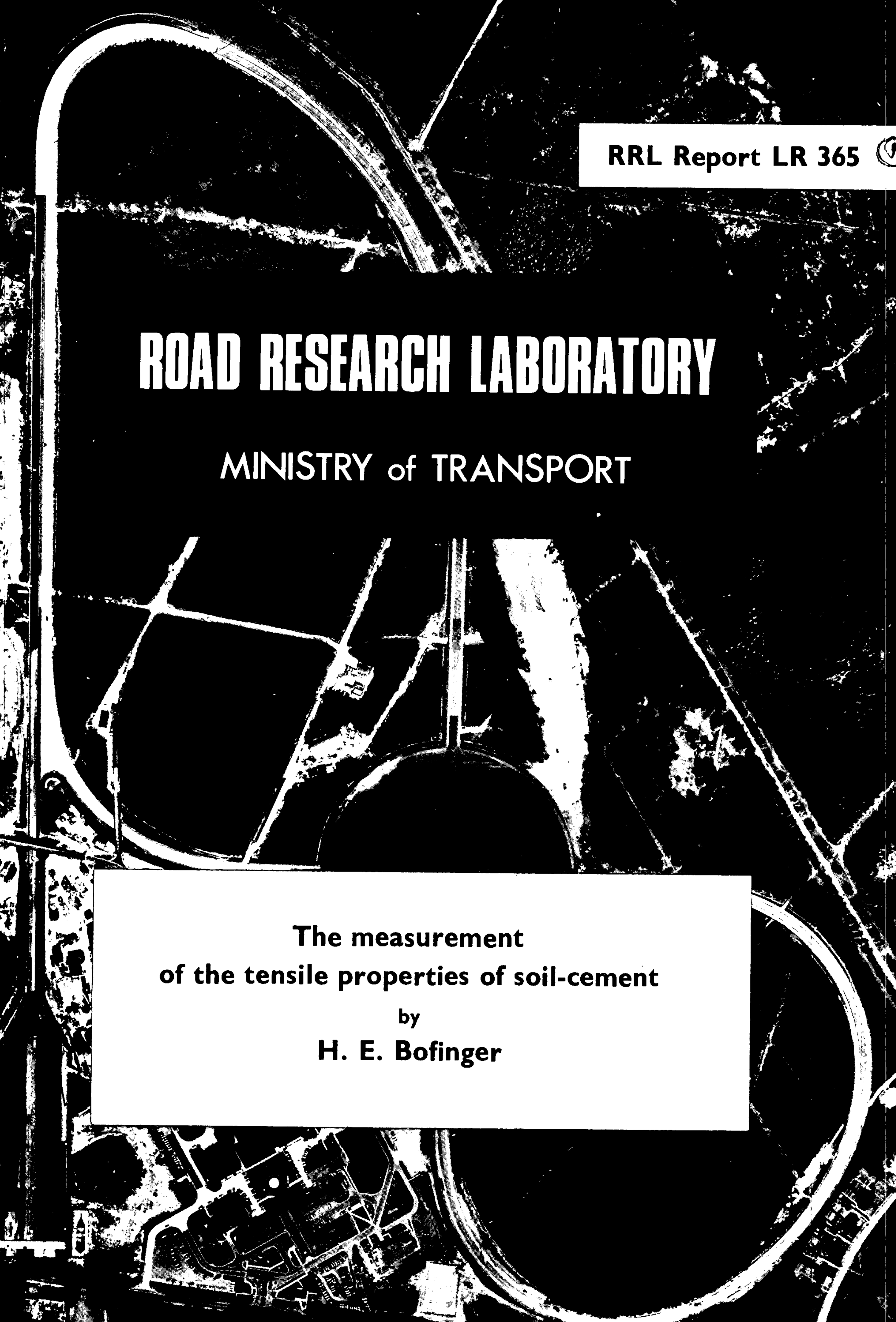

RRL Report LR 365

ROAD RESEARCH LABORATORY

MINISTRY of TRANSPORT

The measurement of the tensile properties of soil-cement

by

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THE MEASUREMENT OF THE TENSILE PROPERTIES OF SOIL-CEMENT

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H. E. Bofinger

Tropical Section

Road Research Laboratory

Crowthorne, Berkshire

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THE MEASUREMENT OF THE TENSILE PROPERTIES OF SOIL-CEMENT

ABSTRACT

As part of an investigation of the design of soil-cement pavements, laboratory tests were carried out using Harmondsworth brickearth to examine the tensile properties of soil-cement and their relation to its compressive properties. The Report discusses three methods used for determining the tensile strength, the direct and indirect tests and the flexural test, and suggests explanations for the differences in the results obtained.

Soil-cement was found to have a much higher elastic modulus when subjected to compressive stresses than when the same average tensile stresses were applied.

Because of the complex behaviour of soil-cement under stress, estimates of its tensile strength from the cylinder splitting or flexural tests are uncertain. The direct tensile test which is independent of the strain characteristics provides a more reliable indication of tensile strength of soil-cement at slow rates of strain.

1. INTRODUCTION

Cement or lime-stabilised soil is widely used for road bases in the tropics and whilst the great majority of roads constructed in this way give good service a significant minority are unsatisfactory because of excessive cracking in the base which reflects through the surfacing. This cracking, which occurs most frequently with the finer-grained stabilised soils, is not related to the thickness of construction and is commonly attributed to 'shrinkage'. In order to understand how and why this cracking occurs it is necessary to find out more about the stress-strain properties of stabilised soil in tension and compression, its shrinkage properties, and the rate which it gains strength with age.

With information on these lines it is possible to examine both the validity of the assumption of elastic behaviour in the case of soil cement and the mechanism of 'shrinkage' cracking.

Most previous investigations of stabilised soil have been concerned chiefly with the compressive properties of the material. This Report describes a laboratory investiagtion of the tensile properties of a soil cement and their relation to its compressive properties. The work is part of a wider research programme in which the cracking of full-sized soil-cement slabs is being investigated under various loading and curing conditions.

Three laboratory methods were used to determine the tensile strength of the soil-cement; the direct tensile test, the indirect tensile test and the flexural test. Each method gave different values for the tensile strength of the material and an explanation of this is that the assumptions that form the basis for calculations of stress in the indirect and flexural tests are invalid for soil-cement.

A major assumption in the elastic theory is that the elastic 'stiffnesses' of the material in tension and compression are equal. However it has been demonstrated that the tensile and compressive stress-strain properties of one clay-cement mixture are significantly different[1]. In this previous study it was found that under tensile loads the stress-strain graph was slightly concave in shape and the failure was typical of brittle fracture, whereas in compression the stress-strain curve was markedly non-linear and at stresses approaching the ultimate definite plastic behaviour was indicated. However the most important difference between the two stress-strain curves was the difference between their slopes. The slope of the compressive stress-strain curve was much greater than the slope of the corresponding tensile curve, indicating that the compressive 'stiffness' is much higher than the tensile 'stiffness'. The work described in this Report is an extension of this previous study.

2. DISCUSSION OF TENSILE TESTS

2.1 The direct tensile test

Researchers have used two types of direct tensile test. In the first, the specimen has enlarged ends which are gripped by a jaw. In the second, the load is applied through plates which are cemented to the ends of the specimen. When specimens of the first type are used (Fig. 1), there is some danger that stress concentrations at the grips will cause premature failure. A second disadvantage is that it is difficult to measure strain during the test. If plates are cemented to the ends of the specimen (Fig 2), it will usually fail in shear near the junction between the specimen and the resin cement. The ultimate stress will then be lower than for the first type of specimen. Alternatively, if plates are cemented to the sides of the specimen (Fig 3), it will withstand a stress as high as the enlarged-end type of specimen.

2.2 The indirect tensile test

In this test, which was originally developed for evaluating concrete, a vertical compressive load is applied to a cylinder of the test material which lies with its axis horizontal between the platens of the test machine (Fig 4)[7].

The load is applied through two packing strips positioned so that their axes lie in the same vertical plane as the cylinder axis. The purpose of these packing strips, which are of some relatively soft material, is to distribute the applied load evenly over any irregularities on the surface of the specimen.

The cylinder fails by splitting along its vertical axial plane and hence the test is also known as the 'cylinder splitting test'. The tensile stress at failure is estimated from the elastic formula,

$$f_t = \frac{2P}{\pi dL}$$

where f_t = ultimate tensile stress
P = applied load
d = diameter of cylinder
L = thickness of cylinder

The formula assumes that the vertical compressive stress does not contribute to the failure of the cylinder. In a cylinder-splitting test, if a maximum strain criterion of failure applies to the material, the orthogonal compressive stress must be taken into account in determining the tensile strength of linear elasto-brittle materials[2]. Consequently the elastic formula above should under-estimate the tensile strength of materials which conform to the maximum strain criterion of failure. Tests on concrete[7] have shown that the indirect tensile strength is higher than the direct tensile strength.

No attempt has yet been made to analyse the true stresses in the cylinder when the elastic modulus in compression (E_c) differs from the elastic modulus in tension (E_t). While an anaylsis is not attempted in this paper, one would expect that the lower value of E_t would reduce the tensile stress which is produced by a given load P. Therefore, the formula should overestimate the tensile strength of soil-cement. The curve relating tensile stress to strain cannot be obtained readily from an indirect tensile test.

Up to the present time, the test has not been standardised for soil-cement and various sizes of cylinders are employed. It has been suggested[3] that packing strips are unnecessary for soil-cement cylinders and that some flattening of the cylinder is not deleterious provided that a brittle failure occurs.

2.3 The flexural test

For convenience, the flexural test is often used to estimate the tensile strength of soil-cement. It is normal practice to use third-point loading and to calculate the extreme fibre stresses from the equation:

$$f = \frac{My}{I}$$

where f = extreme fibre stress
M = applied moment
y = distance from the centroid of the section to the extreme fibre
I = moment of inertia of the section about the centroid

This equation assumes similar elastic behaviour in tension and compression and derives from the theory of simple bending.

However, if E_c is not equal to E_t, the neutral axis is displaced from the centroid of the section and the above equation does not apply. Laboratory tests[4, 1] have shown that this can occur in soil-cement beams, in which case Herbert's equation[5], which allows for different E values in tension and compression and for plastic behaviour, should be used to estimate the extreme fibre tensile stress:

$$bh^2 \frac{\sigma_1 \sigma_2}{\sigma_1 + \sigma_2} = \frac{1}{\phi} \frac{d(M\phi^2)}{d\phi}$$

where b = breadth of the beam
h = depth of the beam
σ_1 and σ_2 = extreme fibre stresses
ϕ = slope of the curved beam
M = applied moment

The position of the neutral axis may be obtained from the equation:

$$\eta_1 = \frac{\epsilon_1 \cdot h}{\epsilon_1 + \epsilon_2}$$

where η_1 = distance from extreme tensile fibre to the neutral axis
ϵ_1 = strain in the extreme tensile fibre
ϵ_2 = strain in the extreme compressive fibre

The strains ϵ_1 and ϵ_2, may be found graphically by equating the areas under the curves relating tensile and compressive stress to strain and by plotting the area under each curve against the strain. When the tensile and compressive stress-strain curves are known, the relationship between M and ϕ may be determined. The extreme fibre tensile stress at failure can be calculated for the measured failure moment.

3. EXPERIMENTAL DETAILS

Within this project one parent soil was used, namely, Harmondsworth Brickearth. The classification test results are given in Section 4 below. As some of the tension specimens were moulded with a cross section of 25.4 mm square, the soil was crushed until its maximum particle size was 3.2 mm. Additions of 6, 8 and 10 per cent of cement were included and the specimens were moulded at moisture contents of 15 and 17 per cent.

3.1 Preparation of specimens

The soil was moistened to 14 per cent moisture content and was allowed to stand in sealed containers for at least 3 days prior to use. The cement and the moistened soil were mixed and the required moulding water was added. Specimens were moulded, extruded, sealed in wax and cured at a temperature of 20°C for 14 days before being tested. The types of specimens prepared are listed in Table 1.

TABLE I

Summary of specimen types used in the testing programme

Test	Investigation	Type of specimen
Direct tension	Ultimate strength	Briquette with 25.4 mm x 25.4 mm cross-section
	Stress-strain behaviour	304.8 mm x 76.2 mm x 76.2 mm block with plates cemented to the sides at each end
Indirect tension	Ultimate strength	101.6 mm x 50.8 mm diameter cylinders
Unconfined compression	Stress-strain behaviour	304.8 mm x 76.2 mm x 76.2 mm blocks
Flexure	Ultimate failure moment	304.8 mm x 76.2 mm x 76.2 mm beams

3.2 Method of moulding

Plates 1, 2 and 3 show the apparatus which was used to mould the briquettes, 304.8 mm x 76.2 mm x 76.2 mm blocks and beams, and 101.6 mm x 50.8 mm diameter cylinders respectively. The briquettes and cylinders were statically compacted to a predetermined density. To help reduce the density gradient in the cylinders, the material was rodded by hand prior to final compaction. The blocks and beams were moulded in three equal layers under a pressure of 1560 kN/m^2. Under this pressure the specimens were compacted to BS maximum dry density, 2.5 kg (5.5 lb) rammer method.

3.3 Method of testing

3.3.1 Briquettes The load was applied to the direct-tensile briquettes through a pair of jaws which were separated at 0.76 mm/min. Because the jaws penetrate into the specimen, the deflection was not recorded and only the ultimate load was noted.

3.3.2 Tensile tests on 304.8 mm x 76.2 mm x 76.2 mm blocks Side plates were glued to each end of these blocks with a quick-setting polyester resin. End caps which incorporated a spherical seat reduced any moment in the specimens to a negligible amount. Plate 4 shows a specimen in position in the testing machine. A stressing rate of approximately 138 $kN/m^2/min$ was used. Dial gauges were attached to the top and bottom platens and the deflection was recorded.

3.3.3 Indirect-tension cylinders The cylinders were placed horizontally between the platens and loaded to failure. Two sets of specimens were tested, one without packing strips and one with 6.4 mm x 3.2 mm rubber strips inserted at the top and bottom. Packing strips are used to minimise the uneven distribution of load along the length of cylinders and they must be much softer than the specimen to accomplish this. Although hardboard is recommended as packing material for the indirect tensile testing of concrete, it is unsuitable for the softer soil-cement specimens. Therefore rubber strips were used in this investigation.

3.3.4 Compression tests on 304.8 mm x 76.2 mm x 76.2 mm blocks The blocks were tested in compression to determine the stress-strain relationship. The stress was applied parallel to the direction of compaction at a rate of approximately 1040 $kN/m^2/min$. Deflections of the top and bottom platens were noted.

A group of blocks was tested to determine the effect of applying the load through side plates glued to the ends of the specimen. The stress-strain curves of these specimens were compared with the stress-strain curves of specimens loaded through the ends in the usual way.

3.3.5 Flexural tests A third-point loading system with a span of 228.6 mm was used to stress the flexural beams. The load at failure was recorded.

4. RESULTS

4.1 Properties of Harmondsworth Brickearth

Liquid limit	=	53 per cent
Plastic limit	=	20 per cent
Plasticity index	=	33 per cent
Specific gravity	=	2.70
Particle size:		7 per cent sand
		55 per cent medium & coarse silt
		10 per cent fine silt
		28 per cent clay (<0.002 mm)

When the soil was mixed with 8 per cent of cement, the BS optimum moisture content was 17 per cent and the maximum dry density was 1778 kg/m^3.

In all of the experimental work, the cement used was a blended 'Typical Ordinary Portland Cement' to BS 12 supplied by the Associated Portland Cement Manufacturers Ltd.

4.2 The effect of side plates

The techniques that are normally used to measure the strain in a tensile specimen are either to attach some form of extensometer to the specimen or to glue resistance gauges to its surface. Both of these techniques are difficult to employ on soil-cement specimens. The sharp pins of extensometers that lightly indent the surface of metal and plastic specimens thus forming accurate gauging points, cause local failure in the relatively weak soil-cement. A pin seated in the disturbed material in this failure zone is not a reliable gauging point. Glues that are used to attach resistance strain gauges to specimens are much stiffer and stronger than hardened soil-cement.

Comparative measurements[1] have shown that resistance strain gauges glued to soil-cement specimens indicated a 'stiffness' approximately 100 times the 'stiffness' calculated from mechanical measurements of elongation.

Therefore, in this series of experiments side plates were glued to the ends of the specimens both for the application of load and as reference points from which to measure elongation.

When side plates are used to transfer the load to a 304.8 mm x 76.2 mm x 76.2 mm specimen, the effective length of the specimen must be estimated so that the strain can be calculated. The effective length must lie somewhere between the total length of the specimen (304.8 mm) and the clear distance between the side plates (152.4 mm). Because the tensile stress-strain specimens can be loaded only through some attachments such as side plates, the effective length problem was studied using a group of compression specimens. The compresssive stress-strain curves for three specimens are drawn in Fig 5. Up to a stress of 1.3 and 1.1 MN/m^2 respectively, specimens 912 and 914, which were loaded through side plates, had curves identical with Specimen 913 which was loaded directly through the ends of the specimen. A gauge length of 228.6 mm (midway between 152.4 and 304.8 mm) was used to calculate the strain in Specimens 912 and 914.

As the tensile strength of this soil-cement is much lower than 1.1 MN/m^2, it was assumed that there would be no slippage between the plates and the tensile specimens. This assumption was supported by the test results which showed brittle characteristics of the tensile stress-strain curves at the failure points and no indication of sudden slippage. Although the loads applied through the side plates to tension specimens are in the opposite direction to the compressive loads, there is no apparent reason why an effective length of 228.6 mm is not satisfactory for tensile strain calculations.

4.3 Stress-strain relationships for soil-cement

Three specimens were tested at each cement and moisture content to determine both the tensile and the compressive stress-strain curves. For each group of specimens, the best-fitting stress-strain curve has been drawn. Only these average curves are included in Figs 6 and 7.

It can be seen that the tensile and compressive stress-strain curves have different characteristics. This confirms the previous observations[1]. The tensile curves are concave upwards and there is an insignificant effect of cement and moisture content on the shape and slope of the curve. Each tensile curve shows a characteristic brittle fracture with no plasticity at failure. The compressive stress-strain curves have a distinct plastic region near failure.

Listed in Table 2 are the tensile and compressive secant moduli of the best fitting curves and the confidence limits at the 95 per cent level. The tensile moduli were determined at failure and the compressive moduli at one-third of the failure stress. Because the extreme fibre compressive stress in a beam at failure is much smaller than the ultimate, the compressive modulus at one-third of the ultimate stress is more representative of the properties of the material. The ratio of $\bar{E}_c/\bar{E}_t$ varies from 7.5 to 11.1.

TABLE 2

Stress-strain test results on cement-stabilised Harmondsworth brickearth

Cement content percent	Moisture content percent	Tensile			Compressive			
		E_t (Modulus) MN/m^2	$\bar{E}_t$ (Modulus of Average curve) MN/m^2	95 per cent confidence limits	E_c (Modulus) MN/m^2	$\bar{E}_c$ (Modulus of Average curve) MN/m^2	95 per cent confidence limits	$\frac{\bar{E}_c}{\bar{E}_t}$
6	15	147 121 119	124	± 39	1510 1606 1344	1380	± 330	11.1
8	15	112 152 132	145	± 50	1100 1100 1100	1110	–	7.7
10	15	162 165 156	158	± 11	2310 1910 1276	1580	± 1294	10.0
6	17	144 138 138	138	± 9	993 1103 1076	1041	± 151	7.5
8	17	194 154 149	165	± 61	1434 1655 1153	1310	± 700	7.9
10	17	171 155 144	152	± 34	1505 1400 1166	1400	± 449	9.2

Similar test results were obtained from specimens cut from a stabilised pavement in Malaya, as is shown in Fig 8, 9, 10 and 11. The material was a clean sand stabilised with cement, and, as before, there was a large difference between E_c and E_t.

4.4 Comparison of tensile failure stresses

The tensile stresses at failure are recorded in Table 3.

TABLE 3

Comparison of tensile stresses at failure

Cement content percent	Moisture content percent	Direct tensile strength		Indirect tensile strength		Extreme fibre flexural stress	
		Briquettes kN/m^2	Blocks kN/m^2	With packing kN/m^2	Without packing kN/m^2	Elastic kN/m^2	Herbert kN/m^2
6	15	269	245	–	–	404	278
8	15	358	360	–	–	491	383
10	15	418	428	–	–	664	485
6	17	373	332	304	271	463	336
8	17	398	418	367	303	630	432
10	17	480	400	405	366	758	543

The tensile stresses for the cylinder-splitting tests were calculated from the existing elastic formula, while both the simple elastic and Herbert analyses were used to estimate the tensile extreme fibre stresses in flexural specimens. Each result in the Table represents the average of five tests, except for the direct tensile blocks for which three tests were averaged.

A statistical analysis of the results in Table 3 has shown that:

1. There is no significant difference (at the 95% confidence level) between the direct tensile strengths obtained from 'briquette' and 'block' specimens.

2. When rubber packing strips were used in the indirect test the calculated failure stresses were higher than when the packing was omitted. The failure stresses of specimens tested with rubber packing strips were 4.9 to 25.1 per cent higher (95% confidence level). It has been previously stated[3] that packing strips should not affect the indirect tensile strength of soil-cement.

3. The results of the indirect test were significantly lower than those of the direct test. This is in contrast to results that have been obtained for concrete[7]. With packing strips the 95%

confidence interval of the difference was 5.0 to 22.6 per cent. Without packing strips the interval was 17.3 to 32.7 per cent.

4. There was little difference between the measured direct tensile strength and the extreme fibre tensile stress calculated by the Herbert equation. The 95% confidence interval showed the beam strengths to be 0.6 to 12 per cent greater than the briquette strengths.

When the simple elastic formula was used the extreme fibre stresses were much greater than the briquette strengths and the 95% confidence interval of the differences was 40.2 to 55.4 per cent.

5. DISCUSSION OF RESULTS

In previous research[1] a heavy expansive clay stabilised with 4, 6 and 8 per cent cement was stressed in compression and tension. The compressive secant modulus, E_c, at a stress of 2/3 of the ultimate was from 2.4 to 4.7 times larger than the tensile secant modulus, E_t, at failure. Within this research programme a lighter, inactive clay was stabilised with 6, 8 and 10 per cent cement and the ratio of E_c to E_t varied from 7.5 to 11.1. Similar tests on sand-cement specimens cut from a road pavement also showed that E_c was much greater than E_t.

This difference in the behaviour of soil-cement under compressive and tensile loads cannot be explained by any mechanism that is supported, at the present, by experimental results. A possible explanation derives from the macro structure of the material in which planes of weakness occur between the soil particles and the stabilised matrix. Under compressive loads these planes of weakness should be closed and the stress transmitted directly across them. Hence, almost all of the cross-section resists part of the compressive load. When tensile loads are applied there can be no transference of load across the weak planes and only a reduced proportion of the gross cross-section is able to resist the load. Therefore the actual tensile stresses in parts of the material will be much larger than the average stress, especially when the concentrations of stress at the ends of cracks are considered. It follows that the tensile 'stiffness' calculated from the average stress should be much lower than the compressive 'stiffness'.

On a micro-scale, the possibility that there are fundamental differences between the tensile and compressive properties of the uncracked material should not be discounted without experimental proof.

It has been demonstrated that rubber packing strips increase the calculated failure stress in cylinder-splitting tests performed on a cement-stabilised silty clay (Harmondsworth brickearth).

Because E_c is greater than E_t, the cylinder-splitting tests should produce calculated tensile strengths which are greater than the direct test. The indirect tensile strengths in this investigation were lower than the direct strengths. Apparently the reduction in the calculated strength which is caused by neglecting the orthogonal compressive stress[2] is more important than the difference in the tensile and compressive stiffness.

The Herbert equation gives extreme fibre flexural stresses which are not markedly different from the direct strengths of the material. It appears that the simplified stress model which is used in the Herbert analysis applies to soil-cement beams. As the elastic flexural equation is invalid for soil-cement because E_c is not equal to E_t, previous flexural test results are suspect and must be treated with discretion. As the static stiffness characteristics are so different in tension and compression the dynamic stiffnesses should be carefully studied before elastic-pavement stress analyses are applied unreservedly to uncracked soil-cement pavements. The effects of variations in the rate of strain are currently being evaluated at the Road Research Laboratory.

6. CONCLUSIONS

1. Soil-cement has a much higher secant modulus when subjected to compressive stresses than when tensile stresses are applied. The ratios of E_c to E_t that were obtained in this series of tests varied from 7.5 to 11 and these figures reinforce other unpublished results.

2. Because the measured failure load in a direct tensile test is independent of the strain characteristics of the specimen, it is the only method which can readily measure the tensile strength of soil-cement. Cylinder-splitting and flexural tests are of little value for assessing the tensile strength of soil-cement unless the actual failure stresses can be calculated. This is much more difficult to achieve than the direct measurement of tensile strength in the simpler direct tensile test.

7. ACKNOWLEDGEMENTS

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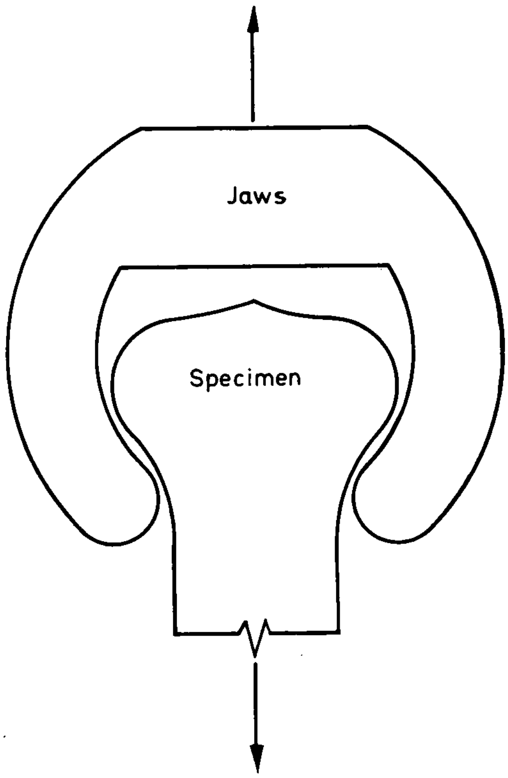

Fig. 1 TENSILE SPECIMEN LOADED THROUGH GRIPPING JAWS

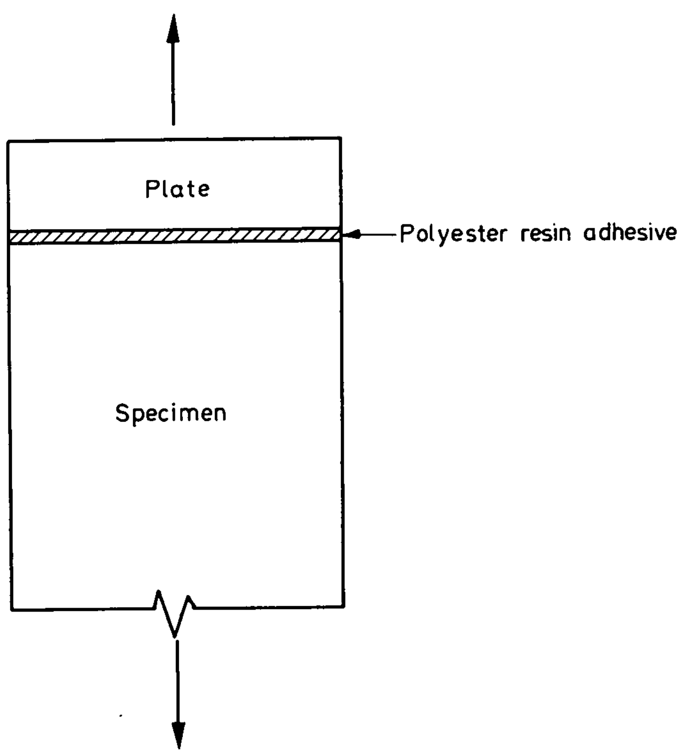

Fig. 2 TENSILE SPECIMEN LOADED THROUGH PLATES CEMENTED TO ITS ENDS

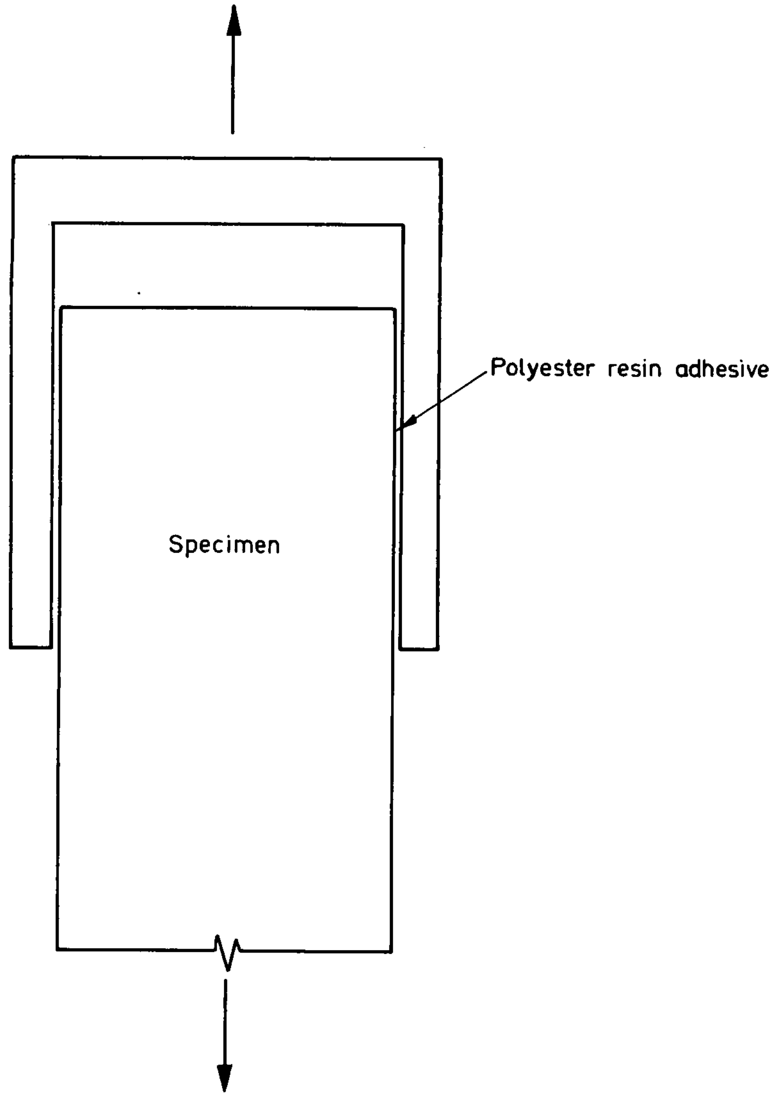

Fig. 3 SCHEMATIC ARRANGEMENT OF TENSILE SPECIMEN LOADED THROUGH PLATES CEMENTED TO THE SIDES OF THE SPECIMEN AT EACH END

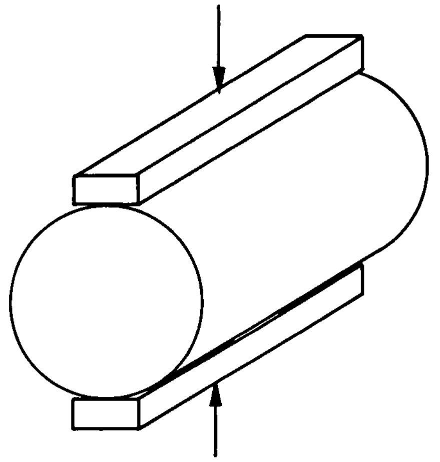

Fig. 4 THE INDIRECT TENSILE TEST

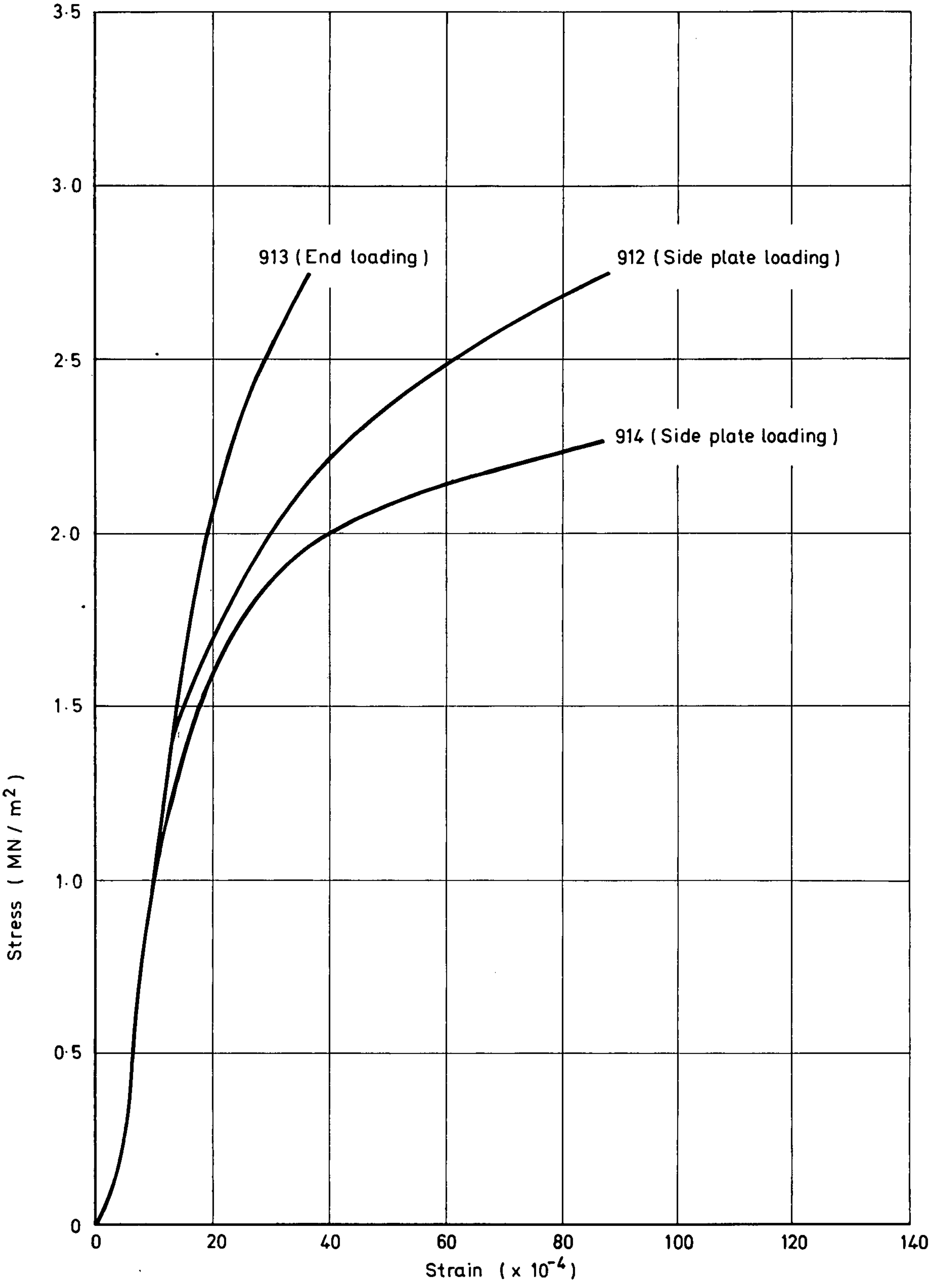

Fig. 5 COMPRESSIVE STRESS-STRAIN CURVES SHOWING THE EFFECT OF SIDE PLATES CEMENTED TO THE ENDS OF THE SPECIMEN

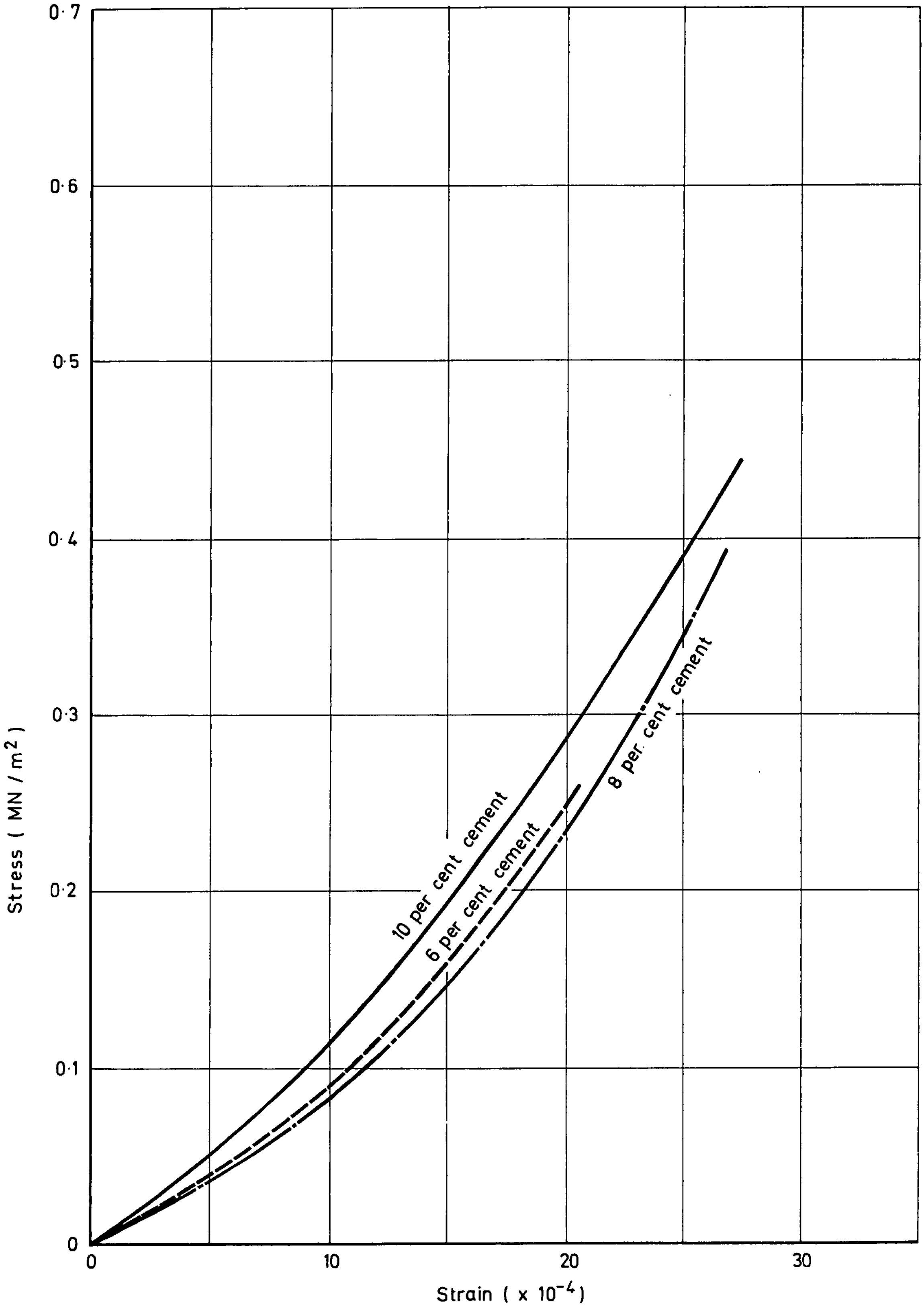

Fig. 6a AVERAGE TENSILE STRESS-STRAIN CURVES FOR CEMENT-STABILISED HARMONDSWORTH BRICKEARTH MOULDED AT 15 PER CENT MOISTURE CONTENT

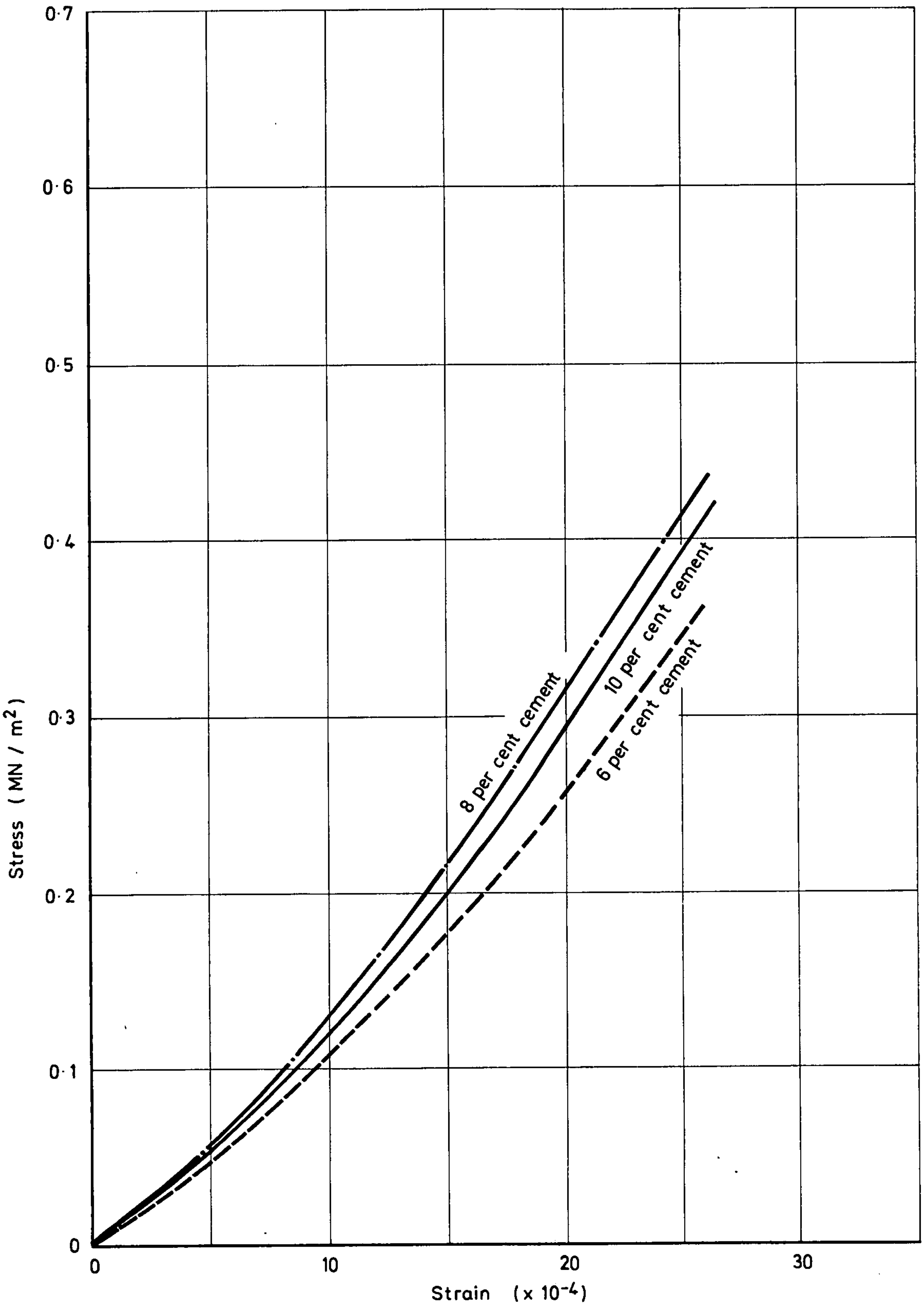

Fig. 6b AVERAGE TENSILE STRESS - STRAIN CURVES FOR CEMENT - STABILISED HARMONDSWORTH BRICKEARTH MOULDED AT 17 PER CENT MOISTURE CONTENT

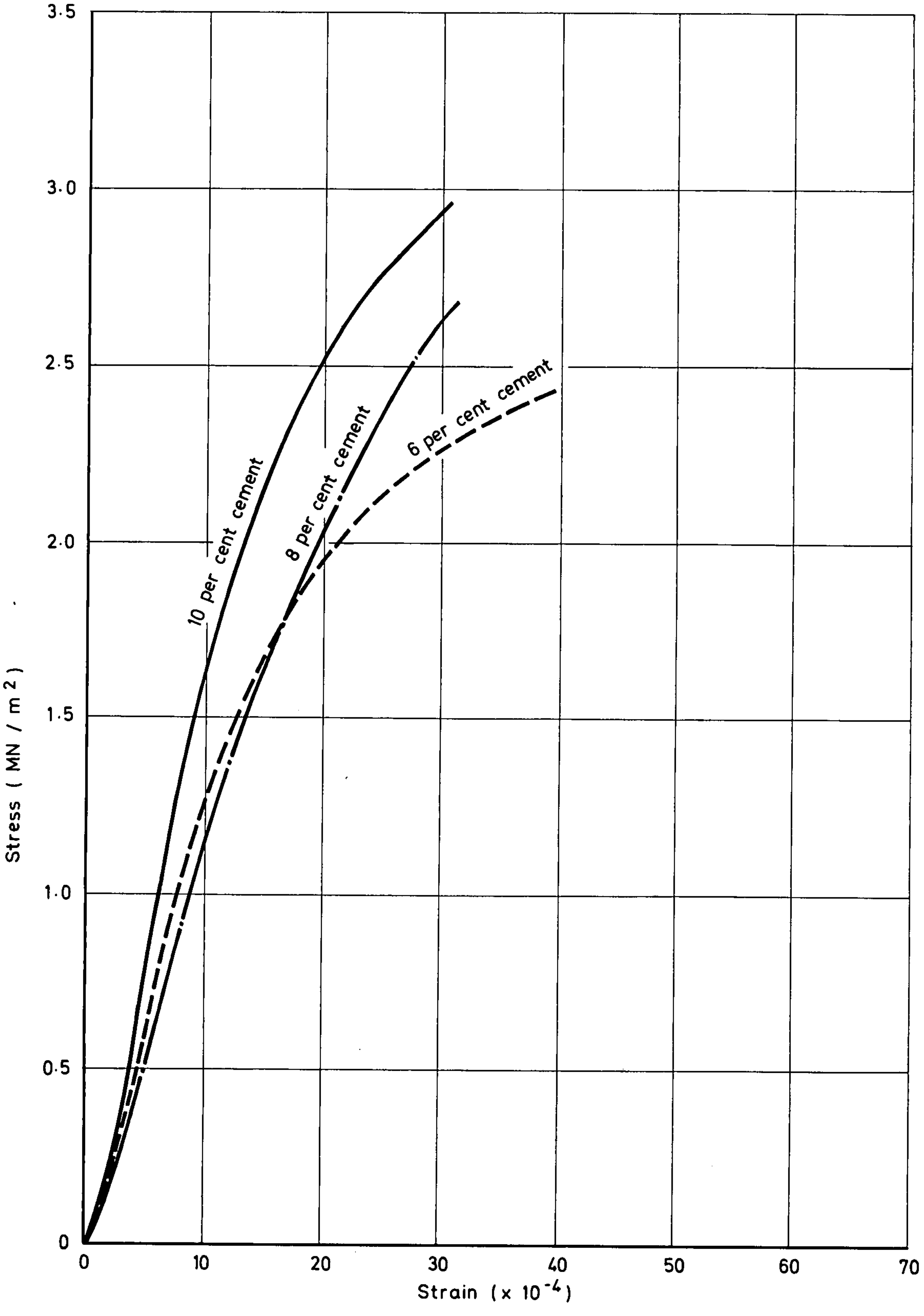

Fig.7a AVERAGE COMPRESSIVE STRESS - STRAIN CURVES FOR CEMENT - STABILISED HARMONDSWORTH BRICKEARTH MOULDED AT 15 PER CENT MOISTURE CONTENT.

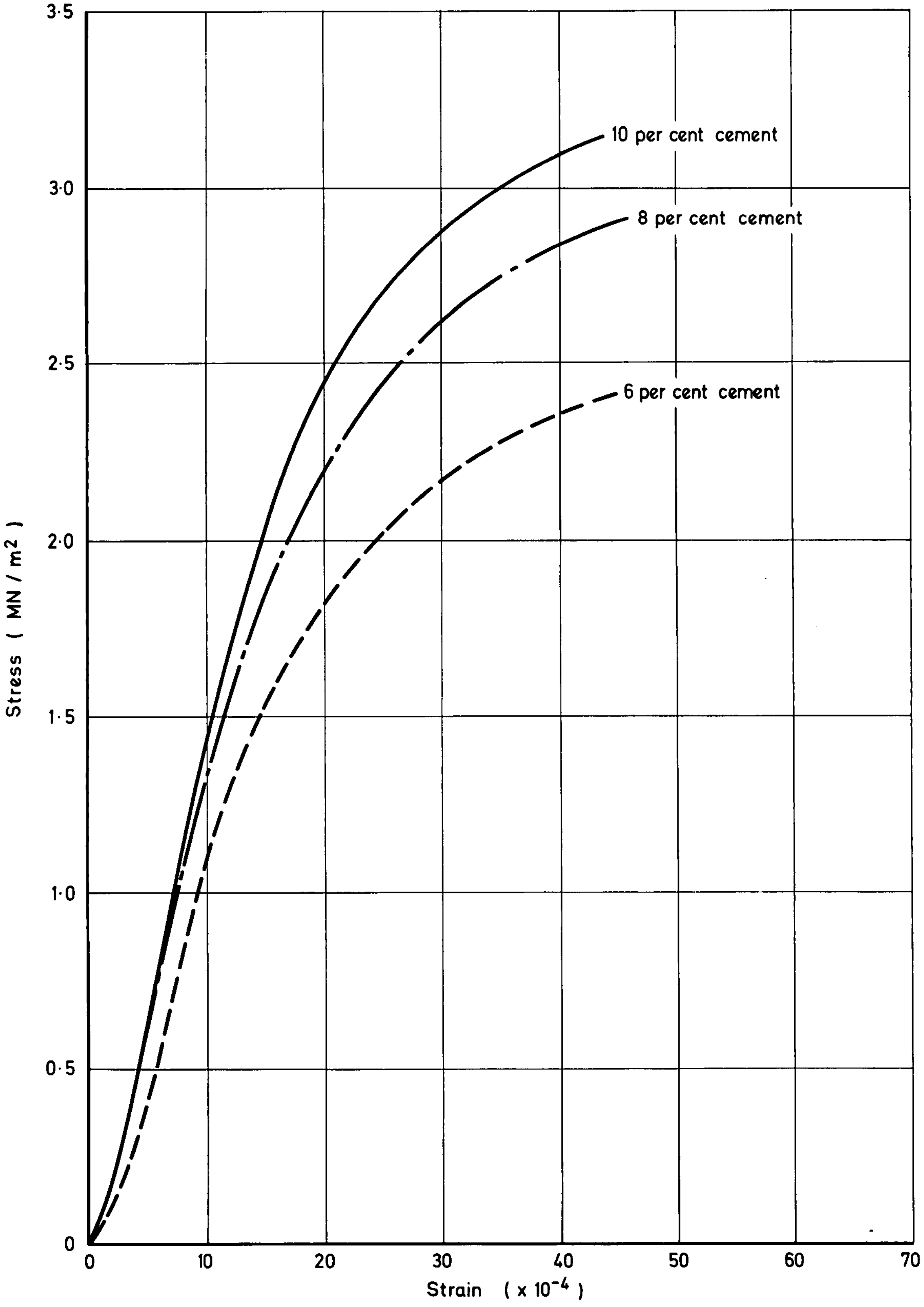

Fig. 7b AVERAGE COMPRESSIVE STRESS - STRAIN CURVES FOR CEMENT - STABILISED HARMONDSWORTH BRICKEARTH MOULDED AT 17 PER CENT MOISTURE CONTENT

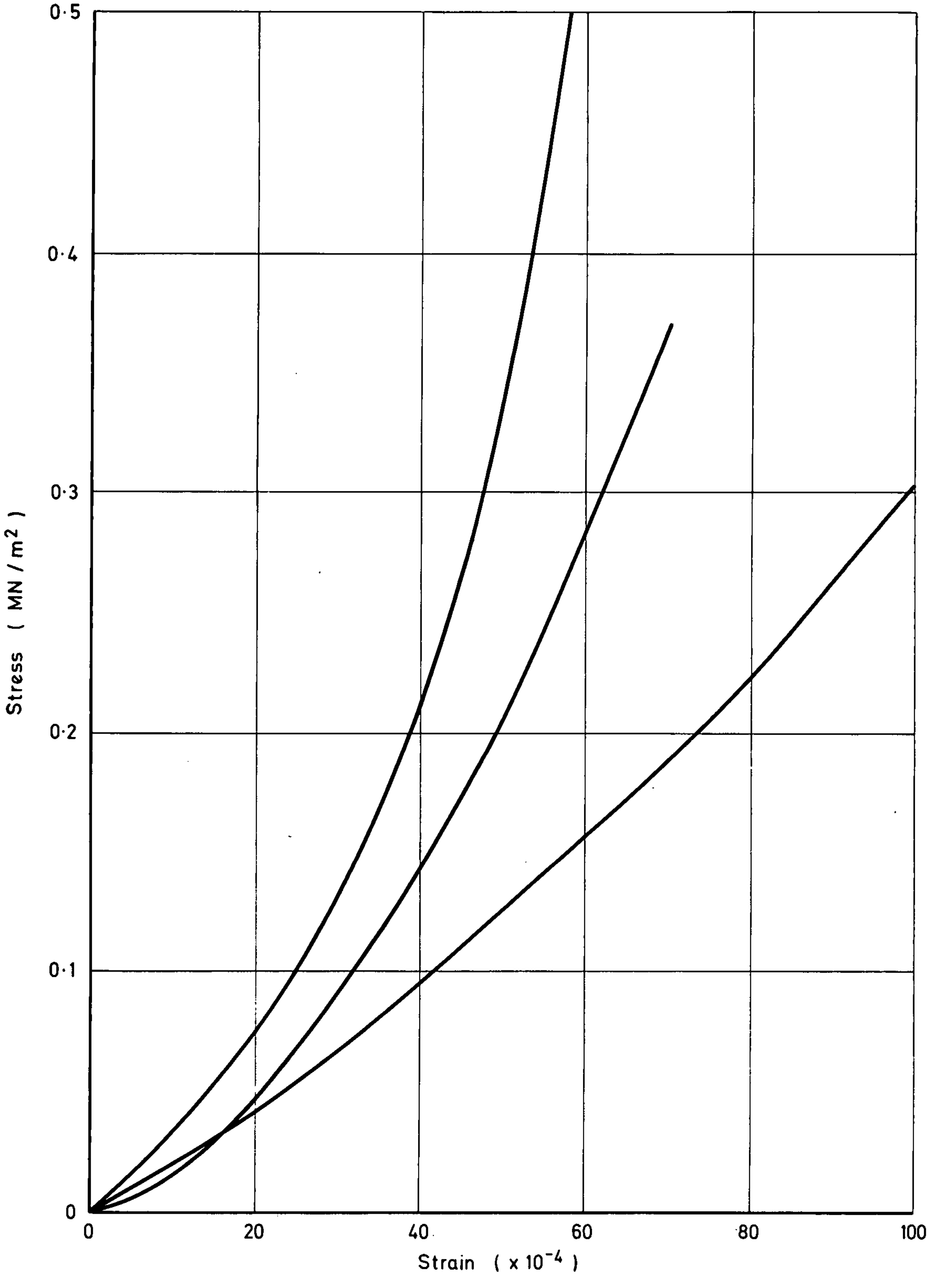

Fig. 8 TENSILE STRESS–STRAIN CURVES FOR SPECIMENS SAWN FROM THE PAVEMENT AT ROMPIN (HOLE 3), MALAYSIA.

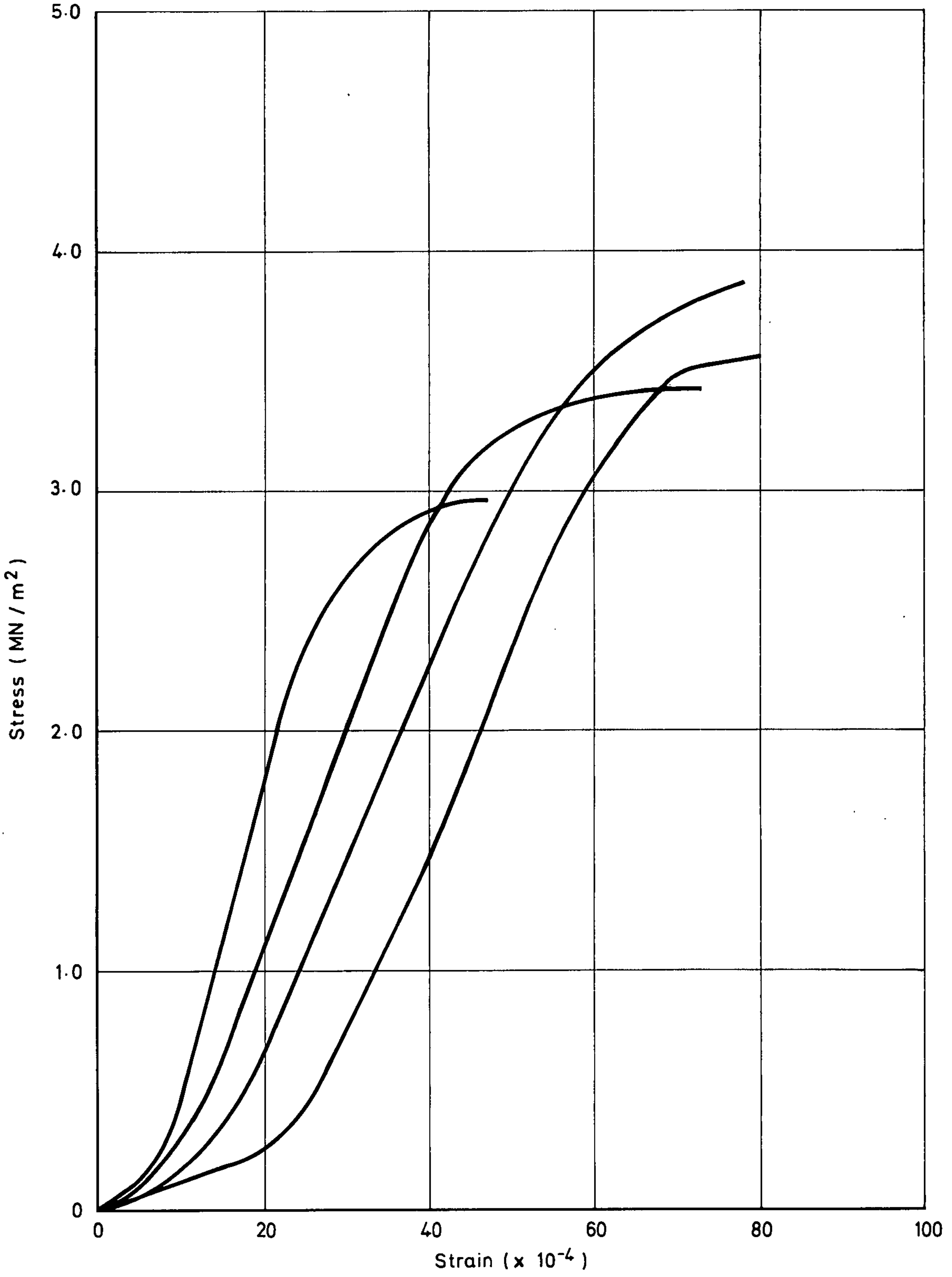

Fig. 9 COMPRESSIVE STRESS-STRAIN CURVES FOR SPECIMENS SAWN FROM THE PAVEMENT AT ROMPIN (HOLE 3) MALAYSIA

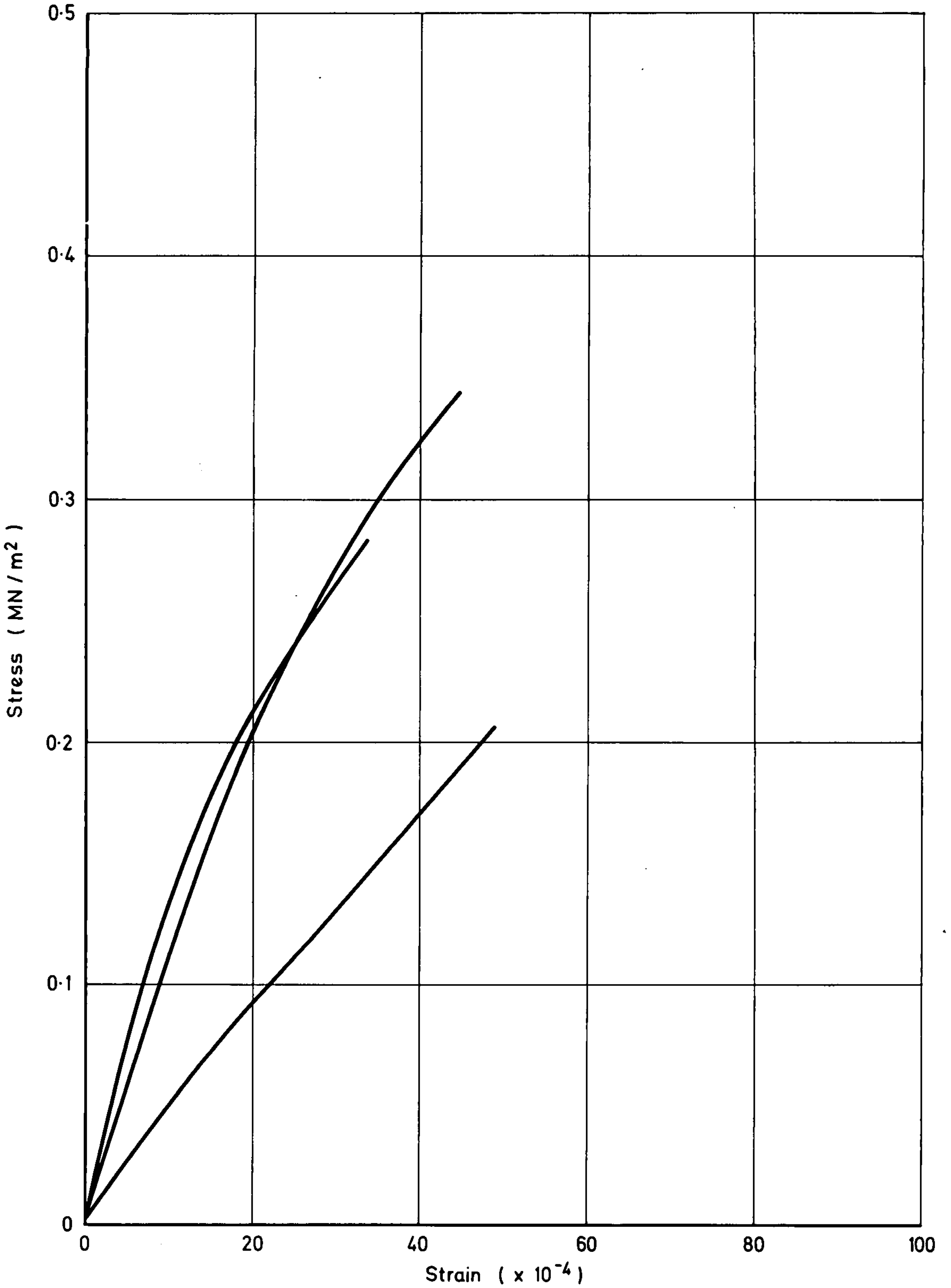

Fig. 10 TENSILE STRESS-STRAIN CURVES FOR SPECIMENS SAWN FROM THE PAVEMENT AT ROMPIN (HOLE 5/6), MALAYSIA.

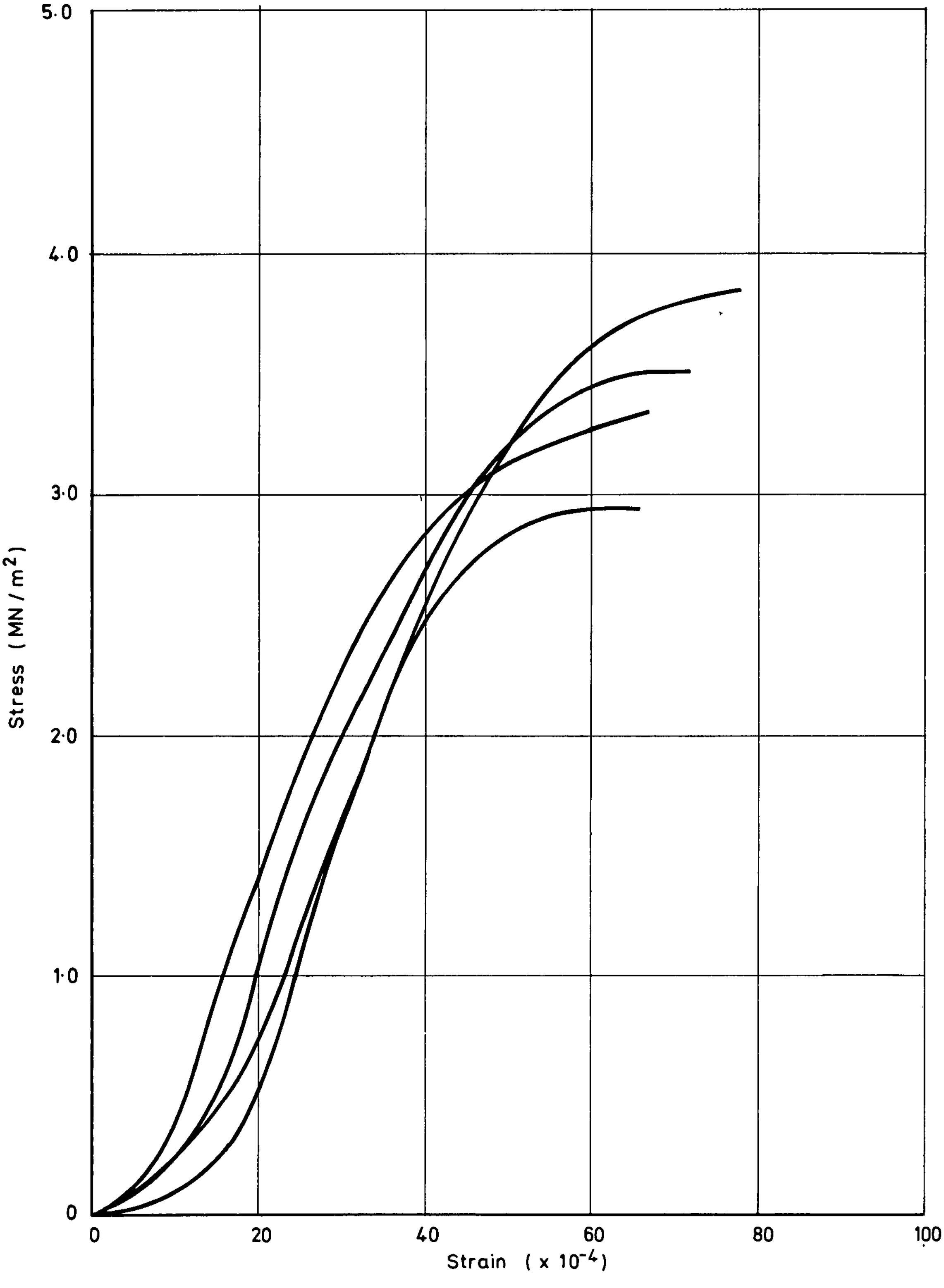

Fig. 11 COMPRESSIVE STRESS-STRAIN CURVES FOR SPECIMENS SAWN FROM THE PAVEMENT AT ROMPIN (HOLE 5/6) MALAYSIA

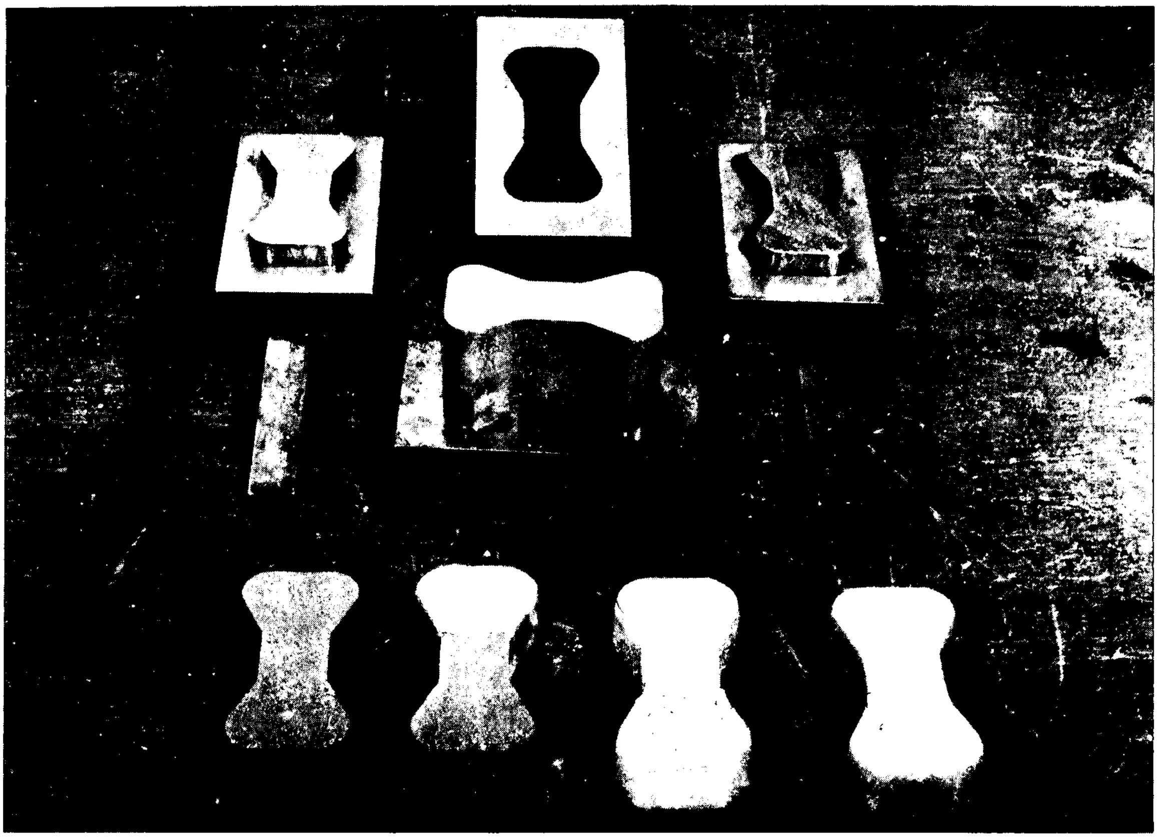

PLATE 1 Neg No B2437/68

Moulding apparatus for tensile briquettes

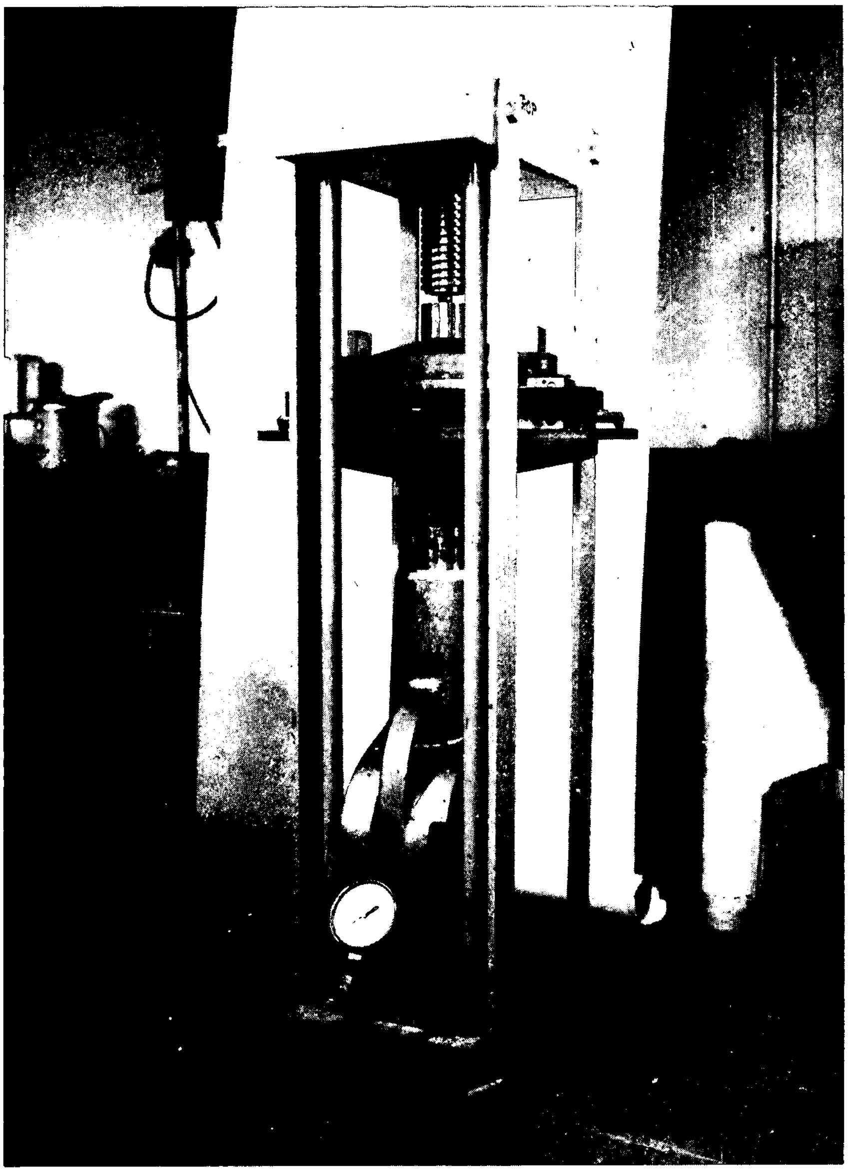

PLATE 2 Neg No B2487/68

Moulding apparatus for blocks and beams

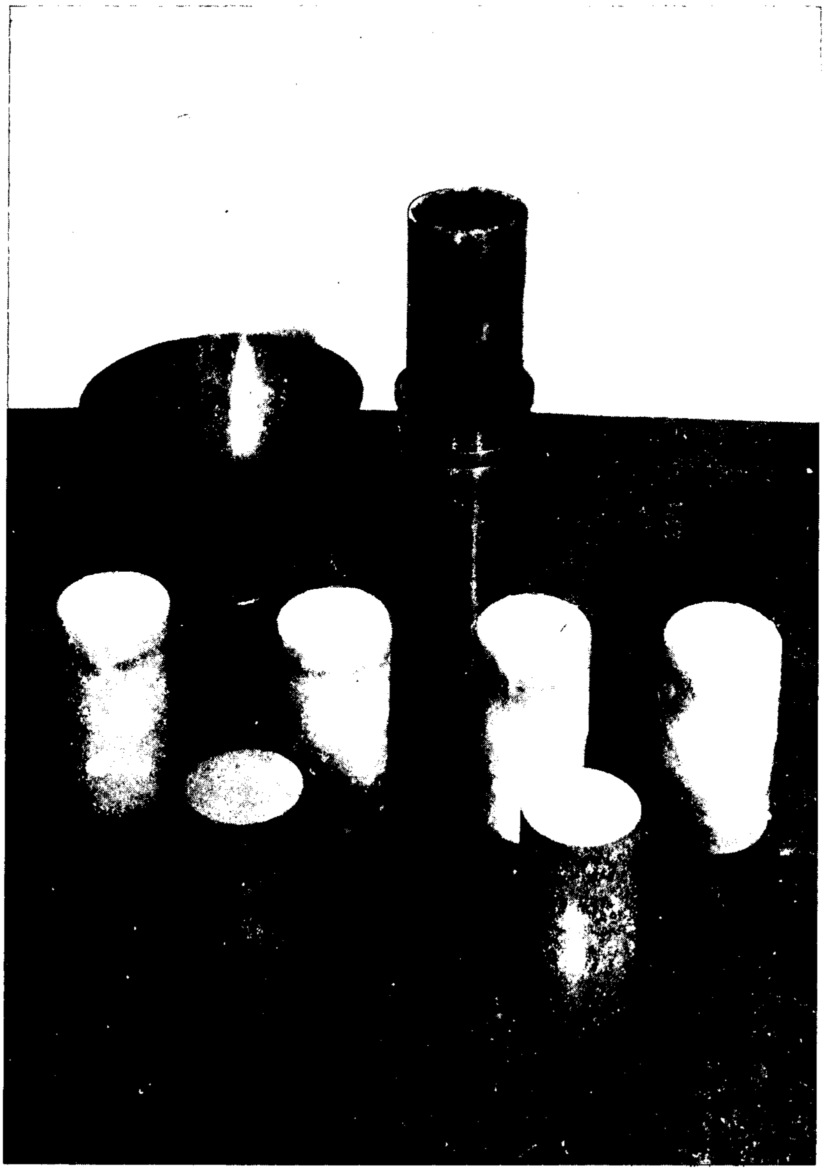

PLATE 3 Neg No B2436/68

Moulding apparatus for indirect-tensile-test cylinders

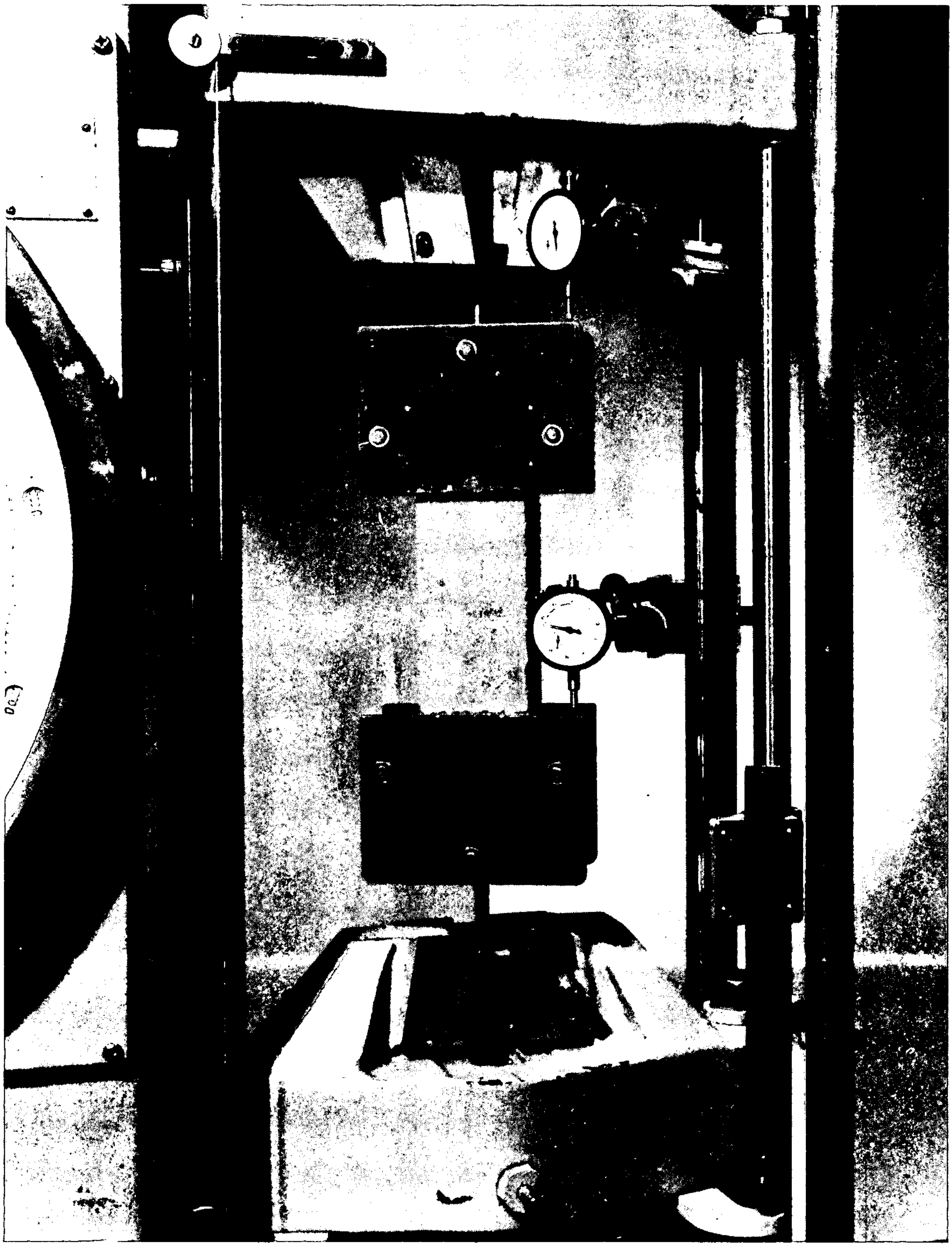

PLATE 4

Neg No B 2364/70

Tensile block in position in the testing machine

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ABSTRACT

The measurement of the tensile properties of soil-cement: H E BOFINGER: Ministry of Transport, RRL Report LR 365: Crowthorne, 1970 (Road Research Laboratory). As part of an investigation of the design of soil-cement pavements, laboratory tests were carried out using Harmondsworth brickearth to examine the tensile properties of soil-cement and their relation to its compressive properties. The Report discusses three methods used for determining the tensile strength, the direct and indirect tests and the flexural test, and suggests explanations for the differences in the results obtained.

Soil-cement was found to have a much higher elastic modulus when subjected to compressive stresses than when the same average tensile stresses were applied.

Because of the complex behaviour of soil-cement under stress, estimates of its tensile strength from the cylinder splitting or flexural tests are uncertain. The direct tensile test which is independent of the strain characteristics provides a more reliable indication of tensile strength of soil-cement at slow rates of strain.

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