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SUCTION TESTS ON BARTON SAND

FROM LINE OF M3 MOTORWAY

by

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ABSTRACT

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It is concluded that the moisture content will be reduced from 24 to 18 per cent for sand lying more than 2m (7 ft) above the lowered water-table. Sand at the completed formation level will remain near its natural moisture content of about 24 per cent unless exposed to dry weather.

The time-lag between lowering the water-table and the reduction in moisture content is estimated to be 1 - 4 weeks, but field measurements should be made during construction to obtain a more reliable value for controlling the rate of excavation.

1. INTRODUCTION

The M3 Motorway will run through a cutting in Barton Sand at Camberley, of about 1.5 km (1 mile) in length and up to 7.5 m (25 ft) in depth. The water-table in the soil is at all times at or near existing ground level, and both temporary and permanent sub-soil drainage measures will be necessary to lower the water-table sufficently to enable the construction of the earthworks to be carried out and to ensure the long term stability of the slopes of the cutting.

It is very likely that temporary well-point drains will have to be installed to enable construction to be carried out. These will stabilise the cutting, and reduce the moisture content of the soil to be excavated which could then be used to form an embankment for an adjacent length of motorway. Finally, when formation level is reached, permanent sub-soil drains 1.5 m (5 ft) deep will be installed at the toe of each slope and in the central reservation of the motorway, to ensure the long-term stability of the completed cutting and formation.

This report describes tests to determine the soil moisture suction properties of samples of soil from the proposed cutting. The results of these tests have been used to estimate the reduction in moisture content of the soil likely to be achieved by lowering the water-table.

2. LOCATION OF SAMPLES

A trial pit was excavated on Nov. 6th, 1967, at Claremont Avenue, Camberley, at a chainage of approximately 1253+00 on the North side of the line of the M3 (National Grid Ref. 889600). The soil is described as Barton Sand on the Geological Survey Drift Map (one inch). The soil profile in the trial pit was as follows:

0 - 0.3 m (0 - 1 ft) Topsoil

0.3 - 1.2 m (1 - 4 ft) Mixture of grey-green silty fine sand and coarser brown sand.

1.2 m (4 ft) Thin layer of stones over part of area.

1.2 - 2.7 m (4 - 9 ft) Grey-green silty sand

There was standing water at ground level, and the excavated soil slurried when disturbed. Water flooded into the pit at a depth of about 2.4 m (7 ft), apparently through seepage layers some 0.3 - 0.6 m (1 - 2 ft) apart. The water level rose about 0.3 m (1 ft) in an hour, and the pit was found to be completely flooded on a visit a fortnight later.

Undisturbed samples were obtained by driving 3.8 cm (1½ in) sampling tubes into the face of the trial pit, at the depths shown in Table 1.

TABLE I

Description of undisturbed samples from trial pit at Camberley

Sample No.	Depth (m)	Natural moisture content (per cent)	Plastic limit (per cent)	Description
1	0.9	22	Non-plastic	Brown sand
2	0.9	23 - 26	18	Grey-green silty fine sand
3 - 5	2.7	23	18	Grey-green silty sand

3. SUCTION TESTS

Each of the samples obtained was ejected from its sampling tube. From each of samples 1, 2, and 3, two specimens of 1.6 cm diameter and about 1.5 cm height were cut. The suction plate apparatus[1] was used to determine the suction/moisture content relation for each speciment drying from its natural moisture content. The volume of the specimens was also measured, using an optical projector. Two further specimens were also cut from sample 3, and used for a repeat determination of the volume/ moisture content relation, the specimens being exposed to air for a few minutes to dry out and then left under cover for an hour, before each volume measurement. The remainder of samples 1, 2, and 3 was used for the determination of plastic limit, and of the disturbed suction curve for samples 1 and 3.

Samples 4 and 5 were used to obtain an estimate of the time taken for water to drain out of the soil. The samples were cut into three different lengths, placed on suction plates, and allowed to reach moisture equilibrium at a suction of 20 cm of water. The suction was then raised to 600 cm, and the change of weight with time noted.

The results of the suction and volume measuremtns are given in Figs. 1 - 4, and the results of the drainage tests in Fig. 5.

4. DISCUSSION

There are considerable variations in the suction curves of specimens cut from the same sample, probably due both to the variability of the soil, and the difficulty of handling the specimens. The natural moisture content of the soil is some 5 to 8 per cent above the plastic limit.

The effect of lowering the water-table on the moisture content can be estimated from the suction/moisture content relation and the equation;[1]

$$s = u - \alpha p \qquad (1)$$

where s is the soil suction

u is the negative pore-water pressure

p is the overburden pressure

α is a constant

α is equal to zero for an incompressible soil, and unity for a fully compressive soil; it is also equal to the slope of the curve obtained by plotting volume per 100 g of dry soil against moisture content. The volume/moisture content curve can also be used to estimate the bulk density of the soil and hence the overburden pressure at any depth.

There are two soil types in the surface layers of the soil profile. The sand (Sample 1) is virtually incompressible ($\alpha = 0$, from Fig. 1). Provided the water-table is lowered 1.2 m (4 ft) or more (i.e. applying in effect a suction of 120 cm), the sand becomes unsaturated with a considerable reduction in moisture content. The silty fine sand (Sample 2) is partially compressible (α about 0.1, from Fig. 2). Lowering the water-table by as much as 6 m (20 ft) (i.e. applying a suction of 600 cm at ground level), will reduce the moisture content only by about 4 per cent. Exposure of the soil to dry weather will, however, produce a much greater reduction in moisture content.

For the deeper silty sand lying between 1.2 and 2.7 m (4 and 9 ft), α is 0.05 and the bulk density is 1.94 gm/cm^3 (121 lb/ft^3) at a moisture content of 20 per cent (Figs. 3-4). These figures have been used in conjunction with Eqn. (1) to estimate the effect of lowering the water-table from its original level to 0.6, 1.5, and 6.1 m (2, 5, and 20 ft) below the surface. The results are shown in Fig. 7.

It is apparent that the water-table must be lowered substantially to reduce the moisture content significantly.

The soil survey report for this length of motorway suggests that the highest moisture content at which compaction plant can operate on the Barton Sand is 18 per cent, and analysis by the electrical analogue technique suggested that with subsoil drains at a depth of 1.5 m (5 ft) the water-table in the completed formation will at best be not more than about 0.9 m (3 ft) below the surface. The results in Fig. 4 show that the moisture content is reduced to 18 per cent only for soil lying more than about 2 m (7 ft) above the water-table. Soil nearer the water-table, and in the completed formation, is therefore likely to be too wet for satisfactory compaction unless further loss of moisture is obtained by carrying out the construction work in dry weather.

The time-lag between the lowering of the water-table and the reduction of moisture content in the soil can be estimated from the results of the drainage tests shown in Fig. 3 and discussed in Appendix 1. The relation between the time-lag (t_{100}) and the drainage path (H cm) is found to be;

$$t_{100} = 0.8H^2 \quad \text{(hrs)} \qquad (2)$$

Visual observation showed that seepage layers in the soil were some 30 - 60 cm apart, corresponding to drainage paths of 15 - 30 cm, and to t_{100} between 180 and 720 hrs. That is, there is a time-lag of 1 - 4 weeks between the lowering of the water-table and the reduction in moisture content of the soil.

It should be noted, however, that this calculation depends upon the assumption of seepage layers existing at intervals of 30 - 60 cm, and the time lag should only be regarded as an estimate. Since this time-lag will also affect the stability of the earthworks, field measurements of pore-pressure should be made during construction to determine the rate of excavation.

5. CONCLUSIONS

Soil moisture suction tests have been made on undisturbed samples of Barton Sand from the line of the M3 at Camberley. The results suggest that lowering the water-table will reduce the moisture content to a value at which compaction plant can operate satisfactorily only in sand lying more than 2 m (7 ft) above the water-table. The moisture content of sand near the water-table, and in the completed formation, will not be substantially reduced unless exposed to dry weather. Pockets of silty fine sand in the surface layers will also remain at a high moisture content.

The best estimate that can be made of the time-lag between lowering the water-table and the reduction of moisture content is 1 - 4 weeks. Field observations should be made during construction to obtain a more reliable value for controlling the rate of excavation.

6. ACKNOWLEDGEMENTS

The trial pit was excavated, and the soil survey report made available, by courtesy of Mr. W. C. Hall, A.M.I.C.E., County Engineer, Surrey County Council. The work described in this report was carried out under the general supervision of Mr. W. A. Lewis, Head of the Earthworks and Foundations Section.

7. REFERENCES

1. CRONEY, D., and J. D. COLEMAN. Pore pressure and suction in soil. **Conf. on Pore Pressure and Suction in Soils.** London, 1960 (Butterworths), pp. 31 - 37.

2. BISHOP, A. W., and D. J. HENKEL. The measurement of soil properties in the triaxial test. London, 1962 (Edward Arnold Ltd.), pp. 125 - 6

8. APPENDIX I

Bishop and Henkel[2] suggest that the coefficient of consolidation (C_v) of a soil sample can be simply estimated by plotting the volume change after application of a stress against the square root of time, and measuring the time intercept of the initial straight line produced with the horizontal asymptote (t_{100}). Then for a cylindrical sample of height H (cm) drained at one end;

$$t_{100} = \frac{4\pi}{C_v} (H)^2 \qquad (3)$$

The results of the present drainage tests are plotted in Fig. 5 as change of weight against square root of time, and t_{100} read off. For all samples, t_{100} is found to correspond to the drainage of 90 per cent of the excess moisture, and is therefore a reasonable measure of the time-lag between the change in applied suction and the reduction of moisture content in the sample.

The effect of height of sample on t_{100} is shown by plotting H against $\sqrt{t_{100}}$ in Fig. 6. The relation in Eqn. (3) is then found to be for this soil;

$$t_{100} = 0.8(H)^2 \qquad \text{(hrs)} \qquad (4)$$

For samples drained at one end, H is equal to the drainage path. Eqn. (4) can therefore be used to estimate the effect of drainage path on time-lag.

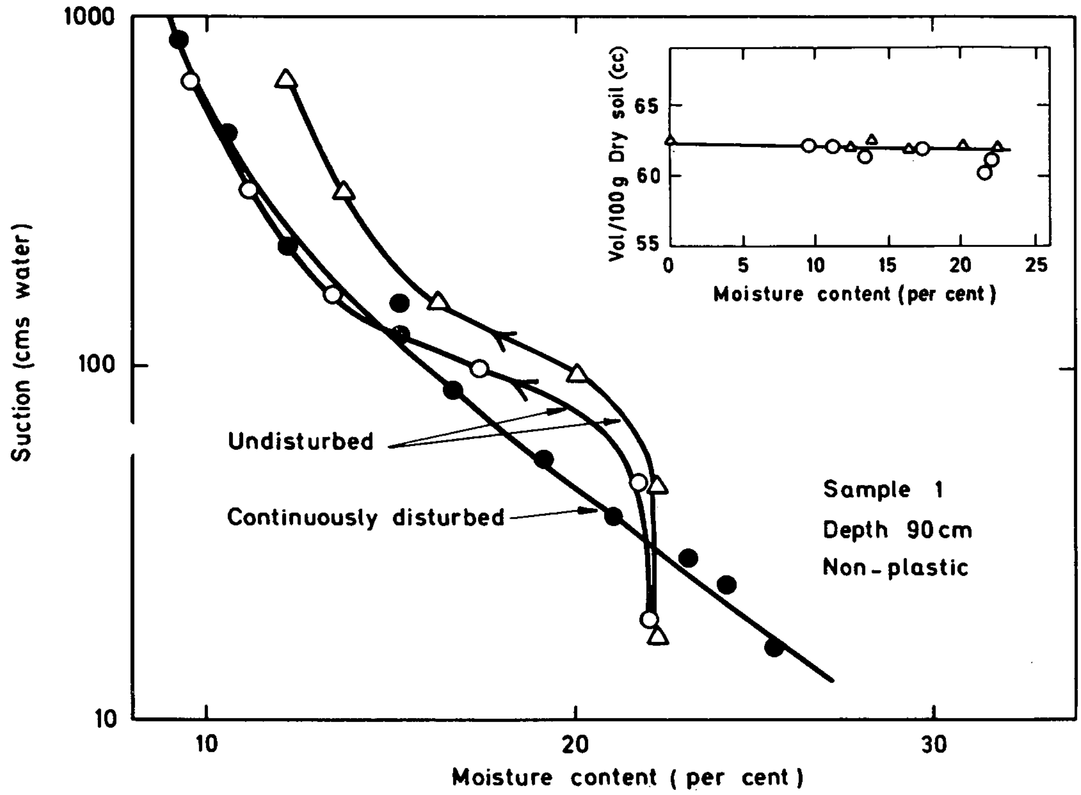

Fig. 1.

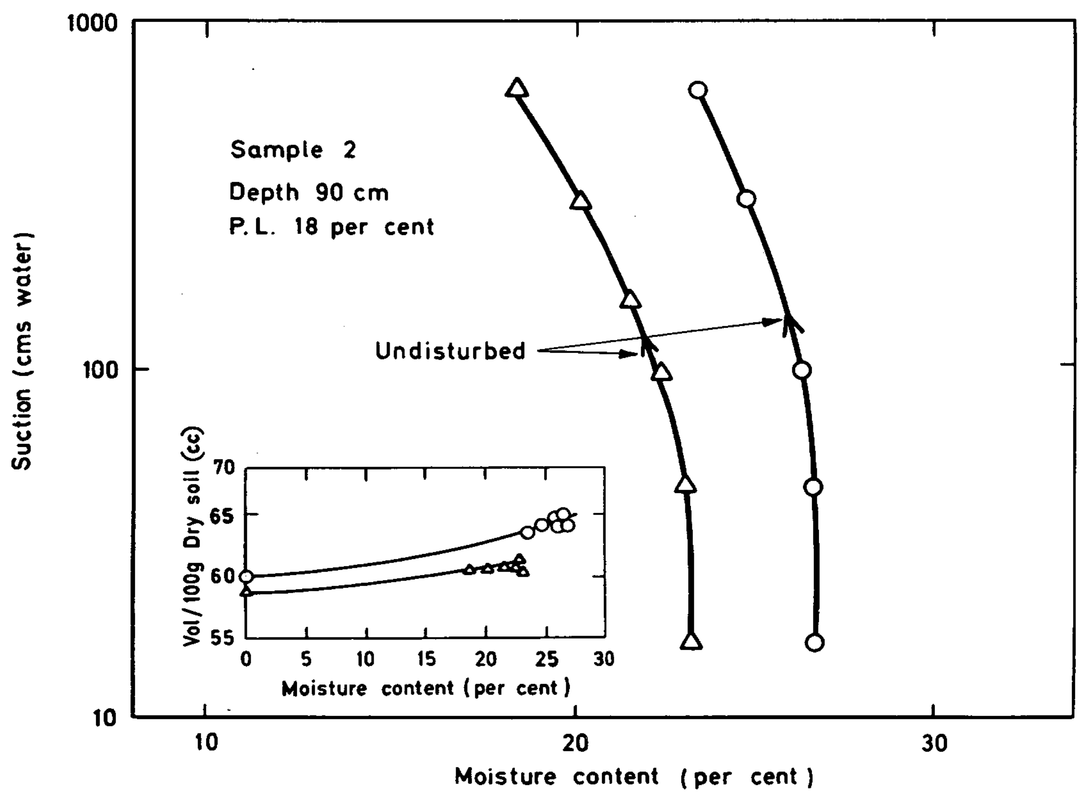

Fig. 2.

SUCTION / MOISTURE CONTENT AND SHRINKAGE RELATIONS FOR SAMPLES 1 & 2, CLAREMONT AVENUE, CAMBERLEY

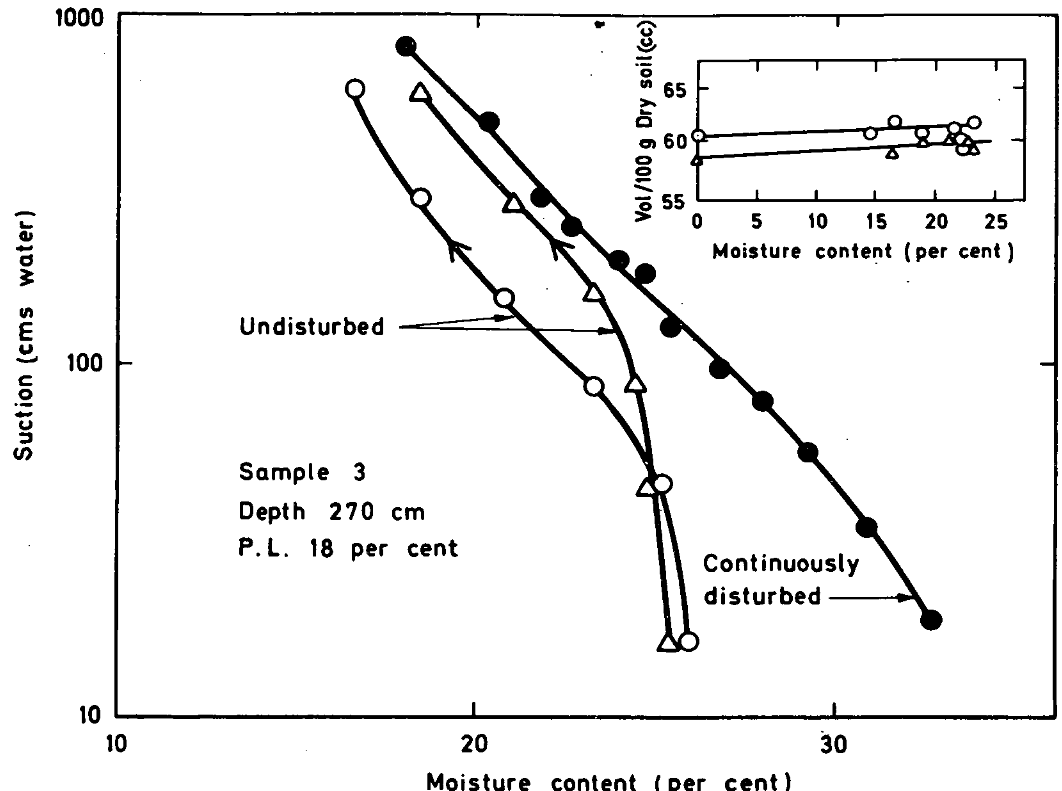

Fig. 3.

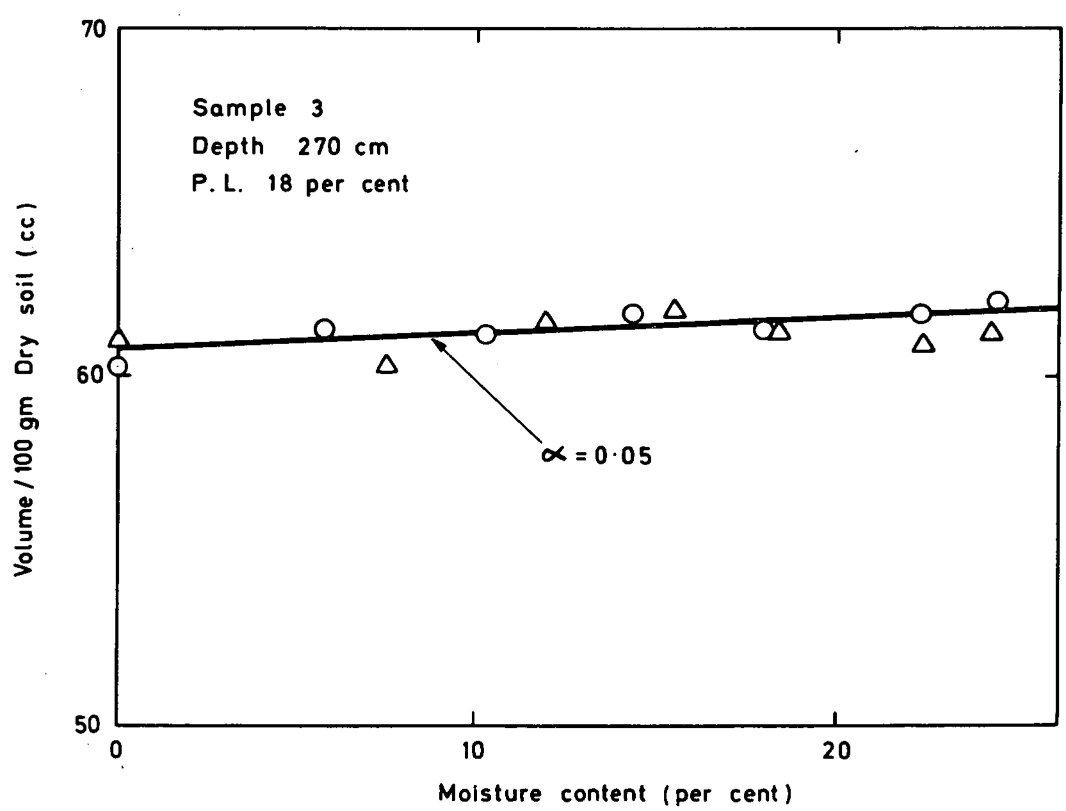

Fig. 4.

SUCTION/MOISTURE CONTENT AND SHRINKAGE RELATIONS FOR SAMPLE 3, CLAREMONT AVENUE, CAMBERLEY

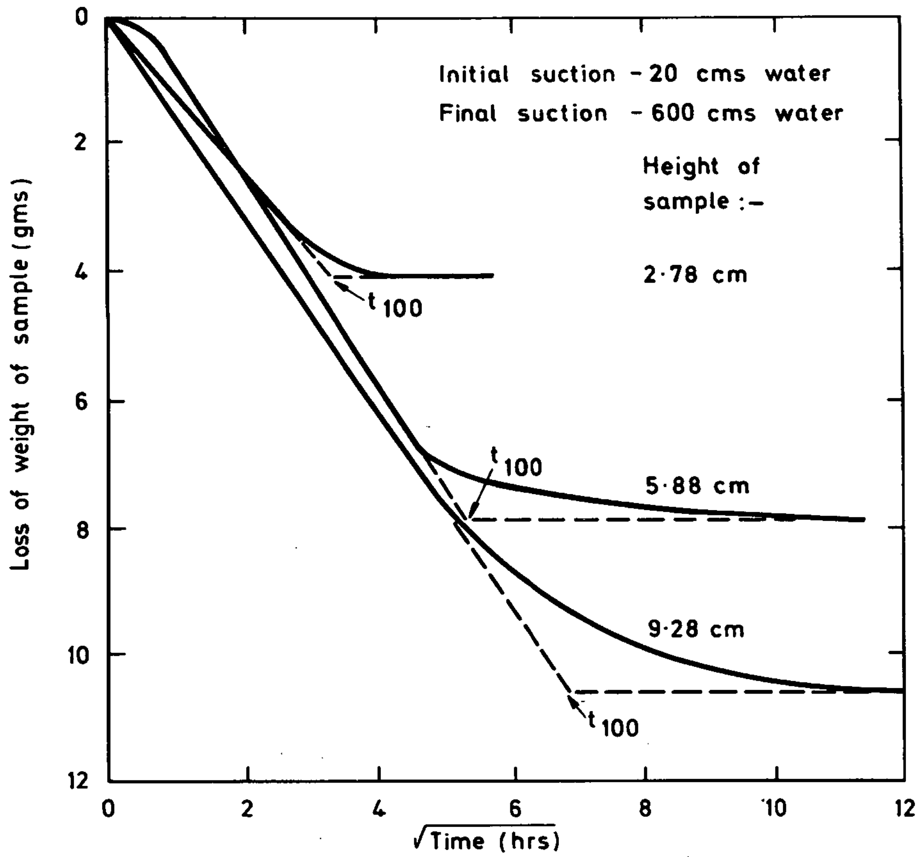

Fig.5. EFFECT OF SPECIMEN HEIGHT ON RATE OF WEIGHT LOSS FROM SAMPLE 4-5, CLAREMONT AVENUE, CAMBERLEY

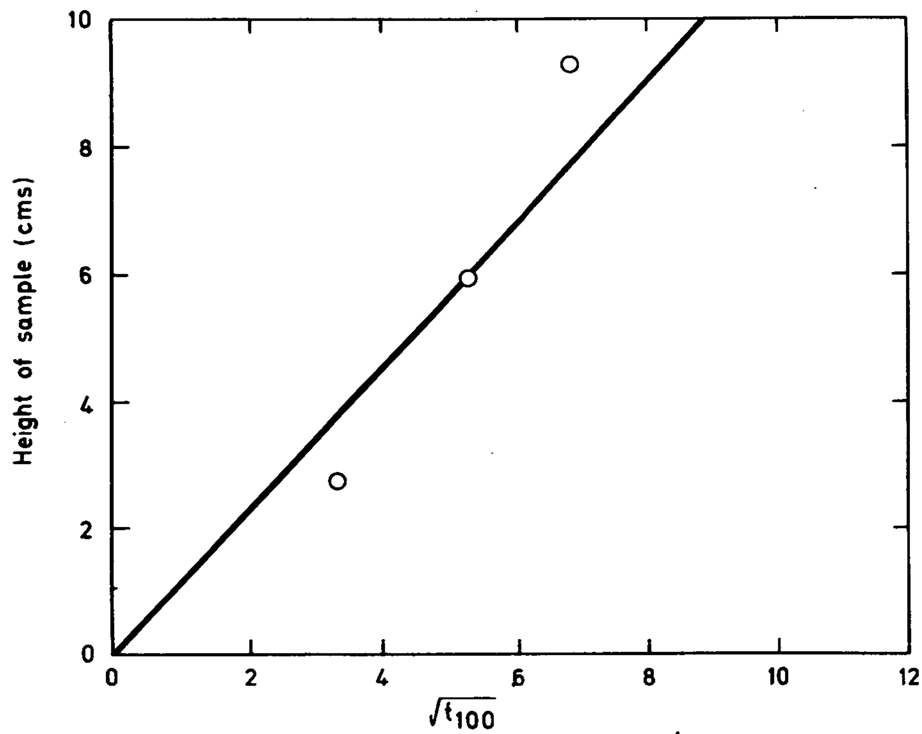

Fig. 6 RELATION BETWEEN HEIGHT OF SPECIMEN AND t 100 FOR SAMPLES 4-5, CLAREMONT AVENUE, CAMBERLEY

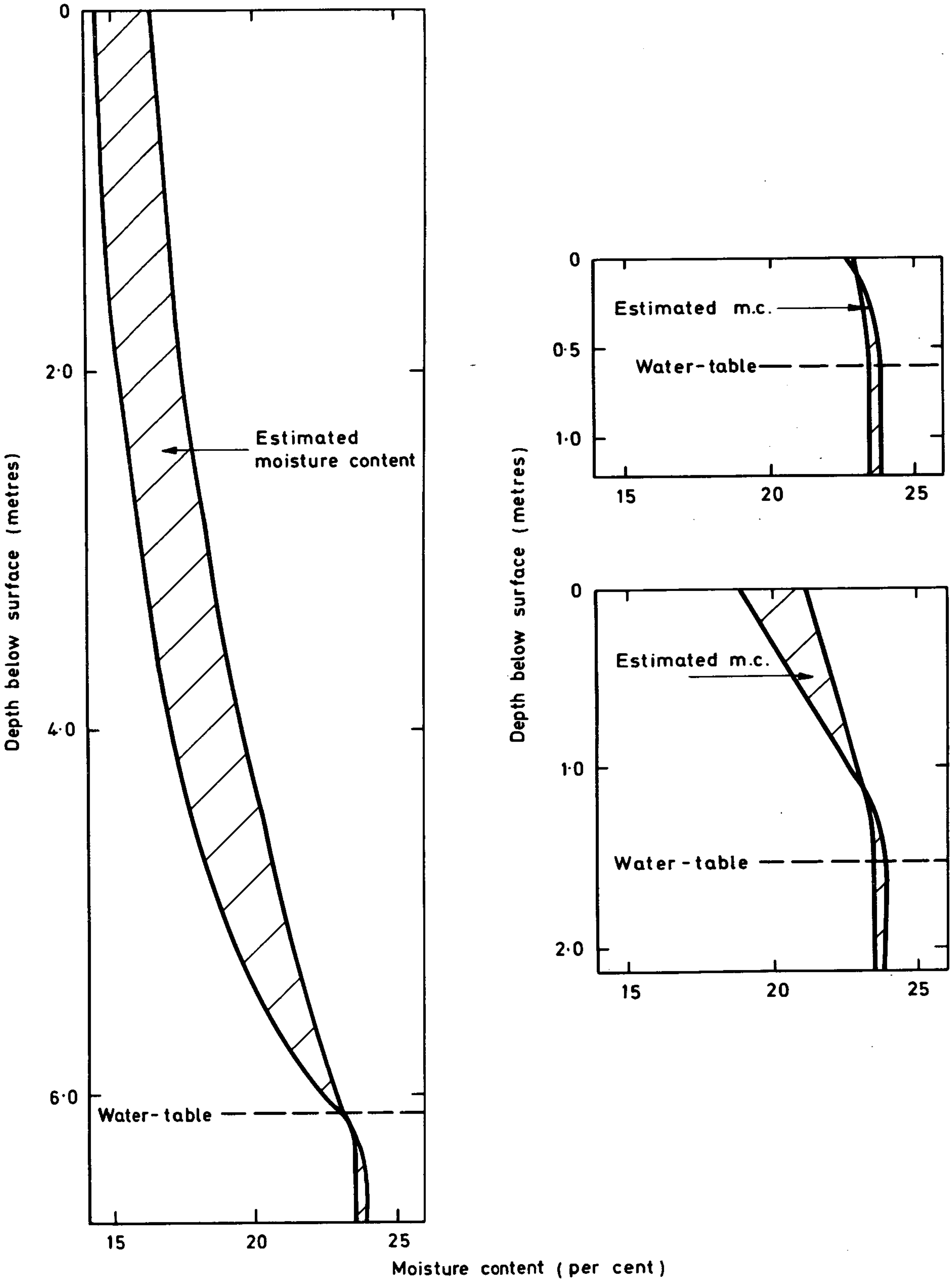

Fig. 7. ESTIMATED EFFECT OF LOWERING WATER-TABLE ON MOISTURE PROFILE IN BARTON SAND (SAMPLE 3)

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