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THE RAPID MEASUREMENT OF THE MOISTURE CONDITION OF EARTHWORK MATERIAL

by

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ABSTRACT

This Report describes the development of a test for the rapid measurement of the moisture condition of earthwork material. It is suggested that the method be considered for use in construction control to assess the suitability of materials in relation to the specified upper limits of moisture content, while avoiding the measurement of moisture content with its associated delays. It could also be used to provide a moisture condition parameter for correlation with the engineering behaviour of soil. The test method is based on the principles of compaction whereby the curves relating bulk density to moisture content tend to converge at moisture content values which depend on the compactive efforts used. The apparatus developed for the test is described and the results of calibrations of the apparatus on a range of soil types are given. The results indicate that a single criterion of control could be applied with the proposed test regardless of variations in soil type.

1. INTRODUCTION

This Report describes a test method developed for the assessment of the moisture condition of earthwork material. The results of tests carried out with the apparatus in the laboratory are included.

In road construction in the United Kingdom it is normal to specify in some way an upper limit for the moisture content of earthwork material. Such a limit is necessary to avoid unstable conditions in embankments, to avoid settlement which might subsequently occur as the moisture content returns to its equilibrium value, and to avoid problems in the operation of earthmoving plant. In the 1969 edition of the Ministry of Transport Specification for Road and Bridge Works[1] the list of unsuitable material includes "materials having a moisture content greater than the maximum permitted for such materials in the Contract, unless otherwise permitted by the Engineer" (Clause 601, Paragraph 1). In the Notes on the Fourth Edition of the Specification advice is given that, for cohesive soils, the upper limit of moisture content should be related to the plastic limit and a value of plastic limit multiplied by 1.2 is suggested as satisfactory. For well-graded granular soils and uniformly graded materials the upper limit of moisture content should be related to the optimum moisture content as determined in the British Standard laboratory compaction test (2.5 kg rammer method)[2], a value ½ to 1½ per cent above the optimum being recommended. However, it is recommended that these values should be regarded as a guide only.

An investigation of the variability of moisture content and plastic limit of cohesive soils in earthwork construction[3] has shown that very large variations in plastic limit and moisture content can occur over very small areas of earthwork construction. The determination of moisture content alone, therefore, would not be sufficient to achieve control of moisture content even in localised areas, except on sites where the soil type was very consistent. In the case of cohesive soils it was concluded that the determination of plastic limit would also have to be made. The investigation showed that, on average, about 12 samples would have to be taken and the moisture content and plastic limit of each sample determined in order to assess, with a reasonable accuracy, the moisture suitability of the soil.

Although no similar research has been carried out with granular soils, the same degree of variability is expected to occur. The adequate control of the moisture content of earthwork material is, therefore, a laborious process, involving either many plastic limit determinations or many laboratory compaction tests, and including delays, possibly up to 24 hours, while awaiting the determination of the moisture contents associated with the tests. Furthermore, recent research[4] has shown that both the plastic limit tests and the laboratory compaction tests are prone to serious errors, as exhibited by large variations in test results carried out on consistent soils by various testing laboratories. In the light of these problems, it is understood that very frequently control of moisture content of earthwork material is considered to be impracticable.

There is clearly a need, therefore, for a simple test procedure for such control which is rapid and gives an immediate result. In addition, the elimination of the human factor as far as possible, and the ability to test a wide range of materials, are essential.

The development of an apparatus which could satisfy these requirements, while also providing a moisture condition parameter for correlation with the engineering behaviour of soil, is described in this Report.

2. PRINCIPLE OF THE TEST METHOD

The test method is based upon the fundamental principles of compaction where the bulk density produced in a given soil depends solely on the moisture content and the compactive effort used. Figure 1 shows idealised relations between bulk density and moisture content of a soil. For each compactive effort the bulk density initially increases with increase in moisture content until the zero-air-void line is approached, after which it decreases with further increase in moisture content. An increase in compactive effort produces a relation between bulk density and moisture content which is displaced upwards and to the left of the original curve. There is a tendency for the curves to converge at moisture contents in excess of the optimum of the lower compactive effort. If, therefore, compactive efforts are selected (see Fig. 1) such that the bulk density/moisture content relations converge, for a given soil, at the specified upper limit of moisture content for that soil, then a comparison of the bulk densities produced by the respective compactive efforts will indicate whether the particular moisture content of the sample is above or below the specified upper limit. Figure 1 shows how a change in the specified upper limit of moisture content from A to B would simply involve a change from initial compactive effort A to initial compactive effort B. If the final compactive effort is the sum of the initial compactive effort and some further effort, e.g. additional blows of a rammer on a specimen already compacted by the initial effort, then comparison of the volumes of the specimen before and after the additional compaction will indicate whether there is a difference in the densities produced by the two compactive efforts.

Minor changes in soil type, such as variations in plasticity or gravel content of a soil, would result in associated variations in the moisture content at which the curves converge. Thus the same effect is obtained as under existing control procedures where such changes in soil type might result in changes in the plastic limit (or in the optimum moisture content obtained in the B.S. laboratory compaction test (2.5 kg rammer method)) while the control criterion, eg 1.2 x plastic limit, remains the same. It might be expected, therefore, that one level for the initial compactive effort will apply in the control of moisture content throughout the range of variations in soil type encountered in any one area of earthwork operations.

The objectives of the research were to develop an apparatus complying with the above principles, incorporating the maximum possible control of compactive effort and a simple and accurate means of measuring the volume or change of volume of a compacted specimen.

3. PRELIMINARY TESTS

3.1 Apparatus

To comply with the need for maximum possible control of compactive effort it was considered that a form of impact compaction, involving a dropping rammer of fixed dimensions and mass, should be used. To achieve easy measurement of volume of the compacted specimen this rammer should have a flat face and cover, as far as possible, the complete area of the material being compacted.

An apparatus which satisfied these requirements with very little modification was the machine used in the determination of aggregate impact value[5]. The modifications necessary to this apparatus for the preliminary tests were the incorporation of moulds of varying heights and of a long threaded rod to allow for adjustment of the height of drop of the rammer over a large range. In addition, a non-standard rammer with a mass of 6.8 kg was used. The apparatus in this form is shown in Plate 1 and details are given in Table 1.

TABLE 1

Details of the modified aggregate impact test apparatus used in the preliminary tests

Mass of rammer	6.8 kg
Diameter of rammer	100 mm
Height of drop of rammer	Adjustable from about 50 to 350 mm
Diameter of mould	102 mm
Height of mould	50 or 115 mm (plus 50 mm removable extension)

3.2 Feasibility of test method

To explore the feasibility of a test of the type proposed in 2, tests were carried out on a number of soils using the apparatus described in 3.1. The particle-size distributions and results of plasticity and specific gravity tests for these soils are given in Fig 2 and the results of laboratory compaction tests are in Table 2.

TABLE 2

Results of laboratory compaction tests (2.5 kg rammer method)[2] with the soils used in laboratory trials of a moisture-condition test

Soil	Maximum dry density (Mg/m^3)	Optimum moisture content (per cent)
Heavy clay	1.62	23
Sandy clay	1.86	15
Uniformly graded fine sand	1.71	15
Well-graded sand	2.11	9.0
Gravel-sand-clay	2.10	8.0

A known mass of soil at the required moisture content was placed loosely in the mould, the height control adjusted to give the required height of drop of the rammer, and the specimen compacted by successive blows of the rammer. At stages during the compaction process the height of the compacted specimen and the mass of the mould and soil were measured and the bulk density calculated, and the height of drop readjusted to allow for the deformation of the specimen. This procedure was repeated at various moisture contents and some typical results are given in Fig 3.

In all the preliminary tests, relations between bulk density and moisture content of a given soil converged on a common line as moisture content was increased. The values of moisture content at which the relations converged depended predominantly on the number of blows of the rammer. Where 1000 g samples of well-graded sand were compacted (Fig 3), the moisture content at which the curves converged varied from about 10 to 15 per cent, values of 1 to 6 above the optimum moisture content of the BS laboratory compaction test (2.5 kg rammer method) (Table 2). The moisture content range for 1500 g samples of heavy clay (Fig 3) was about 22 per cent to in excess of 45 per cent; values roughly equivalent to 0.8 to 1.6 x plastic limit (Fig 2).

It was concluded that the feasibility of using a test of this general form to determine the moisture condition of a soil was confirmed. The range of moisture contents over which control would be achieved might be expected to be adjusted by variation of sample size and of the height of drop of the rammer.

3.3 Size of sample and height of drop of rammer

The results in Fig 3 indicate that with cohesive materials such as the heavy clay the range of moisture contents at which the bulk density/moisture content curves converge is large, and easily contains the likely upper limits of moisture content applied to earthwork construction in practice. With more granular material, however, such as well-graded sand (Fig 3) the range of moisture contents was smaller and the need to apply upper limits of moisture contents outside the range achieved by using a single size of sample and a single height of drop could arise.

Tests were carried out, therefore, with samples of well-graded sand and uniformly graded fine sand where the mass of the specimen was either 500, 1000 or 1500 g and heights of drop of the rammer were varied from

30 to 230 mm. Not all combinations of mass and height of drop were used and sometimes only a limited range of moisture contents was explored, but curves of a similar form to those shown in Fig 3 were established for each combination used. Multiple regression analyses were made of the data to determine the potential range of moisture contents over which control could be achieved. The results are shown in Fig 4.

The results in Fig 4 indicate that by varying the number of blows of the rammer and its height of drop together with the mass of the sample the potential ranges of moisture contents over which convergence of the bulk density/moisture content curves occurred were approximately doubled with well-graded sand and trebled with the uniformly graded fine sand when compared with those achieved by the sole variation of the number of blows. With both soils the variation of the mass had a greater effect than variation of height of drop within the ranges used. Thus the range of control can be extended, if necessary, with non-plastic materials, by variations in the mass of the sample and/or the height of drop of the rammer.

It was decided that further test work with a prototype apparatus should be on the basis of the largest practicable size of sample, ie 1500 g. It was also decided that a 250 mm height of drop should be used, with the rammer of approximately the same mass (7 kg) as that of the modified aggregate impact test machine. Facilities were to be incorporated for reducing the mass of the sample and for reducing the height of drop of the rammer to allow the range of moisture contents under control to be varied if necessary.

4. PROTOTYPE APPARATUS

4.1 Description

The apparatus is illustrated in Plate 2 and Fig 5, and main details are given in Table 3.

TABLE 3

Main details of the prototype moisture condition apparatus

Mass of rammer	7 kg
Diameter of rammer	97 mm
Height of drop of rammer	Adjustable, but normally 250 mm
Internal diameter of mould	100 mm
Internal height of mould	About 200 mm
Total mass of apparatus, with mould empty	50 kg
Mass of base of apparatus	31 kg
Mass of soil sample used	Normally 1.5 kg

The heavy base of the apparatus is recessed to locate the base of a cylindrical mould. The mould, with its easily detachable base, is held down by simple spring clips. A free falling rammer is located by two guide rods so that it falls accurately into the barrel of the mould.

The rammer is lifted by means of handles attached to a cross-member which slides on the guide rods and incorporates an automatic catch which engages with the top of the rammer structure. When the rammer is lifted to the top of its intended travel, a striker attached to a further cross-member releases the automatic catch and allows the rammer to fall. This striker support cross-member may be raised or lowered and is located by a pair of spring catches engaging in racks on the guide rods.

One half of a vernier scale is attached to one of the lower guides of the rammer and the other half to a rod connected to the striker support cross-member. The length of this rod may be adjusted, but is usually such that the height of drop of the rammer is 250 mm when the vernier is zeroed, by raising or lowering the striker support cross-member, with the rammer resting on the soil in the mould.

The rammer also has a scale attached which can be used to measure the penetration of the rammer into the mould.

The rammer release mechanism has a trip counter to indicate the number of times that the rammer has been released.

A retaining pin is provided to lock the rammer and sliding cross-member to the striker support cross-member (see Plate 2) for easy removal of the mould.

4.2 Special features

4.2.1 Permeability of base of mould. To avoid the entrapment of air within the lower part of the compacted specimen it was found necessary to create a loose fitting base to the mould with gaps through which air could escape. This feature is necessary, in particular with wet clays, to achieve compaction to low air contents. This aspect did not arise in the preliminary tests as the moulds used had comparatively loose fitting bases. The mould of the prototype apparatus, with details of the permeable base, is shown in Fig. 6.

4.2.2 Soil retaining disc. With wet clays a further problem to be overcome was the extrusion of soil between the rammer and the sides of the mould and the adherence of soil to the bottom of the rammer. These effects could cause variations in the compactive effort exerted by the rammer and an inaccurate measurement of the depth of the compacted specimen. To avoid these difficulties a light-weight disc of laminated phenolic sheet, 99 mm in diameter and 5 mm thick, was used. This was placed on top of the sample of soil in the mould. The minimal clearance between the disc and the sides of the mould completely eliminated the extrusion of wet materials and the rammer did not contact the surface of the soil. The use of the light-weight disc was adopted as part of the routine procedure.

4.2.3 Heavy base of apparatus. The base of the prototype apparatus (Fig 5) was required to be sufficiently heavy to eliminate, as far as possible, the effects of its use under varying conditions. Thus, whether the apparatus is used on soft soil on site or on a concrete floor in the laboratory the results should not be significantly different. However, the mass of the base is limited by the need for overall portability and the eventual mass was fixed at about 31 kg, producing an overall mass for the apparatus, including rammer and empty mould, of about 50 kg.

5. CALIBRATION OF THE MOISTURE CONDITION APPARATUS

5.1 Procedure

To avoid determining bulk density and plotting relations between bulk density and moisture content, as in the preliminary tests (Fig 3), the penetration of the rammer into the mould was measured, using the scale attached to the rammer, at stages during the compaction of each 1.5 kg specimen of soil. For practical purposes the number of blows of the rammer beyond which no further increase in bulk density occurred was considered to be that at which the additional penetration of the rammer, with further blows equal to three times those already applied, was only 5 mm. A table of typical results and the resultant relation between change in penetration and the initial number of blows of the rammer (the latter on a logarithmic scale) are shown in Fig. 7.

Calibrations were made on the five soils that were used in the preliminary tests (see 3.2 and Fig 2). For each soil a sample was prepared at the required moisture content and passed through a 20 mm sieve to break down the larger aggregations of particles. A 1.5 kg portion of the prepared soil was placed loosely in the mould, the soil-retaining disc placed on top of the soil, and the rammer lowered gently to contact the disc. The position of the striker support cross-member was then adjusted to give an approximate zero reading on the vernier scale, thus setting the height of drop of the rammer to 250 mm. One blow of the rammer was given, the penetration scale read, and the vernier re-zeroed to correct the height of drop for the decrease in height of the soil sample. This process was repeated, with readings of penetration after selected numbers of blows (Fig 7), and adjustments to the striker support cross-member as necessary, until no further significant increase in penetration occurred. The change in penetration between any given number of blows and a further three times as many was calculated as shown in Column 3 of the Table in Fig 7. This change in penetration was plotted against the initial number of blows to produce a relation such as shown in Fig 7, and the precise initial number of blows equivalent to a change in penetration of 5 mm was determined.

The above procedure was repeated at a number of different moisture contents and the relation established between moisture content and the initial number of blows beyond which there was only a 5 mm change in penetration. The results for the five test soils are given in Figs 8 to 12.

5.2 Discussion of results

Within the range of moisture contents used, the relations between the change in penetration and the initial number of blows (Figs 7 to 12) all cross the 5 mm level with initial numbers of blows ranging from about 2 to 40. In some instances, especially with the uniformly graded fine sand (Fig 10) the changes in penetration measured were all less than 10 mm, producing relations with fairly flat slopes so that the precise points at which the curves cross the 5 mm level are less easily determined than with the other soils. If, with certain soils, this problem becomes too difficult, the solution would be to increase the number of blows over which the change in penetration is measured. Thus, instead of a further 3n blows, where n is the initial number of blows, 4n, 5n, 6n or 7n could be applied. The initial number of blows to produce 5 mm change in penetration at a given moisture content would not change significantly, due to the convergence of the bulk density/moisture content relations (Figs 1 and 3).

For all soils (Figs 8 to 12) the resultant relations between moisture content and the initial number of blows (log scale) can be drawn as straight lines within the range of moisture contents shown. Only with the gravel-sand-clay (Fig 12) is it possible that a curve, concave downwards, would better represent the trend of the points.

The ranges of moisture contents include, in all cases, the moisture contents at which the soils are likely to be used for earthwork construction. However, should it be necessary to vary the range, i.e. raise or lower the line relating moisture content to initial number of blows, then the mass of the sample can be decreased (to lower the line) or the height of drop decreased (to raise the line) (see 3.3).

In current earthwork practice in road construction the upper limits of moisture content are often defined as 1.2 x plastic limit for plastic soils and about 1½ per cent + the optimum moisture content (per cent) as determined in the BS laboratory compaction test (2.5 kg rammer method) for non-plastic soils. The initial number of blows in the moisture condition apparatus equivalent to these upper limits for the five test soils are given in Table 4. The equivalent number of blows varies from 4 to 7, although the range is affected by the use of 1.2 x plastic limit with two clay soils of widely varying plasticity characteristics (Fig 2).

It can be advocated that liquidity index* is a better parameter for suitability of clay soils, especially as it can be related to undrained shear strength[6]; however its use is avoided in practice because of the added complexity of control testing. A liquidity index of 0.15 would be equivalent, on average, to the currently adopted standards. Relations between liquidity index and initial number of blows for 5 mm change in penetration (log scale) for the two clay soils are given in Fig 13. These relations are very similar for both the heavy clay and sandy clay and a limit of suitability defined in terms of the initial number of blows in the moisture condition apparatus could, therefore, equally apply over a range of clay soils of widely varying plasticity characteristics. On inspection of Table 4 and Fig 13 it appears that the upper limits of suitability currently being applied in earthwork construction for roads is equivalent to about 6 initial blows in the moisture condition apparatus.

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*Liquidity index = $\dfrac{\text{Moisture content} - \text{Plastic limit}}{\text{Plasticity index}}$

TABLE 4

Calibration of moisture condition apparatus with regard to upper limits of moisture content often used in practice

Soil	Upper limit for suitability often used in practice		Initial number of blows from calibration (Figs 8 to 12)
	Parameter	Moisture content (per cent)	
Heavy clay	1.2 x plastic limit (Fig 2)	32.5	7
Sandy clay		24	4
Uniformly graded fine sand	1½ + optimum moisture content of BS laboratory compaction test (2.5 kg rammer method) (Table 2)	16.5	5
Well-graded sand		10.5	6
Gravel-sand-clay		9.5	6

With granular soils, e.g. gravel-sand-clay (Fig 12), small changes in penetration can occur at very low moisture contents even though the specimen has not reached the state of compaction at which the bulk density/moisture content relations converge. Thus an apparent low initial number of blows beyond which only 5 mm penetration occurs could be registered at a low moisture content (see extension of calibration line in Fig 12). A further test with an increased moisture content will result, if this is the case, in an increase in the initial number of blows registered, so indicating that the effective part of the calibration line has not been reached.

6. RECOMMENDED TEST PROCEDURES

The results obtained in the calibration of the moisture condition apparatus (Figs 8–13) indicate that the method can be used, after suitable calibration, as an indirect rapid means of measuring moisture content and of controlling the moisture suitability of earthwork materials. Additionally, used in a standardized way, i.e. with a constant mass of soil and a constant height of drop of the rammer, the moisture condition of the material, expressed as a function of the initial number of blows applied, could be related to the engineering behaviour of the soil in the same way that the ratio of moisture content to plastic limit is used at present.

There would, therefore, be three possible modes of operation of the apparatus:—

(i) At the earthwork design stage, the calibration of the apparatus with the soils to be encountered to set the parameters equivalent to the designed upper limit of moisture content.

(ii) At the construction stage, the use of the apparatus to determine the suitability or unsuitability of earthwork material in relation to the upper limits of moisture content.

(iii) At site investigation and construction stages, the determination of the moisture condition of the soil to relate to the engineering behaviour, e.g. to determine the ability of heavy earthmoving plant to operate efficiently or to determine the effort required to achieve a high state of compaction in the soil.

The procedures for use of the apparatus for each of these three purposes are described in the following sections.

6.1 Calibration

The procedure for calibration has already been described in detail in 5.1. In view of the straight line relation that usually exists between moisture content and the logarithm of the initial number of blows over the moisture content range normally encountered, a total of four different moisture contents, using material passing a 20 mm sieve, should be sufficient to establish a calibration, provided that the intended upper limit of moisture content is included in the range.

The initial number of blows of the rammer which relates to the intended upper limit of moisture content to be specified (as determined by normal engineering criteria) can be read from the calibration line. The results described in 5.2 indicate that, provided the same engineering criteria are applied, the same number of blows might be expected with a number of soil samples, even with appreciable variations in soil type.

If, for the reasons given in 5.2, any of the calibration parameters are changed, e.g. the mass of the sample, care must be taken to ensure that all uses of the apparatus in conjunction with such a calibration incorporate the same changes. It would clearly be preferable to use the normal parameters, 1.5 kg of soil with 250 mm height of drop, whenever possible to avoid potential errors.

6.2 Control tests

These tests would normally be carried out on the construction site or in the site laboratory, with a knowledge of the designer's calibration and the initial number of blows which are equivalent to the specified upper limit of moisture content.

A sample of the soil in question is taken and passed through a 20 mm sieve to break down the larger aggregations of particles and remove large particles. A 1.5 kg portion of the sieved soil is placed loosely in the mould, the soil retaining disc placed on top of the soil, and the rammer lowered gently to contact the disc. The position of the striker support cross-member should then be adjusted to give an approximate zero reading on the vernier scale, thus setting the height of drop to 250 mm. One blow of the rammer is then given and the vernier re-zeroed to correct the height of drop for the decrease in height of the soil sample. Further blows should be applied, resetting the height of drop as necessary (a 10 mm error in height of drop is acceptable) until the total reaches the initial number of blows equivalent to the upper limit of moisture content.

The striker support cross-member should then be adjusted to give an approximate zero reading on the vernier scale and the reading should be accurately noted. Further blows of the rammer are then applied, equal to three times the initial number, without any further adjustment to the striker support cross-member. After completion the vernier scale is read again and the difference between the original and final readings calculated. If the difference is more than 5 mm the soil is below the upper limit of moisture content, if less than 5 mm it is above this limit.

This simple procedure assesses the suitability of each soil sample without determining the degree to which it may be suitable or unsuitable. If this further information is required, then a procedure similar to that given in 6.3 should be used, and the degree of suitability or unsuitability determined by reference to the original calibration line.

6.3 Determination of moisture condition

This procedure would be similar to that for the determination of a single point on the calibration line (see 6.1), but should be carried out with the soil in its natural condition, i.e. at its existing moisture content. A curve of the type given in Fig 7 should be plotted and the initial number of blows equivalent to a further penetration of only 5 mm determined.

This initial number of blows could be quoted as the moisture condition but, in view of the straight line relation between moisture content and the logarithm of the initial number of blows, the moisture condition could be converted to a linear scale of convenient proportions by quoting it in the form $10 \log_{10}$ (initial blows). This would give a linear scale of 0 to 20 for a range of initial numbers of blows from 1 to 100. This proposed scale is shown at the top of Fig 13. Thus 12 would indicate a very dry condition, 3 a very wet and weak condition. If the initial number of blows equivalent to the upper limit of moisture content often used in practice is 6 (see 5.2), the equivalent moisture condition would be $10 \log_{10} 6 = 7.8$ to two significant figures.

For the moisture condition so determined to be meaningful it is essential that the mass of the sample and the height of drop be standardized, i.e. 1500 g and 250 mm respectively.

Care must be taken to ensure that the moisture condition so quoted is not associated with the ineffective part of the relation between moisture content and initial number of blows (see 5.2 and Fig 12). This is most likely to occur with granular soils. If it is suspected that the material is more dry than the average condition and the initial number of blows too low for such a dry condition, the moisture content of the sample should be increased and a further test carried out as in 5.2. If the sample is found by this means to be outside the effective calibration range the moisture condition should be noted as 16 + (or in excess of 40 blows).

7. CONCLUSIONS

A test method for assessing the moisture condition of earthwork material has been proposed and experimental work with a prototype apparatus has shown the method to be feasible. It can be used over a wide range of soil types, from heavy clay to gravel-sand-clay mixtures, and can rapidly measure the moisture condition of a soil sample, the time for a single test being only 5 to 10 minutes.

Using appropriate calibrations, which may be made at the earthwork design stage, the apparatus could provide a rapid method of controlling the moisture suitability of earthwork materials at the construction stage, avoiding the conventional measurement of moisture content with its associated delays. Variations of soil type normally encountered in earthwork construction would not affect the criterion used for judging suitability.

The apparatus effectively measures the moisture condition of the soil and a convenient scale has been proposed. Further research and site experience will be required to relate engineering behaviour of various soils to the moisture condition so measured. For example, studies are in progress to determine the relations between the productivity of various types of earthmoving plant and the moisture condition.

8. ACKNOWLEDGEMENTS

The work described in this Report was carried out in the Earthworks and Underground Pipes Division (Division Head: Mr J B Boden) of the Structures Department of TRRL. The author was assisted in the experimental work by Mr A F Toombs. The prototype apparatus was designed in the Experimental Equipment Engineering Section of the Technical Services Unit.

9. REFERENCES

1. MINISTRY OF TRANSPORT. Specification for road and bridge works. London, 1969 (HM Stationery Office).

2. BRITISH STANDARDS INSTITUTION. Methods of test for soils for civil engineering purposes. *British Standard* BS 1377:1975. London, 1975 (The Institution).

3. ANON. Control of moisture content of plastic soil. *Department of the Environment, Road Research Laboratory Leaflet* LF 26 Issue 2. Crowthorne, 1971 (Road Research Laboratory).

4. SHERWOOD, P T. The reproducibility of the results of soil classification and compaction tests. *Ministry of Transport, RRL Report* LR 339. Crowthorne, 1971 (Road Research Laboratory).

5. BRITISH STANDARDS INSTITUTION. Methods for sampling and testing of mineral aggregates, sands and fillers. Part 3 Mechanical properties. *British Standard* BS 812: Part 3: 1975. London, 1975 (The Institution).

6. SKEMPTON, A W and R D NORTHEY. The sensitivity of clays. *Geotechnique*, 1952, *III* (1), 30–53.

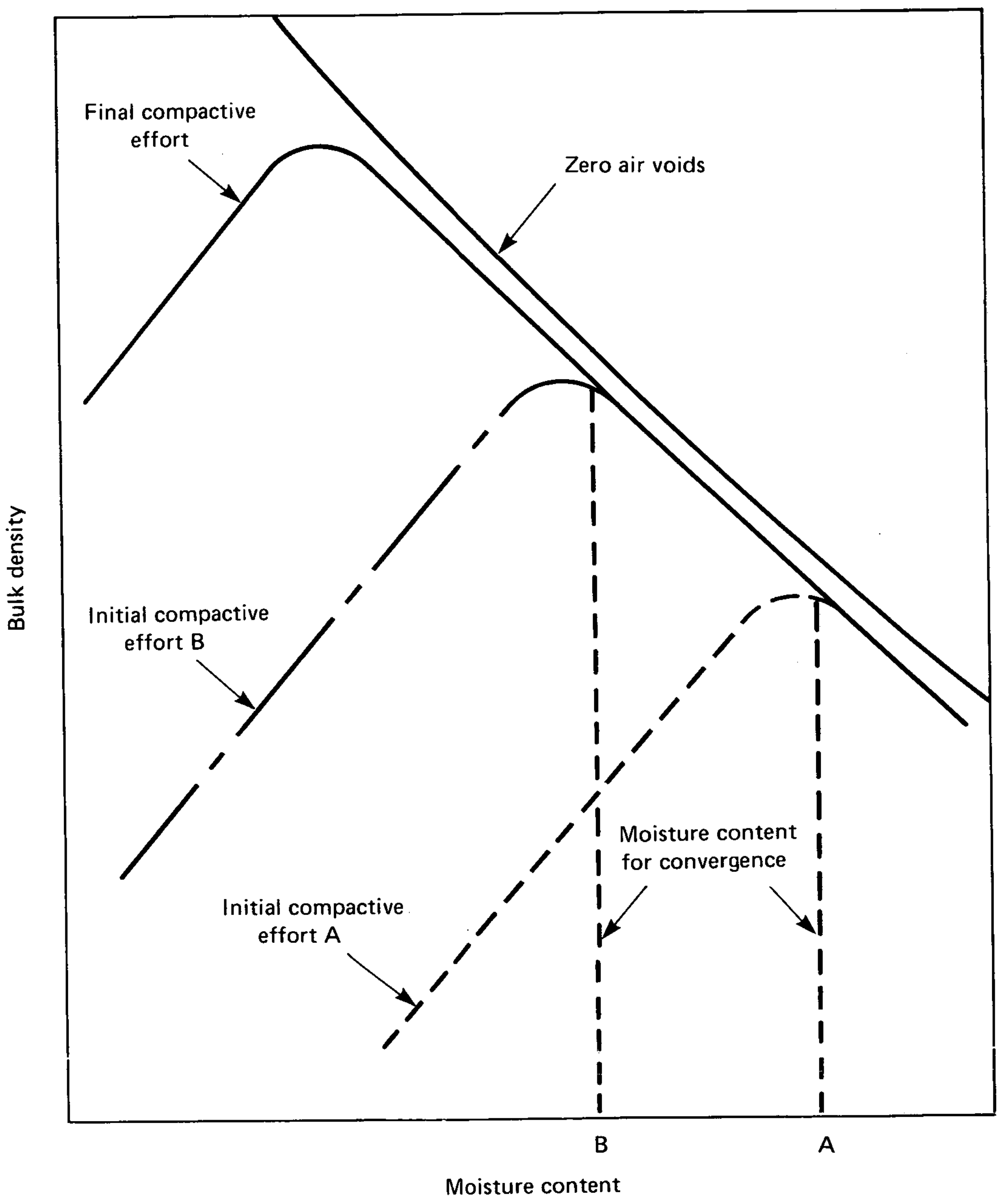
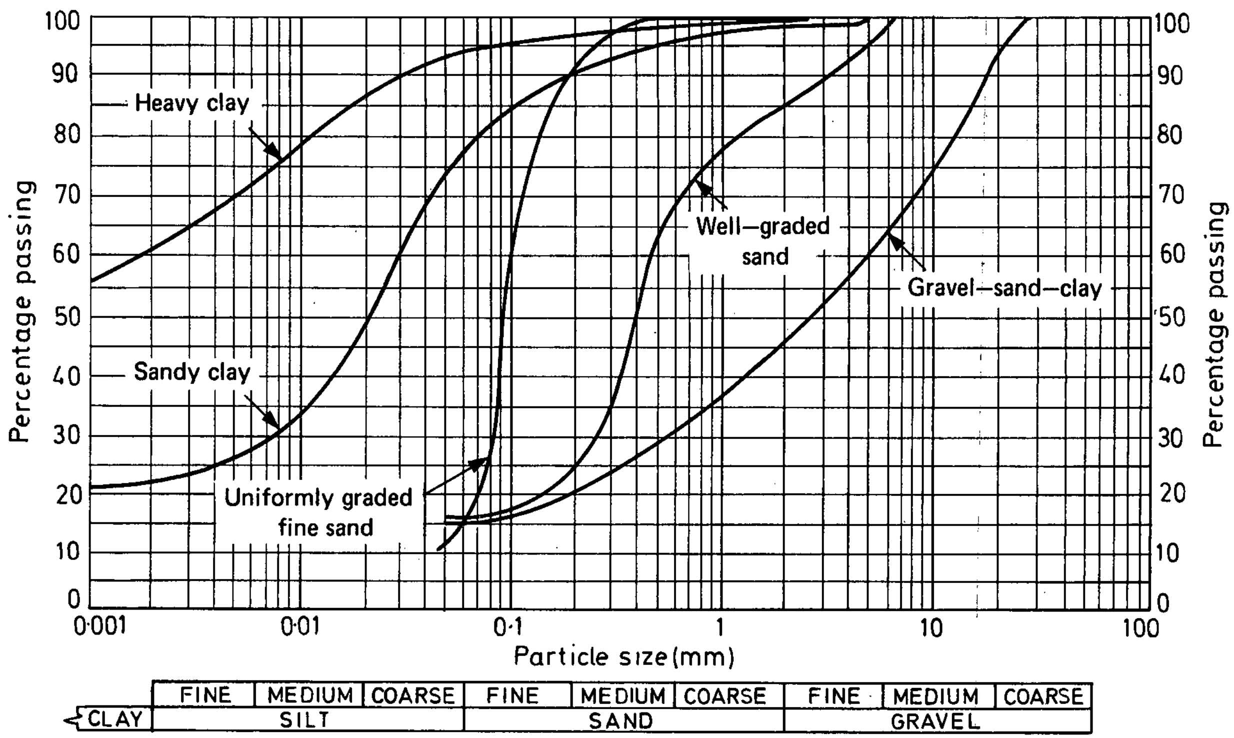


Fig.1 IDEALISED RELATIONS BETWEEN BULK DENSITY AND MOISTURE CONTENT OF A SOIL PRODUCED BY VARIOUS COMPACTIVE EFFORTS



Soil	Liquid limit	Plastic limit	Plasticity index	Specific gravity
	(per cent)			
Heavy clay	76	27	49	2.75
Sandy clay	40	20	20	2.72
Uniformly graded sand	Non-plastic			2.67
Well-graded sand	Non-plastic			2.69
Gravel-sand-clay	Non-plastic			2.64

Fig.2 PARTICLE-SIZE DISTRIBUTIONS AND RESULTS OF PLASTICITY AND SPECIFIC–GRAVITY TESTS FOR THE SOILS USED IN LABORATORY TRIALS OF THE MOISTURE CONDITION TEST

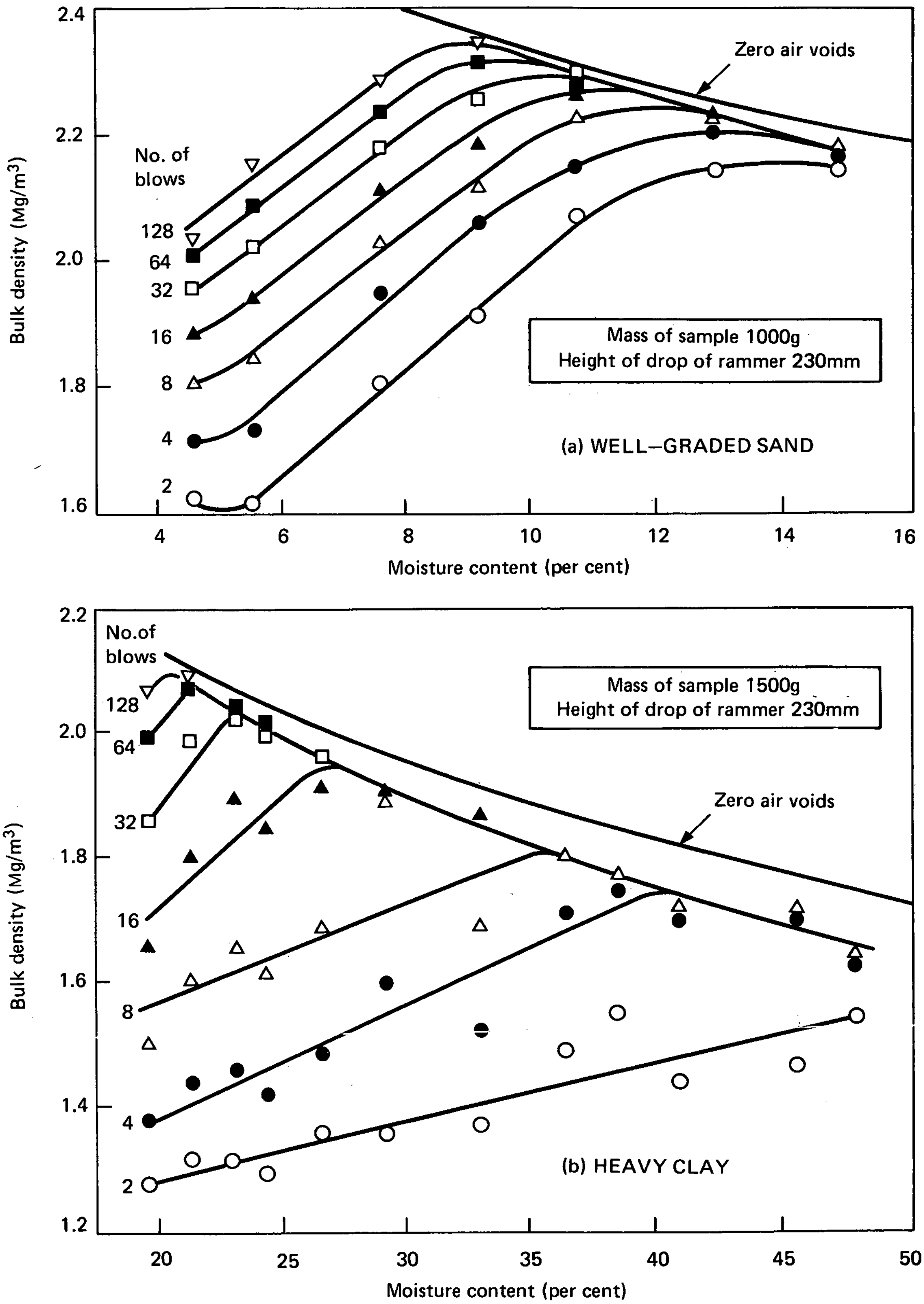


Fig. 3 TYPICAL RELATIONS BETWEEN BULK DENSITY AND MOISTURE CONTENT OBTAINED IN PRELIMINARY TESTS WITH THE MODIFIED AGGREGATE IMPACT TEST MACHINE

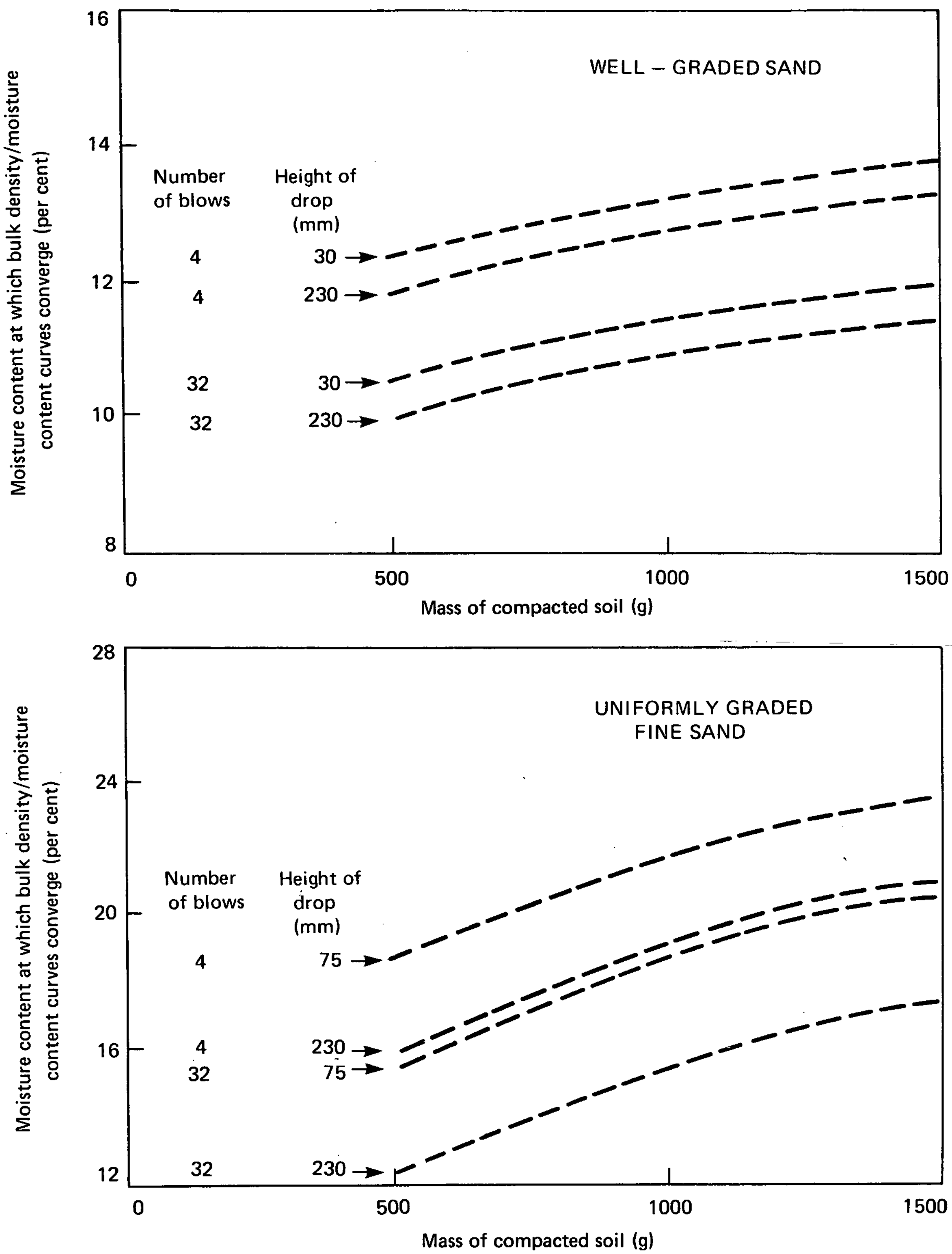


Fig. 4 EFFECTS OF VARIATIONS IN MASS OF COMPACTED SOIL ON MOISTURE CONTENT FOR THE CONVERGENCE OF BULK DENSITY/MOISTURE CONTENT CURVES (PRELIMINARY TESTS WITH MODIFIED AGGREGATE IMPACT TEST MACHINE)

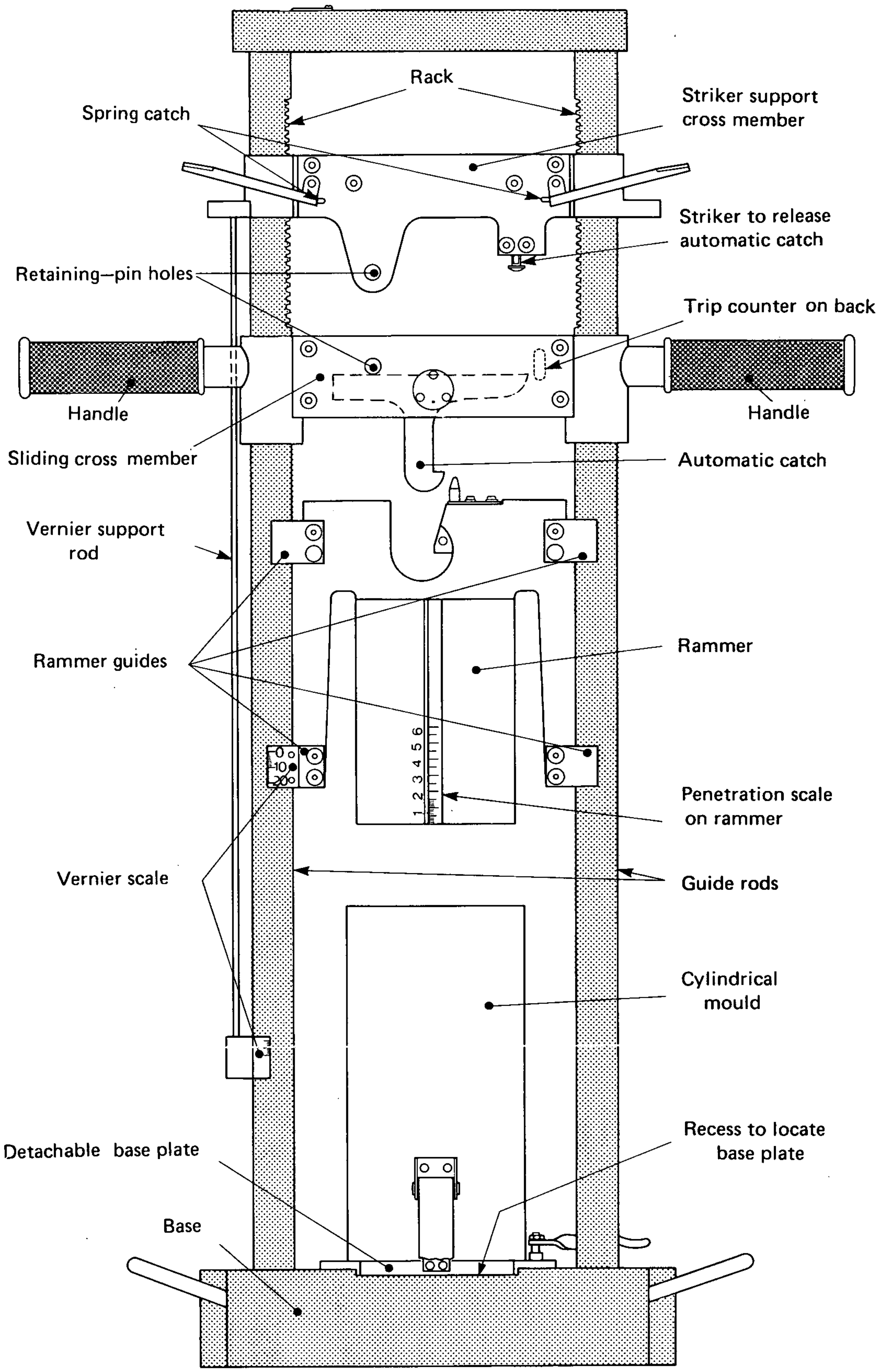


Fig. 5 THE PROTOTYPE MOISTURE CONDITION APPARATUS

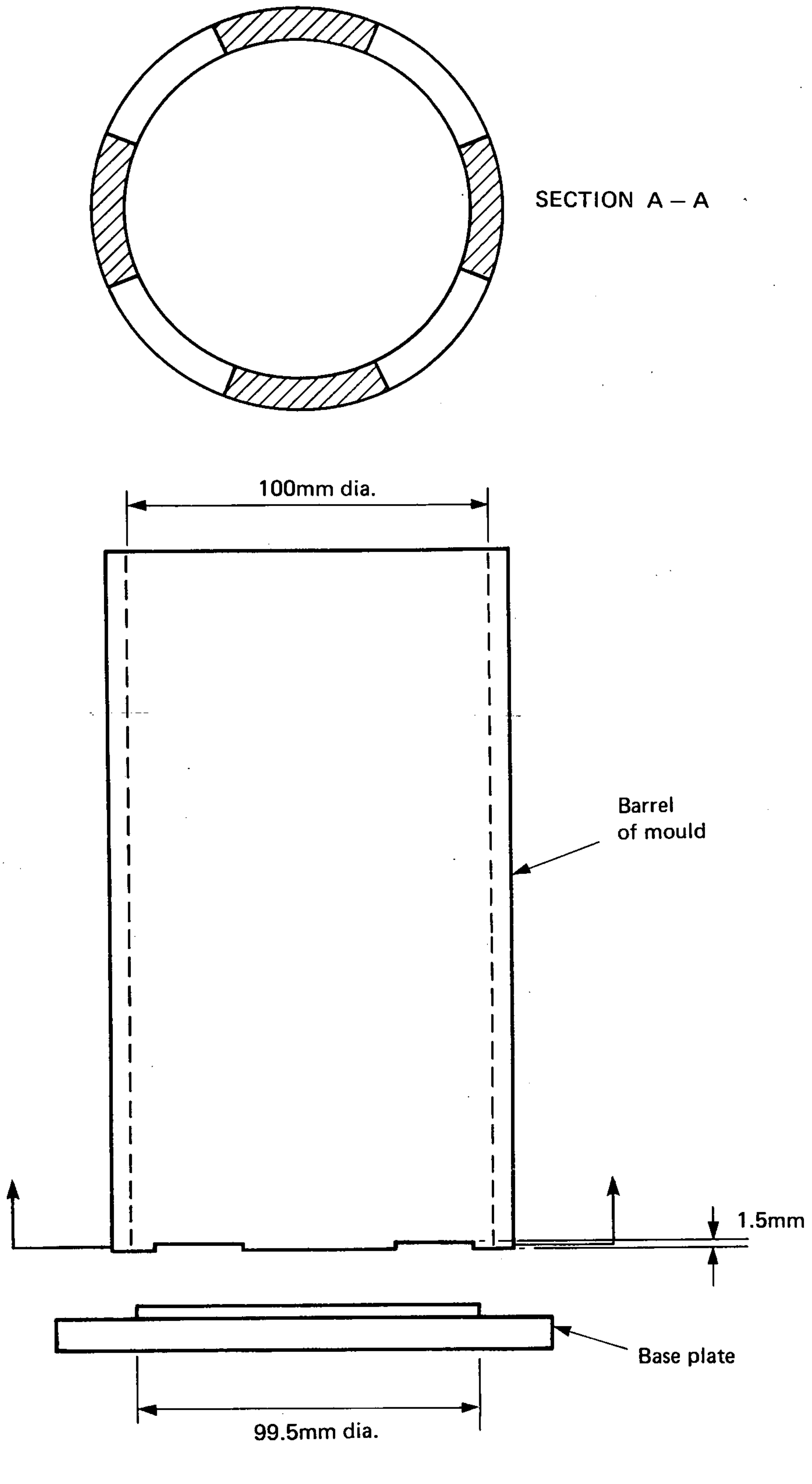


Fig. 6 MOULD FOR MOISTURE CONDITION APPARATUS–DESIGN NECESSARY TO ACHIEVE ADEQUATE PERMEABILITY AT BASE

Soil:- Heavy clay

Moisture content:- 26.3 per cent

Number of blows of rammer (n)	Penetration of rammer into mould (mm)	Change in penetration with additional 3n blows of rammer (mm)
1	41	33.5
2	57.5	33
3	67	33.5
4	74.5	26.5
6	84	17
8	90.5	10.5
12	100.5	0.5
16	101	
24	101	
32	101	
48	101	

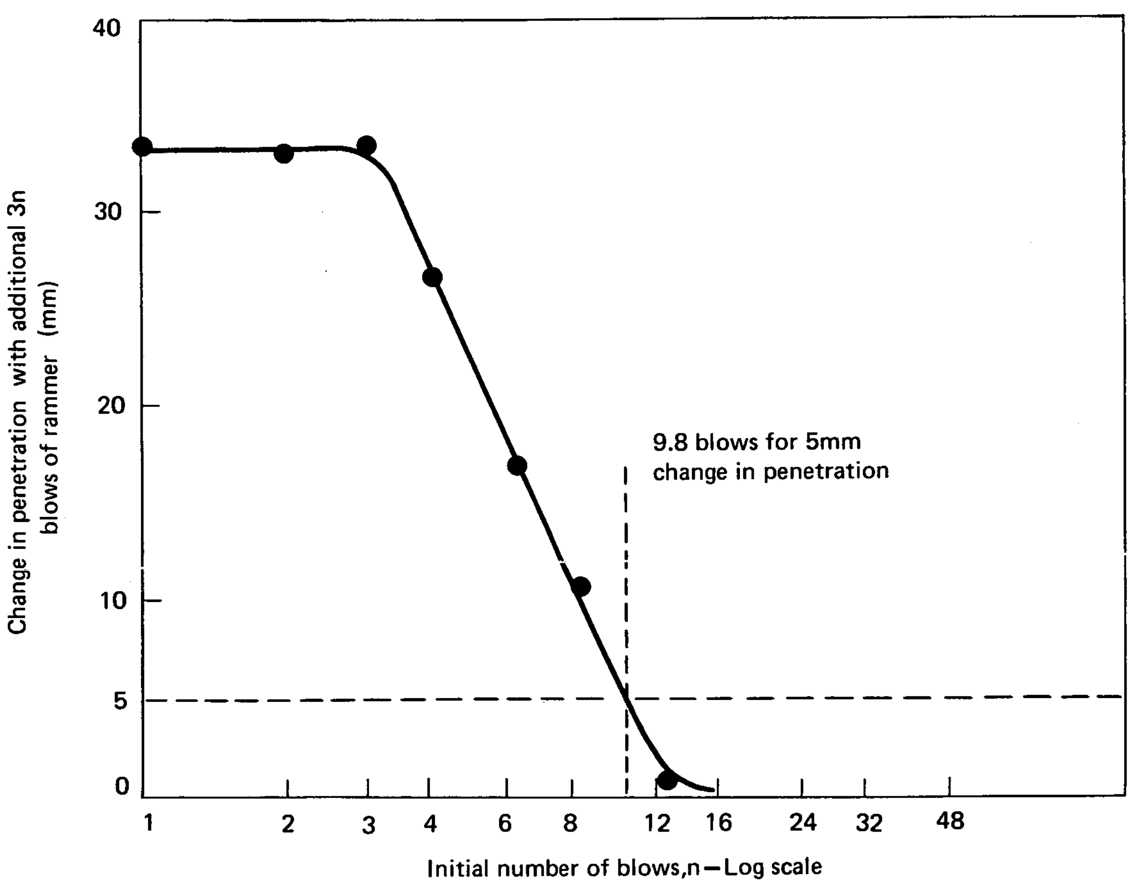


Fig. 7 TYPICAL RESULT IN THE CALIBRATION OF THE MOISTURE CONDITION APPARATUS WITH THE HEAVY CLAY SOIL. THE MEASUREMENT OF SOIL CONDITION WOULD BE SIMILAR EXCEPT THAT THE MOISTURE CONTENT WOULD BE UNKNOWN

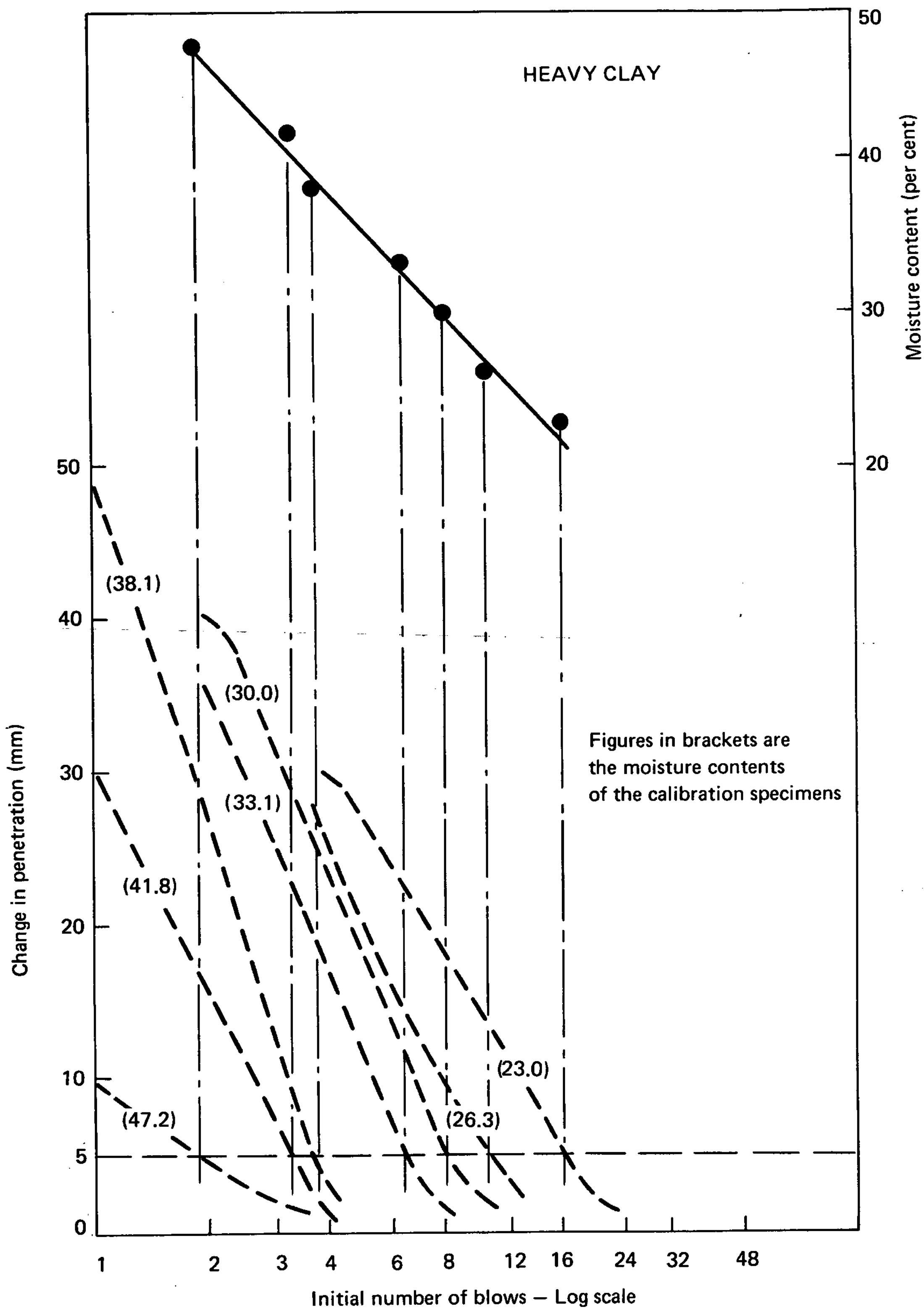


Fig. 8 CALIBRATION CHART OBTAINED WHEN USING THE PROTOTYPE MOISTURE CONDITION APPARATUS WITH HEAVY CLAY

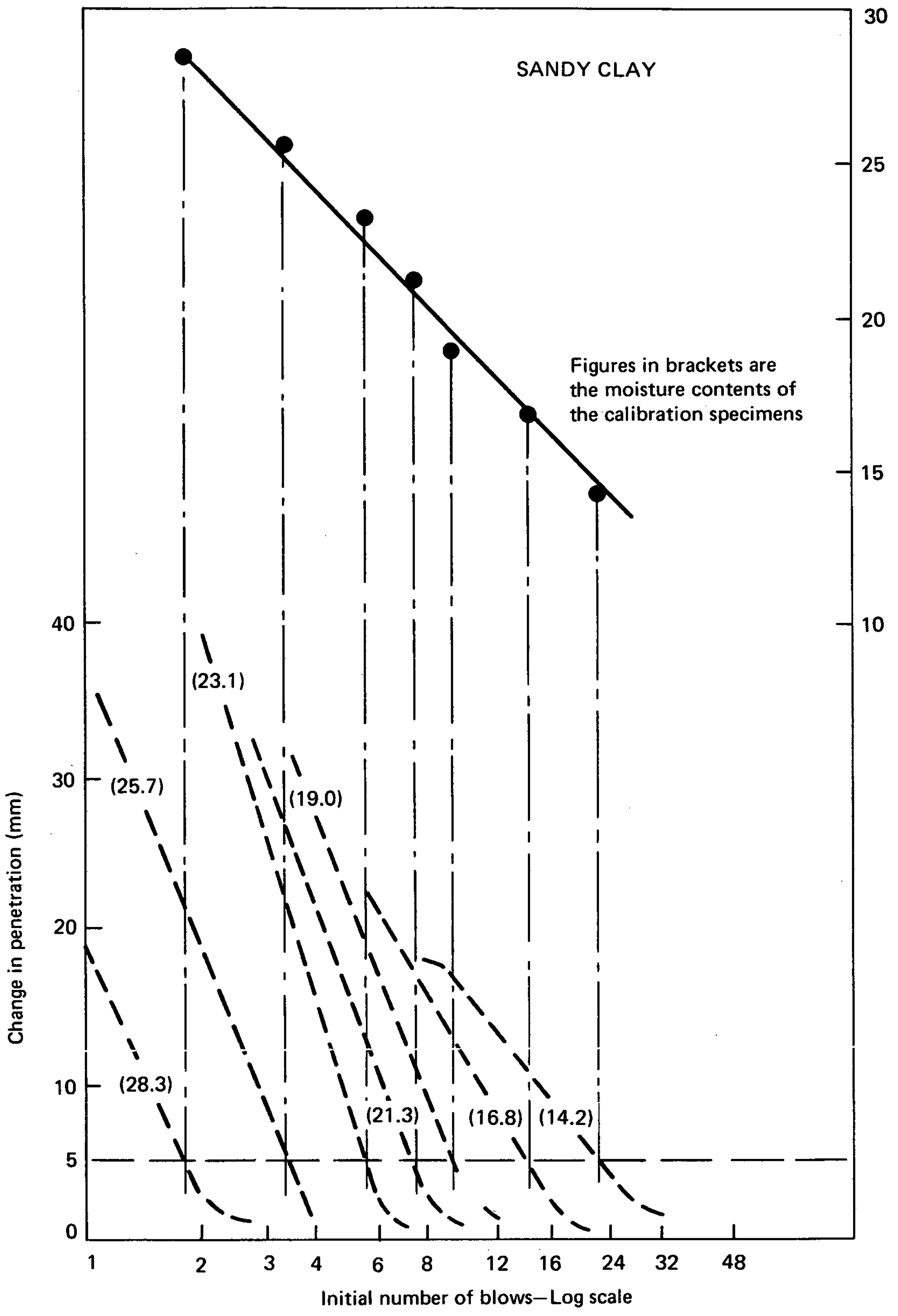


Fig. 9 CALIBRATION CHART OBTAINED WHEN USING THE PROTOTYPE MOISTURE CONDITION APPARATUS WITH SANDY CLAY

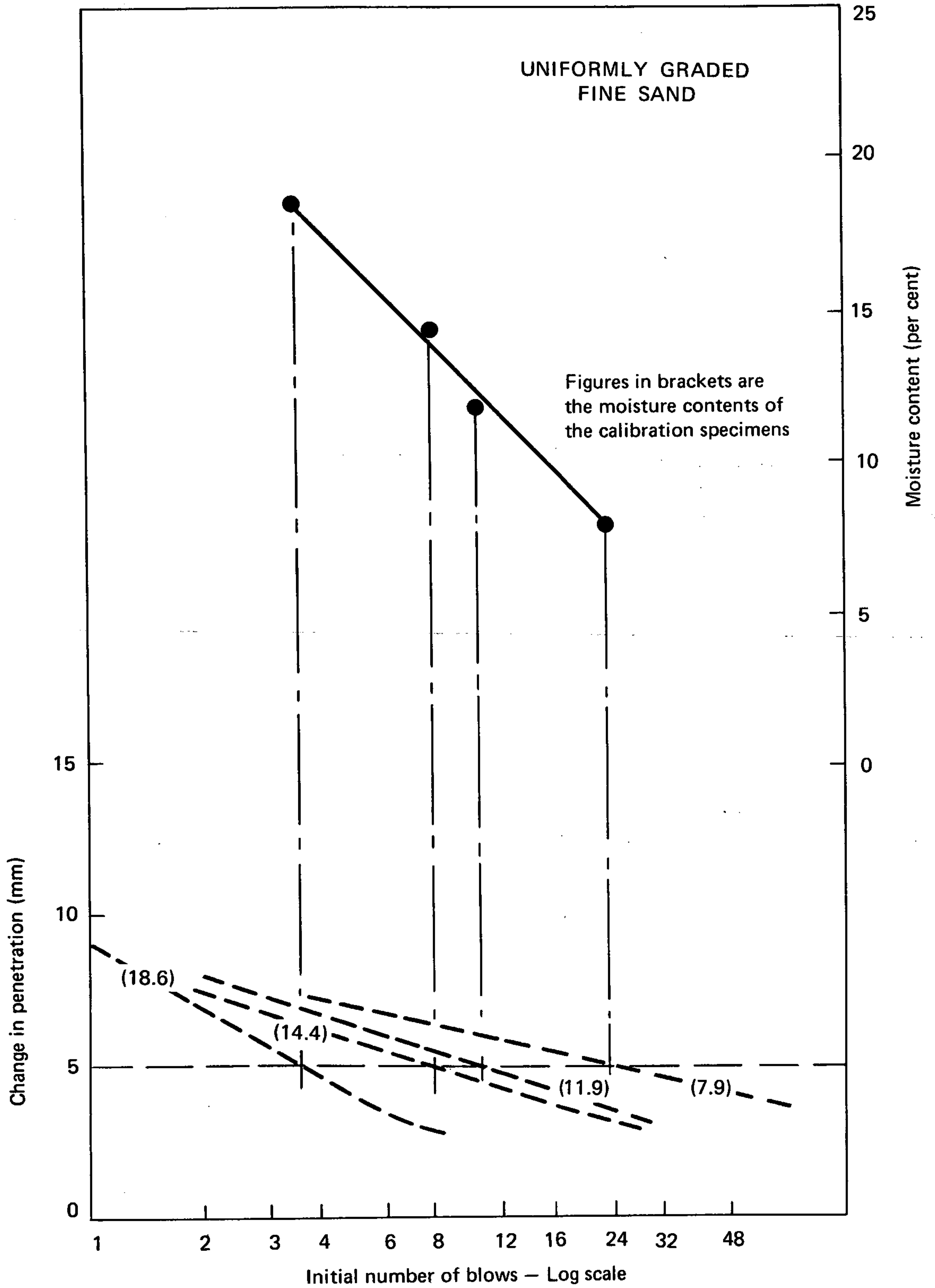


Fig. 10 CALIBRATION CHART OBTAINED WHEN USING THE PROTOTYPE MOISTURE CONDITION APPARATUS WITH UNIFORMLY GRADED FINE SAND

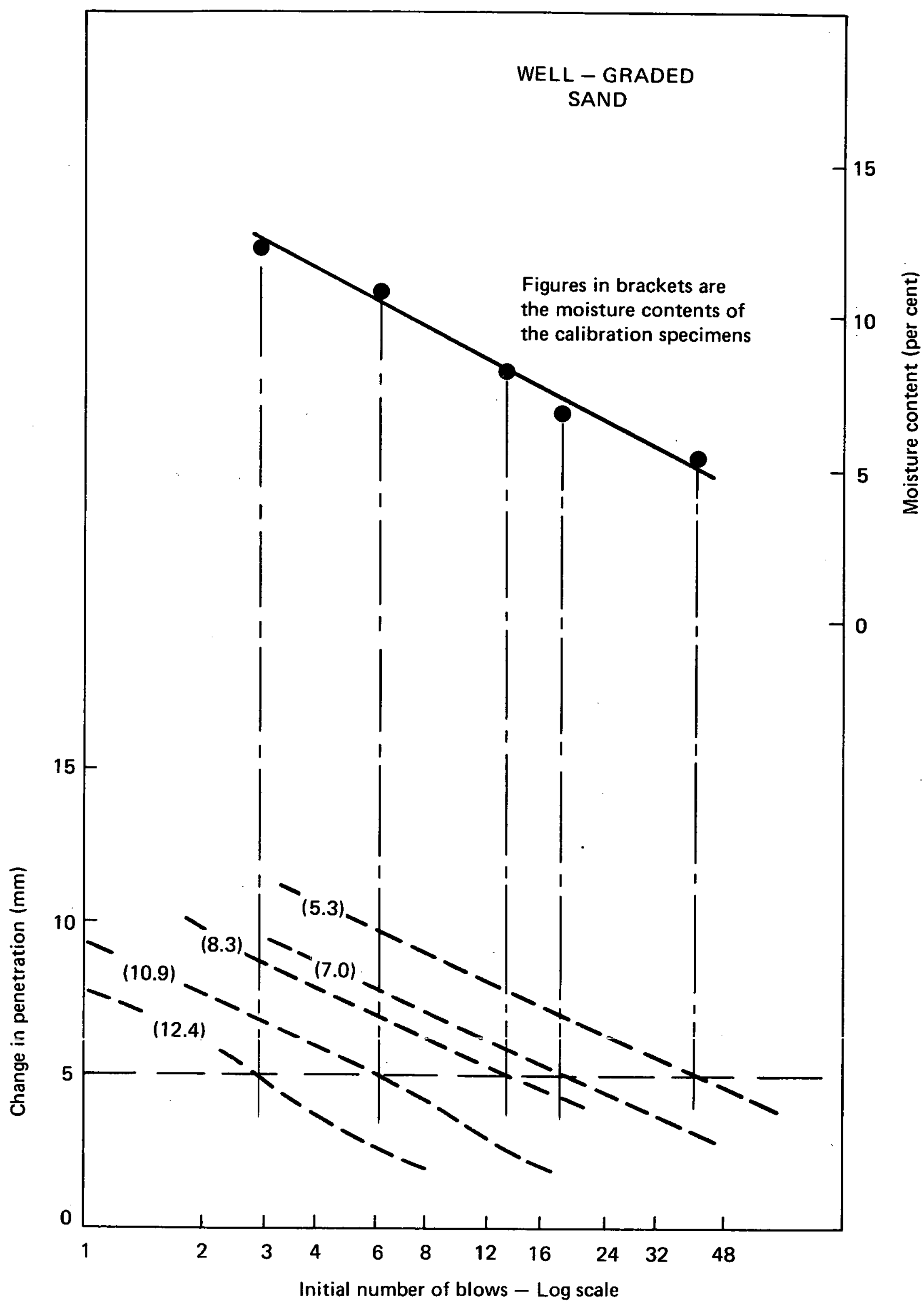


Fig. 11 CALIBRATION CHART OBTAINED WHEN USING THE PROTOTYPE MOISTURE CONDITION APPARATUS WITH WELL–GRADED SAND

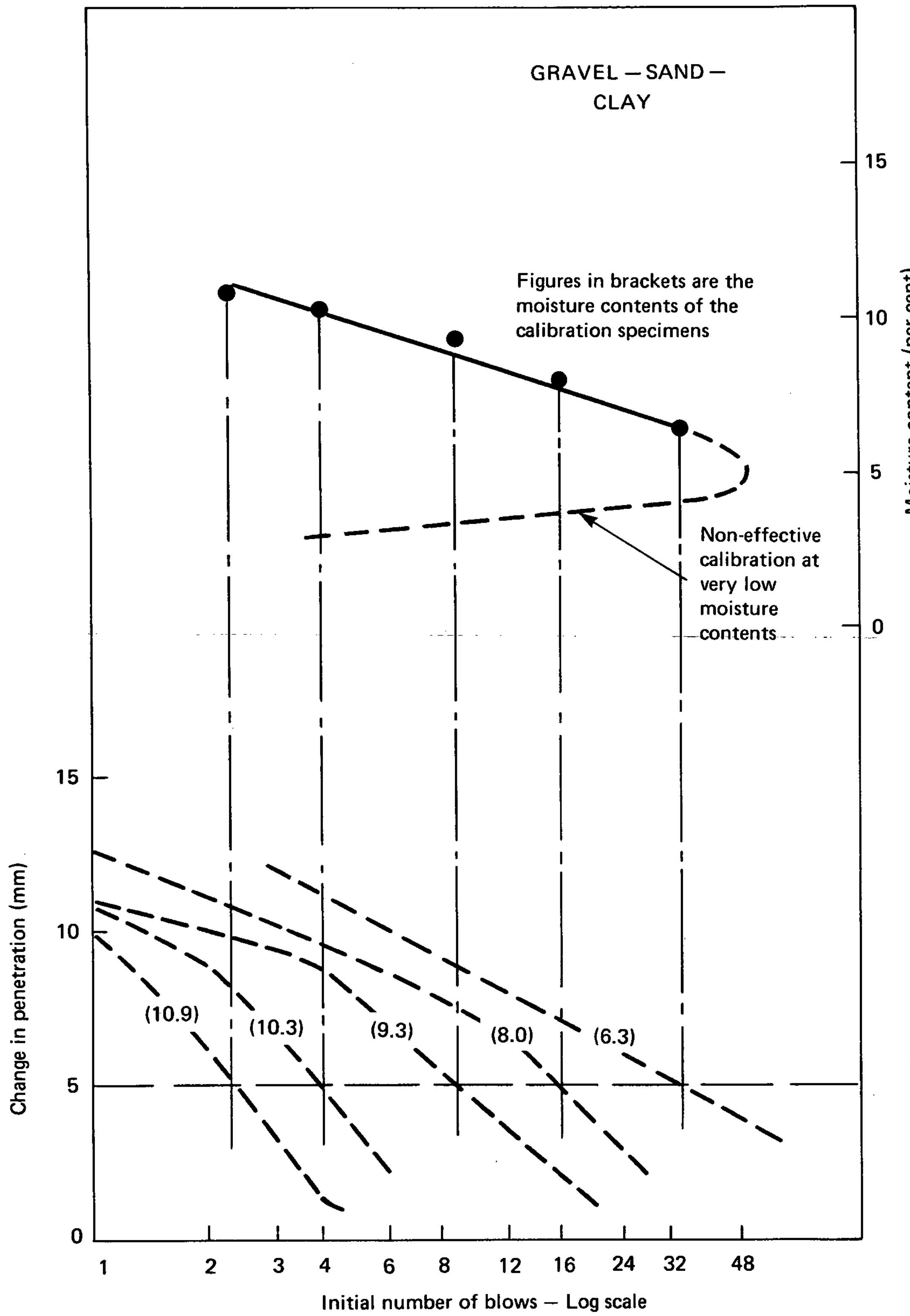


Fig. 12 CALIBRATION CHART OBTAINED WHEN USING THE PROTOTYPE MOISTURE CONDITION APPARATUS WITH GRAVEL–SAND–CLAY

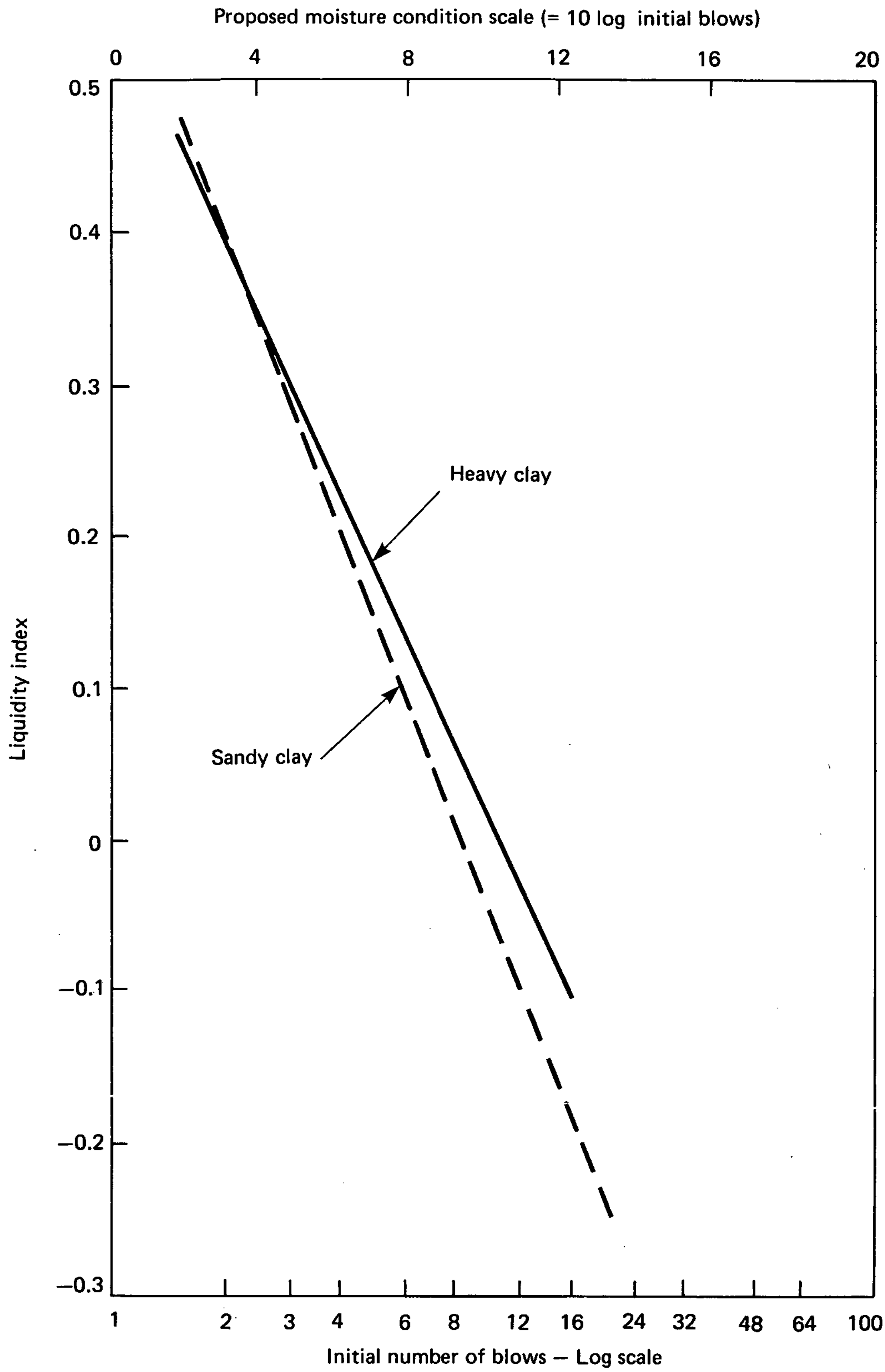
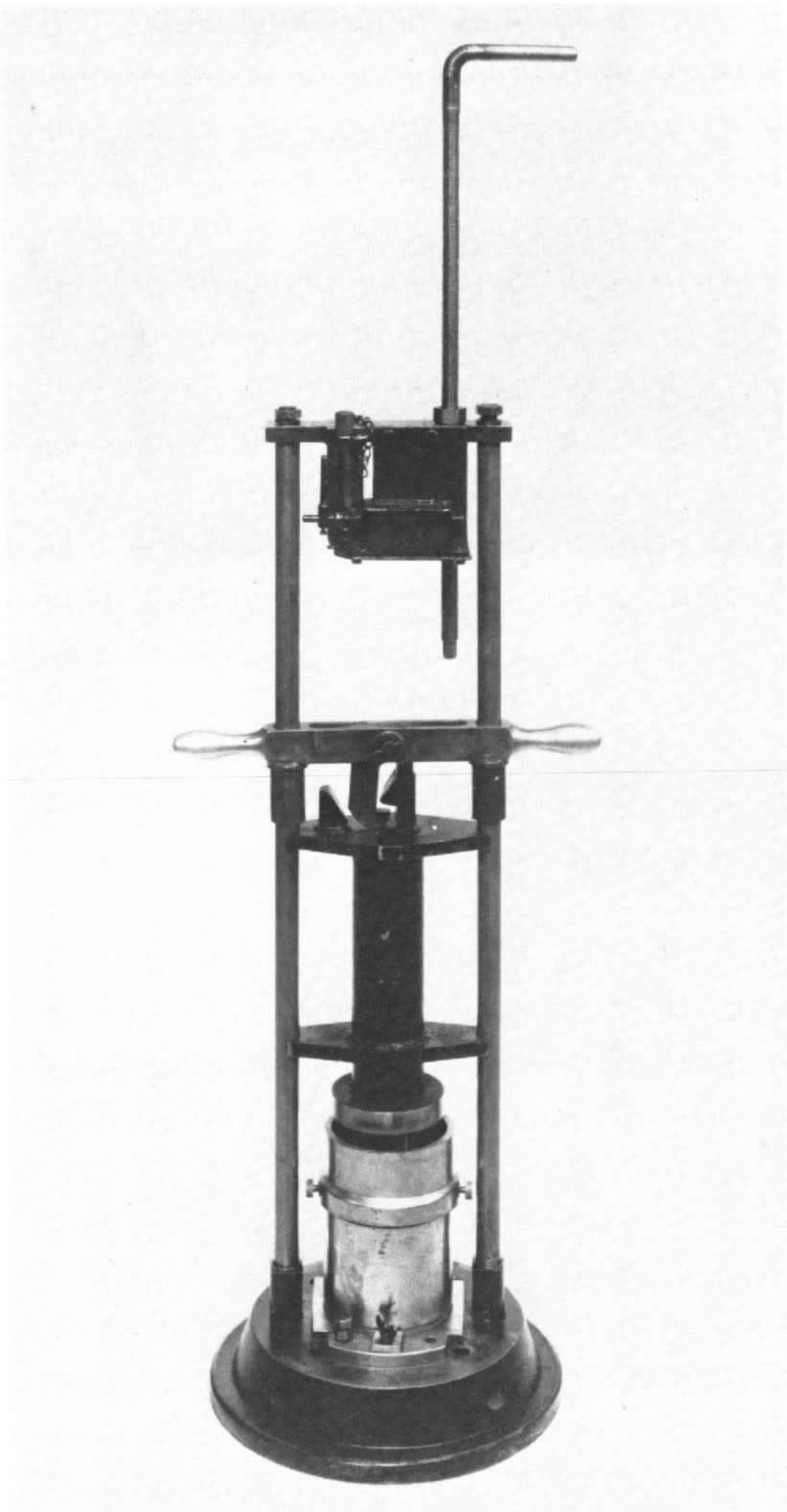


Fig.13 CALIBRATION OF THE MOISTURE CONDITION APPARATUS IN TERMS OF LIQUIDITY INDEX FOR THE TWO CLAY SOILS
(See Figs. 8 and 9)



Neg No H247/68

PLATE 1: The modified version of the aggregate impact test apparatus used for the early experimental work

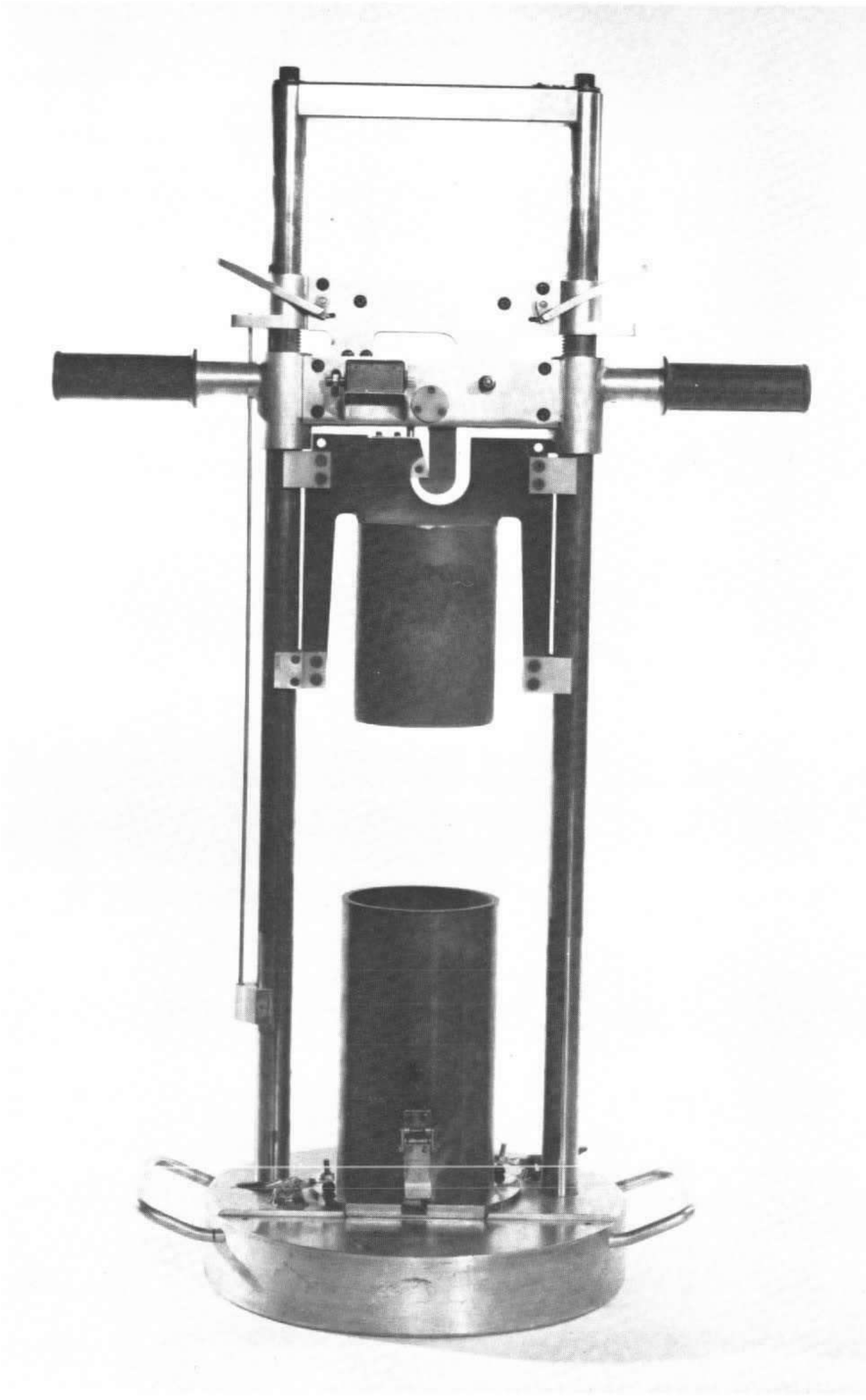


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PLATE 2: The prototype moisture condition apparatus as used for the experimental work

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ABSTRACT

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