22 27.1	17 28.0	26 29.3	19 27.3	- - -	16.6	7" -8"	*Subgrade soft & wet but some disturbance possible
6.	a.	1/ 7/58	CBR % M.C %	17 50.6	11 43.1	16 45.9	17 41.8	22 43.9	30 40.2	25 40.0	32 36.8	25 39.8	21 41.6	-	21.6	8"	
		5/11/58	CBR % M.C %	13 53.1	23 54.2	19 48.6	23 44.3	27 38.1	25 38.8	32 35.5	28 39.1	20 36.7	16 30.0	-	22.6	$8\frac{1}{4}$"-$9\frac{3}{4}$"	
		8/ 5/59	CBR % M.C %	17 41.1	15 44.7	25 41.2	19 40.9	30 42.7	20 44.1	25 45.7	27 41.6	29 42.4	23 39.5	29 38.9	23.5	8" -9"	
7.	a.	15/10/58	CBR % M.C %	20* 12.6	14 33.0	13 34.7	21+ 20.8	27+ 20.3	30+ 16.5	30+ 14.1	25+ 19.7	23+ 16.3	21+ 18.5	- -	22.4	15"	*Pocket of murram at subgrade level. +Contaminated blackcottom soil greyish in colour.
		7/11/58	CBR % M.C %	15 22.4	14 31.7	18 27.2	7 32.5	5° 33.4	8° 33.2	8° 31.4	7° 32.7	7° 32.3	- -	- -	9.9	17" -23"	See note (a). °Over 20" deep
		10/11/58	CBR % M.C %	9 36.2	15 34.3	14 36.0	8 34.2	7 34.2	6 36.0	7 36.5	10 36.1	7 36.6	6 38.4	-	8.9	27" -30"	See note (a)
		20/ 5/59	CBR % M.C % *Classification	14+ 24.8 Samp. No. 1	15+ 19.1	12+ 20.7	18+ 20.5 Samp. No. 2	20 24.3	16 28.2	20 29.7 Samp. No. 3	20 32.1	22 28.2	28 29.1 Samp. No. 4	-	18.5	15" -19"	+Greyish soil *See App. 10
7. Chainage	170'	25/11/58	CBR % M.C %	13 27.3	14 26.9	15 30.6	13 27.8	25 22.0	25 22.9	23 27.0	21 23.7	27 20.5	28 20.8	-	20.4	13" -$14\frac{1}{2}$"	See note (a)
	164'	21/ 5/59	CBR % M.C % *Classification	10 44.1 Samp. No. 5	20+ 25.7	26+ 23.2	24+ 19.6 Samp. No. 6	15+ 29.4	17 33.6	12 33.0 Samp. No. 7	20 34.4	20 34.7	10 32.2 Samp. No. 8	- -	17.4	$13\frac{1}{2}$"-$16\frac{1}{2}$"	+Greyish soil See App. 10
	221'	26/11/58	CBR % M.C %	14 30.3	15 24.9	15 32.0	11 31.0	16 25.1	13 27.2	18 15.5	27 18.2	22 17.8	15 22.1	-	16.6	14" -$16\frac{1}{2}$"	See note (a)
	333'	11/12/58	CBR % M.C %	11 25.3	11 30.6	14 32.2	12 31.4	11 31.3	19 30.9	13 30.1	16 30.2	9° 32.0	9° 32.1	9° 30.2	12.2	16" -23"	See note (a) °Over 20" deep

Note: (a) Material having a moisture content below 28% will most probably be similar to the greyish soil mentioned in tests carried out on the 20. 5.59 and 21. 5.59.

/APPENDIX 9 contd

In situ C.B.R. tests on Murram base and sub-base materials

Site No.	Sub-site	Date	Test	Distance from verge 0' 6"	1' 6"	2' 6"	3' 6"	4' 6"	5' 6"	6' 6"	7' 6"	8' 6"	9' 6"	10' 6"	Average C.B.R. %	Depth of test	Remarks
1.	a.	3/ 6/58	C.B.R. %	50	59	40	71	>74	-	49	66	>84	-	-	62	2½"	
			M.C. %	19.1	20.7	20.6	19.7	17.8	-	18.4	19.5	15.7	-				
		21/10/58	C.B.R. %	41	38	44	36	28	32	50	49	41	-	-	39.9	3½"-4½"	
			M.C. %	25.0	23.3	21.7	21.2	21.2	19.8	15.2	15.8	13.6	-	-			
		14/ 5/59	C.B.R. %	-	-	-	32	35	47	41	31	-	-	-	37.2	3½"-5½"	
			M.C. %	-	-	-	23.9	18.5	17.8	19.0	18.5	-	-	-			
	b.	16/ 6/58	C.B.R. %	21	31	38	34	42	36	47	34	30	-	-	34.8	5"	
			M.C. %	20.0	17.2	18.6	19.9	14.0	23.0	20.5	19.3	19.3	-	-			
		11/11/58	C.B.R. %	46	41	56	45	52	49	49	55	>47	>70	-	>51	3" -5½"	
			M.C. %	19.6	20.7	20.1	18.9	20.5	18.7	21.2	25.6	21.8	22.2	-			
		28/ 4/59	C.B.R. %	>45	44	62	56	-	>36	>24	42	28	30	-	>41	3½"-5½"	
			M.C. %	14.4	12.3	16.8	18.6	-	-	-	21.9	15.9	26.7	-			
	c.	4/ 7/58	C.B.R. %	22	22	29	65	40	87	85	54	55	30	-	48.9	4"	
			M.C. %	17.7	19.8	14.1	13.4	14.0	14.8	11.5	12.4	10.9	9.4				
		28/10/58	C.B.R. %	43	43	53	>50	>50	>50	>50	51	69	>93	-	>55	4"	
			M.C. %	18.8	15.9	-	15.0	11.1	11.3	12.8	11.1	12.9	13.6				
		19/ 5/59	C.B.R. %	-	-	-	-	-	-	36	67	>100	>87	-	>72	4"	
			M.C. %	-	-	-	-	-	-	12.6	12.3	12.3	11.8				
2.	a.	3/ 7/58	C.B.R. %	18	35	28	46	36	27	37	42	56	37	-	36.2	6" -7"	
			M.C. %	26.8	23.3	26.0	21.5	22.4	18.6	18.6	18.1	13.7	17.4				
		27/10/58	C.B.R. %	17	38	30	46	45	60	33	44	48	52	-	41.3	6¼"-8½"	
			M.C. %	24.1	22.4	24.3	22.0	19.9	18.2	18.7	16.2	16.4	15.0				
		15/ 5/59	C.B.R. %	26	29	37	40	37	29	45	42	50	24	-	35.9	7" -8¼"	
			M.C. %	22.6	24.8	23.3	23.6	22.6	21.8	24.0	20.4	17.8	16.1				
	b.	10/ 6/58	C.B.R. %	9	37	25	31	31	25	-	-	-	-	-	26.3	8"	
			M.C. %	22.6	22.7	25.9	28.8	26.7	27.7	-	-	-	-	-			
		22/10/58	C.B.R. %	13	24	21	26	29	22	29	25	21	24	-	23.4	8" -9"	
			M.C. %	27.4	24.4	23.8	24.2	26.2	28.3	28.1	29.2	28.7	23.9				
		11/ 5/59	C.B.R. %	20	22	24	22	29	47	37	30	26	49	-	30.6	8½"-13½"	
			M.C. %	22.8	22.1	21.6	21.7	20.7	19.1	21.1	24.8	32.3	28.6				
	c.	8/ 7/58	C.B.R. %	40	15	17	21	21	21	18	-	32	23	-	22.0	14"	
			M.C. %	20.3	21.2	22.0	21.0	22.8	20.1	19.9	-	20.3	20.3				
		20/10/58	C.B.R. %	61	50	25	12	17	28	18	24	23	34	-	29.2	9½"-12½"	
			M.C. %	15.9	15.4	22.1	20.4	20.0	18.7	19.3	18.6	17.4	17.9				
		18/ 5/59	C.B.R. %	27	13	18	17	9	11	11	11	15	12	-	14.4	15½"-19"	
			M.C. %	20.4	24.6	20.3	23.8	22.3	22.5	21.0	23.5	17.5	21.4				
3.	a.	9/ 7/58	C.B.R. %	>60	>100	76	-	>100	>100	>100	>100	-	>100	-	>92	3" -4½"	Mixture of murram and stone.
			M.C. %	47.0	38.9	13.9	-	11.8	11.9	11.1	10.5	-	8.0				
		12/11/58	C.B.R. %	15	13	16	20	20	24	-	-	-	-	-	18.0	8" -10½"	
			M.C. %	23.2	22.2	23.0	24.3	20.2	20.7	-	-	-	-	-			
		12/ 5/59	C.B.R. %	-	36	66	-	>70	-	-	70	78	79	71	>66	12"-15"	
			M.C. %	-	10.6	11.1	-	13.3	-	-	9.1	8.4	8.1	7.1			
	b.	17/ 6/58	C.B.R. %	56	67	75	81	95	69	62	74	-	-	-	72.4	2"	As above
			M.C. %	11.4	12.1	13.0	8.0	10.5	7.8	7.7	7.2	-	-	-			
		16/10/59	C.B.R. %	-	-	-	62	60	80	-	-	>100	-	54	>71	8"	
			M.C. %	-	-	-	17.6	16.6	11.9	-	-	32.1	-	12.2			
		30/ 4/59	C.B.R. %	-	-	3*	-	16	13	-	21	58	-	38	24.8	13"-18"	*Very poor seating.
			M.C. %	-	-	32.5	-	18.8	22.2	-	16.6	17.1	-	13.5			

/APPENDIX 9 (contd)

APPENDIX 9 (Contd)

In situ C.B.R. tests on murram base and sub-base materials

Site No.	Sub-site	Date	Test	Distance from verge 0' 6"	1' 6"	2' 6"	3' 6"	4' 6"	5' 6"	6' 6"	7' 6"	8' 6"	9' 6"	10' 6"	Average C.B.R. %	Depth of test	Remarks
7	a.	14/10/58	C.B.R. %	69	78	>100	29	-	-	-	-	-	-	-	69	2"-4"	
			M.C. %	9.3	11.4	7.4	5.8	-	-	-	-	-	-	-			
		14/10/58	C.B.R. %	32	13	-	18	29	22	14	11	-	17	-	19.9	$7\frac{1}{2}$"	
			M.C. %	16.2	19.6	-	19.1	21.0	18.4	18.4	20.2	-	-	-			
		15/10/58	C.B.R. %	>150	>140	-	>150	-	>150	-	-	-	-	-	148	$10\frac{1}{2}$"	Murram base under old road surface
			M.C. %	-	-	-	-	-	-	-	-	-	-	-			
		9/7/59	C.B.R. %	-	53	-	-	85	-	59	-	-	-	-	62.8	2"	
			M.C. %	10.1	9.1	10.5	9.3	9.3	-	6.6	-	-	-	-			
		9/7/59	C.B.R. %	37	71	83	73	64	45	37	55	51	66	74	53.3	$4\frac{1}{2}$"-6"	
			M.C. %	15.7	11.5	11.7	13.4	10.5	9.8	11.7	13.0	13.5	14.6	12.0			
		10/7/59	C.B.R. %	>130	>200	>130	>200	100	150	-	-	-	-	-	>152	$7\frac{1}{2}$"-$8\frac{1}{2}$"	Murram base under old road surface
			M.C. %	9.5	10.0	8.8	9.1	9.5	14.6	-	-	-	-	-			

/APPENDIX 9 (Contd)

In situ C.B.R. tests on stone base and sub-base materials

Site No.	Sub-site	Date	Test	Distance from verge 0' 6"	1' 6"	2' 6"	3' 6"	4' 6"	5' 6"	6' 6"	7' 6"	8' 6"	9' 6"	10' 6"	Average C.B.R. %	Depth of test	Remarks
4.	a.	11/6/58	C.B.R. %	-	-	-	-	-	87	89	>100	56	>100	-	>86	2"	The road structure consists of mixtures of crushed stone and sand with the proportion of the latter increasing with depth.
			M.C. %	-	-	-	-	-	0.7	0.8	0.7	1.4	1.1	-			
		24/10/58	C.B.R. %	47	>117	72	62	55	66	65	-	-	-	-	> 69	8"-10"	
			M.C. %	20.0	13.5	12.9	15.4	14.7	15.4	13.4	-	-	-	-			
		29/4/59	C.B.R. %	72	-	63	53	-	-	-	52	63	-	53	59.3	14½"-16"	
			M.C. %	10.1	-	9.3	8.4	-	-	-	7.5	7.7	-	7.7			
	b.	10/7/58	C.B.R. %	-	>300	>200	80	56	90	81	>74	>240	-	-	>140	2"	As above.
			M.C. %	-	7.3	2.6	2.0	1.8	1.6	4.3	1.5	1.7	-	-			
		17/10/58	C.B.R. %	>45	43	55	86	51	33	-	-	-	-	-	> 52	10"	
			M.C. %	11.1	9.9	10.3	11.8	13.0	11.9	-	-	-	-	-			
		13/5/59	C.B.R. %	-	18	30	47	-	30	38	55	-	33	-	35.9	16"-20"	
			M.C. %	-	12.2	9.5	6.9	-	10.0	7.0	7.5	-	8.4	-			
6.	a.	1/7/59	C.B.R. %	-	25	52	34	45	43	62	60	90	-	-	51.4	4"	Green weak pumice like stone.
			M.C. %	-	20.4	14.3	14.5	13.1	9.8	9.5	11.4	9.8	-	-			
		5/11/59	C.B.R. %	>50	26	26	-	29	>90	35	42	38	36	-	>41	5"-7"	
			M.C. %	8.8	8.6	9.2	-	9.9	7.3	7.6	7.2	9.4	9.6	-			
		8/5/59	C.B.R. %	32	36	32	-	28	27	74	74	55	33	-	43.4	4"-5"	
			M.C. %	12.0	10.3	11.5	-	11.1	10.4	8.8	9.8	9.4	8.1				

/APPENDIX 10

APPENDIX 10

Results of classification tests on subgrade soil from Site No. 7

Date	Sample Ref: No.	Distance from verge ft in.	Depth in.	Liquid limit %	Plastic limit %	Plas-ticity Index %	Percentage passing B.S. sieve No. 7	25	72	200	Remarks
20.5.59	1	0'-6"	16"	72	32	40	99.9	99.2	96.8	91.8	Greyish coloured soil.
	2	3'-6"	17½"	79	33	46	99.9	99.5	98.1	95.0	Greyish coloured soil.
	3	6'-6"	15½"	87	38	49	100	99.7	98.8	96.9	Black soil
	4	9'-6"	15"	87	37	50	100	99.9	99.1	97.1	Black soil
21.5.59	5	0'-6"	13½"	104	39	62	100	99.8	98.8	97.0	Black soil
	6	3'-6"	15¾"	51	29	22	100	99.3	97.4	93.5	Greyish coloured soil.
	7	6'6"	15"	89	38	51	99.9	99.6	98.7	97.0	Black soil.
	8	9'-6"	16½"	94	37	57	100	99.8	98.7	96.4	Black soil.

App. to RN/3807.

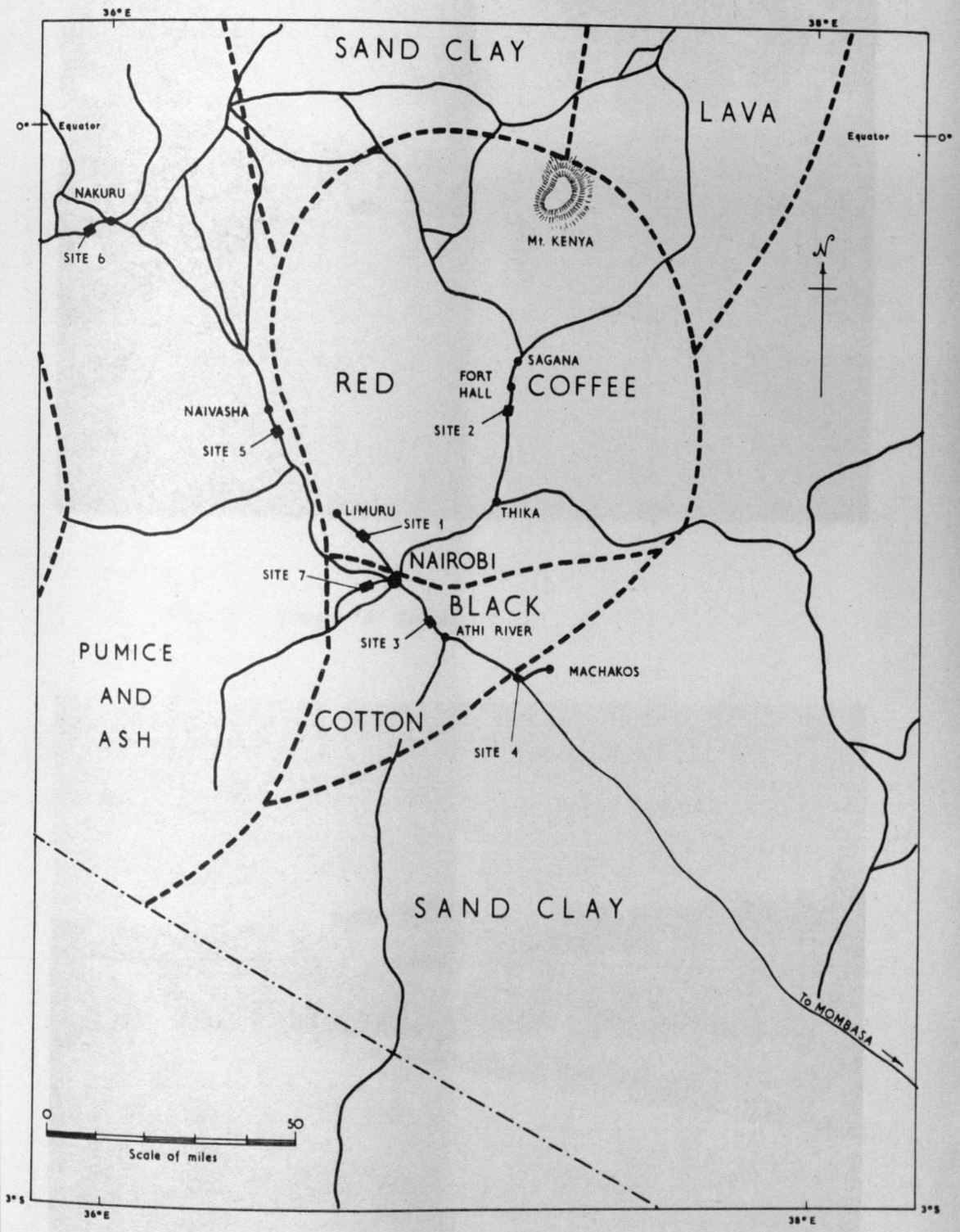

Fig. 1. PRINCIPAL ROADS IN THE CENTRAL AREA OF KENYA SHOWING THE APPROXIMATE LOCATION OF SITES UNDER INVESTIGATION AND THE MAIN SOIL TYPES ENCOUNTERED

Fig. 2. Limuru 'A' Route.

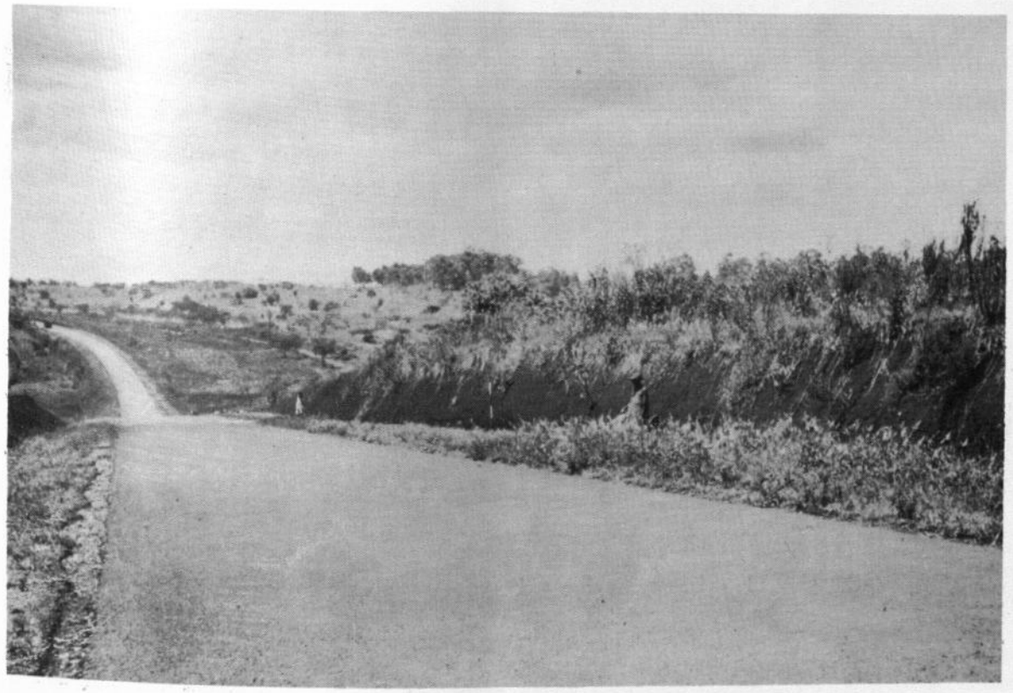

Fig. 3. Thika-Sagana Road.

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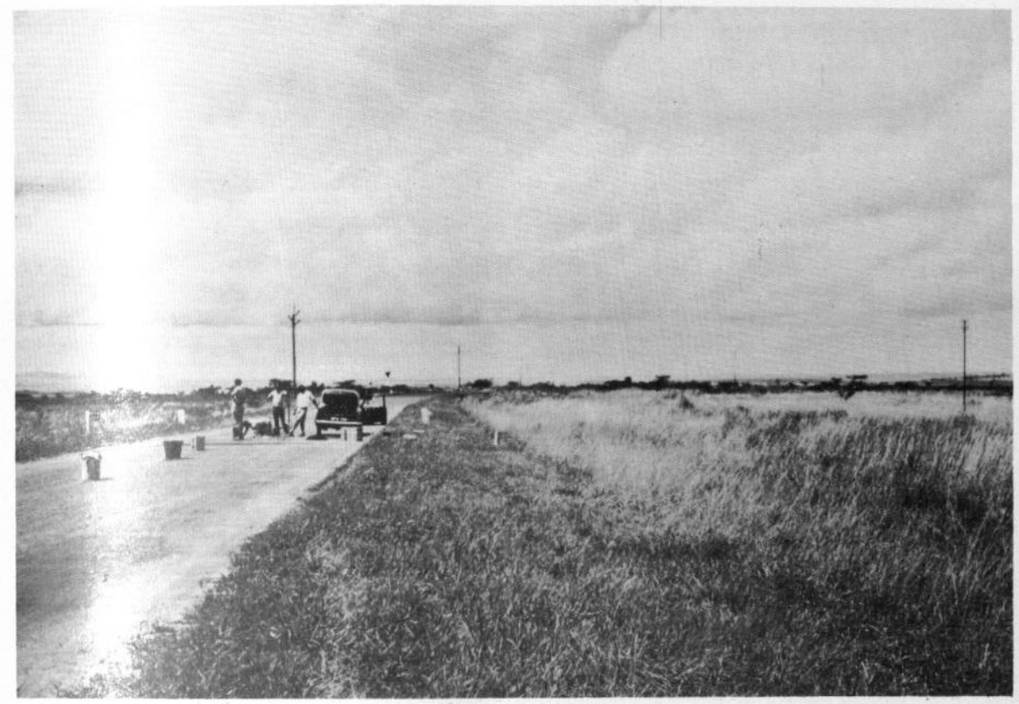

Fig. 4. Mombasa Road. Mile 12.

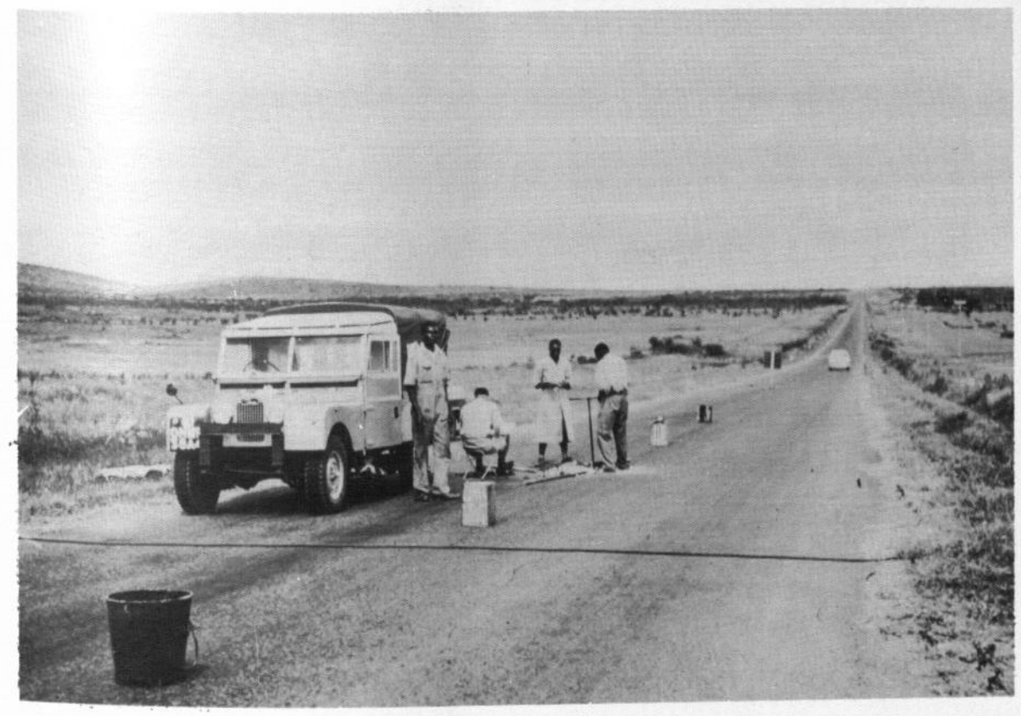

Fig. 5. Mombasa Road. Mile 27.

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Fig. 6. Naivasha.

Fig. 7. Nakuru.

Fig. 8. Ngong Road.

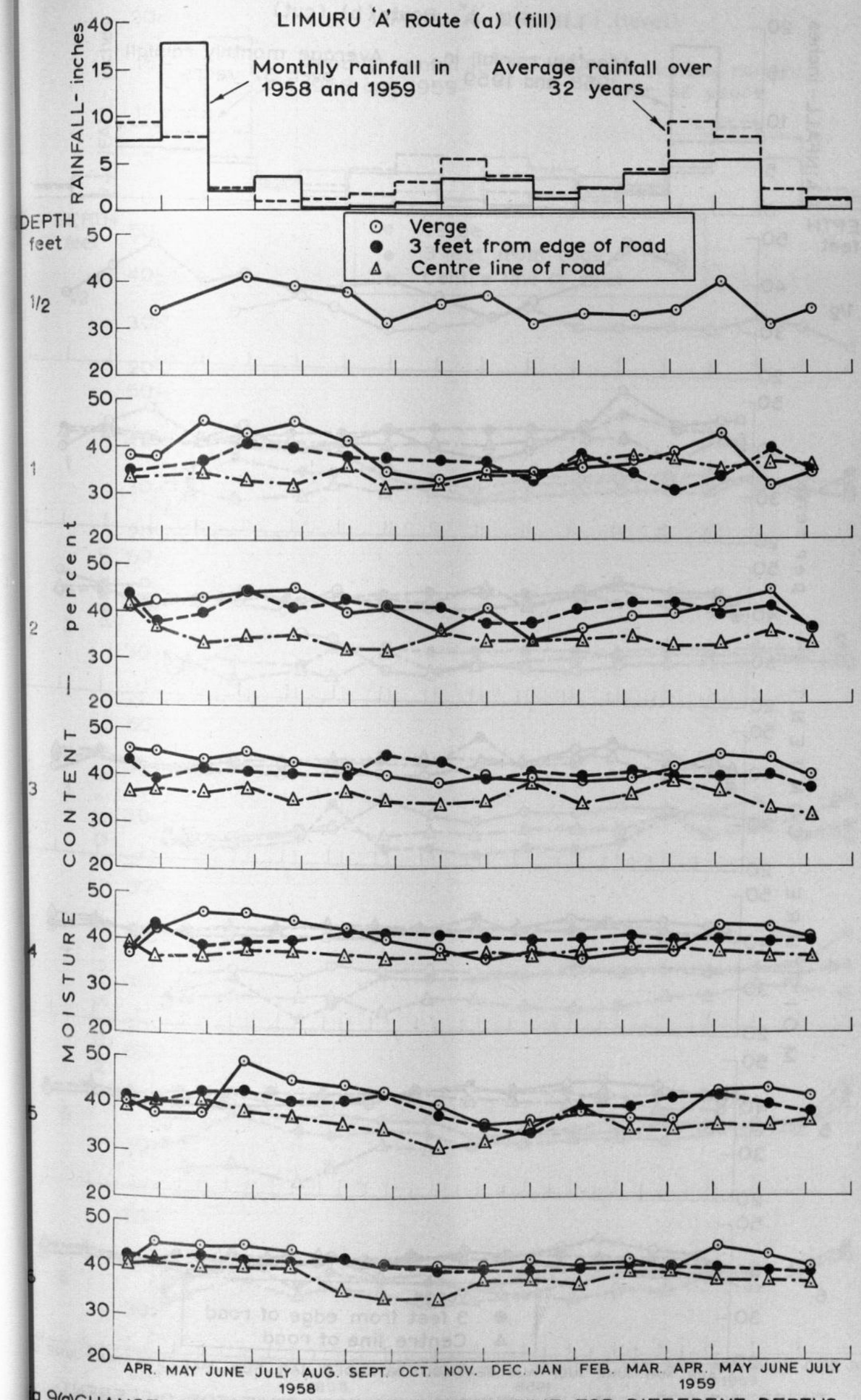

Fig.9(a) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

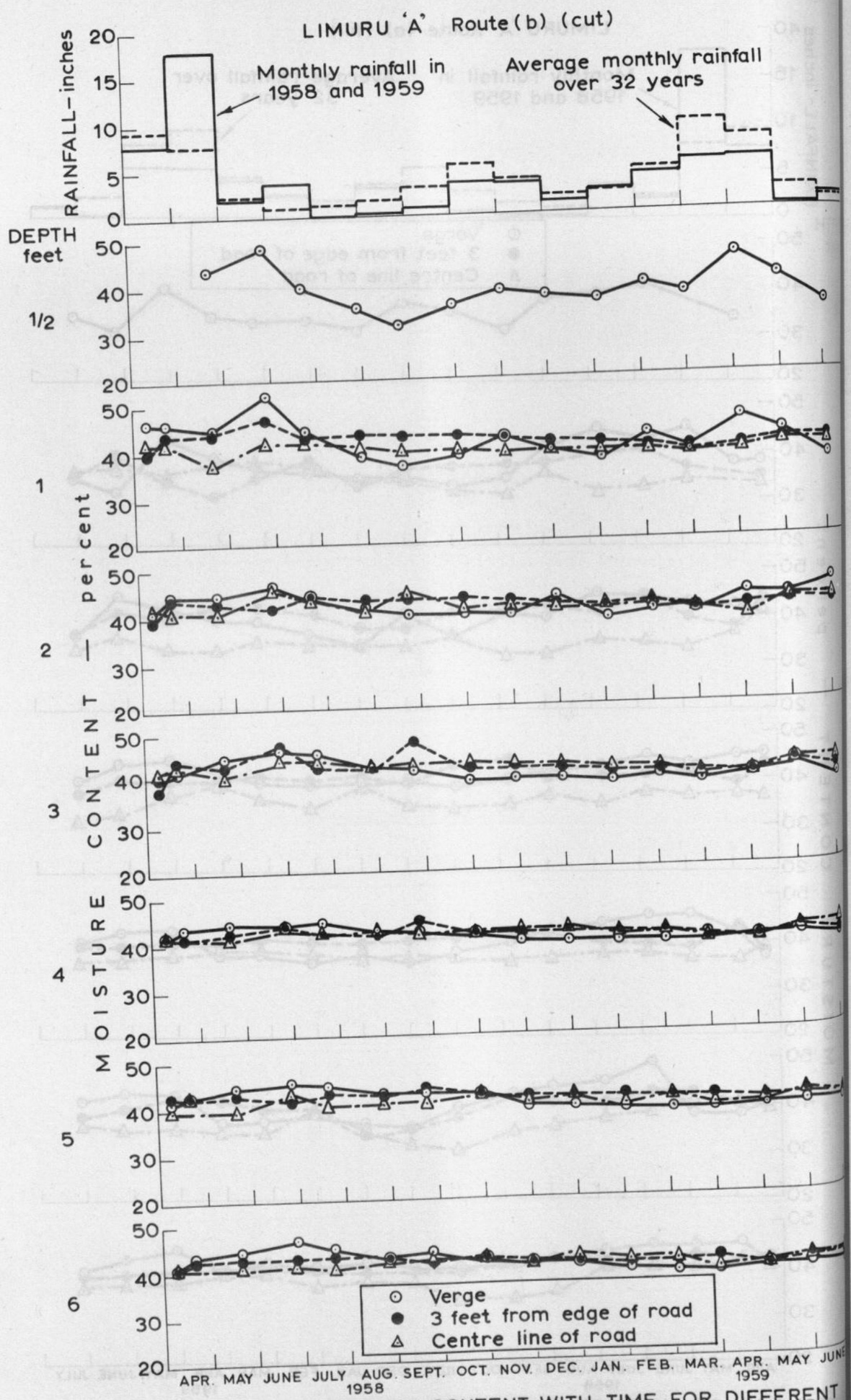

Fig.9.(b) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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FS.16476

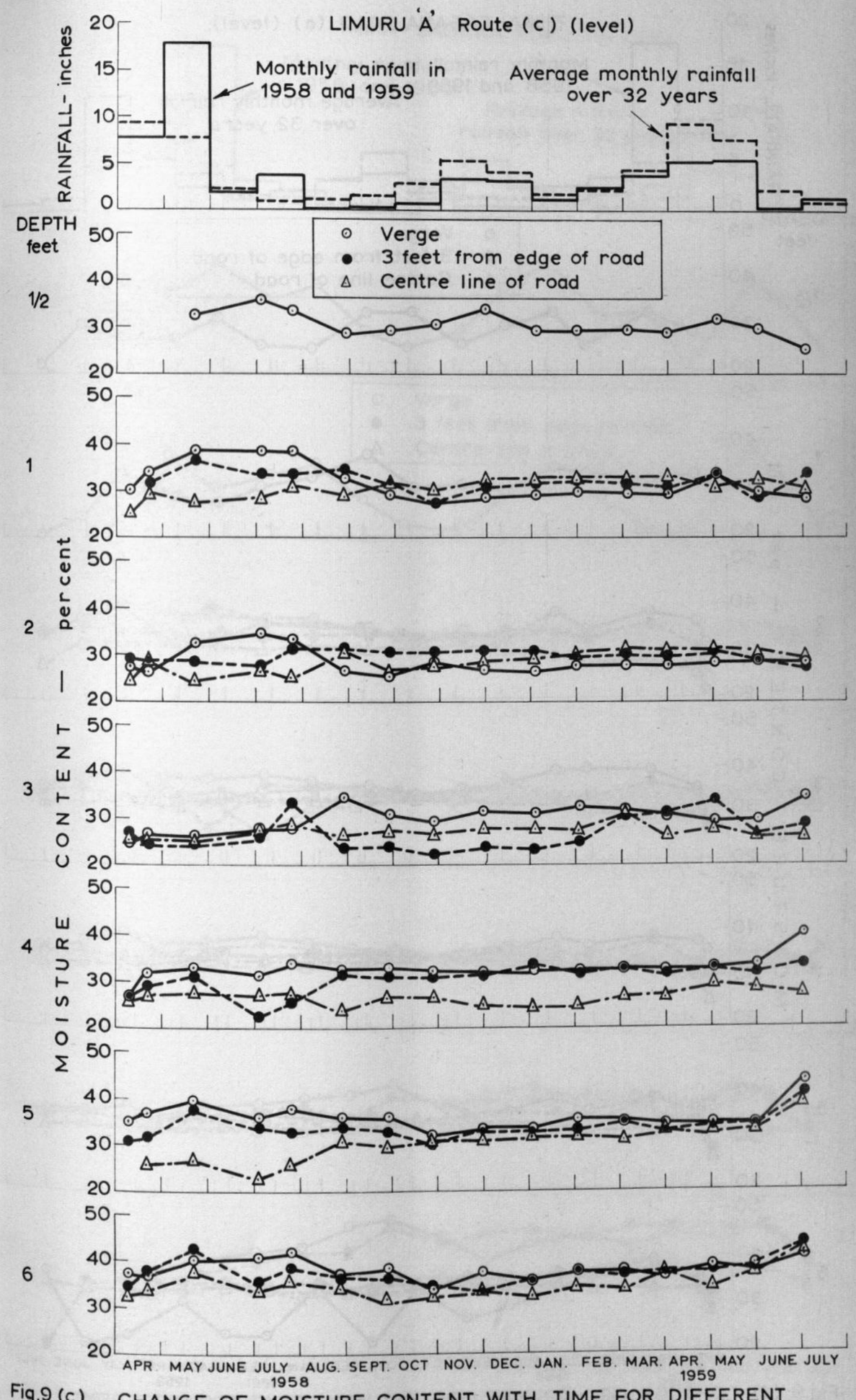

Fig.9.(c) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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FS.16477

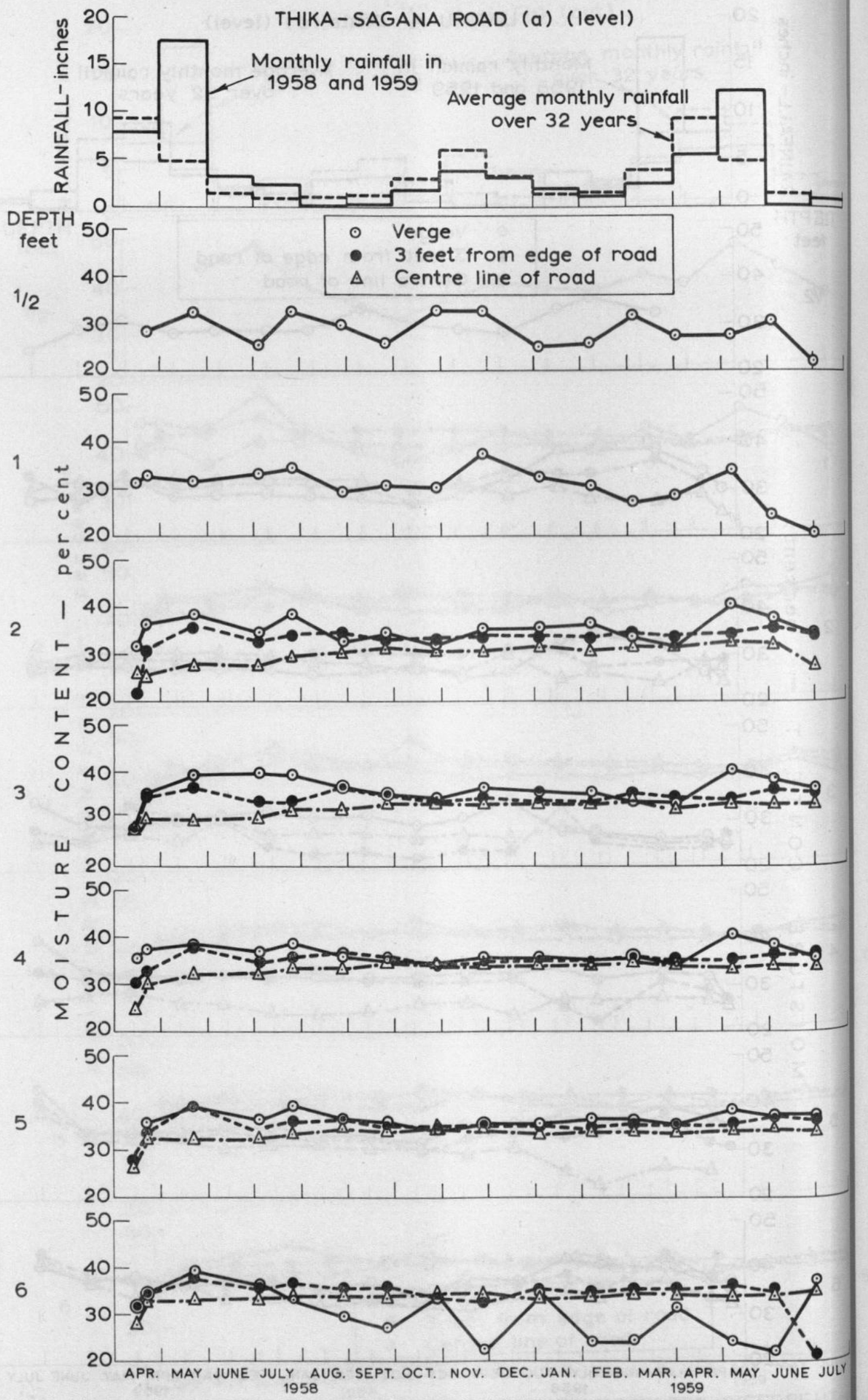

Fig.9. (d) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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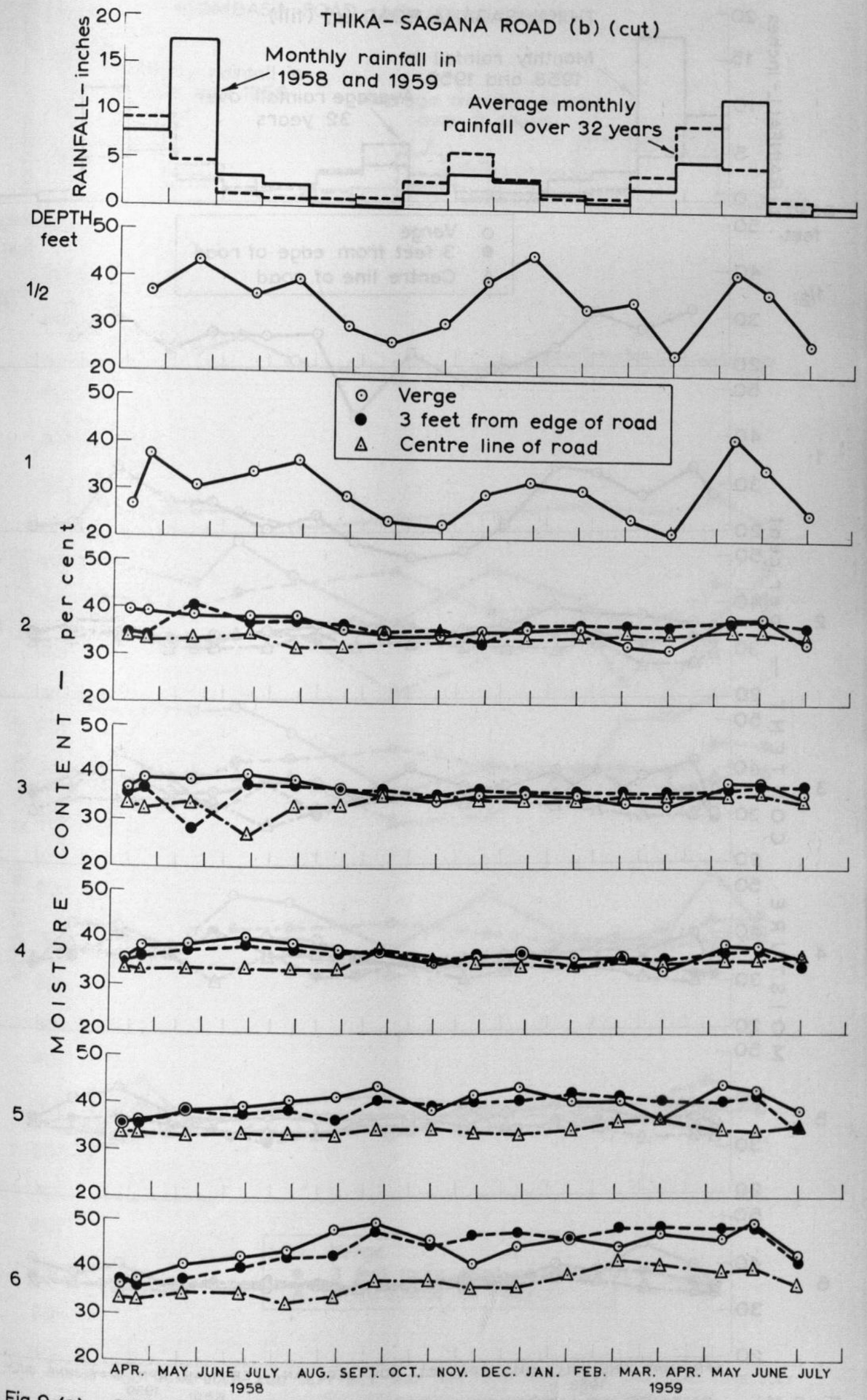

Fig.9. (e) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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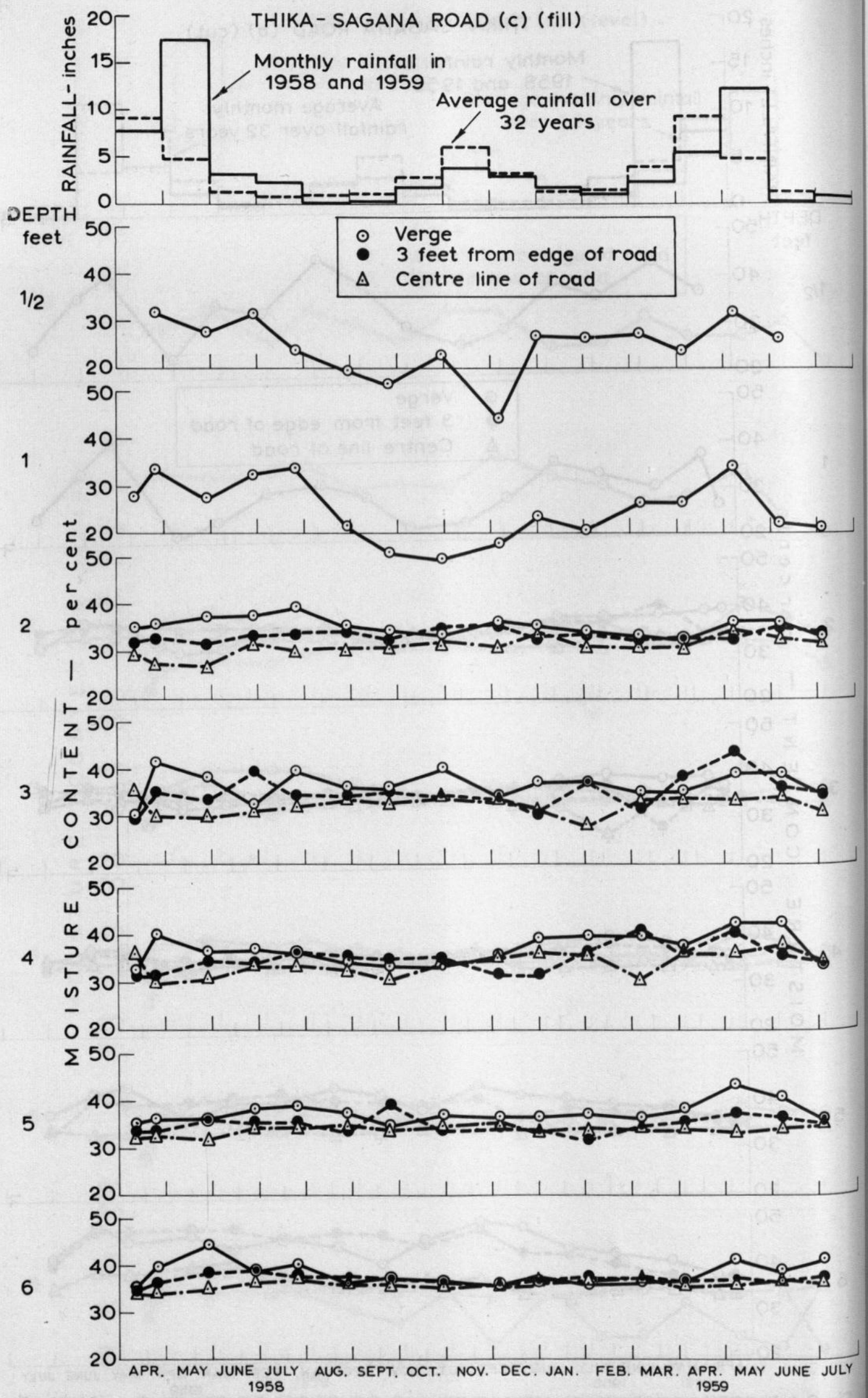

Fig.9.(f) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

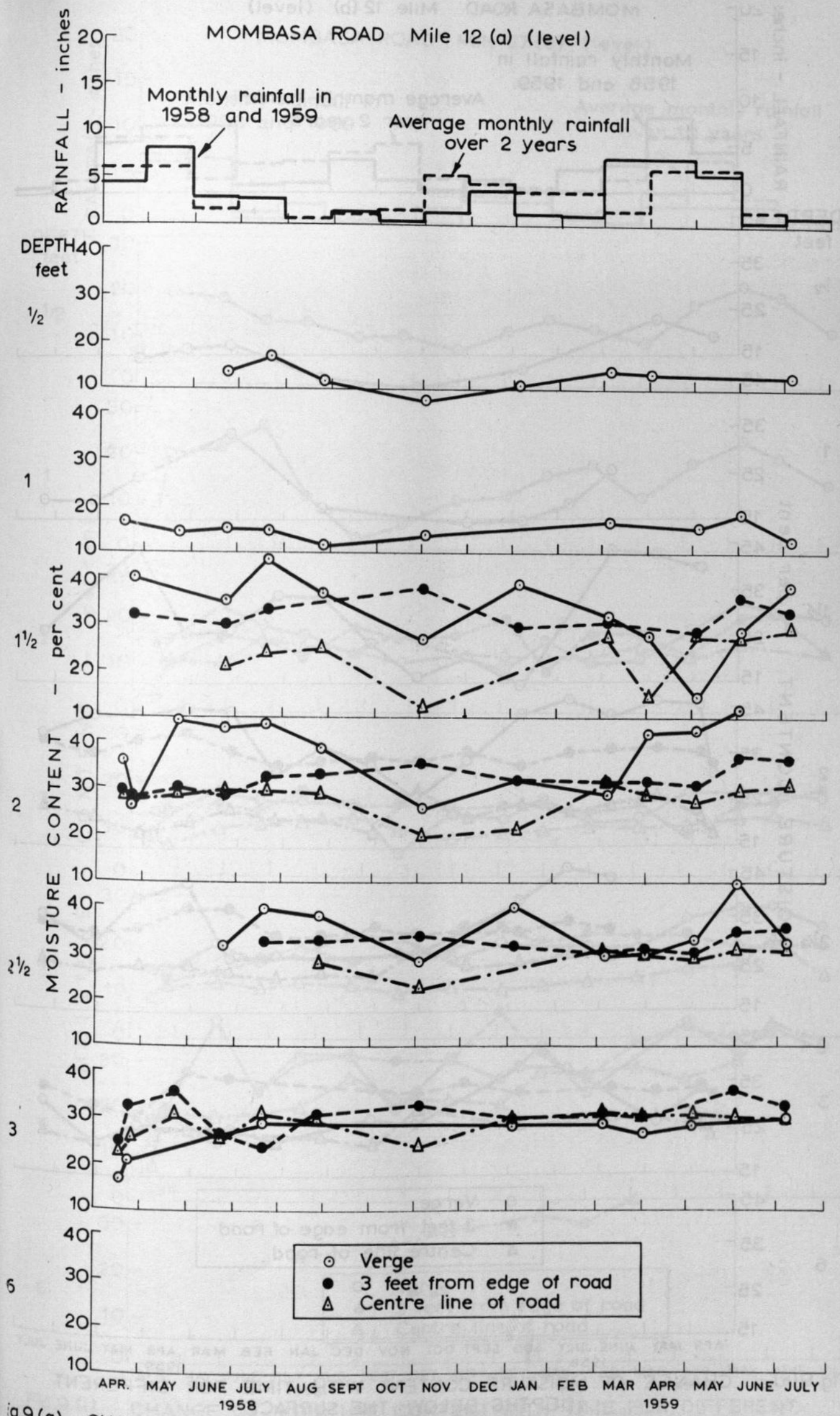

Fig.9.(g) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

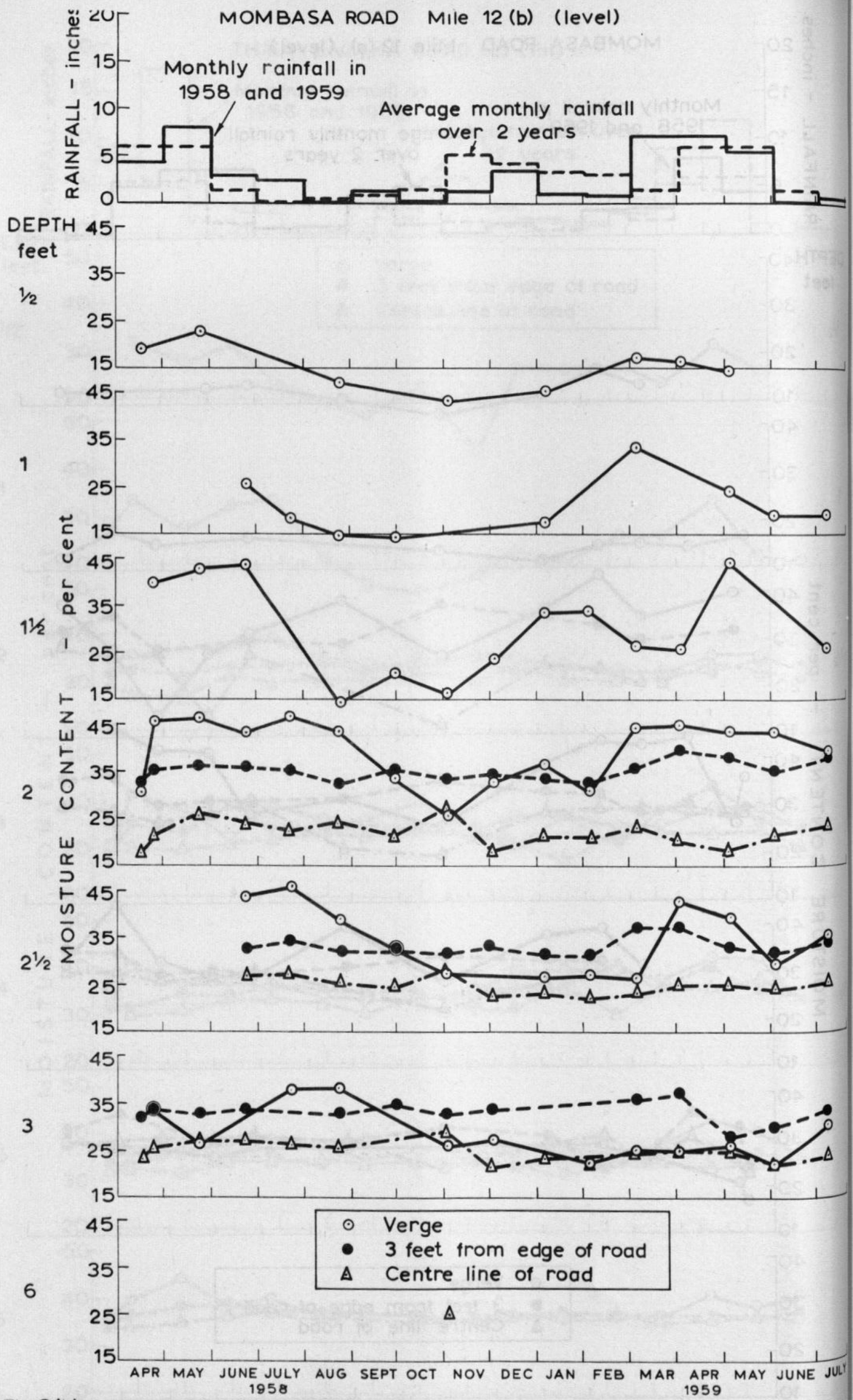

Fig. 9.(h) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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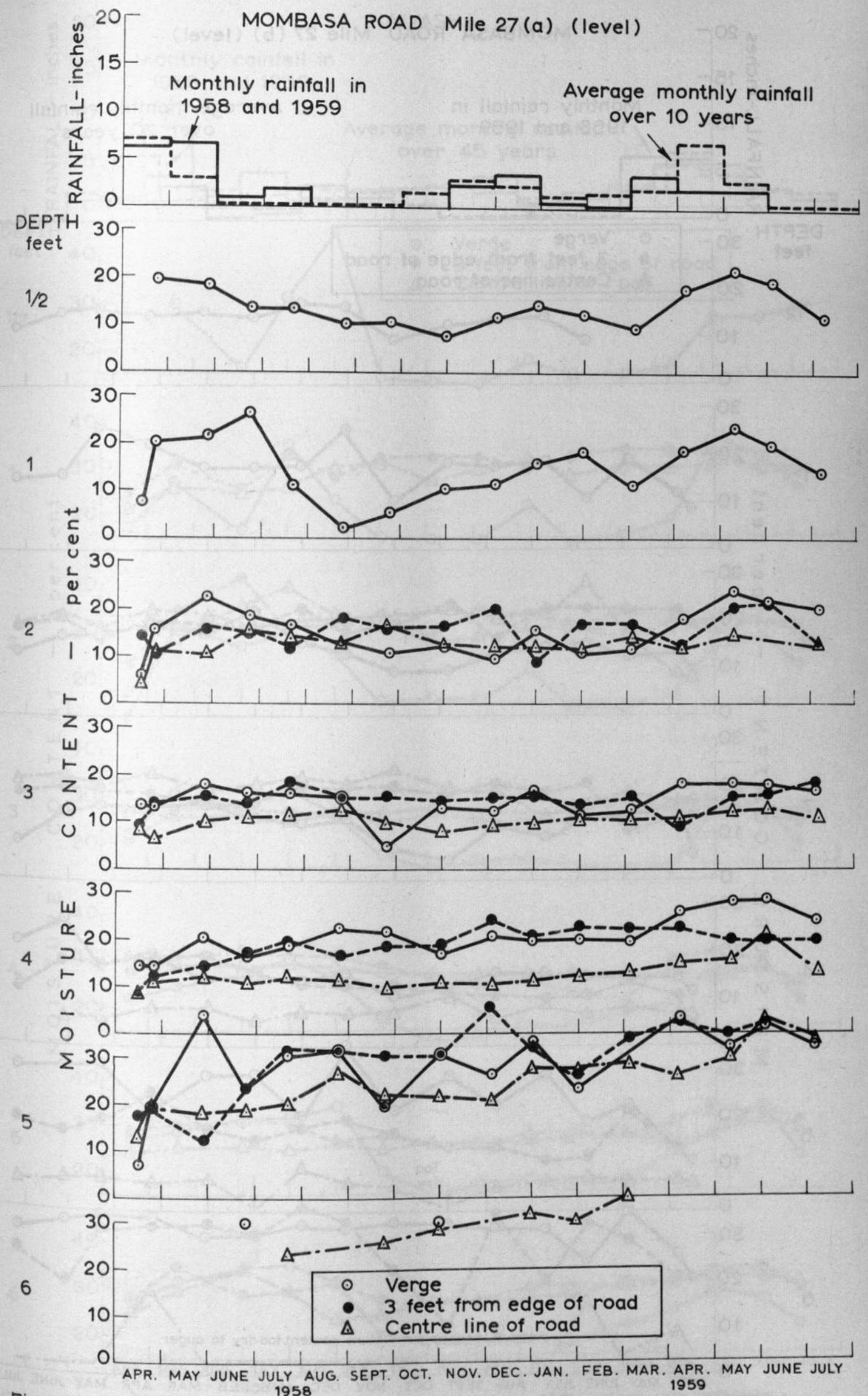

Fig. 9.(i) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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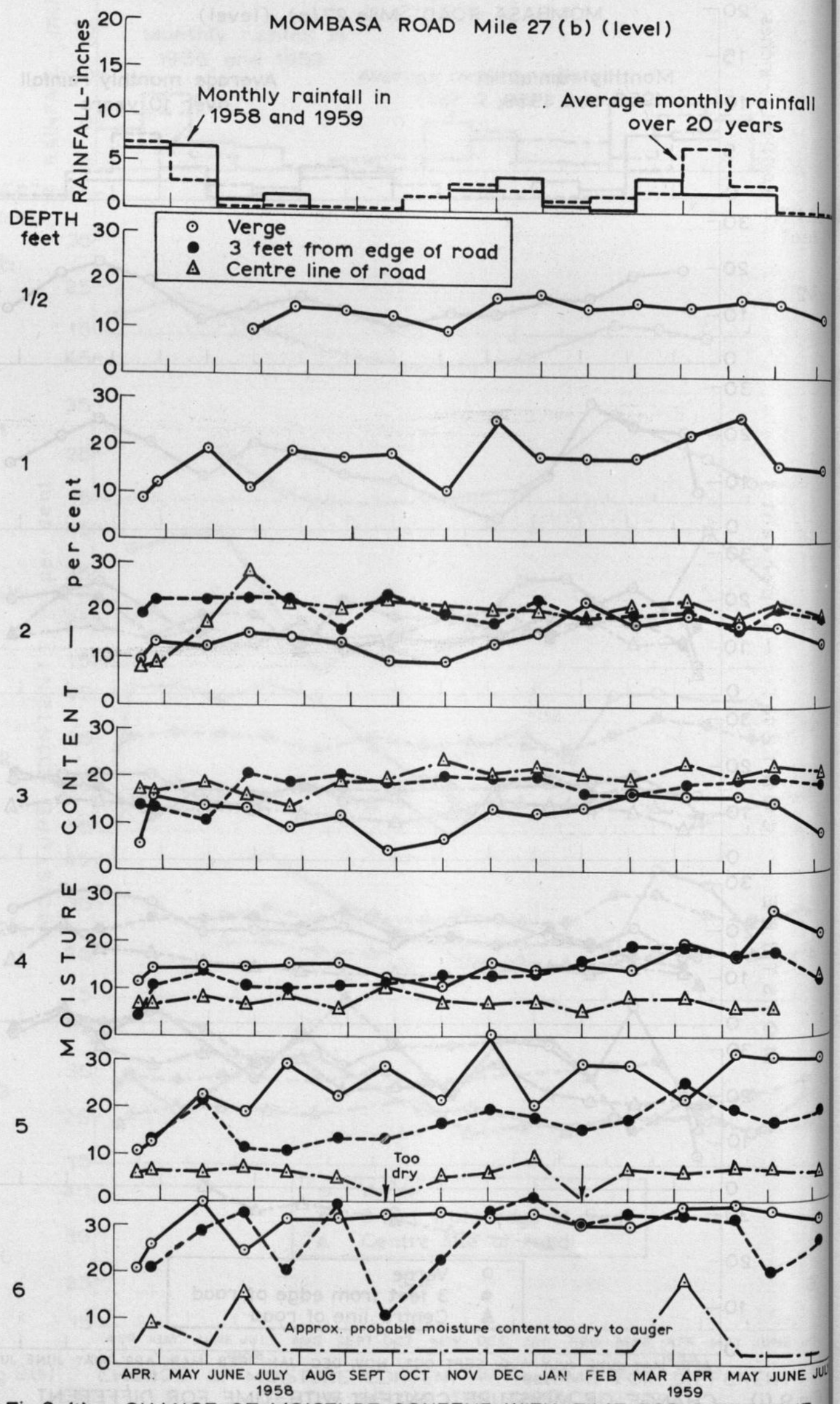

Fig.9. (j) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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FS.16484

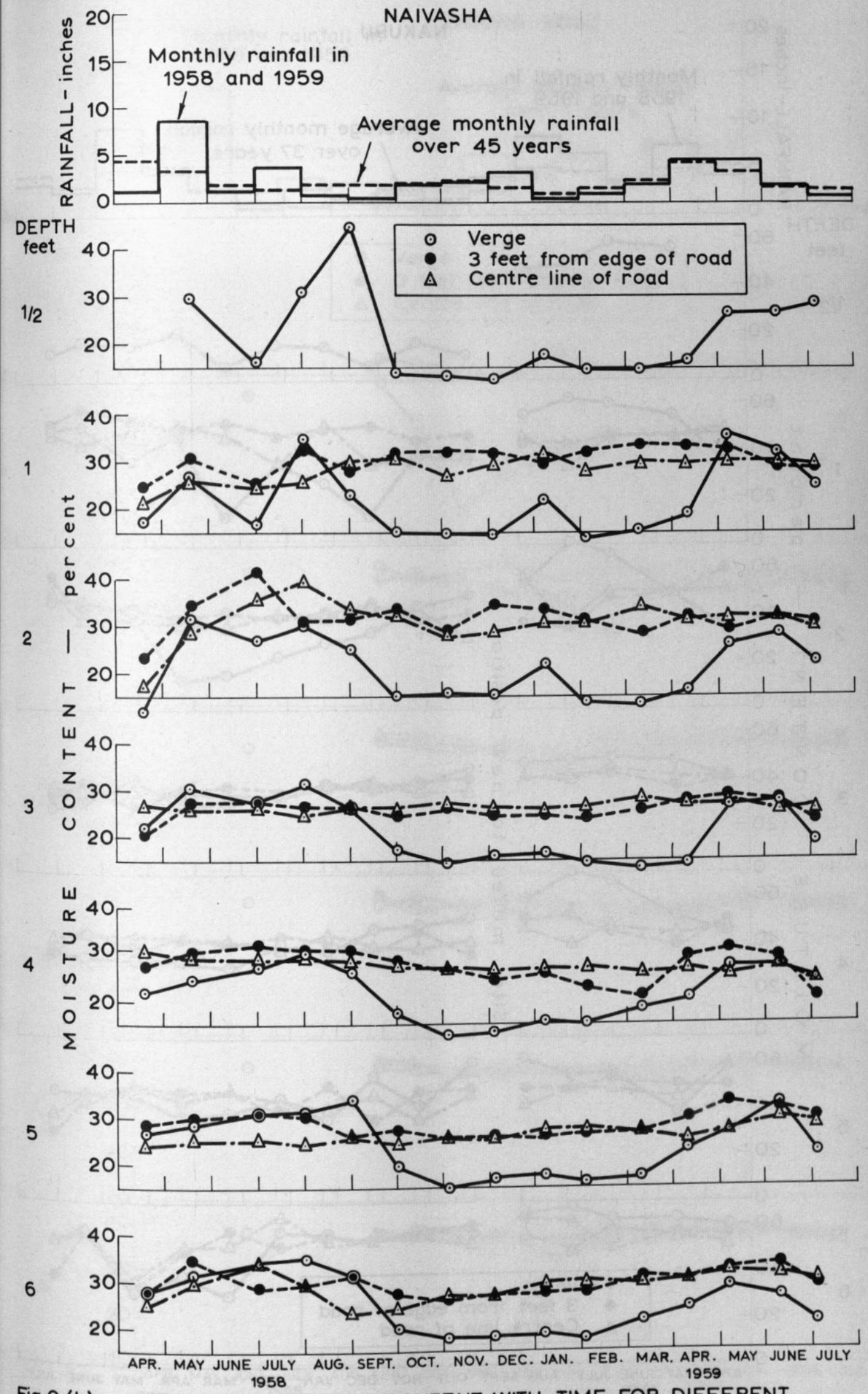

Fig.9. (k) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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FS.16485

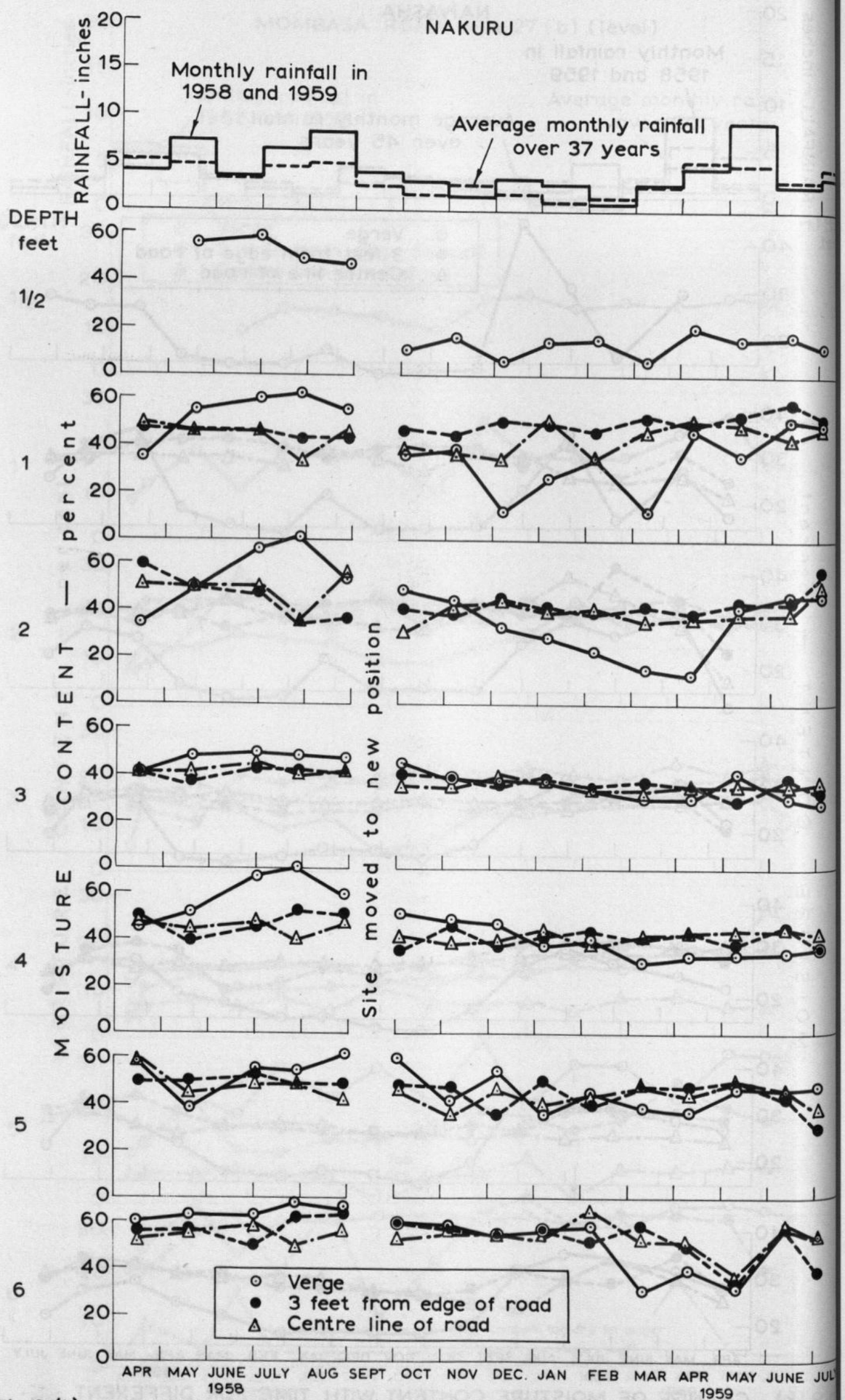

Fig.9.(l) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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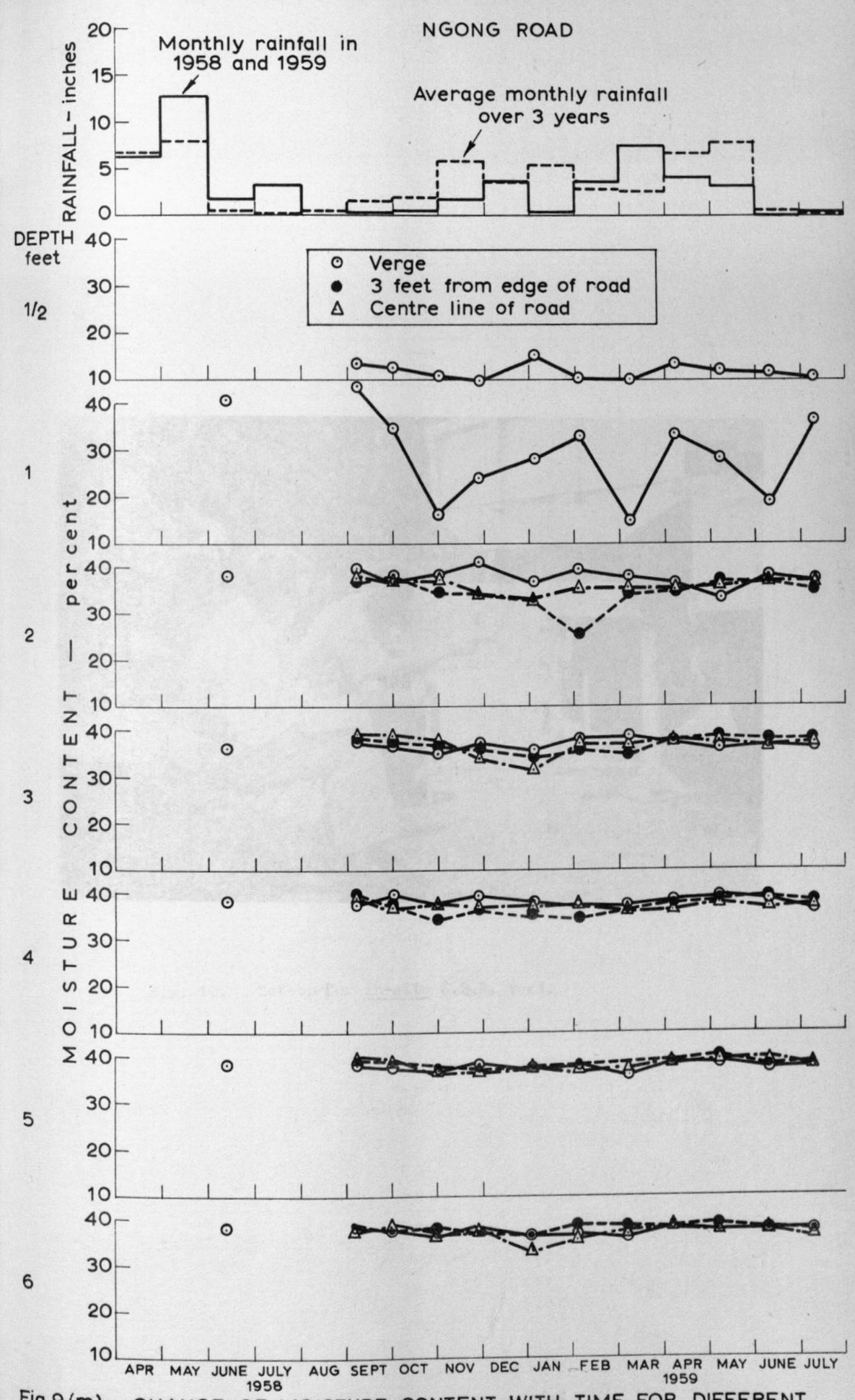

Fig.9.(m) CHANGE OF MOISTURE CONTENT WITH TIME FOR DIFFERENT DEPTHS BELOW THE SURFACE

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Road Research Laboratory Note No. RN 3807/MPO'R. FHPW FS.16487

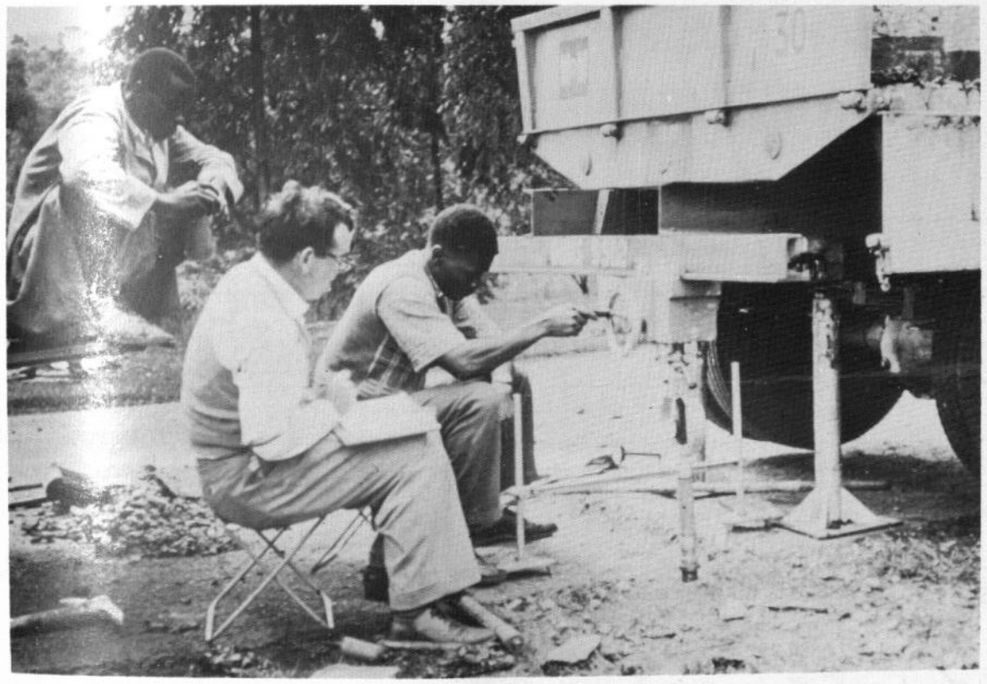


Fig. 10. Set-up for in-situ C.B.R. test.

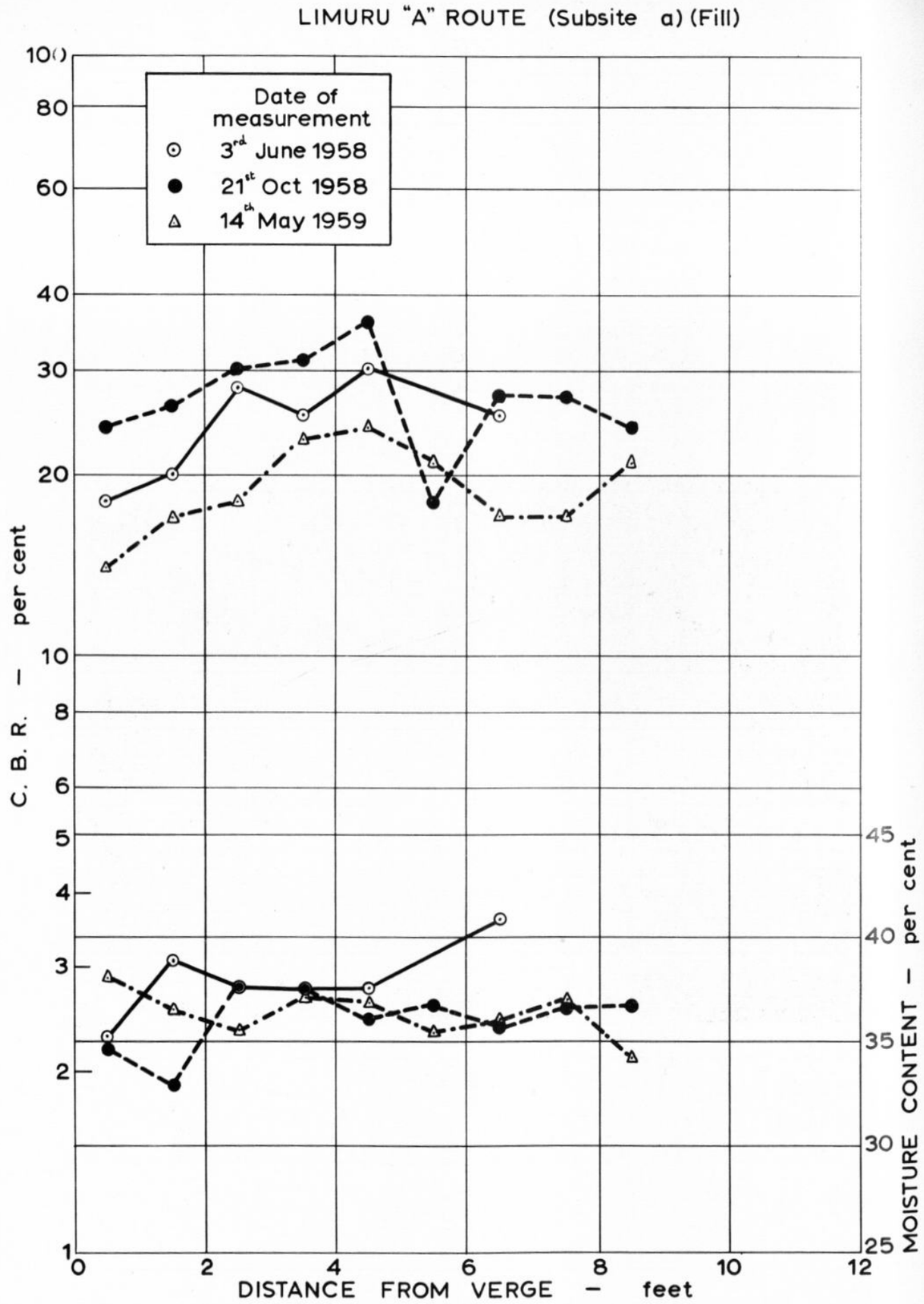


Fig. 11.(a)

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

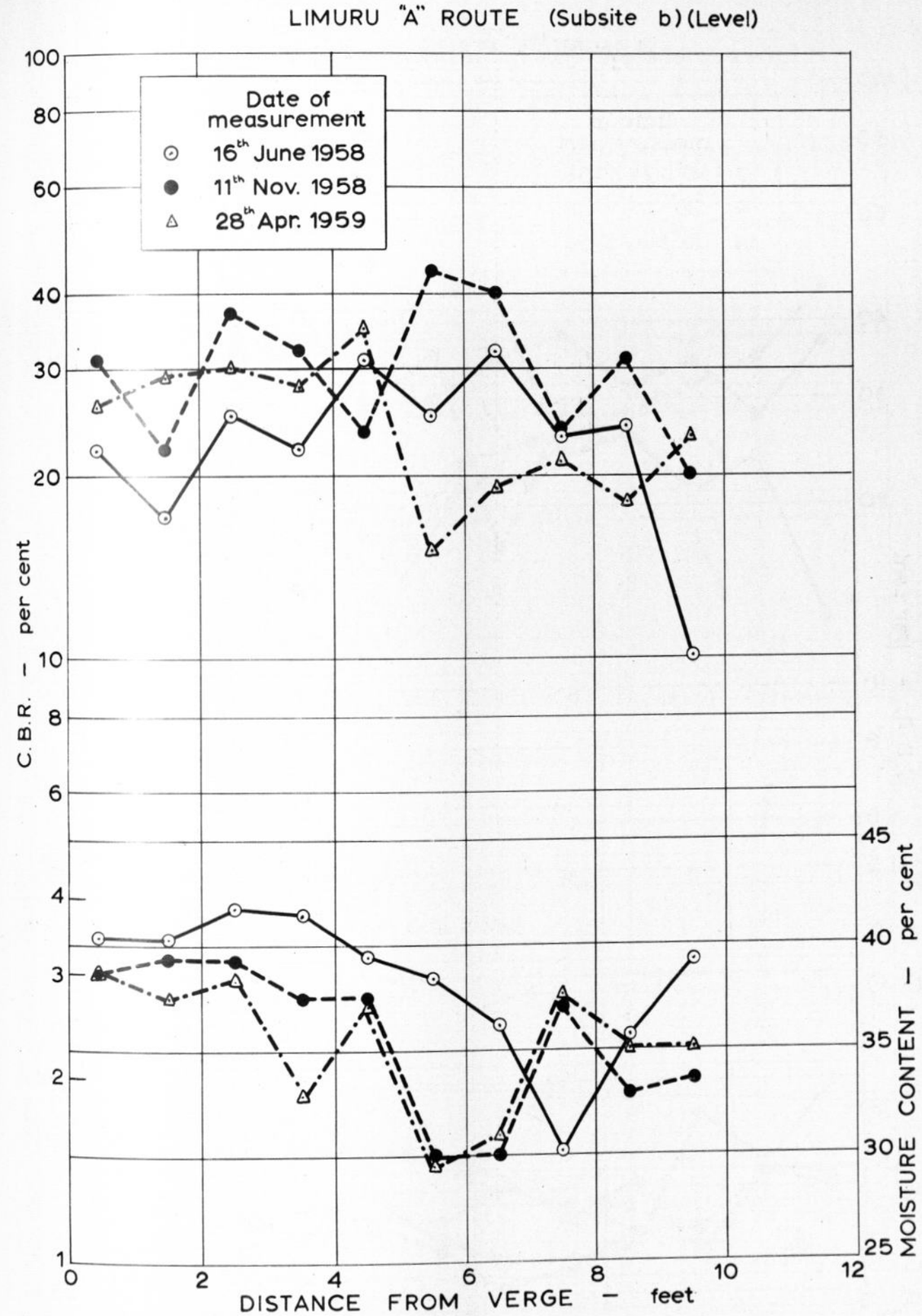


Fig. 11.(b)

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

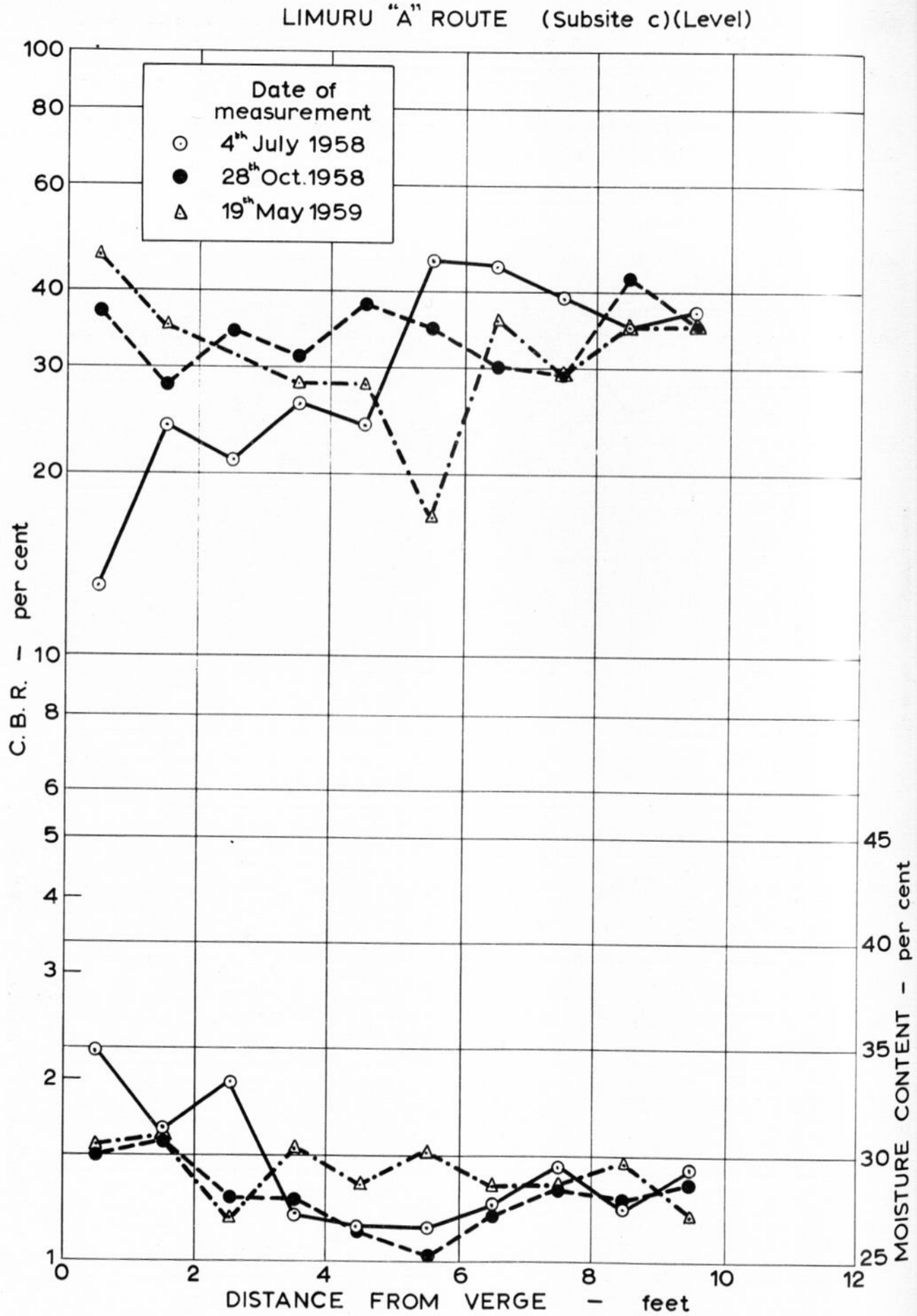


Fig. 11. (c)

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

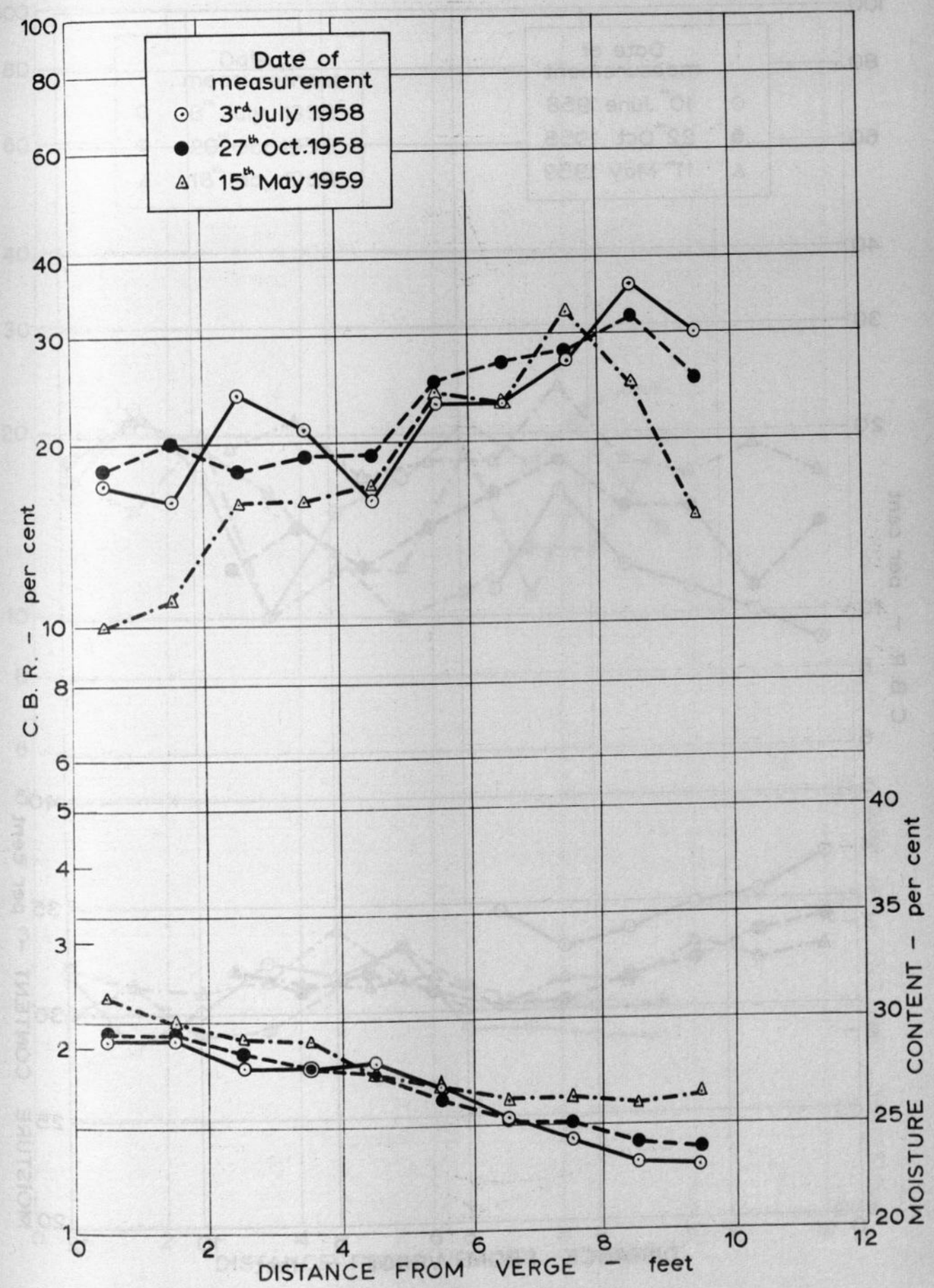


Fig. 11.(d)

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

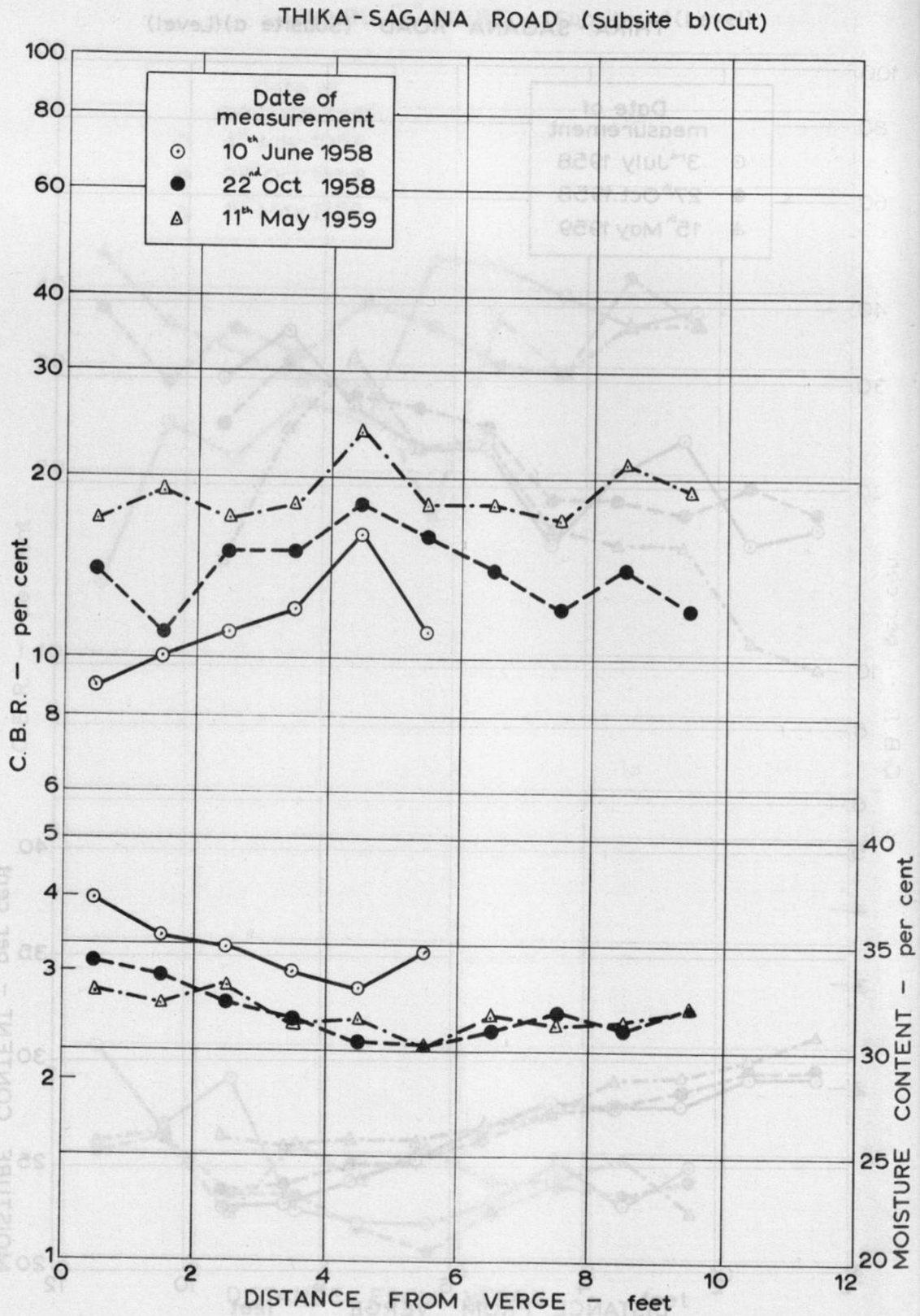


Fig. 11.(e)

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

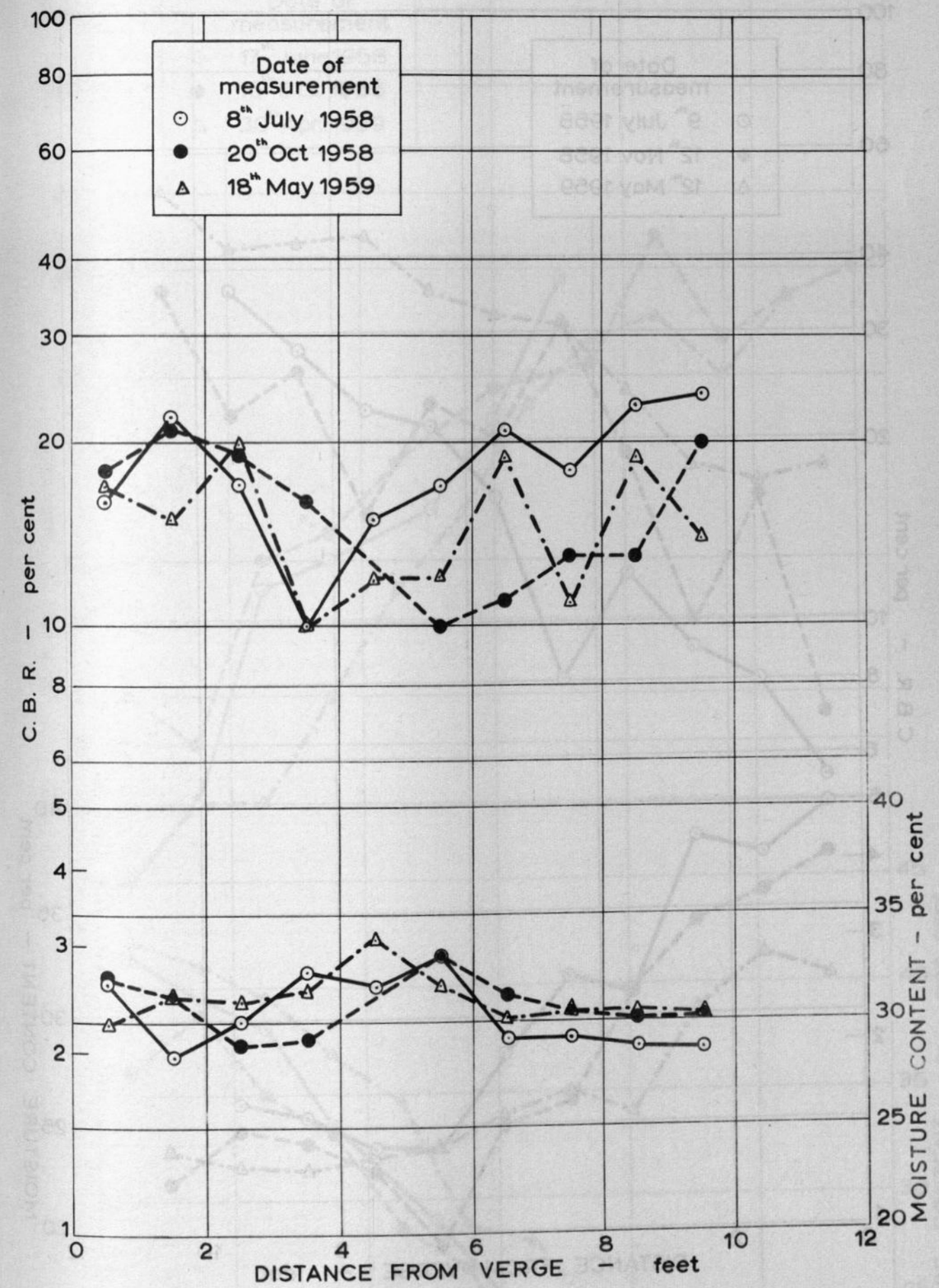


Fig. 11.(f)

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

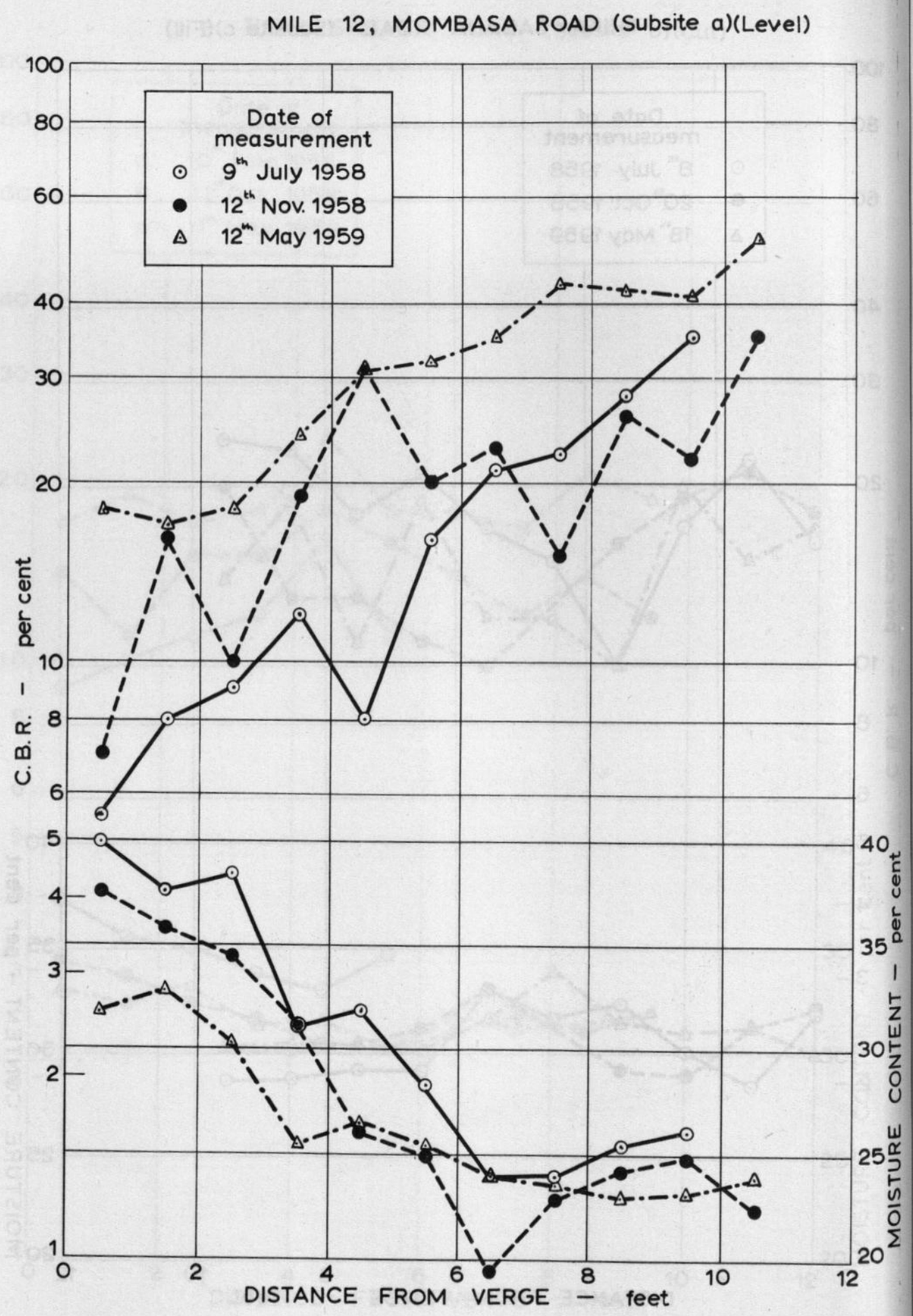


Fig. 11.(g)

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

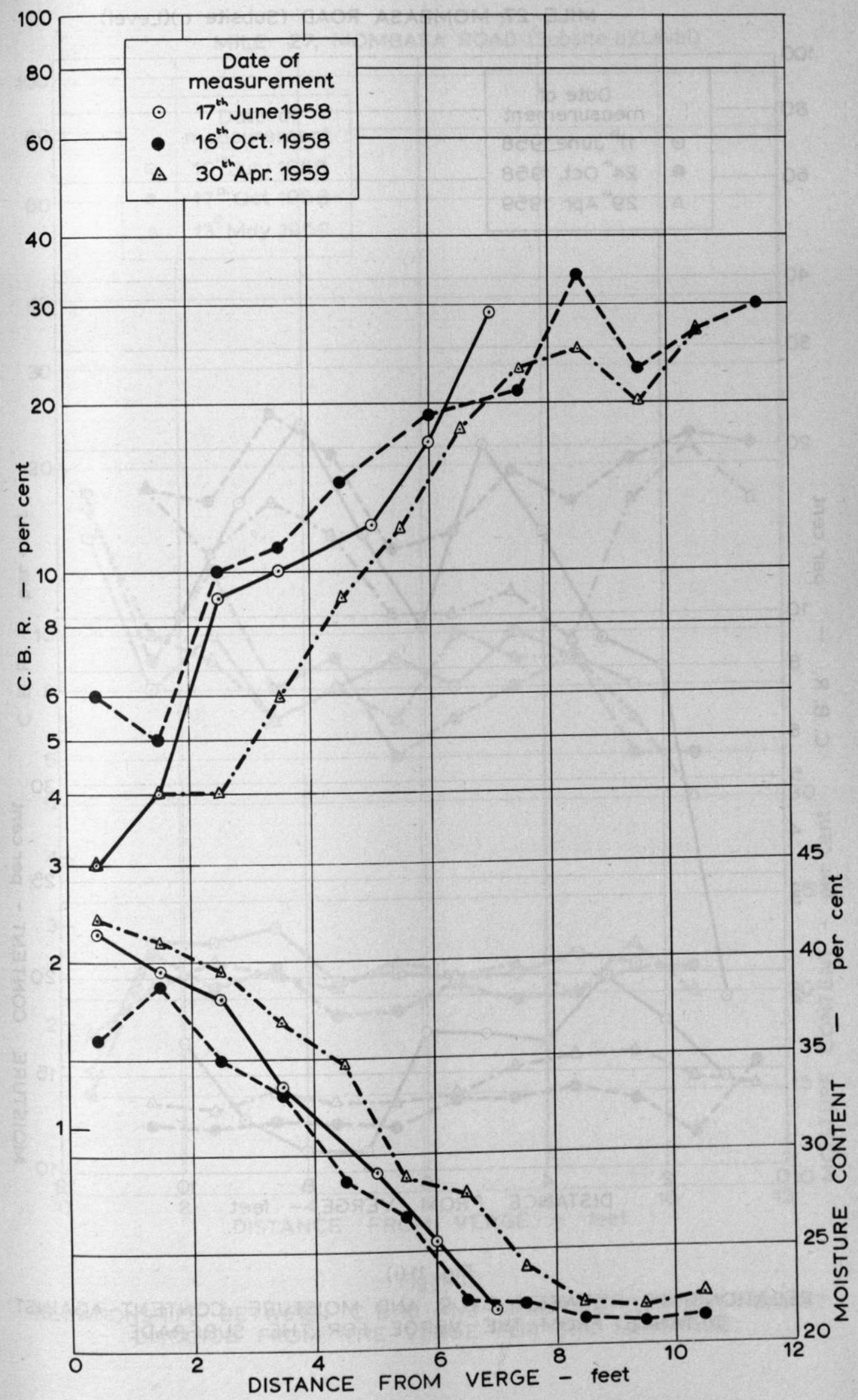


Fig. 11.(h)

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

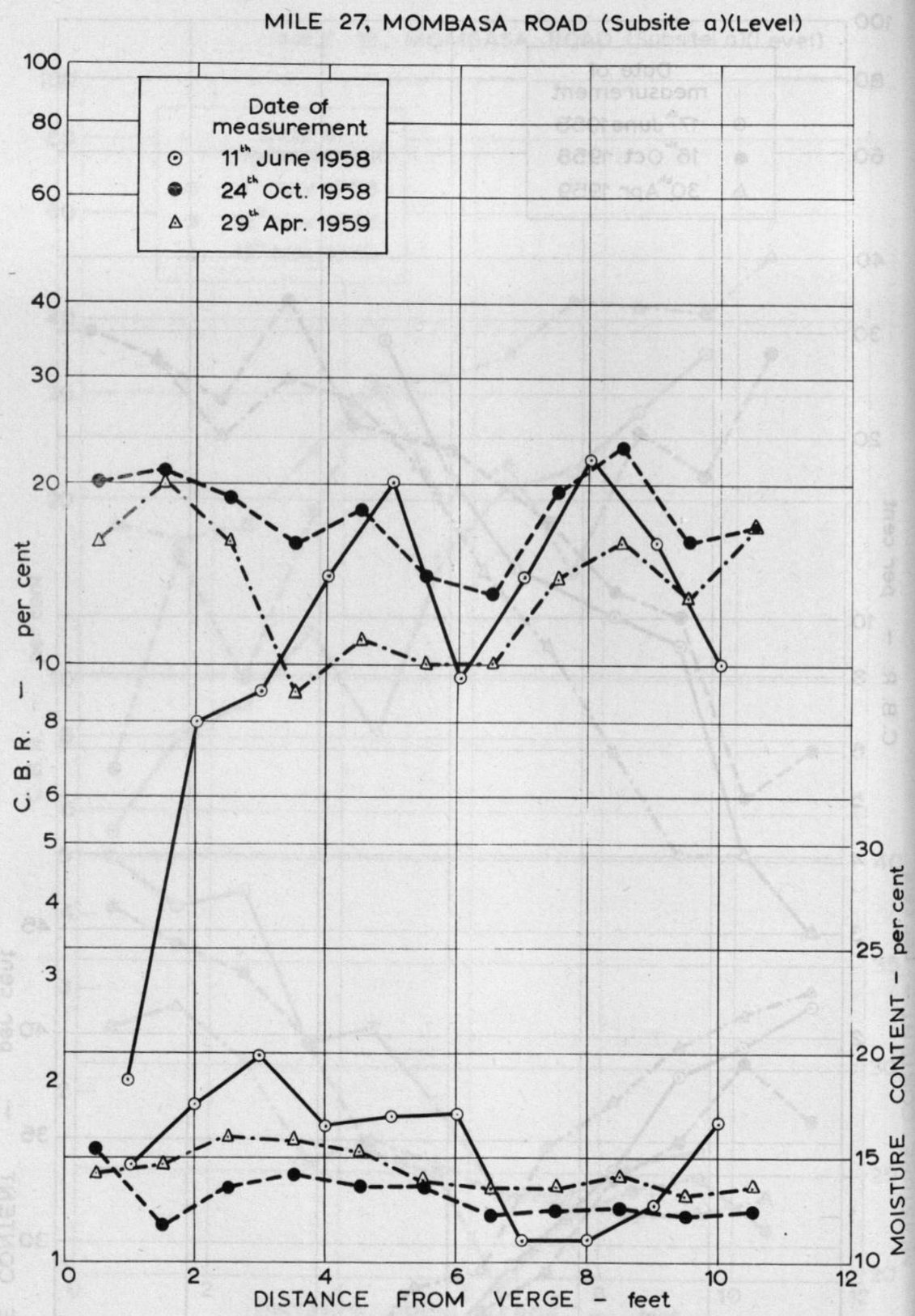


Fig. 11.(i)

RELATIONSHIPS BETWEEN C. B. R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

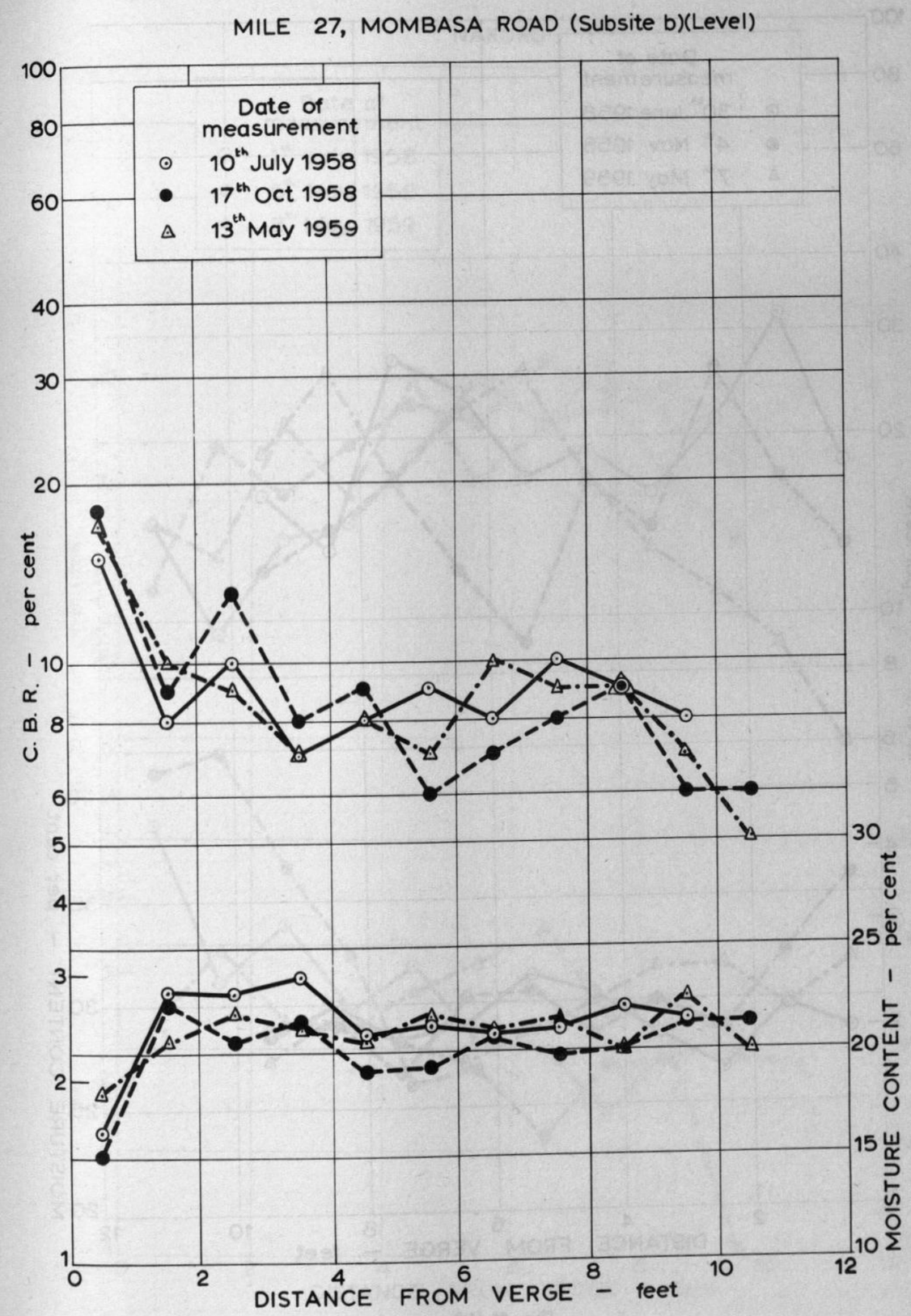


Fig. 11.(j)

RELATIONSHIPS BETWEEN C. B. R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

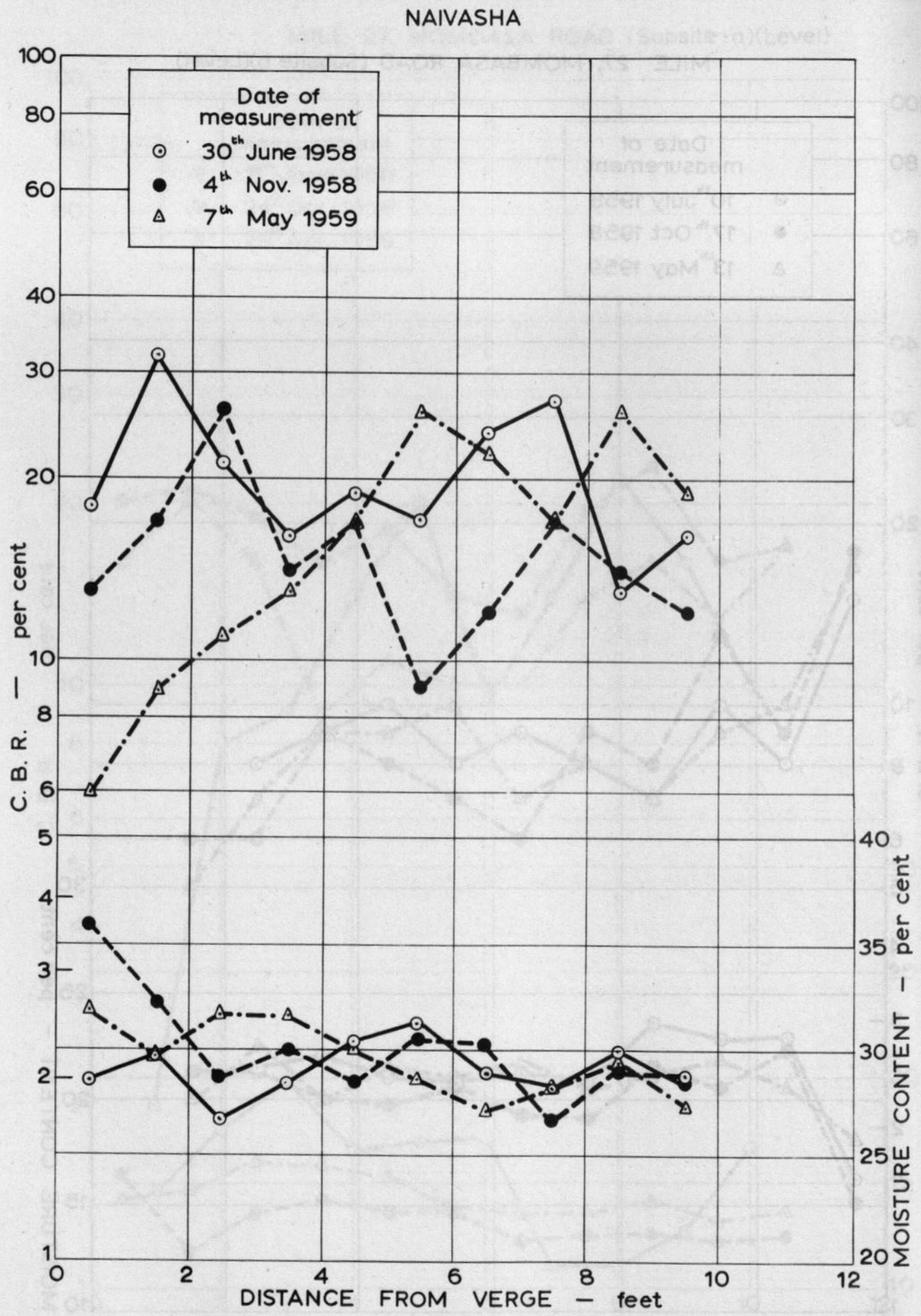


Fig. 11.(k)

RELATIONSHIPS BETWEEN C. B. R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

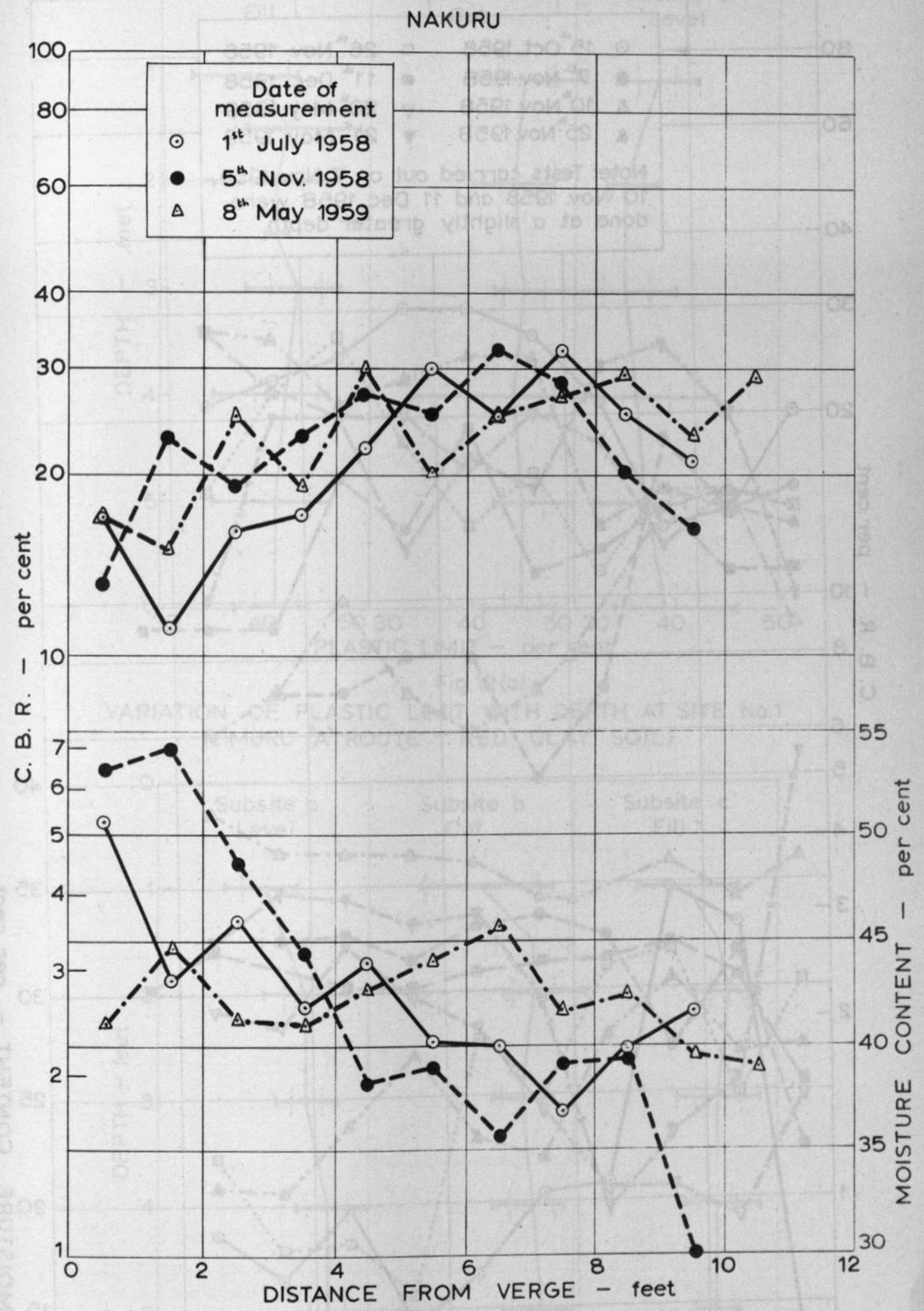


Fig. 11.(l)

RELATIONSHIPS BETWEEN C. B. R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

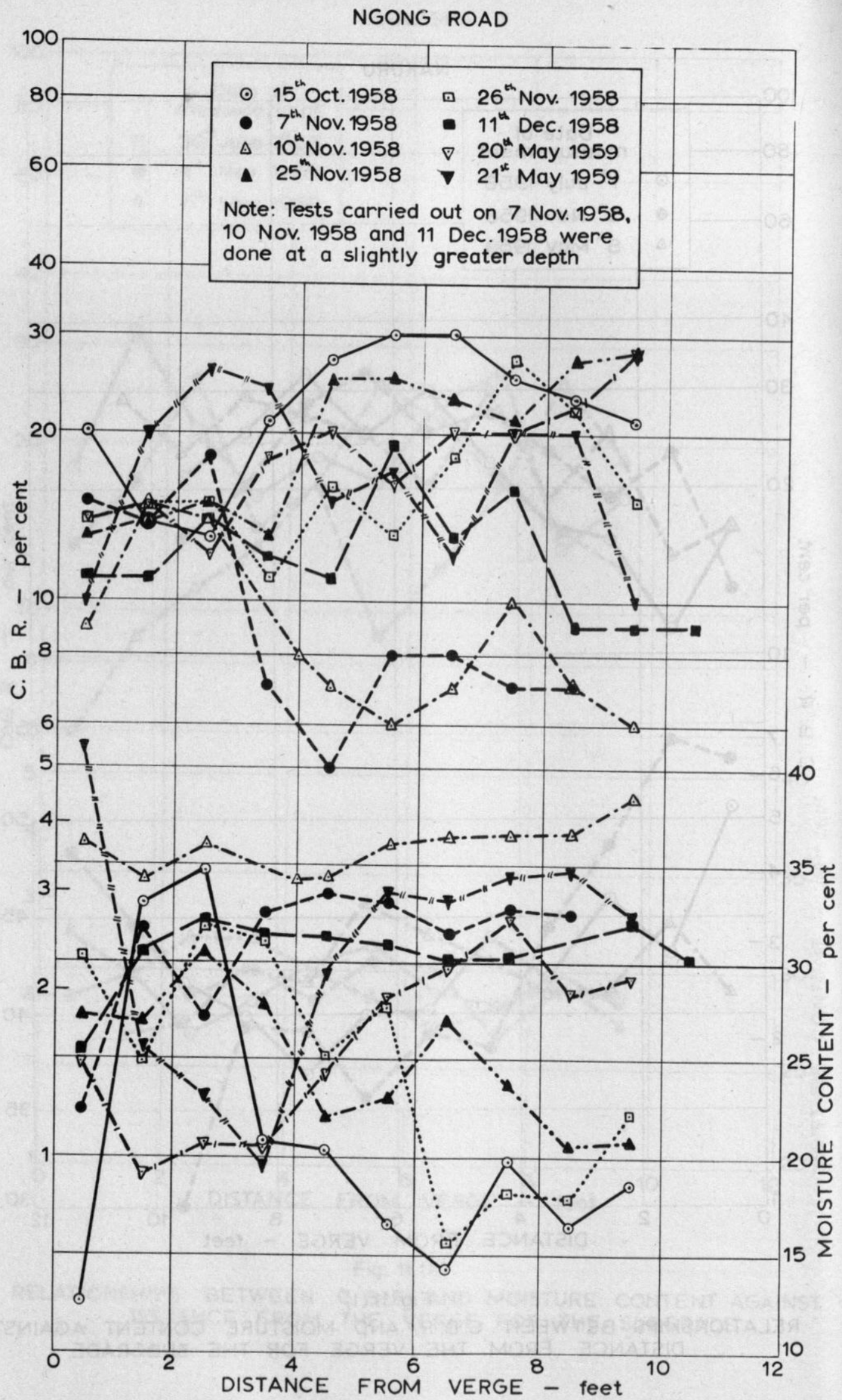


Fig. 11. (m).

RELATIONSHIPS BETWEEN C.B.R. AND MOISTURE CONTENT AGAINST DISTANCE FROM THE VERGE FOR THE SUBGRADE

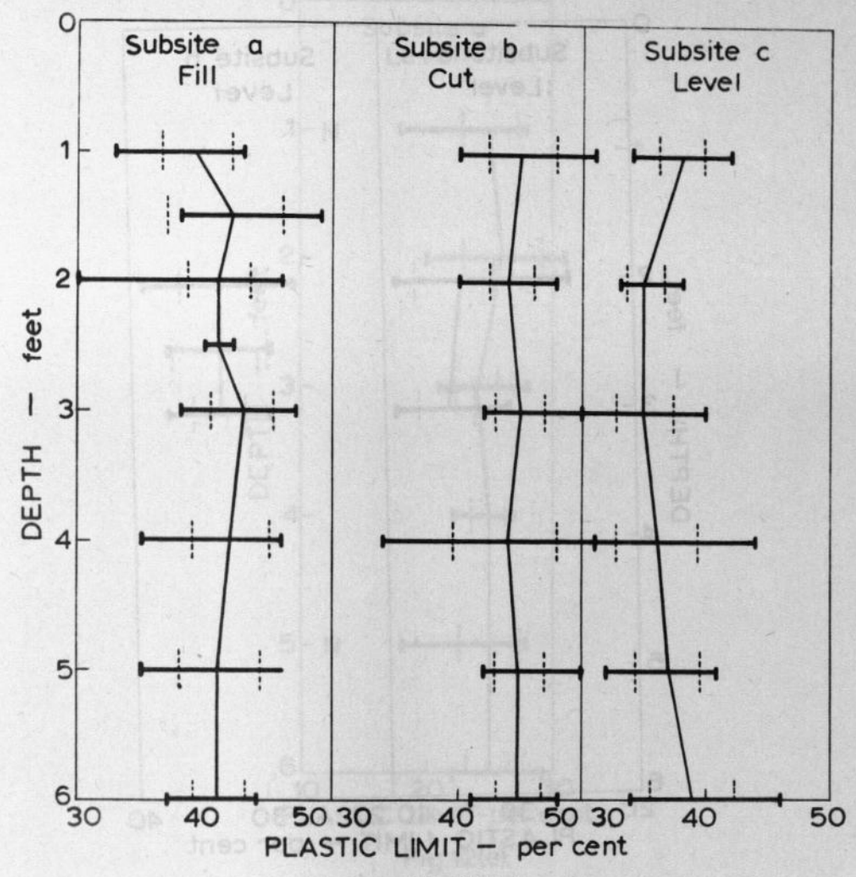


Fig. 12 (a).

VARIATION OF PLASTIC LIMIT WITH DEPTH AT SITE No. 1 (LIMURU 'A' ROUTE — RED CLAY SOIL)

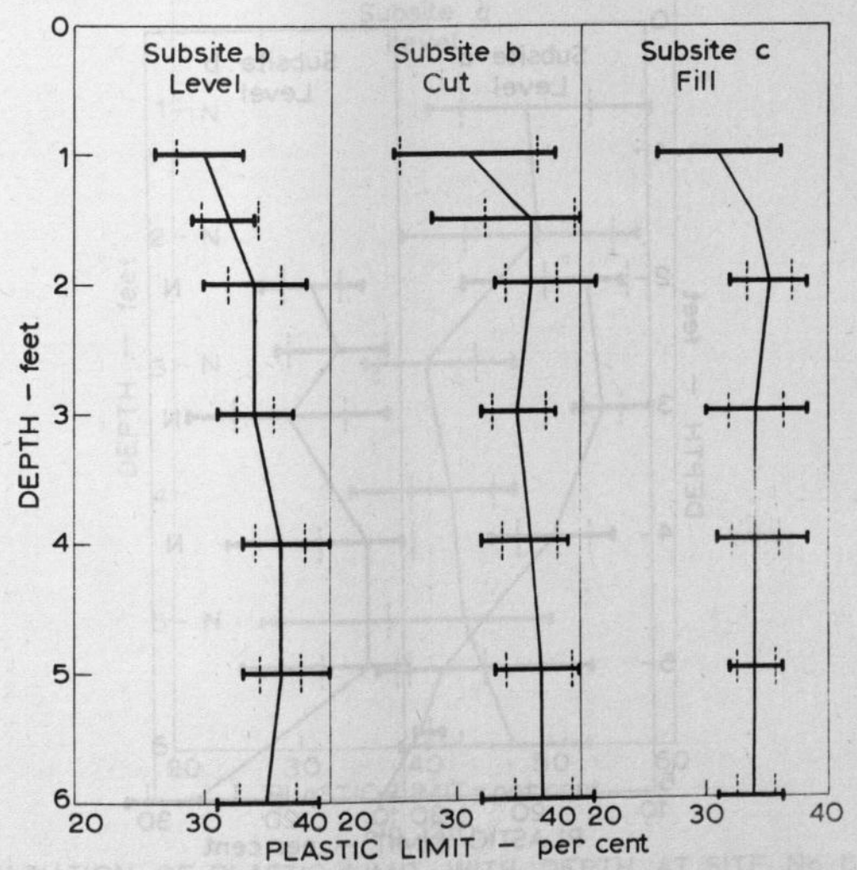


Fig. 12 (b).

VARIATION OF PLASTIC LIMIT WITH DEPTH AT SITE No. 2 (THIKA-SAGANA ROAD — RED CLAY SOIL)

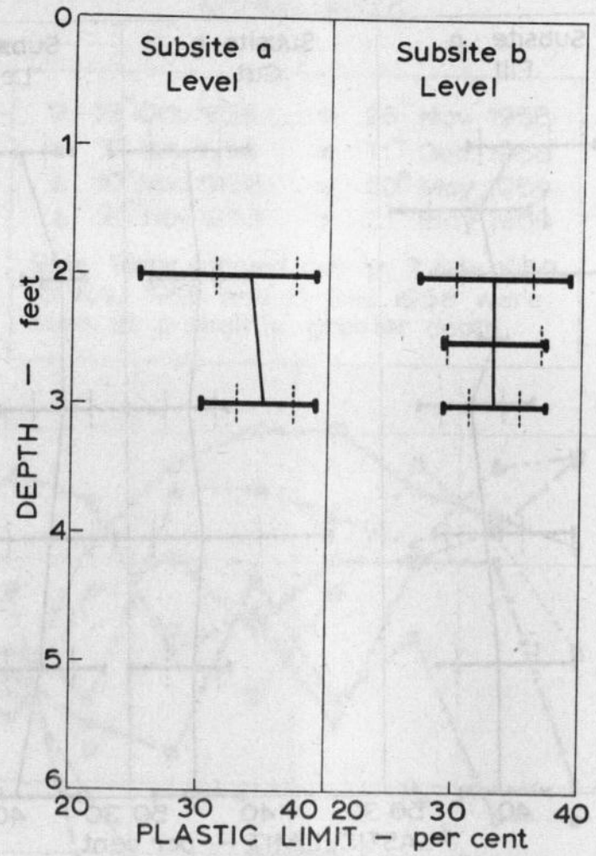


Fig. 12 (c).
VARIATION OF PLASTIC LIMIT WITH DEPTH AT SITE No. 3
(MILE 12, MOMBASA ROAD - BLACK CLAY SOIL)

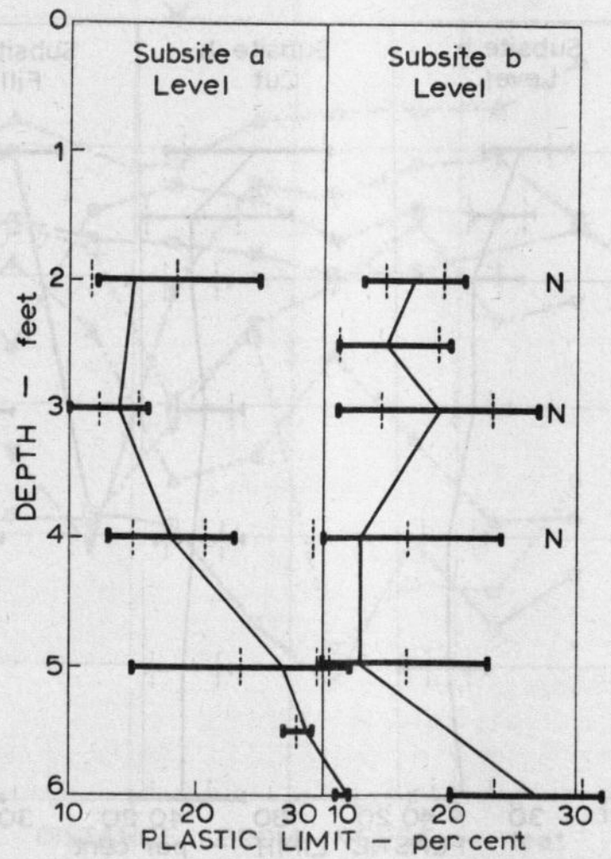


Fig. 12 (d).
VARIATION OF PLASTIC LIMIT WITH DEPTH AT SITE No. 4
(MILE 27, MOMBASA ROAD - SANDY CLAY SOIL)

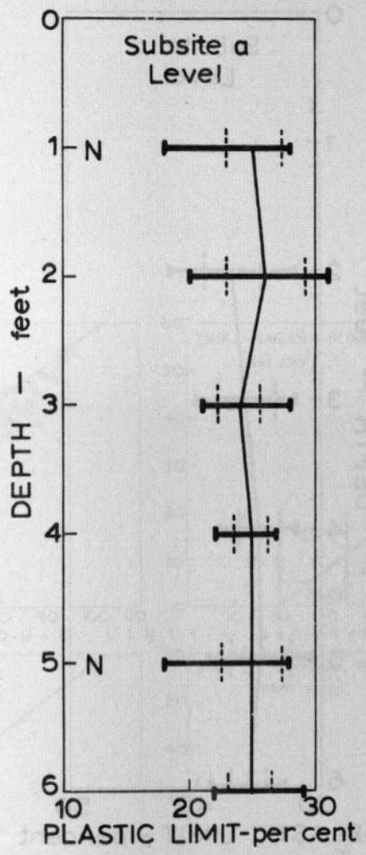


Fig.12(e).
VARIATION OF PLASTIC LIMIT WITH DEPTH
AT SITE No. 5 (NAIVASHA - PUMICE SOIL)

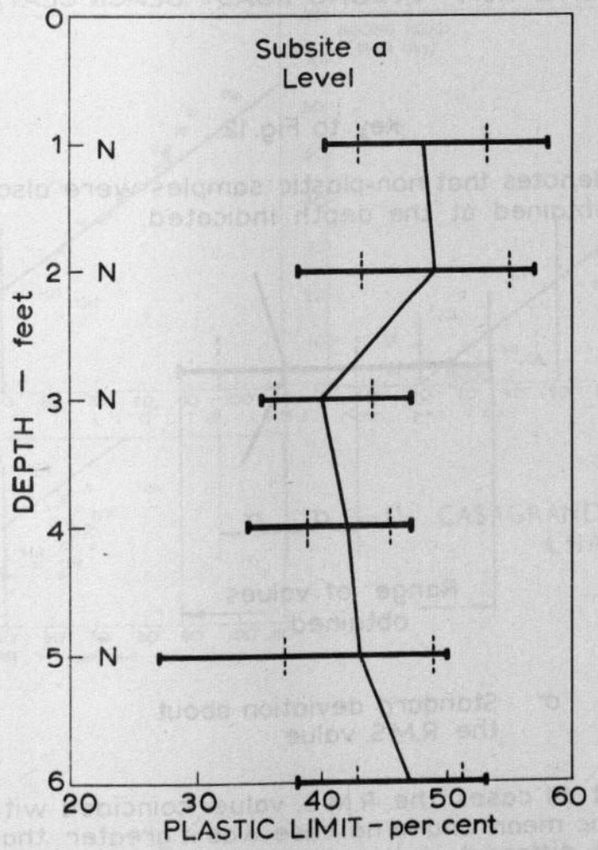


Fig. 12(f).
VARIATION OF PLASTIC LIMIT WITH DEPTH AT SITE No. 6
(NAKURU — PUMICE SOIL)

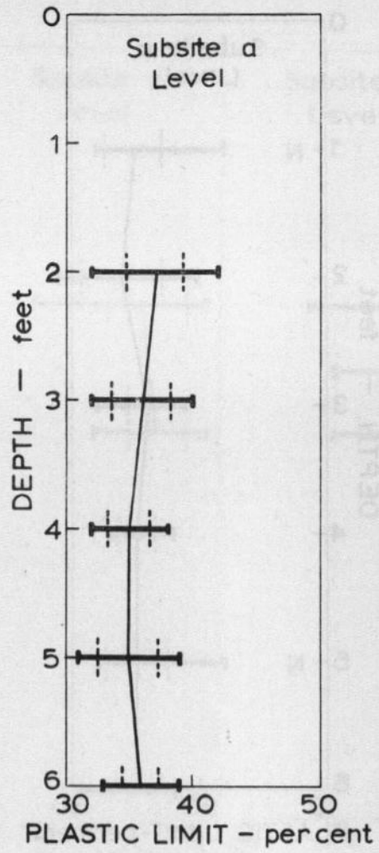
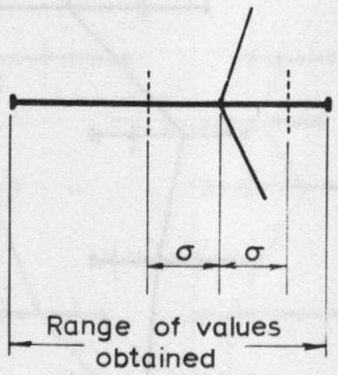


Fig. 12(g).

VARIATION OF PLASTIC LIMIT WITH DEPTH AT SITE No. 7 (NGONG ROAD - BLACK CLAY)

Key to Fig. 12.

N denotes that non-plastic samples were also obtained at the depth indicated.



σ Standard deviation about the R.M.S. value

In almost all cases the R.M.S. value coincided with the arithmetic mean and in no case was it greater than 1 per cent different

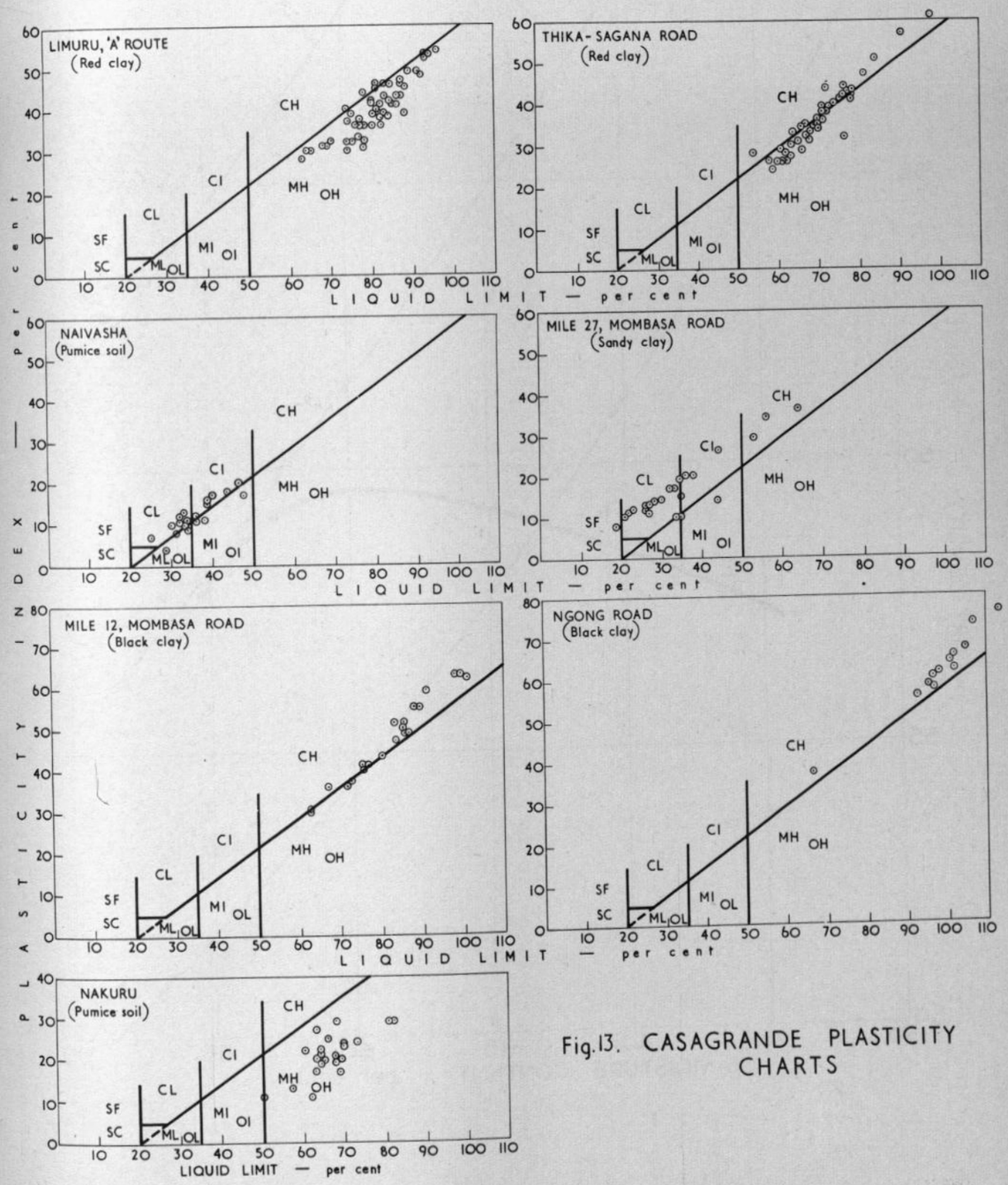


Fig. 13. CASAGRANDE PLASTICITY CHARTS

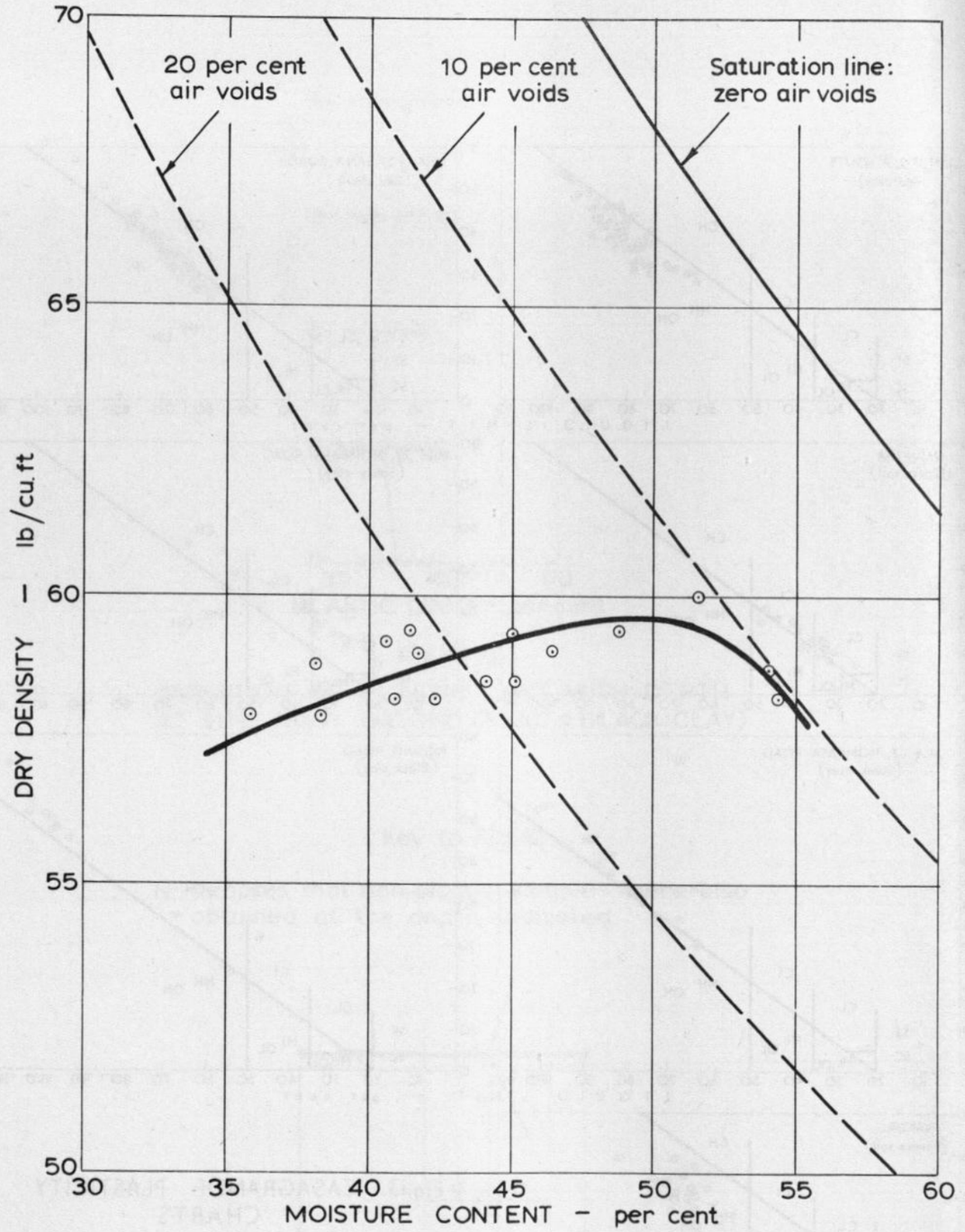


Fig. 14.

TYPICAL RESULT OF B.S. COMPACTION TEST ON SOIL FROM SITE No. 6 (NAKURU)