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USE AND APPLICATION OF THE MCA WITH PARTICULAR REFERENCE TO GLACIAL TILLS

by G D Matheson and M G Winter

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EXECUTIVE SUMMARY

The Moisture Condition Apparatus (MCA) was originally developed by TRL in the 1970s to facilitate the rapid assessment of soil acceptability for earthworking. Further work extended the use of the MCA to most granular soils and led to its introduction as the routine method for soil acceptability determination on trunk roads and motorway projects in Scotland in 1983. Since then the procedures have been operated successfully, with only one revision in 1989; this report presents a further major revision to the procedures.

Detailed test procedures and extensive guidance on the use and application of the MCA for determining soil acceptability for earthworks compaction are given. The test procedures included are for determination of the Moisture Condition Value (MCV), determination of the MCV after saturation and determination of the MCV calibration line. Guidance is given on each of these test procedures and on the use of the MCA at both the ground investigation and earthworking stages of a project. The procedures augment the current British Standard. In particular, data interpretation is simplified while retaining the MCA's advantage in precision over alternative methods of soil acceptability determination.

Additional guidance is given on the limits of use of the MCA in terms of the particle size distributions of potential earthworks materials, on the effect of large particles on the application of the MCA, on appropriate upper and lower limits of acceptability, and on the precision of the MCV test.

MCA operators are required to attend an appropriate training course, on the principles of earthworking and the use of the MCA, before using the MCA on Scottish trunk road and motorway projects. Similarly, MCA machines are required to be certificated, by means of a series of checks on function, before use on Scottish trunk road and motorway projects. Detailed procedures are given for MCA machine certification.

USE AND APPLICATION OF THE MCA WITH PARTICULAR REFERENCE TO GLACIAL TILLS

ABSTRACT

Detailed test procedures are given for the use of the Moisture Condition Apparatus (MCA) to determine soil acceptability for earthworks at the ground investigation and earthworking stages of a project. Guidance is given on the particle sizes of soils which can be tested using the MCA, on the effect of large particles on the application of the MCA, on appropriate limits of acceptability, on Moisture Condition Value (MCV) precision test data, and the certification of MCA machines and operators.

1 INTRODUCTION

The assessment of soil acceptability for earthworks compaction is important to road construction. Early techniques were based on either visual recognition of undesirable soil types or on the establishment of an upper limit of moisture content beyond which the soil was deemed to be unworkable. This upper limit was set by reference to the results of two standard soil tests, one for cohesive and one for granular soils, the results being 'adjusted' according to simple guidelines and experience. Although experienced Engineers had a fair degree of success difficulty was regularly found in predicting and assessing acceptability.

Research (Parsons, 1976; Parsons and Boden, 1979) indicates that a relationship exists between maximum bulk density, moisture content, air voids and compactive effort. To exploit these points the Moisture Condition Apparatus (MCA) was developed by TRL and further work extended its use to granular soils (Matheson and Oliphant, 1991). Using results obtained from the MCA it is possible to predict the potential acceptability of widely differing soil types. A guide to determining whether the MCA test can be applied can be obtained by considering the proportions of fines, sand and gravel in the excavated, or "as-dug", soil (Oliphant and Winter, 1997). Three categories can thus be defined (see Figure 1):

a) MCA can be used.

b) MCA cannot be used.

c) MCA may be useable.

For soils falling into category (c) above then the MCA may still be useable. A single Moisture Condition Value (MCV) test performed on the material in a saturated state can provide further guidance on whether a calibration line should be attempted. If the result of such a test indicates that there is a potential for unacceptability then a calibration line should be attempted. If a calibration line with a clearly defined section of negative slope and a satisfactory correlation coefficient is obtained then the MCA can be used over that specific range of moisture contents.

The limits in Figure 1 are based on a lower limit of acceptability of MCV=8.5. Those soils which fall in the 'MCA cannot be used' category may be considered 'free-draining'. Such soils do not therefore have a potential to become unacceptable, provided that they are placed in free-draining environments (see Section 4.1). Although the data presented by Oliphant and Winter (1997) can be used to develop limits of MCA use based on alternative lower limits of acceptability (see Section 5.1) the effect on the limits of use given in Figure 1 is small. Consequently it is considered that the limits presented should be adequate for most, if not all, purposes.

The MCV test is carried out only on the particles passing a 20mm test sieve. The effect of larger particles (20mm to 37.5mm) has been studied by Winter and Suhardi (1993). If an excavated sample contains more than 45% to 50% of particles larger than 20mm then the results of the MCV test are not representative of the material being excavated, transported, placed and compacted. In this case alternative approaches to acceptability determination are required.

This guide explains the basic principles of the MCA for soils satisfying categories (a) and (c) above and with less than 45% to 50% of particles larger than 20mm. It gives detailed instructions for test procedures and offers guidance on the interpretation and use of results. Forms for recording data and carrying out evaluations are given along with worked examples. The basic procedures have been used successfully (Matheson and Oliphant, 1991) on Trunk Road Projects since 1983.

2 PRINCIPLES OF COMPACTION

In compaction testing (British Standards Institution, 1990a), bulk density and moisture content ideally show a relationship in which bulk density initially increases until the zero air voids line is approached, reaches a maximum and then decreases with increasing moisture content (Figure 2). This is the compaction curve and its apex defines the maximum bulk density which corresponds with the optimum moisture content for that soil. Soils compacted at their optimum moisture content will thus give maximum bulk density.

An increase in the compactive effort, resulting for instance

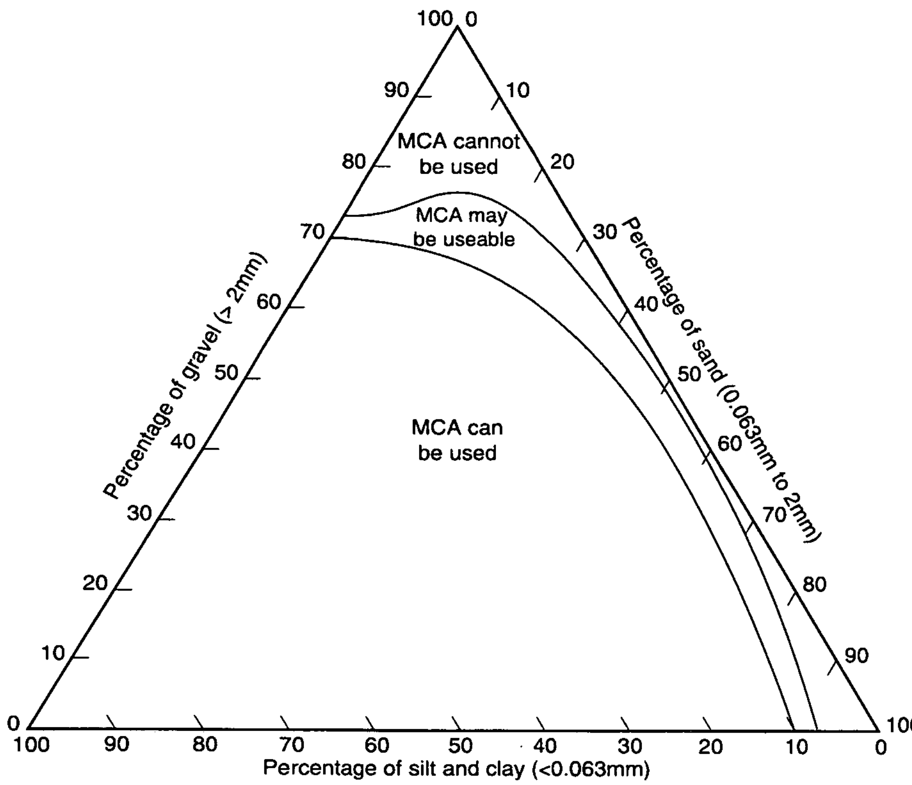

Fig. 1 Application potential of the MCA

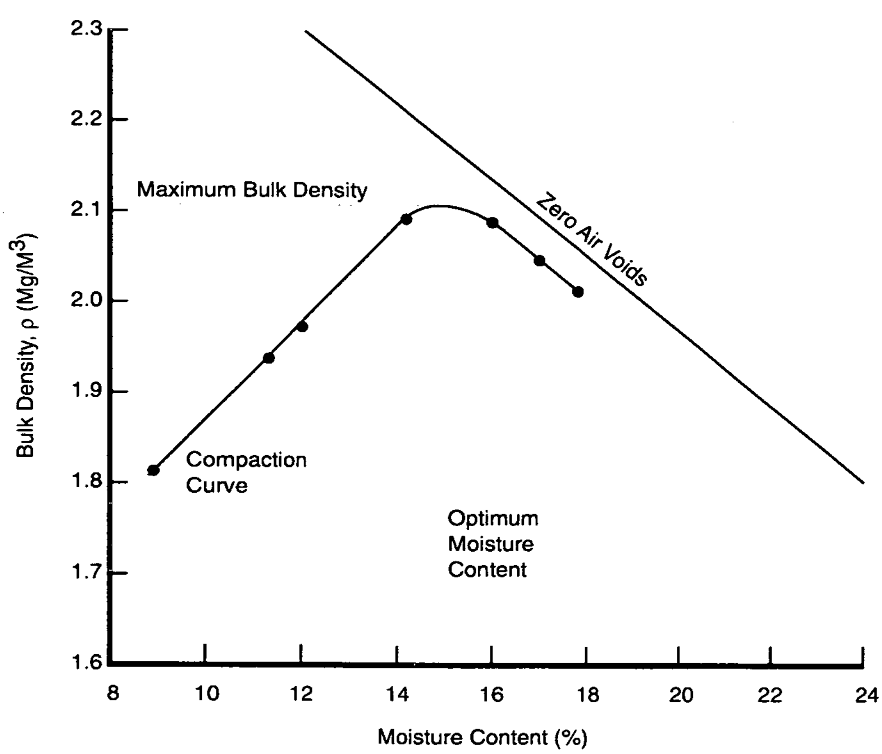

Fig. 2 Relation between bulk density and moisture content

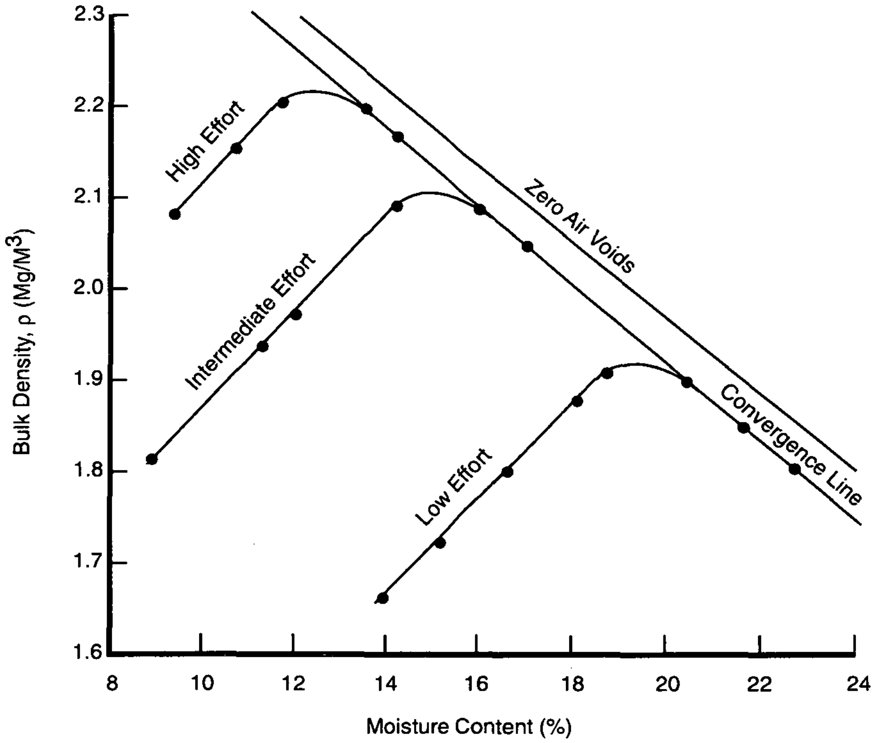

Fig. 3 Displacement of compaction curve with different comparative efforts: convergence line

from an increase in weight or height of fall of the compaction rammer, produces a curve which is displaced upwards and to the left. Conversely, a decrease in compactive effort moves the curve downwards and to the right (Figure 3). At moisture contents in excess of each optimum all such curves converge to form a single line approximating to between 2% and 5% air voids. The point of intersection of each compaction curve and convergence line therefore relates maximum bulk density, moisture content and compactive effort. Using the degree to which air voids have been eliminated as a measure of the degree of compaction, the convergence line corresponds to the maximum practical level of compaction which can be achieved during testing.

The maximum bulk density achieved is related to the compactive effort applied and does not necessarily equate to the highest bulk density attainable. In the field, terms such as 'maximum bulk density' and 'full compaction' are therefore only meaningful when they are linked to the plant used.

At moisture contents below optimum full compaction will only be achieved when the convergence line is reached. Soils which are compacted at too low a moisture content therefore require additional compactive effort to achieve a state of full compaction.

The compaction test is carried out in undrained conditions: that is, water is not permitted to escape from the sample mould. The bulk density increases in each test with moisture content until the convergence line is reached. At this point no further increase in bulk density is possible unless water is allowed to escape, further compactive effort being absorbed by the incompressible water creating pore water pressures which dissipate with time. In drained boundary conditions, as frequently occur naturally, the bulk density increases to the convergence line and then moves upwards along the convergence line as water is forced out. The time taken to final compaction and the extent to which porewater pressures are developed are a function of the permeability of the soil. Those soils compacted at very high moisture contents develop pore water pressures related to the compactive effort applied and the permeability.

A test procedure attempting to simulate the above conditions must therefore be carried out in controlled or measured conditions of compactive effort, maximum bulk density and moisture content in an environment allowing water to escape from the system if pore pressures develop. These requirements are satisfied during moisture condition testing.

3 MOISTURE CONDITION TESTING

The moisture condition test is a form of strength test in which the compactive effort for near full compaction (between 2% and 5% air voids) of a sample of soil is determined. The MCV is used to quantify the compactive effort and correlates with moisture content, shear strength and with CBR at the same level of compaction for remoulded soils. It should be remembered that the prime purpose of earthworks compaction is to achieve a stable soil structure with low air voids and, consequently, to minimise the potential for future moisture ingress and loss of strength.

The procedures given for the use of the MCA are intended to augment those given in BS1377 (British Standards Institution, 1990a).

3.1 THE APPARATUS

The MCA (Figure 4) basically consists of a frame containing a drop rammer and a mould to hold the sample. Both the weight of the rammer and the height of fall are kept constant. Each blow of the rammer is triggered during the lifting operation. A counter recording the accumulated blows allows the compactive effort to be measured.

A list of equipment necessary to carry out the test is given in Appendix A (Section A1).

3.2 PRINCIPLES

As described in Section 2, three basic parameters define a soil system being compacted - compactive effort, moisture content and maximum bulk density. The MCA is designed with these in mind. The moisture content, calculated as a percentage of the dry weight of the sample, remains constant throughout the test. The compactive effort applied is measured by counting the number of blows of a rammer of fixed weight falling from a constant height onto the sample contained in a mould. The bulk density at any stage during compaction is equal to the weight of the sample divided by the volume occupied. Since the weight is constant maxi-

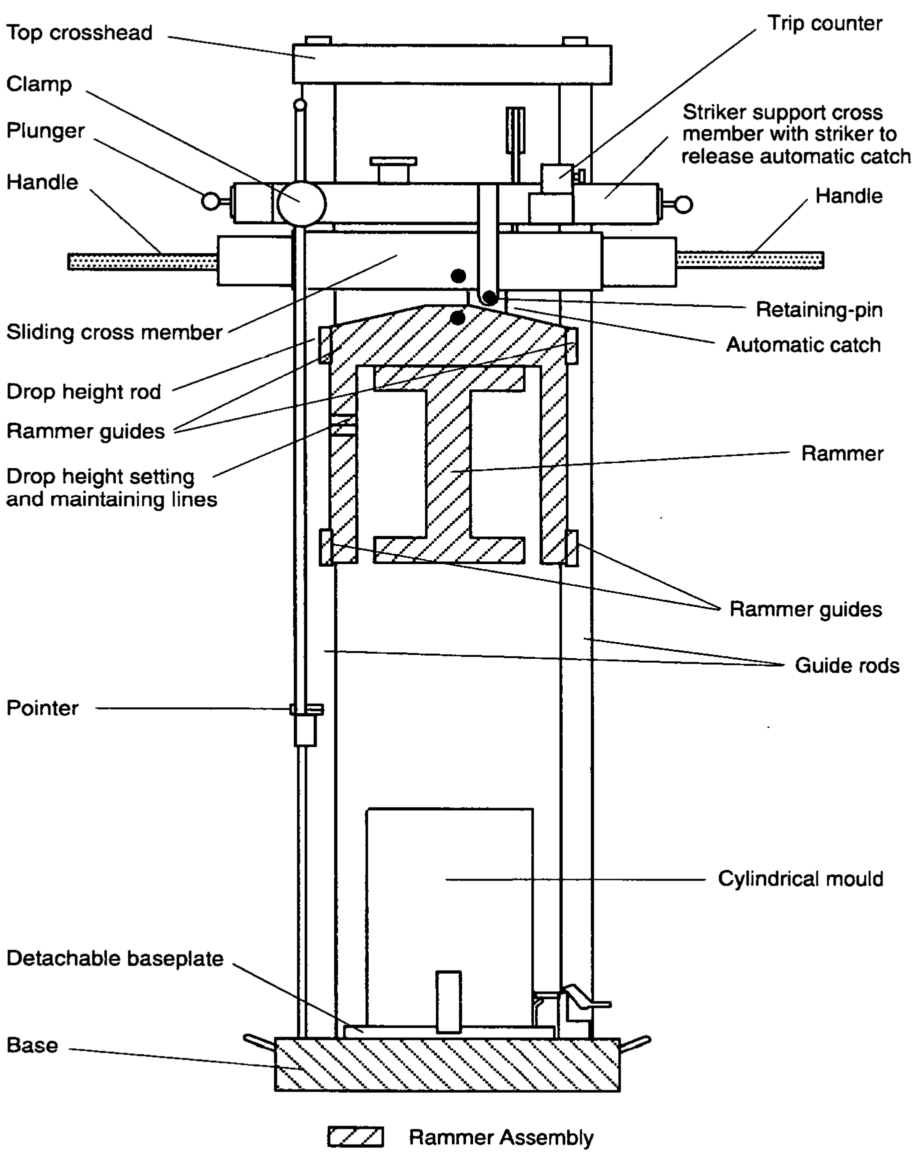

Fig. 4 The moisture condition apparatus

mum bulk density will occur at minimum volume. Full compaction therefore occurs when the rammer attains maximum penetration into the mould. In order to simulate field conditions slots are incorporated into the base of the mould. The onset of pore water pressure can thus be judged from the appearance of water at the base of the mould. This also indicates that the line of increasing bulk density at constant moisture content has reached the convergence line. Further reduction in volume can only occur by a loss of water from the system. Testing is therefore normally stopped when water appears at the base of the mould.

3.3 TEST PROCEDURES

The MCV is defined in terms of the effort required to compact a 1.5kg sample of soil. Each MCV relates to a specific moisture content and the moisture content can be varied to give a calibration line typifying the material. Determination of the MCV on a saturated sample can provide guidance on whether a calibration line should be attempted for soils in category (c), as defined in Section 1.

Two forms, Form MCA1 and Form MCA2 (Appendix B), allows test results to be recorded systematically. Their use is strongly recommended. Full instructions for testing are given in Appendix A. Examples of MCV test results are given in Appendix C, these should be used as an aid for inexperienced operators in determining a suitable range of moisture content over which testing is to be carried out.

3.3.1 Determination of MCV

It is a requirement that MCA operators successfully complete an appropriate training course prior to use of the MCA on Scottish trunk road or motorway contracts. It is also required that MCA machines are certificated as described in Appendix D. The results should be recorded on Form MCA3 (Appendix B).

3.3.1.1 Sample preparation

Sample preparation for an MCV test is straightforward. A sample of the soil is passed through a 20mm sieve, 1.5kg weighed out and then placed directly into the sample mould. A fibre disc is placed on top of the sample to avoid rammer contamination. A flowchart shows the procedure to be followed (Figure 5). Detailed instructions are given in Appendix A (Section A3).

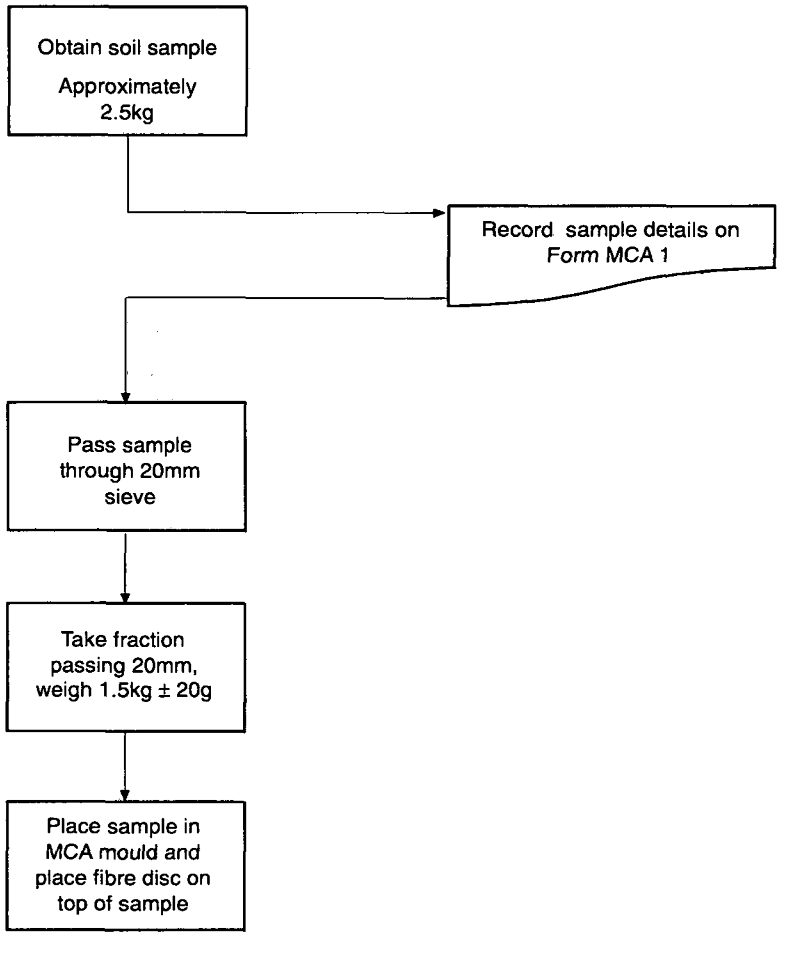

Fig. 5 Sample preparation for determination of MCV

3.3.1.2 Testing

As a preliminary to testing, the apparatus should be checked in accordance with Appendix A (Section A2) to ensure that the height of drop of the rammer is 250mm and that the rammer does not foul the mould during descent. Checks should also be made to ascertain that the drop height vernier assembly is securely fastened and that all fittings (screws, nuts and bolts) are secure.

The mould is placed in position on the base of the apparatus, secured, and testing commenced. The penetration of rammer into mould is measured at set numbers of blows (B) until a state of near full compaction is reached or until water is expelled from the base of the mould. Near full compaction is recognised when the penetration difference between the readings at 4B and B blows drops below 5mm. During the test the height of the rammer drop is regularly checked and if necessary adjusted. Test measurements should be meticulously recorded on Form MCA1 as they are gathered. Detailed instructions (Appendix A, Section A3) and a flowchart (Figure 6) give the procedures to be followed.

Each test can be expected to take between 6 and 10 minutes to perform.

3.3.1.3 Processing of results

Differences in penetration are calculated by subtracting each penetration reading for a given number of blows from the reading at four times that number of blows. This technique facilitates recognition of the state of near full compaction. For convenience the change in penetration is recorded against the lower number of blows. The resultant differences are then plotted against the number of blows, the latter on a log scale .

3.3.2 Determination of MCV after saturation

3.3.2.1 Sample preparation

Water is added to the sample in a container until an excess over that required to saturate the soil is reached. Free-standing water should be just visible on top of the sample. Further water is added as required and the sample allowed to attain a uniform moisture content which need not be measured. A flowchart shows the preparation required (Figure 7).

3.3.2.2 Testing

The procedure followed is that for a normal MCV test except that water escaping from the mould is ignored. Instructions for testing are given in Appendix A (Section A4).

3.3.2.3 Processing of results

Results are processed according to procedures for a normal MCV test (Section 3.3.1.3).

3.3.3 Calibration lines

A calibration line characterises the relationship of MCV to moisture content in a soil type and is obtained by determining MCVs over a range of moisture contents.

3.3.3.1 Sample preparation

A bulk sample weighing approximately 25kg is obtained, air dried and then passed through a 20mm sieve. The percentage retained should be noted. At least four and preferably six representative samples weighing approximately 2.5kg each are then made up at a range of moisture contents such that the resultant estimated MCV range is approximately 3 to 15. A flowchart shows the procedure to be followed (Figure 8). Detailed instructions are given in Appendix A (Section A5).

3.3.3.2 Testing

Each sample should be prepared and tested according to Section 3.3.1 and its MCV determined. Immediately on completion of each test the sample should be removed from the mould and a determination of moisture content initiated. This is the true moisture content of the tested sample and may differ from that estimated at the start of the test. The true moisture content is of course used in subsequent calculations. Results should be recorded on Forms MCA1 and MCA2. A flowchart shows the procedure to be followed (Figure 9). Detailed instructions are given in Appendix A (Section A5).

3.3.3.3 Processing of results

When the MCV of each sample has been determined a plot of sample moisture content against MCV is drawn up. The points should lie on a straight or near-straight line. This is the calibration line for the soil. The line should be negatively sloping, contain at least three but preferably four or more points within its effective part (see Section 3.4.3) and have a correlation coefficient greater than or equal to the values given in Table 1, to achieve a statistical confidence level of at least 95%. The intercept on the moisture content axis and slope of line are then calculated. The sensitivity of the soil to moisture content changes is an important property and is easily calculated by taking the reciprocal of the value obtained for the slope. Results should be recorded in the relevant sections of Forms MCA1 and MCA2.

Except for the extrapolation to the intercept, it is important not to extend the calibration line beyond the points on which the calibration is based (see Section 3.4.2).

Detailed instructions are given in Appendix A1 (Section A5).

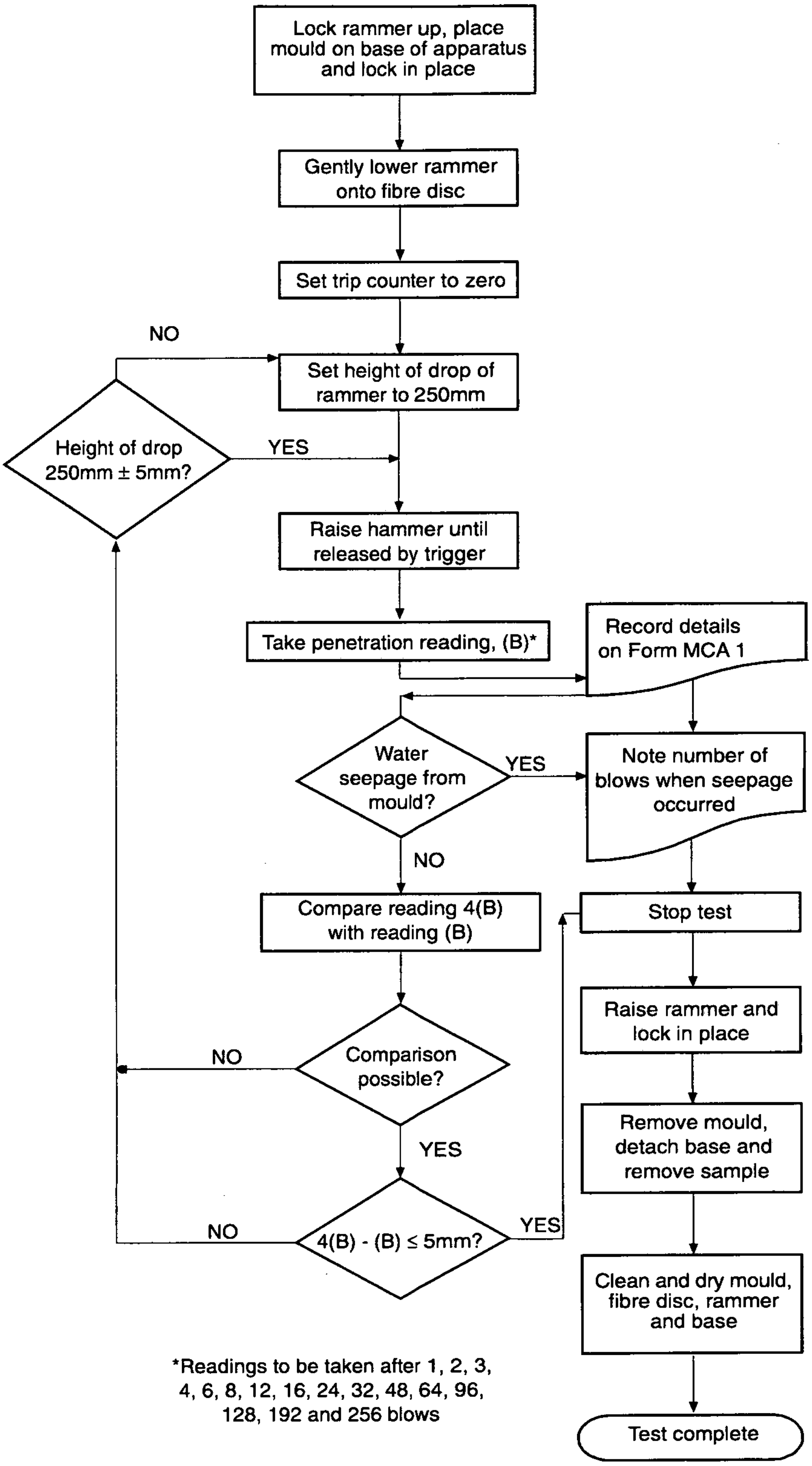

Fig. 6 Test procedure for determination of MCV

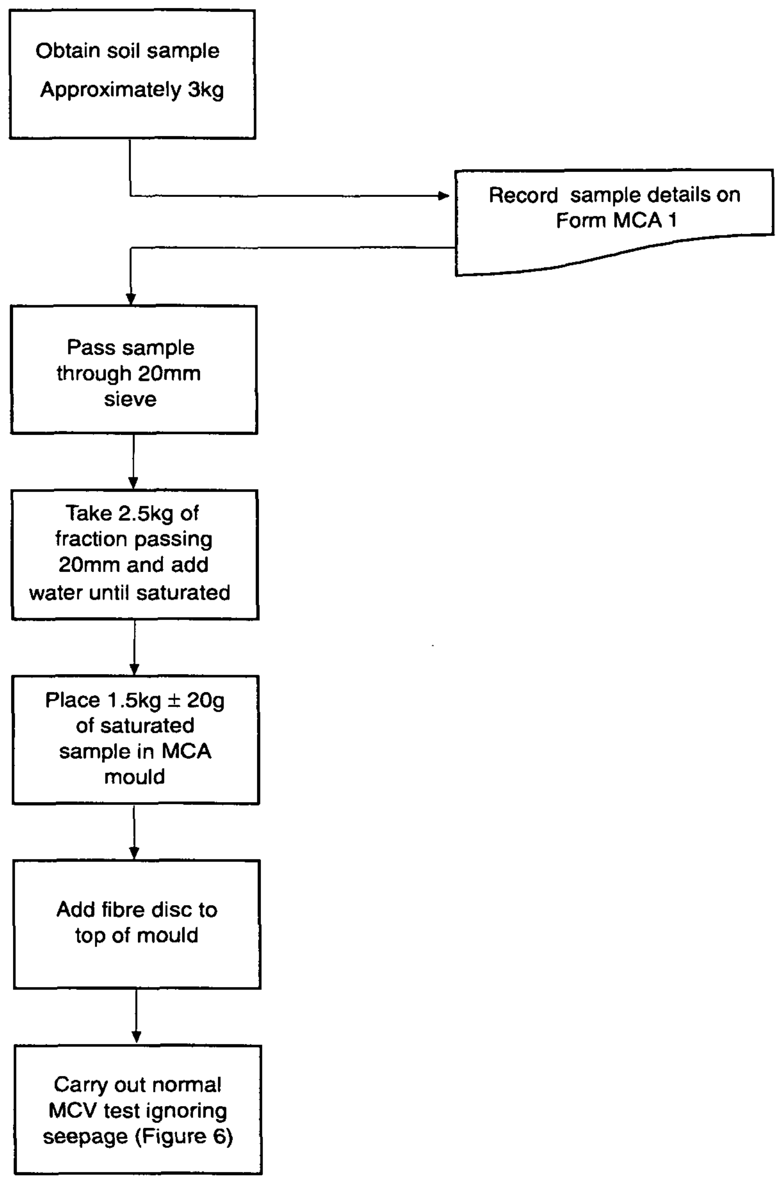

Fig. 7 Test procedure for MCV testing of saturated sample

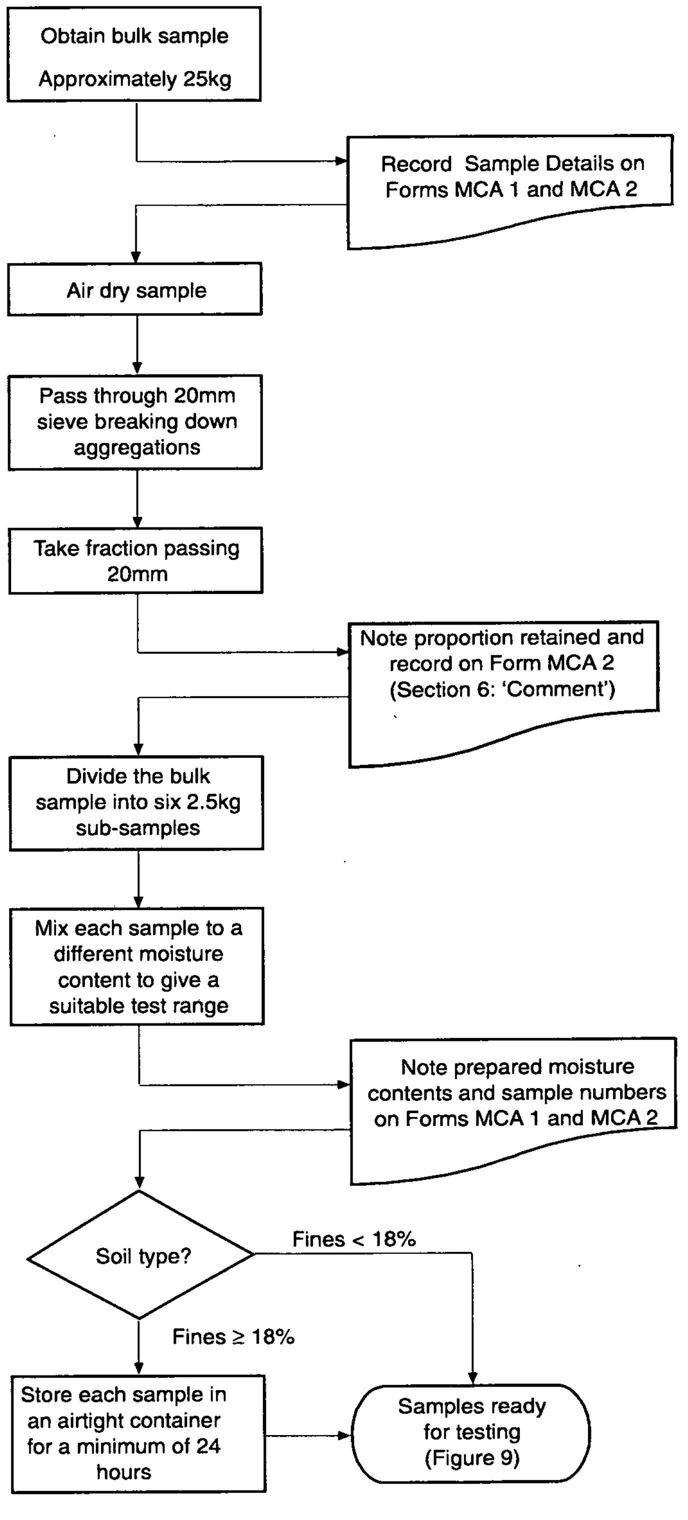

Fig. 8 Sample preparation for calibration testing

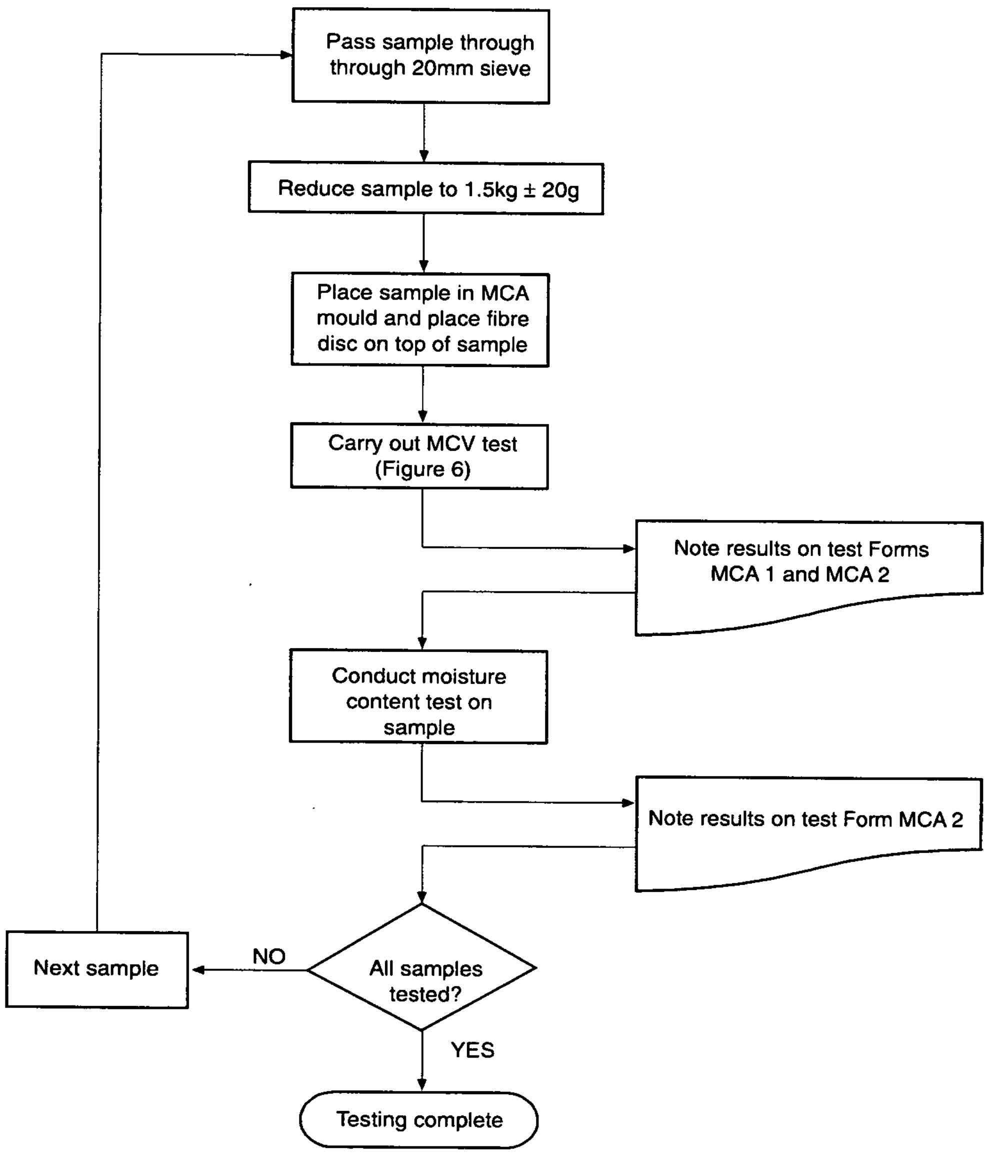

Fig. 9 Test procedure for calibration testing

TABLE 1

Correlation coefficient values corresponding to 95% confidence

Number of Points[1]	Required Value of Correlation Coefficient[2], r
3	≥0.99
4	≥0.90
5	≥0.81
6 or more	≥0.73

[1]Number of points forming the effective part of the calibration line.

[2]The value of the correlation coefficient, slope and intercept of a line can be calculated using most modern scientific calculators.

3.4 GENERAL GUIDANCE

3.4.1 MCV testing

No difficulty will be experienced with the majority of soils, particularly those of a cohesive nature and characteristic curves (Figure 10) can be obtained. However problems may arise during the testing of samples having either a relatively low or a relatively high moisture content. This will be particularly true in the testing of granular glacial tills.

Samples which are of a relatively low moisture content usually produce a plot (Figure 11) in which the change in penetration is uniformly low and the 5mm line is either not reached or crossed repeatedly. A total in excess of 256 blows may be necessary to achieve a change in penetration of less than 5mm. The test consequently takes appreciably longer and it is arguable whether continuing the test to such a high number of blows is necessary.

Tests on samples of relatively high moisture content (Figure 12) may experience seepage of water from the base of the mould. Unless the amount of water escaping from the base of the sample is measured or an accurate determination of moisture content made prior to testing, it is imperative that testing is stopped when seepage first occurs. Continuing the test after the seepage point is reached leads to an inappropriate moisture content determination on completion of the test as the system has been altered by allowing a change in moisture content to take place and this may affect results. In this context seepage is differentiated from the occasional spurt of water ejecting from the base slots as air escapes from the sample. Warning of the seepage condition can be obtained by observing the condition of the rammer sides as testing progresses. Noticeable liquid (usually in the form of a mud slurry) occurring on the lower face indicates that the saturated state is being reached. The possibility of obtaining a valid MCV on such samples depends on the number and value of the penetrations taken before seepage. Insufficient points can lead to a 5mm intersection not being achieved or one inaccurately determined. This behaviour can be expected in samples with a low fines content and relatively high permeability.

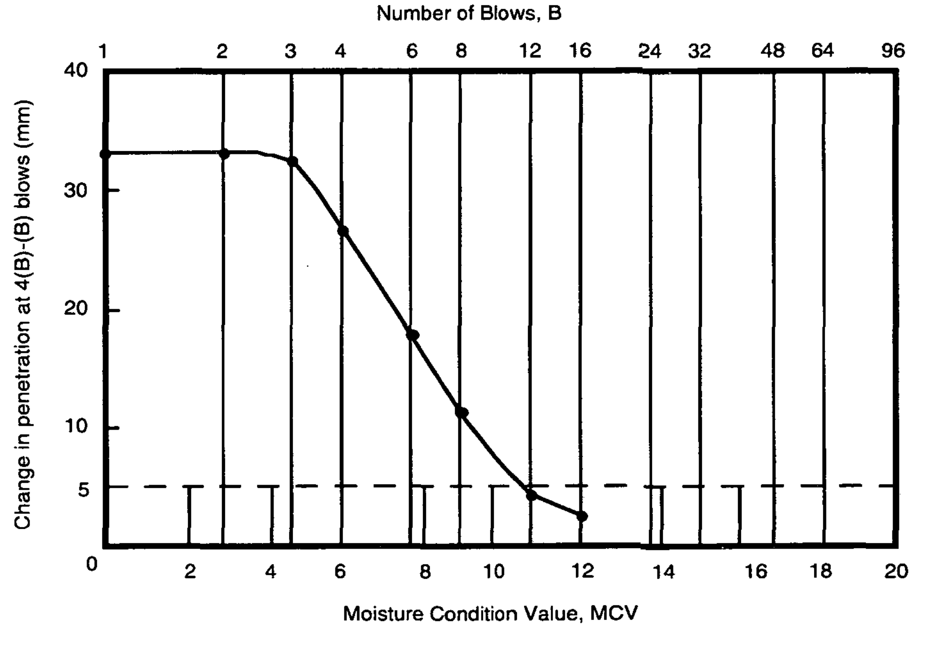

Fig. 10 Characteristic MCV test curve

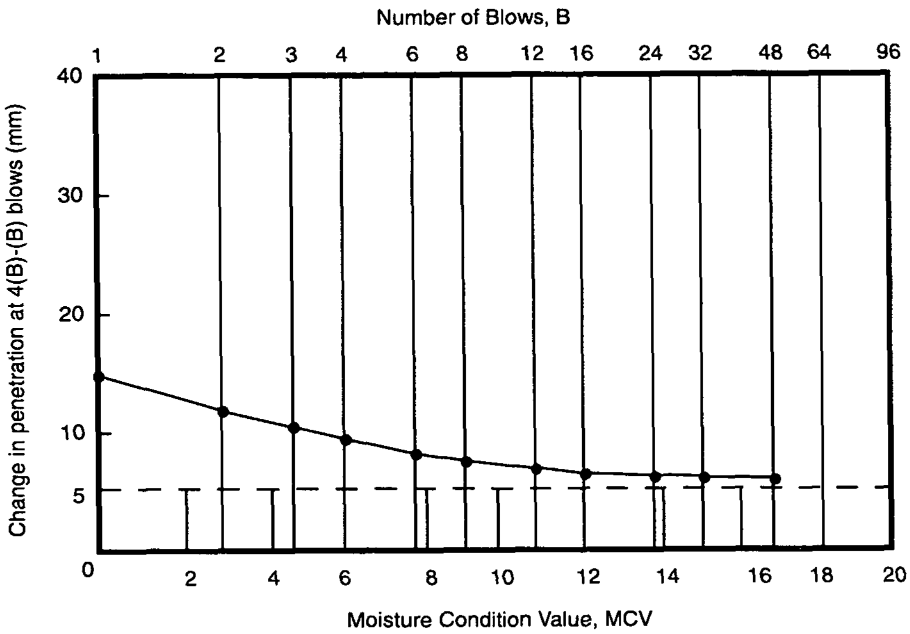

Fig. 11 MCV test curve for sample with relatively low moisture content

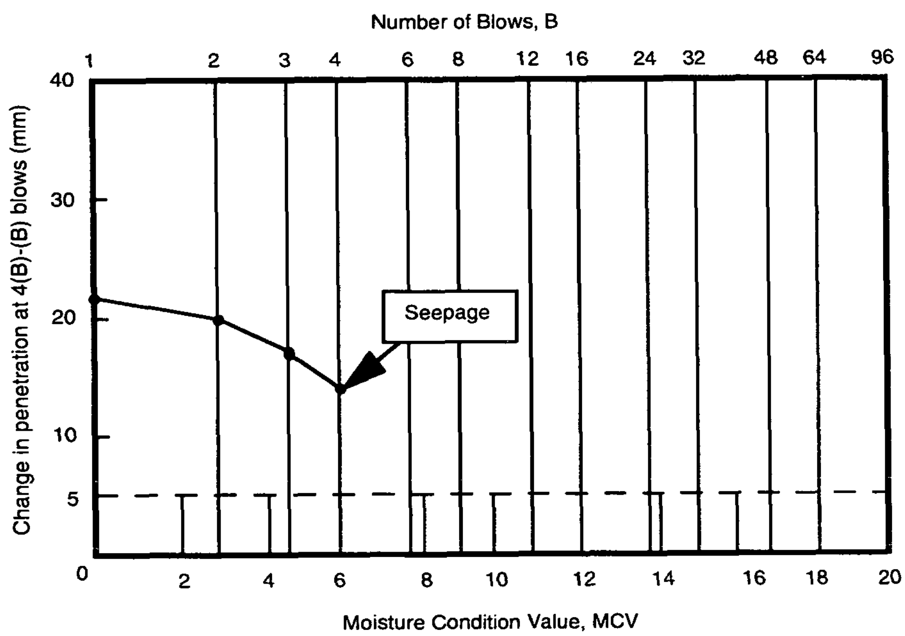

Fig. 12 MCV test curve for soil with relatively high moisture content

3.4.2 Calculation of MCV

The mechanism involved in the compaction of a cohesive soil is one almost solely involving densification in its original state. The original concept of the MCV test, as introduced by Parsons and Boden (1979) recognised this by calculating graphically the MCV from the steepest straight line on the change in penetration plot to give MCV_{ss} (Figure 13). Any difference from an MCV calculated from the 'best fit' line MCV_{bf} was minimal and explained as arising from processes other than simple densification and which were assumed not to be of importance to normal earthworking on site. Such differences that were observed were assumed to arise only as a result of mould confinement and as such were unique to the test procedure. In any event MCV_{ss} gave a conservative (pessimistic) result favouring rejection of the soil rather than acceptance. For most cohesive soils there is effectively no difference between MCV_{ss} and MCV_{bf} (Figure 13a).

In the case of granular soils (particularly glacial tills) the situation can be different and substantial difference between MCV_{ss} and MCV_{bf} can occur (Figure 13b). Such differences imply that energy is being used up in processes other than simple densification. Movement of air, water and grain rounding and/or crushing are possibilities. An

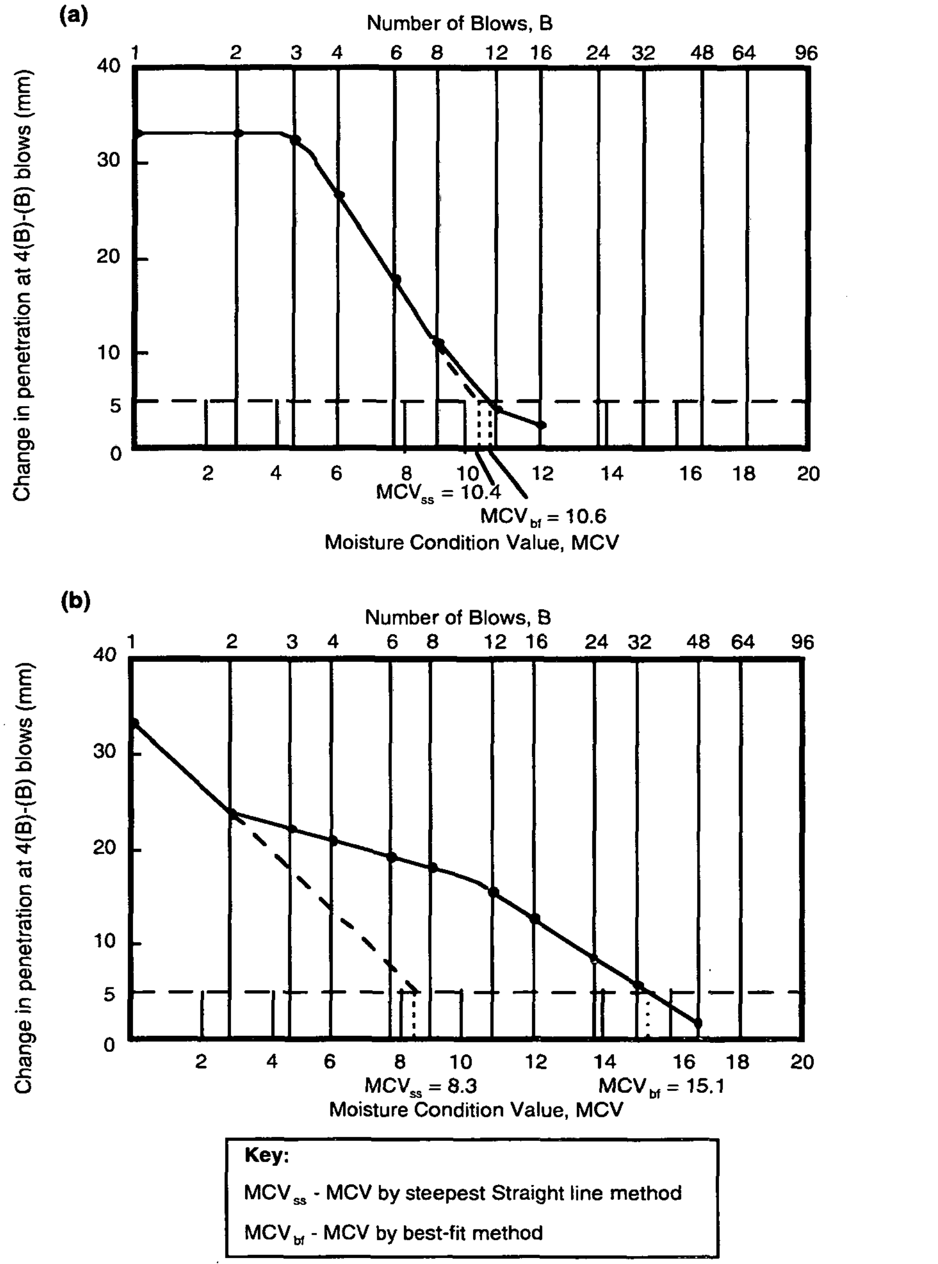

Fig. 13 Determination of MCV: (a) cohesive materials; and (b) granular materials

TABLE 2

Precision test results

Soil Type	Repeatability	Reproducibility
Sandy CLAY of intermediate plasticity[1]	0.5	1.2
Silty CLAY of very high plasticity[2]	0.8	1.6
Well graded very gravelly SAND[1]	1.5	2.3
Well graded slightly clayey silty gravelly SAND[2]	1.6	2.3

[1]Matheson and Oliphant (1991)
[2]Parsons and Toombs (1987)

understanding of the compaction process actually occurring with any soil and the degree to which the MCV test simulates this process will be the deciding factor in whether MCV_{ss} will be adequate.

The current standard (British Standards Institution, 1990a) recognises these difficulties by requiring the MCV_{ss} to be determined except in those cases where the penetration-blows curve does not concur with an idealised relation similar to that shown in Figure 10. In such cases the British Standard requires that the MCV_{bf} be determined. MCV_{bf} will however give an acceptable result with all soil types providing the mechanism of compaction is simulated by the test. Experience, particularly with granular tills, indicates that MCV_{bf} is the more satisfactory of the two techniques of calculating MCV and its use is recommended.

It is important therefore to realise that for granular soils in particular, MCV_{ss} and MCV_{bf} may be different. Consistent use of one method at both ground investigation and contract stages of a project is thus vital. Similarly conclusions reached through the use of MCV_{ss} regarding correlations with undrained shear strength and plant performance (Parsons and Boden , 1979; Parsons and Darley, 1982) may not be able to be applied directly to MCV_{bf}. This applies particularly to granular material in a relatively dry state.

The results of MCV precision tests on cohesive and granular soils are given in Table 2. The precision of the MCV test compares favourably with the data reported (Sherwood, 1970) for tests previously used to determine acceptability.

3.4.3 Calibration testing

The quality of calibration lines can be linked directly to the certainty by which individual MCV points are obtained. Characteristic curves lead to calibration lines with an excellent degree of correlation. Off-line values are nearly always the result of poor or suspect test data. MCVs used in drawing up calibration lines should therefore be assessed for quality before being accepted. Attempts to use all test results without regard to validity can lead to very poor lines.

Until experience is gained, difficulty is often found in obtaining an artificial moisture content range to cover the optimum MCV spread. Samples which are relatively too wet yield either incorrect MCVs or no MCV at all, samples which are relatively too dry yield MCVs lower than expected. This is particularly true of soils having a calibration line with a low slope. Reasons for this have already been described (Section 3.4.1). The solution in most cases lies in reducing the range and carefully selecting the moisture content values. The range is determined by the position and slope of the calibration line, those with a low gradient requiring samples prepared over a narrow range of moisture contents. Experience of similar soil types is the best guide.

An attempt to calibrate soil tending towards a very wet state is given in Figure 14 and one tending towards a very dry state in Figure 15. In the former the number of points obtained is insufficient for good calibration. In the latter two lines are apparent, that with a positive slope resulting from the relatively low MCVs. Positive slopes of this nature are referred to as the 'ineffective' part of the calibration line, and are at least in part due to the complex relationship between interparticular friction and moisture content.

Testing of freely-draining soils, usually uniformly graded sands and gravels, will give most trouble. In contract terminology they are classed as 'all weather' materials which will not develop excess pore water pressures during compaction. Calibration of such soils should not be attempted. A simple method of recognising such soils is to use the MCV test on a sample in a saturated state (Section 3.3.2).

Except for the determination of intercept it is important not to extrapolate calibration lines beyond established limits. Such extrapolation can hide the effect of high permeability and the existence of an ineffective part to the line.

The characteristics of calibration lines as described above are shown diagrammatically in Figure 16.

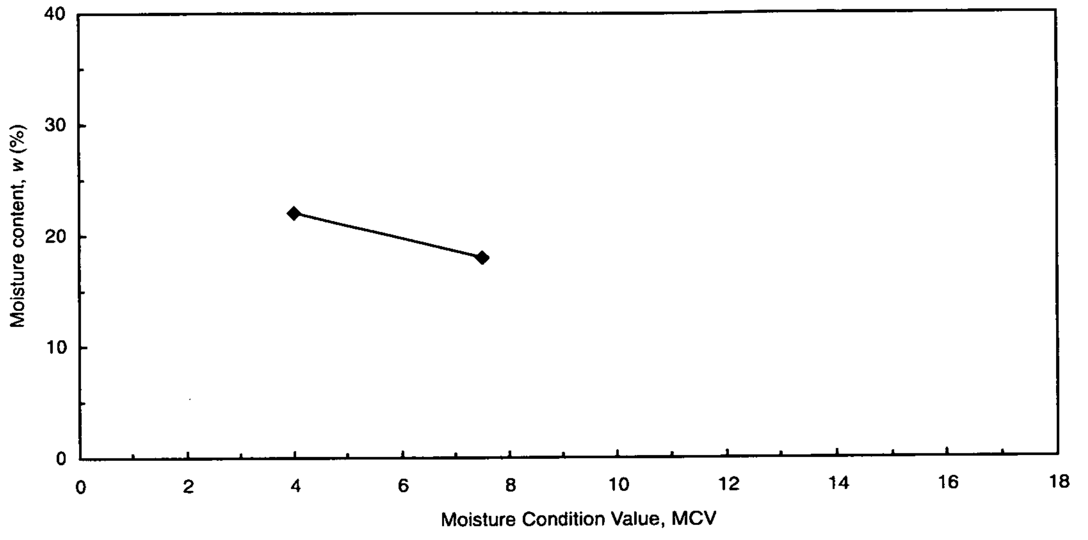

Fig. 14 Calibration line determined under relatively wet conditions

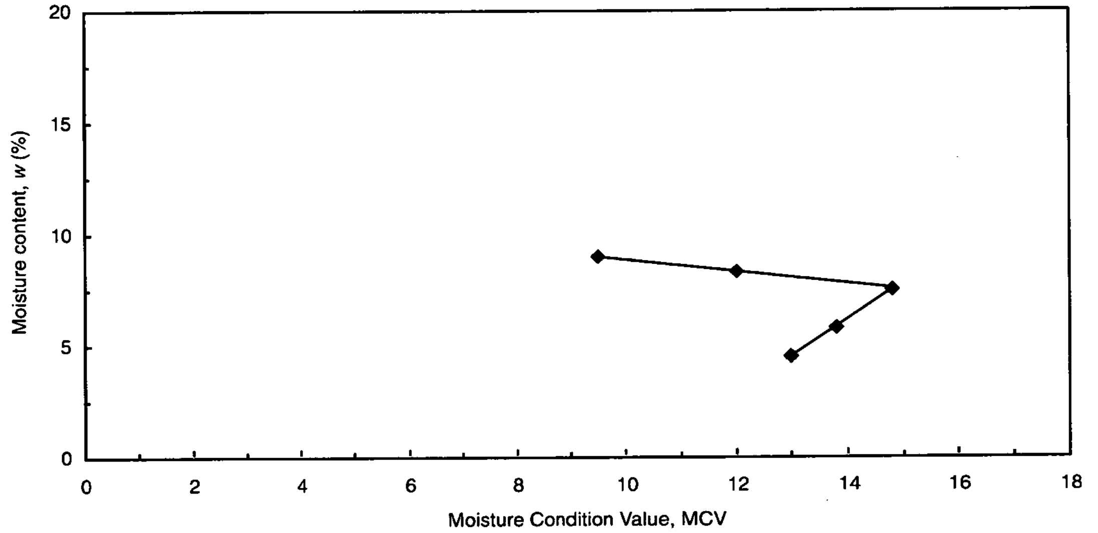

Fig. 15 Calibration line determined under relatively dry conditions

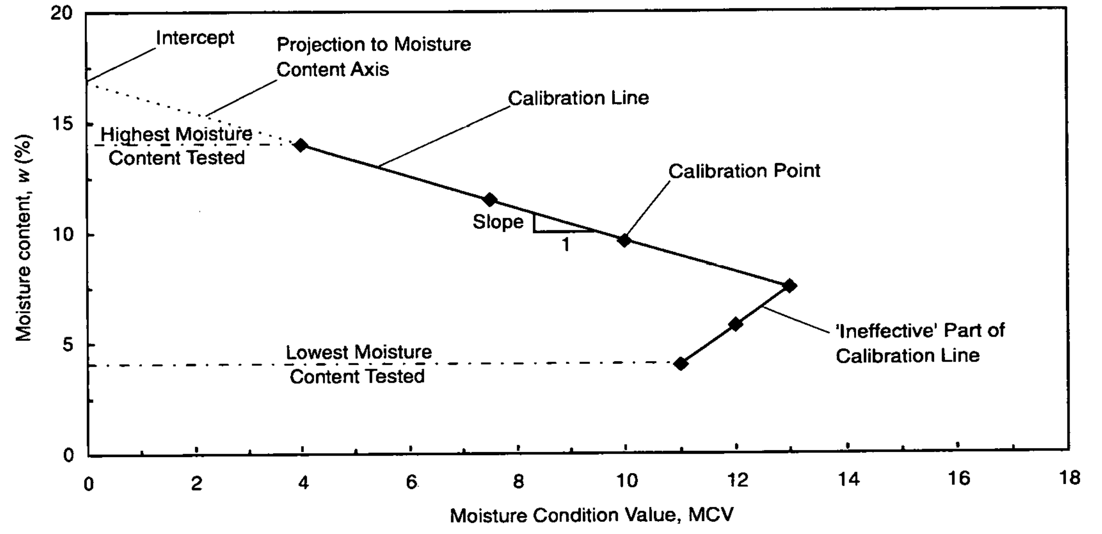

Fig. 16 Calibration line determined under relatively dry conditions

4 APPLICATION

4.1 GROUND INVESTIGATION

The objective of using the Moisture Condition Apparatus at the ground investigation stage is to allow recognition of those soils likely to cause problems during construction and to prepare calibration lines for later use. The existence of a calibration line for the soil type considerably speeds up determination of unacceptability immediately prior to and during earthworking.

To define a calibration line the intercept on the moisture content axis, the slope and limits of the line, including any ineffective part, are required. The higher the intercept the greater the potential of the soil to retain moisture in a state of very low compaction, the lower the slope of the line the more sensitive the soil is to moisture content changes. This forms the basis of a useful classification for earthworking purposes and clearly allows differentiation of those soils particularly sensitive to moisture content changes. It is suggested that this information is vital to efficient earthworking. A slope-intercept plot should be made from all calibration lines obtained. This will allow easy differentiation of the relative sensitivity of soils to moisture content change. An example of such a plot, including a grouping of the soil types according to sensitivity, is given in Figure 17.

Early recognition of those soils in the 'all weather' category is important. Attempted calibration testing of freely-draining material is not recommended.

In terms of the calibration line, increasing permeability restricts the low end of the range of MCV values obtained during calibration. A freely draining 'all weather' material is one in which MCVs below the specified limit for the Contract cannot be obtained during testing no matter how much water is added to the sample during preparation. If an MCV equal to or greater than the specified limit is obtained then the permeability of the material is such that pore water pressures are dissipating quickly and that no loss in shear strength is experienced during compaction. It is suggested that a test in a saturated state be carried out on all granular soils before calibration is attempted. It is important to note that materials classified as 'free-draining' must be used in freely draining environments. Classification of soils in categories as defined in Section 1 should be carried out at an early stage.

The need to obtain calibration lines on all soil types with a potential acceptability problem is of vital importance if on-site testing of acceptability is envisaged during construction. The presence of an ineffective part to the calibration line can make the interpretation erroneous if its presence is not realised as a single MCV value could have two possible moisture content equivalents.

4.2 EARTHWORKING

Earthworking can be divided into earthmoving and compaction. In earthmoving soil is excavated, transported and deposited in a disturbed state some distance from its source. When used as fill, it is then formed according to the design and strengthened by compaction until it is capable of withstanding the stresses of the expected loading. Both processes are essential features of any construction contract and require separate treatment for MCV application.

4.2.1 Earthmoving

Glacial tills are prevalent in Scotland and common in most northern parts of the remainder of the United Kingdom, often having a relatively high proportion of cobbles and boulders. Problems of working mainly arise from a loss of shear strength in the matrix. The MCV test is performed on a sieved sample corresponding to the matrix of such soils and consequently is successful in predicting acceptability for earthmoving.

Under site conditions earthmoving plant operate either on soil in a naturally compacted or in a disturbed state. Depending on plant size, compaction of both the in-situ and the disturbed soil is likely to take place. Under wet conditions significant reductions in shear strength can result. The economics of making use of on-site soils are critically dependant on the selection of appropriate plant for the soil conditions.

The productivity of various types of earthmoving plant has been related to the soil conditions measured by means of the moisture condition test (Parsons and Daley, 1982). Factors that have been related to the MCV include speed of travel when loaded and empty, depth of rut produced by a single pass, loss of productivity due to bogging down, and the times of loading and unloading. Minimum MCV values at which various types of plant can operate effectively have also been predicted and a formula derived which relates MCV to travel speed of motorised scrapers and dump trucks.

4.2.2 Compaction

The disturbed soil is used in a series of layers as fill to form earth structures such as embankments. Each layer is compacted after placement with the prime intention of decreasing its air voids and consequently increasing its density and shear strength. Generally the maximum bulk density at the natural moisture content is targeted. To assist plant operation the Specification for Highway Works (MCHW 1: Table 6/4) tabulates the compactive effort required in terms of the number of passes and layer thickness for different types of plant.

The process of taking a disturbed soil and compacting it to its maximum possible density is followed in the moisture condition test. The test therefore broadly simulates con-

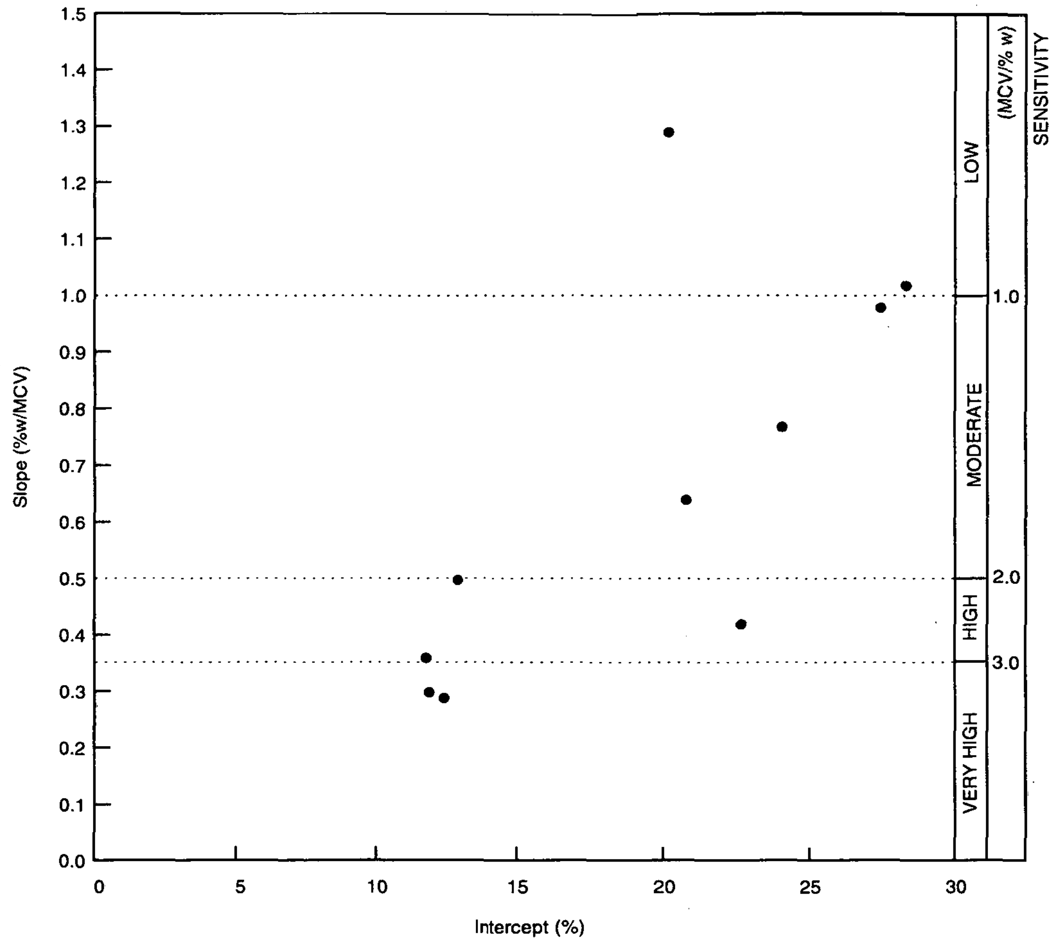

Fig. 17 Plot of MCV calibration line slope versus intercept

struction compaction to measure the potential MCV. Consequently on-site MCV testing allows acceptability for compaction to be determined and indicates the compactive effort required to produce a state of near full compaction. As already discussed (Section 2) a soil in a relatively dry state will require higher compactive effort to achieve compaction than one in a relatively wet state. Indeed once the moisture content drops below a particular level it may not be possible to compact it sufficiently using reasonable compactive effort. De-watering or stockpiling may be necessary in very wet soils. Such requirements can be predicted by the use of the MCA.

The MCA indicates the potential shear strength (in terms of MCV) of a 1.5kg sample passing a 20mm sieve. In soils containing a very coarse fraction an increase in the overall shear strength can be expected after incorporation into an earth structure such as an embankment. An increase in overall shear strength beyond that predicted by the MCV test can therefore be expected when using materials with high cobble and boulder contents - providing that near maximum bulk density is achieved. It may be necessary to increase the compactive effort due to the effect of the large boulders, or it may be possible to use material at a lower MCV than normal.

5 RECOMMENDED PROCEDURES

5.1 GROUND INVESTIGATION

Testing should be carried out on each major variety of soil likely to prove problematical in terms of acceptability. Calibration lines should be drawn up for each soil type. A plot of Slope against Intercept will enable the most problematical soils (those with the highest sensitivity) to be recognised (Figure 17). Calibration lines are important in the characterisation of the relationship between MCV and moisture content and can be the basis of any subsequent moisture condition testing for acceptability.

Samples taken for testing must be representative. Bulk samples formed by combining smaller samples may not reflect either the true properties of the components or the performance of the material during earthworking.

MCV tests carried out on samples as they are obtained during ground investigation will give an indication as to the existing acceptability provided that the sample is representative and at its natural moisture content. However, such results should be used with caution as natural moisture contents are likely to vary considerably both in the host soil and in the period between ground investigation and contract earthworking.

Recommendations should be made in the ground investigation interpretative report regarding the MCV lower and upper limit(s) for acceptability in the contract. It is important when setting these figures to be realistic and to allow the maximum use of on-site materials as well as taking into consideration the type of plant a competent contractor could be expected to use. Estimates of the quantities of acceptable and unacceptable materials will of course depend on the accuracy of the MCVs at natural moisture content and the variations occurring between ground investigation and contract working. Seasonal, climatic, local and other possible variations in weather and moisture content must therefore be taken into consideration. Smith *et al.* (1993) have shown that it is possible to successfully forecast the MCV at the earthworking stage from ground investigation data. Work in this area is ongoing with the intention of producing computer software to aid the planning and execution of earthworking operations, including the estimation of quantities of acceptable and unacceptable fill materials.

As a general guide an MCV of 8.5 is recommended as the lower limit of acceptability; a soil having an MCV less than this limit is thus deemed unacceptable. Specific conditions may however require that the 8.5 limit be lowered or raised marginally. In addition, flexibility to marginally alter the limit on the contract should be allowed for. This decision should be the responsibility of the Designer and be based on the local situation, the known behaviour of the material and the type of plant proposed and used by the Contractor. The possibility of adjustments to the lower limit of acceptability requires a continuous appreciation of the earthworks situation during construction. The Designer should be satisfied that the material is capable of forming a stable fill and will not impair the satisfactory operation of the construction plant at the revised lower limit of acceptability. It is strongly recommended that variations from the conventional lower limit of MCV=8.5 be supported by adequate, appropriate and robust test data. Alternative lower limits of acceptability are unlikely to fall outside the range $7.5 \leq MCV \leq 9.0$.

For cohesive soils maximum MCVs of 12.5 and 11.5 roughly correspond to the moisture contents at which 10% and 5% air voids, or less, would be achieved. The equivalent maximum MCV for granular soils will be higher: for example, a well graded sand will have a maximum MCV of 14.5 to achieve 10% air voids, or less. In general, an upper limit of MCV in the range 14 to 15 is found to be suitable for use with most glacial tills.

It is important to realise that the MCV test indicates the potential acceptability of material in a drained condition. Attempts to conduct earthmoving in an environment where moisture cannot escape - such as found in conditions of closed drainage - can fail even though saturation tests showed MCVs above the specified limit. Excessively high moisture contents in 'all weather' materials may indicate the need for advanced drainage prior to earthworking.

A flowchart of the recommended procedure for ground investigation is given in Figure 18.

5.2 EARTHWORKING

Difficulties in earthworking of most soils should be expected when the MCV drops below the lower limit(s) set for the contract. Soils having MCVs of equal to or above this limit will generally be able to be moved and compacted satisfactorily, provided that their MCV is not so high as to impede the compaction process.

The procedure recommended is to study the existing calibration line for the soil type and then to conduct single MCV determinations whenever and wherever a measure of acceptability is required. As already indicated this can be carried out under site conditions within 6 to 10 minutes. The need to refer MCV points to a calibration line has been pointed out in Section 4.1.

Familiarity with each soil type considerably facilitates the interpretation and use of MCV test results. Even faster MCV test techniques (2 to 3 minutes) are possible (Appendix A, Section A6). Such rapid techniques are not recommended until familiarity with the soil type has been obtained. It should also be noted that the rapid technique is approximate and does not determine the MCV - only the acceptability or otherwise of the soil.

It is suggested that appropriate times for the testing of soils during earthworking could be as follows:

1 Prior to earthmoving.

2 During earthmoving.

3 Prior to use on haul roads.

4 During trafficking of haul roads.

5 At intervals on stockpiled material.

6 Prior to compaction - on fill material ready for compaction.

7 Prior to fill placement - on previously compacted surfaces.

A flowchart of the recommended procedure during earthworking is given in Figure 19.

Specifications for earthworks generally recommend that MCV tests are carried out at the rate of one or two per $1000m^3$ of general fill (up to a maximum of five tests per day) and one per 400 tonnes of selected fill (HA44 - DMRB 4.1.1). However, the scale of testing depends on the size of the contract, variability of the material and how critical the results are to the design. Consequently, this information is given only as a guide and it is important that a high degree of engineering judgement is exercised in such matters. In particular, if the materials are known to be of marginal acceptability then the frequency of testing may need to be increased.

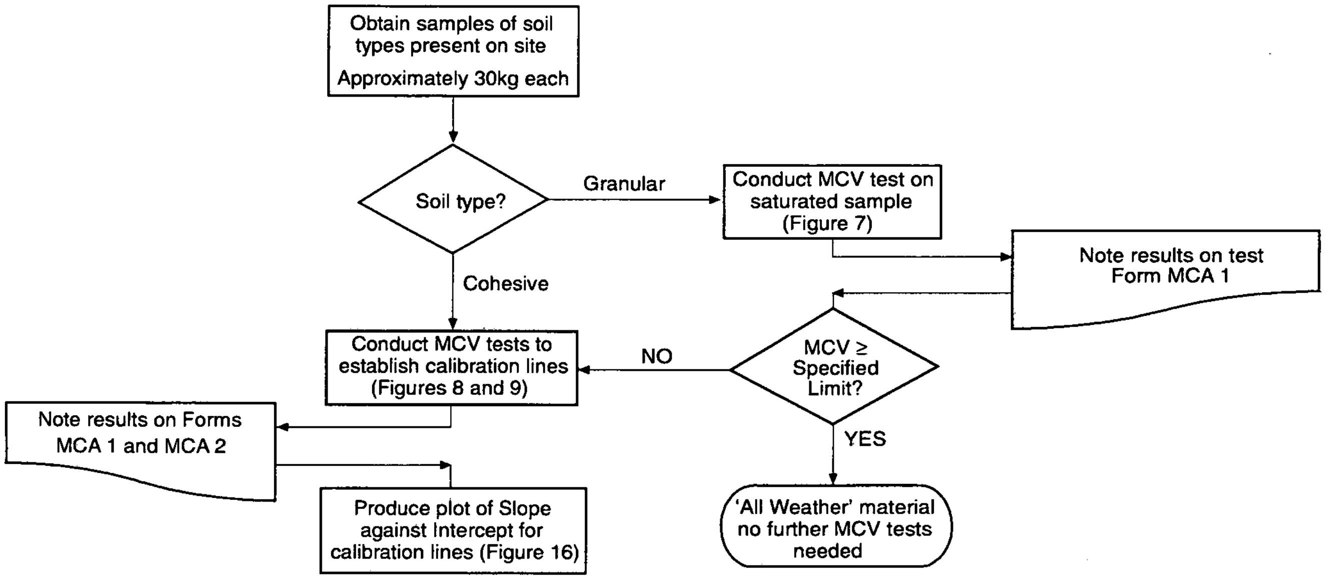

Fig. 18 Use of the MCA in ground investigation

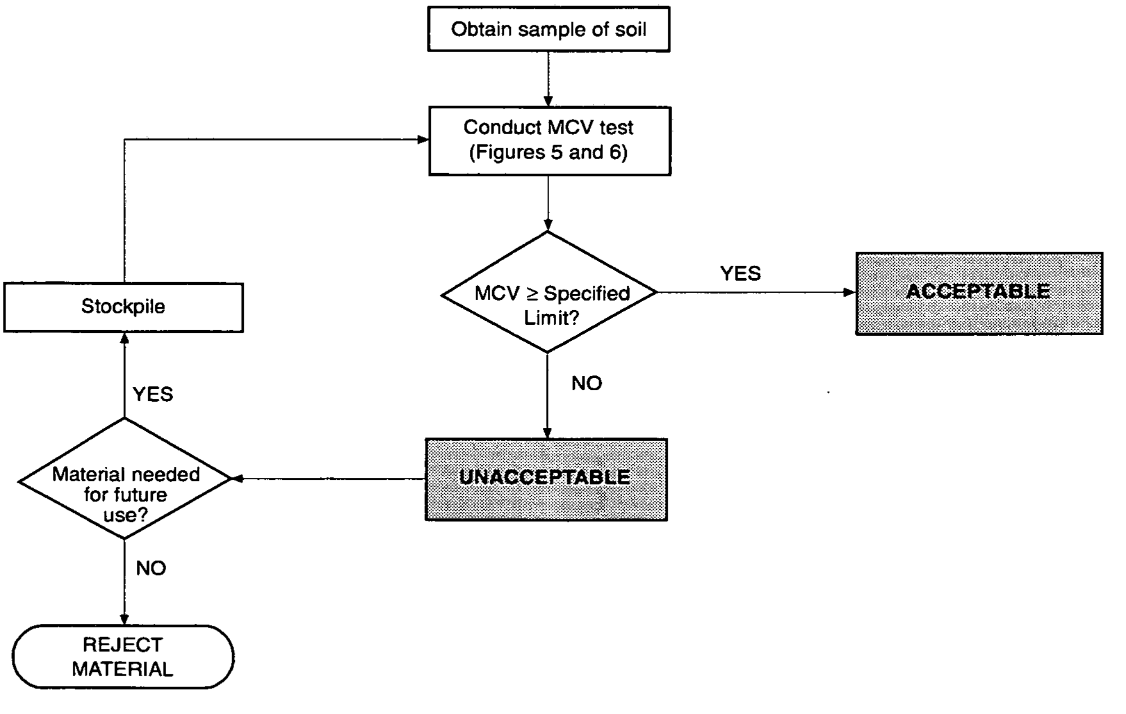

Fig. 19 Use of the MCA in earthworking

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APPENDIX A: INSTRUCTIONS FOR MOISTURE CONDITION TESTING

A1 EQUIPMENT REQUIRED

1.1. A moisture condition apparatus and mould as described by Parsons (1976).

1.2. A circular fibre disc, 99mm diameter and 5mm thick

1.3. A 9mm vernier scale accurate to 0.1mm, or a depth gauge of the same accuracy.

1.4. A balance readable to 2.5kg and accurate to ±20g.

1.5. A 20mm British Standard (BS) test sieve and receiver.

1.6. A metal tray (a convenient size is 600mm x 500mm x 80mm deep).

1.7. Apparatus for extracting specimens from the mould.

1.8. Forms MCA1 and MCA2 for recording and plotting results (Appendix B).

A2 CHECKS PRIOR TO TESTING

2.1. Prior to a series of tests the apparatus should be checked for the features described in Paragraphs 2.2 to 2.6.

2.2. The height of drop of the rammer is 250mm. This can be easily achieved by laying the apparatus on its side and resting the upper cross member on a suitable support such as a spare sample mould. The retaining pin is removed and the rammer and the sliding cross member is moved a short distance down along the guide rods. The rammer and sliding cross member are then pulled gently upwards along the guide rods until the automatic catch just releases the rammer. The distance between the top mark on the vernier scale on the rammer guide and the zero mark on the vernier support rod scale is then the drop height. The height can be adjusted by loosening the screw clamping the vernier support rod to the striker support cross member and sliding the rod through the clamp as necessary.

2.3. The rammer falls freely and does not foul the mould during descent.

2.4. The drop height vernier is securely fastened to the vernier support rod.

2.5. All the socket head screws on the apparatus are secure.

2.6. The vernier support rod is securely held by the clamp. This should be checked before each test.

A3. DETERMINATION OF MCV

A3.1 Procedure

3.1. Information on site, date, sample number, soil type and fines content shall be recorded on Form MCA1 in the appropriate places.

3.2. The soil shall be passed through a 20mm BS sieve, removing only individual particles coarser than 20mm, and a 1.5kg±20g sample taken. Note the proportion retained by the sieve on Form MCA1 under Evaluation (Part 3).

3.3. The 1.5kg sample shall be placed loosely in a clean mould (the soil may be pushed into the mould if necessary) and the fibre disc placed on top of the soil.

3.4. With the sliding cross member and rammer held in the raised position by the retaining pin, the mould shall be placed in the recess on the base of the apparatus and clamped in position.

3.5. The sliding cross member supporting the rammer shall be held steady and the retaining pin removed. The rammer shall then be lowered gently on to the fibre disc and allowed to penetrate into the mould under its own weight until it comes to rest.

3.6. The counter shall be zeroed.

3.7. The height of the drop shall be set at 250mm by moving the striker support cross member to give an approximate zero (±5mm) on the drop height vernier scale.

3.8. The sample shall then be given one blow of the rammer by raising the sliding cross member with rammer attached until the rammer is released by the automatic catch.

3.9. The penetration of the rammer into the mould shall be measured by using the vernier scale provided and the drop height vernier re-zeroed by adjusting the striker support cross member. The measurement shall be recorded against one blow under the correct sample number on Form MCA1 (Part 1). Alternatively a depth gauge can be used and the protrusion of rammer from the mould measured.

3.10. The process shall then be repeated with readings of penetration being taken after selected numbers of blows, and the drop height vernier re-zeroed as necessary until the change in penetration between B and 4B blows is less than 5mm. The results shall be recorded in the appropriate positions on Form MCA1 (Part 1).

3.11. The rammer attached to the sliding cross member shall then be carefully raised and the retaining pin inserted.

3.12. The mould shall be unclamped from the apparatus, its base removed and the specimen extracted.

3.13. The mould and base of the rammer shall be cleaned ready for further testing.

3.14. If samples from the same site are tested on the same day up to six test results can be recorded on the same form.

A3.2 Calculations

3.15. The change in penetration between any given number of blows, B, and four times that number of blows (e.g., 1 and 4, 2 and 8, etc.) shall be calculated and recorded on Form MCA1 (Part 1).

3.16. The above change in penetration shall be plotted against the initial number of blows (B) on Form MCA1 (Part 2).

3.17. A best-fit line shall be drawn through the points.

3.18. The intersection of the best-fit line or, in cases where the 5mm line is not crossed, the steepest possible extrapolation of this line, with the 5mm line shall be determined.

3.19. The MCV is then defined to the nearest 0.1 units, as $10\log_{10}(B)$, where B is the number of blows at which the change in penetration equals 5mm, as read from the best-fit line. MCV may be read directly by projection onto the horizontal axis on the plot.

3.20. Information as to the sample number, MCV determined and the inferred acceptability should be summarised on Form MCA1 (Part 3) with any comments.

A4 DETERMINATION OF MCV AFTER SATURATION

4.1. A 2.5kg sample of the soil passing a 20mm sieve shall be taken.

4.2. The sample shall be placed in a suitable container, water added, and the sample mixed until excess water is evident after it is allowed to stand for a short period (e.g., 1 minute).

4.3. An MCV determination on a 1.5kg±20g sample of the saturated soil shall then be carried out in accordance with Section A3 (Paragraphs 3.3 to 3.13). Water seepage during the testing should be ignored.

4.4. The MCV of the sample shall then be calculated according to Section A3 (Paragraphs 3.15 to 3.19). This is the MCV at maximum moisture content under drained conditions.

A5 CALIBRATION TESTING

A5.1 Procedure

5.1. The site and date shall be recorded on both Form MCA1 and Form MCA2.

5.2. Information as to the location of the bulk sample and the soil type shall be recorded on MCA2.

5.3. A sample (approximately 25kg) of the soil to be tested shall be air dried.

5.4. The sample shall be passed through a 20mm BS test sieve, removing only individual particles coarser than 20mm. Note the proportion retained by the sieve on form MCA2 (Part 6). With cohesive soils a mortar and rubber pestle may have to be used to break up the soil before sieving.

5.5. At least four, and preferably six, 2.5kg samples of soil shall be taken. The samples shall be mixed thoroughly with different amounts of water to give a suitable range of moisture contents. The moisture contents should be such as to give MCVs between 3 and 15. Sample numbers and estimated moisture contents should be recorded on Form MCA 2 (Part 1). These sample numbers shall also be recorded on Form MCA1 (Part 1).

5.6. For granular soils (fines < 18%) the 2.5kg sample shall be reduced to 1.5kg±20g and may be tested immediately. For cohesive soils (fines > 18%) the 2.5kg sample shall be allowed to lie in a sealed container for at least 24 hours after mixing with the calculated amount of water to ensure uniform moisture distribution. The sample shall then be passed through a 20mm sieve ensuring that any aggregations of clay are broken down before being reduced to 1.5kg±20g prior to testing.

5.7. The MCV of each sample shall be determined according to Section A3 using Form MCA1 (Parts 1 and 2). A summary of sample number and MCV should be made on Form MCA1 (Part 3) and any relevant comments added. Particular attention should be made to the validity of MCVs as described in Section 3.4.3 in the main text.

5.8. After each test the mould shall be unclamped from the apparatus and its base removed. The specimen shall then be extracted from the mould and placed on a metal tray and the moisture content determined in accordance with BS 1337: Part 2 (British Standards Institution, 1990c). Results shall be recorded on Form MCA2 (Part 2) and the relationship of MCV and true moisture content summarised on Form MCA2 (Part 3). At least four and, if possible six, tests should be carried out for each calibration line.

A5.2 Calculations

5.9. The moisture content of each sample shall then be plotted against MCV on Form MCA2 (Part 4). The best straight line through points lying on the true part of the calibration should then be calculated and drawn on Form MCA2 (Part 4). The intercept, slope and correlation coefficient should be recorded on Form MCA2 (Part 5). (Most modern scientific calculators include a program to calculate the regression line intercept, slope and correlation coefficient.) It is important to note that this may not be the best straight line through all the points present. The line drawn shall not be extrapolated outwith the plotted points at this stage.

5.10. The intercept on the moisture content axis shall then be drawn by extrapolation. Any extrapolation should be clearly distinguishable from the calibration line.

5.11. The sensitivity shall then be calculated and recorded on Form MCA2 (Part 5).

5.12. Relevant comments can be recorded on Form MCA2 (Part 6). Additional information can be written on the back of the Form.

5.13. Form MCA2 shall be attached to Form MCA1, Form MCA2 in front.

A6 RAPID DETERMINATION OF ACCEPTABILITY

6.1. This method should only be used when familiarity with the soil type has been gained. It does not determine the MCV of the sample.

6.2. The number of blows (B) corresponding to the specified MCV limit of acceptability shall be calculated or read off Form MCA1. B should be rounded up to the nearest integer value.

6.3. The sample shall be prepared according to Section 3.3.1.1 of the main text.

6.4. The sample shall be given one blow of the rammer by raising the cross member with rammer attached until the rammer is released by the automatic catch.

6.5. The vernier shall be re-zeroed to correct the height of drop for the decrease in height of the sample.

6.6. Further blows shall be applied, resetting the height of drop as necessary, until B blows have accumulated. The penetration of the rammer into the mould after the initial B blows shall be measured and recorded.

6.7. The striker support cross member shall then be adjusted to give an approximate zero reading on the drop height vernier scale.

6.8. Further blows shall then be applied until the total reaches 4B, without any further adjustment of the striker support cross member.

6.9. The rammer vernier scale shall be accurately read and the penetration of the rammer into the mould after 4B blows recorded. The difference between the initial and final readings shall be calculated. A difference of more than 5mm indicates that the soil is acceptable, a difference of less than 5mm indicates that it is unacceptable. The results of the test should be recorded on Form MCA1.

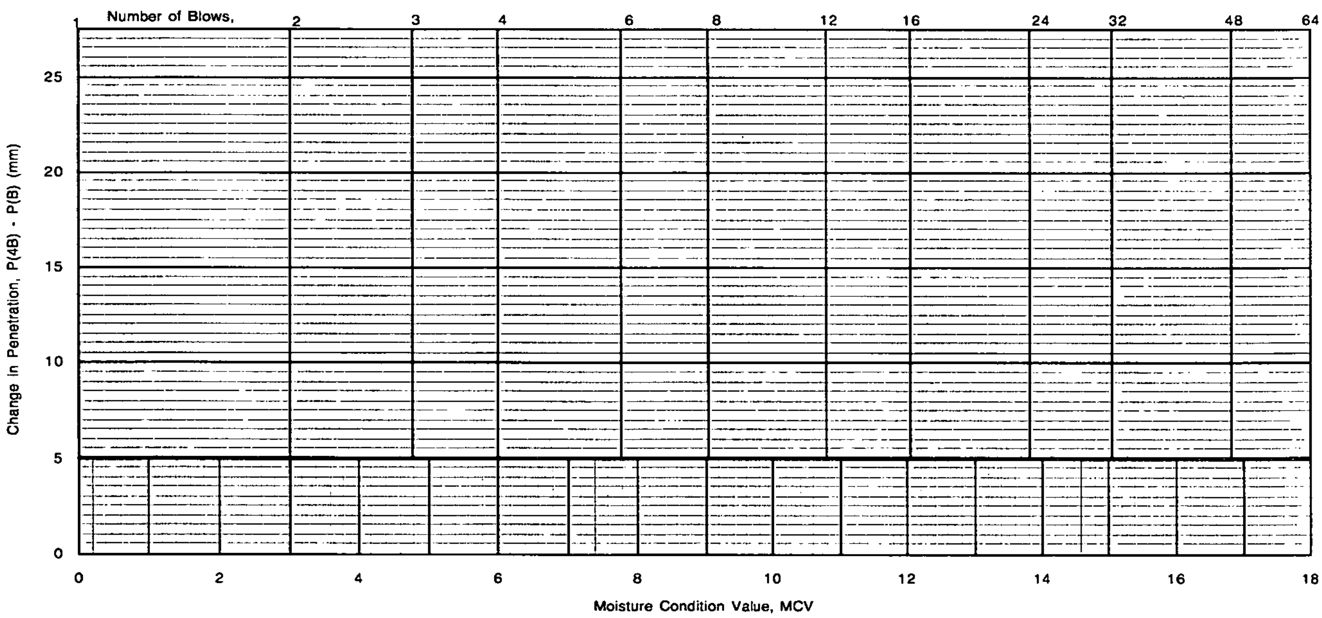
APPENDIX B: FORMS MCA1, MCA2 AND MCA3

MCV TESTING SITE ______________________ Form MCA 1

1. PENETRATION MEASUREMENTS DATE ______________

SAMPLE NO.												
SOIL TYPE												
NUMBER OF BLOWS, B	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)
1												
2												
3												
4												
6												
8												
12												
16												
24												
32												
48												
64												
96												
128												
192												
256												

2. CHANGE IN PENETRATION PLOTS



3. EVALUATION

SAMPLE NO.	MCV	ACCEPTABLE/UNACCEPTABLE	FINES CONTENT	COMMENTS

MCV TESTING

Form MCA 2

SITE ______________ Bulk Location ______________ Fines Content ______________

1. SAMPLE DETAILS

Soil Type ______________ DATE ______________

SAMPLE NO.						
ESTIMATED MOISTURE CONTENT						

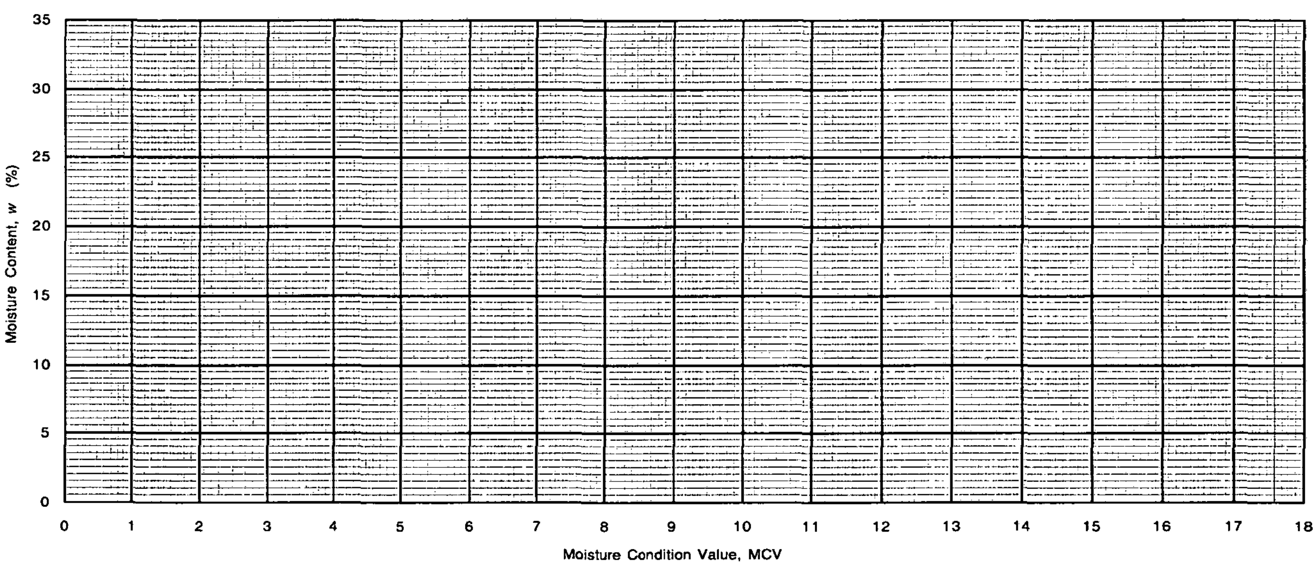
2. MOISTURE CONTENT DETERMINATION (after MCV testing)

CONTAINER NO.						
CONTAINER MASS (C)						
MASS OF WET SOIL AND CONTAINER (W)						
MASS OF DRY SOIL AND CONTAINER (D)						
MOISTURE CONTENT, w = ((W-D)/(D-C))*100						

3. MOISTURE CONDITION VALUES AND MOISTURE CONTENTS

MCV (from Form MCA 1.3)						
MOISTURE CONTENT (from Form MCA 2.2)						

4. CALIBRATION LINE



6. CHARACTERISTICS OF CALIBRATION LINE

INTERCEPT (extrapolation to moisture content axis) in %	
SLOPE (tangent of the angle between calibration line and MCV axis) in % *w* /MCV	
SENSITIVITY (1/Slope) in MCV/%*w*	
CORRELATION COEFFICIENT	

7. COMMENTS

MCV TESTING

Form MCA 3

The Contractor is required to provide a test certificate to show that each Moisture Condition Apparatus is functioning correctly. Test certificates for MCA function are normally valid for six months or until the end of the Contract.

TESTING COMPANY ____________ CONTRACT ____________ MCA REFERENCE ____________

1. MASS OF RAMMER ASSEMBLY

Mass = ____________ g	Specification: 7000g±50g	ACCEPT	REJECT

2. TIGHTNESS OF FITTINGS

ACCEPT	REJECT

3. FOULING BETWEEN RAMMER AND MOULD

ACCEPT	REJECT

4. RAMMER ASSEMBLY SPEED OF DROP (TICKER TIMER)

READING NUMBER	DISTANCE OF FREE FALL			THEORETICAL SPEED OF DROP	ACTUAL SPEED OF DROP
	s_1 (mm)	s_2 (mm)	s_3 (mm)	$V_T = (2*9.81 s_2)$ (m/s)	$V_A = (s_3 - s_1)/0.04$ (m/s)
1					
2					
3					
4					
5					
MEAN					

5. PERCENTAGE DIFFERENCE BETWEEN V_T AND V_A

Percentage Difference, $V_P = 100\%*(V_T - V_A)/V_T$ = %	Specification: ±6%	ACCEPT	REJECT

The MCA Reference Number ______________ is accepted/rejected for use on the above contract.

Signed ______________________________

Company ______________________________

Date ______________________________

APPENDIX C: EXAMPLES OF MCV TESTING

C1 CALIBRATION TEST ON SILTY SANDY CLAY

MCV TESTING **Form MCA 2**

SITE M876 **Bulk Location** Baxter Cut Ch4+80 **Fines Content** 26%

1. SAMPLE DETAILS **Soil Type** Sandy silty CLAY with gravel **DATE** 4/7/79

SAMPLE NO.	1	2	3	4	5	
ESTIMATED MOISTURE CONTENT	21%	18%	15%	13%	11%	

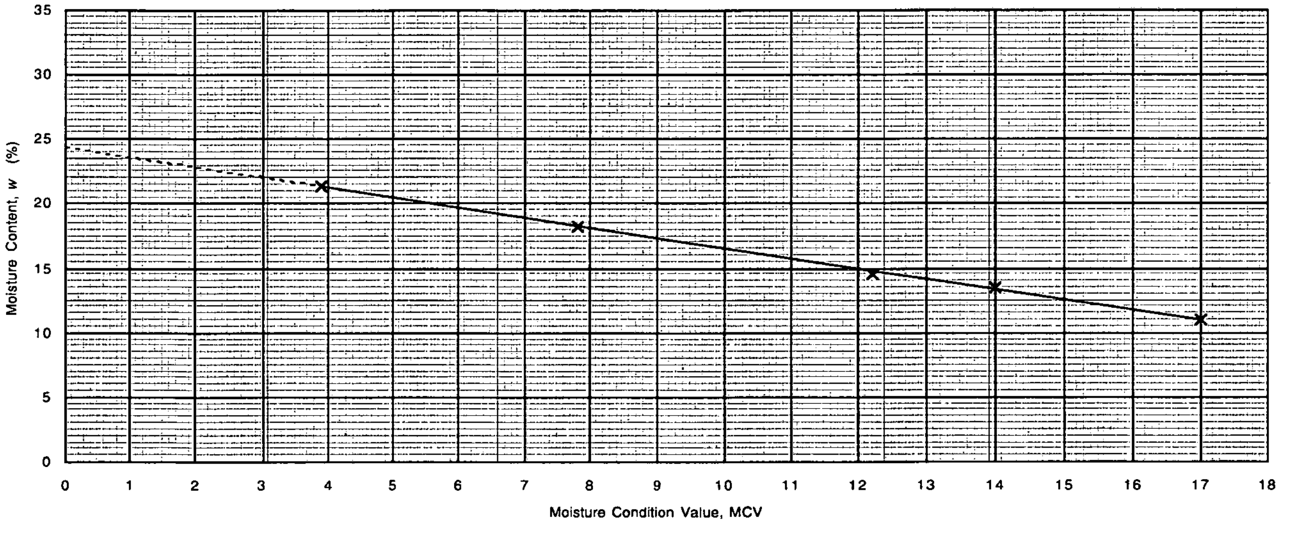
2. MOISTURE CONTENT DETERMINATION (after MCV testing)

CONTAINER NO.	71	72	73	74	75	
CONTAINER MASS (C)	496g	495g	497g	496g	496g	
MASS OF WET SOIL AND CONTAINER (W)	1989g	1985g	1982g	1985g	1980g	
MASS OF DRY SOIL AND CONTAINER (D)	1726g	1755g	1793g	1808g	1833g	
MOISTURE CONTENT, w =((W-D)/(D-C))*100	21.4	18.3	14.6	13.5	11.0	

3. MOISTURE CONDITION VALUES AND MOISTURE CONTENTS

MCV (from Form MCA 1.3)	3.9	7.8	12.2	14.0	17.0	
MOISTURE CONTENT (from Form MCA 2.2)	21.4	18.3	14.6	13.5	11.0	

4. CALIBRATION LINE



6. CHARACTERISTICS OF CALIBRATION LINE

INTERCEPT (extrapolation to moisture content axis) in %	24.4
SLOPE (tangent of the angle between calibration line and MCV axis) in % w /MCV	-0.791
SENSITIVITY (1/Slope) in MCV/%w	1.264
CORRELATION COEFFICIENT	0.999

7. COMMENTS Good calibration line, no 'ineffective' part.

MCV TESTING

SITE M876

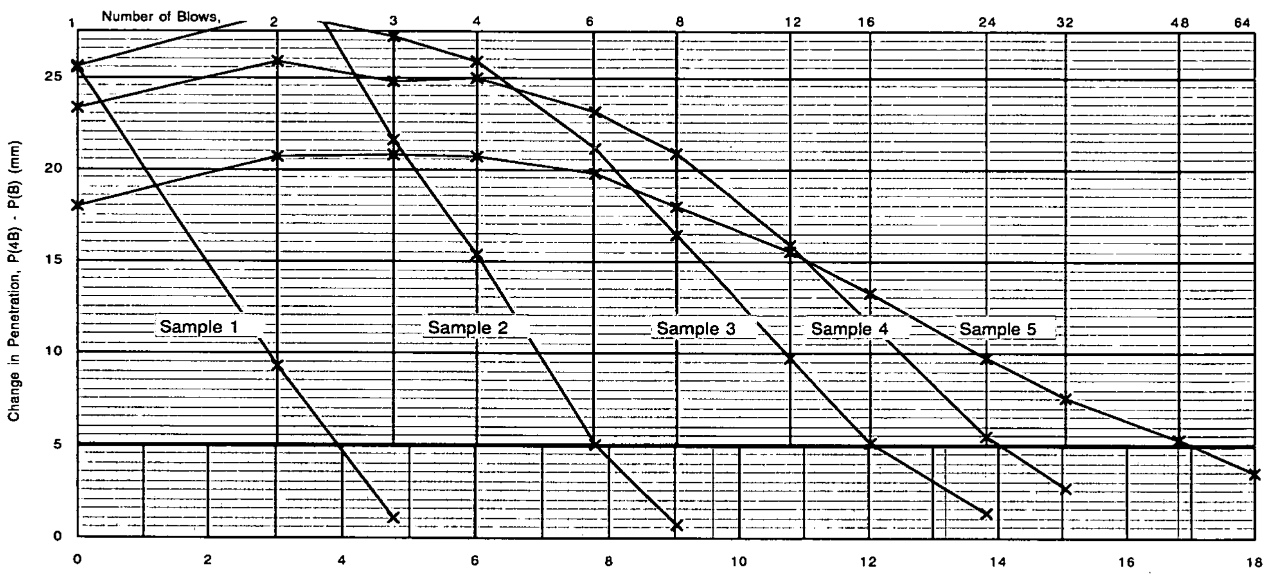
Form MCA 1

1. PENETRATION MEASUREMENTS

DATE 4/7/79

SAMPLE NO.	1		2		3		4		5			
SOIL TYPE	Sandy silty CLAY with gravel		As 1		As 1		As 1		As 1			
NUMBER OF BLOWS, B	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)
1	71.1	25.5	50.5	34.2	47.2	25.6	44.5	23.3	47.8	18.0		
2	87.3	9.3	67.2	32.2	58.8	28.5	55.1	25.9	55.8	20.7		
3	95.6	1.1	78.2	21.6	66.8	27.2	63.2	24.8	61.6	20.8		
4	96.6		84.7	15.4	72.8	25.9	67.8	25.0	65.8	20.7		
6	96.6		95.0	5.1	81.3	21.2	75.8	23.2	71.9	19.8		
8	96.6		99.4	0.7	87.3	16.5	81.0	20.9	76.5	18.0		
12	96.7		99.8		94.0	9.8	88.0	15.9	82.4	15.6		
16			100.1		98.7	5.2	92.8	11.7	86.5	13.3		
24			100.1		102.5	1.4	99.0	5.5	91.7	9.8		
32			100.1		103.8		101.9	2.7	94.5	7.6		
48					103.8		103.9		98.0	5.3		
64					103.9		104.5		99.8	3.5		
96					103.9		104.5		101.5			
128							104.6		102.1			
192									103.3			
256									103.3			

2. CHANGE IN PENETRATION PLOTS



3. EVALUATION

SAMPLE NO.	MCV	ACCEPTABLE/UNACCEPTABLE	FINES CONTENT	COMMENTS
1	3.9		26%	
2	7.8		26%	
3	12.1		26%	
4	14.0		26%	
5	17.0		26%	

C2 CALIBRATION TEST ON SILTY SANDY TILL

MCV TESTING **Form MCA 2**

SITE A9 Calvine-County Boundary **Bulk Location** Ch25+80 **Fines Content** 20%

1. SAMPLE DETAILS

Soil Type Silty sandy TILL **DATE** 18/5/78

SAMPLE NO.	1	2	3	4	5	6
ESTIMATED MOISTURE CONTENT	5%	6%	7%	8%	9%	11%

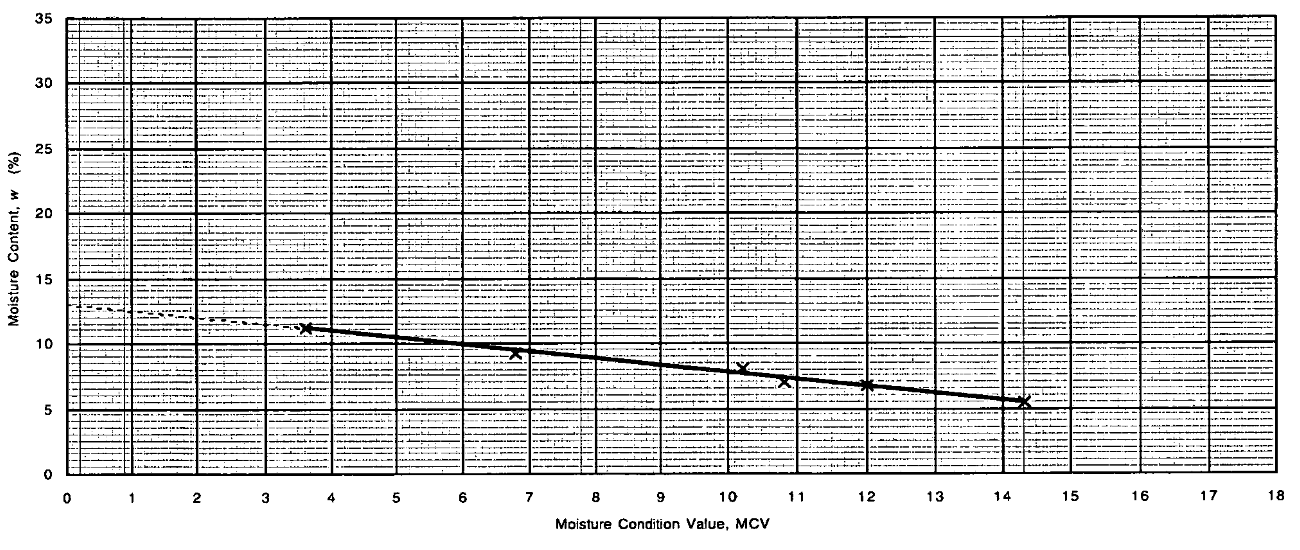
2. MOISTURE CONTENT DETERMINATION (after MCV testing)

CONTAINER NO.	100	101	102	103	104	105
CONTAINER MASS (C)	501g	498g	501g	502g	501g	499g
MASS OF WET SOIL AND CONTAINER (W)	2082g	2088g	2101g	2117g	2130g	2163g
MASS OF DRY SOIL AND CONTAINER (D)	2001g	1988g	1996g	1997g	1993g	1995g
MOISTURE CONTENT, w =((W-D)/(D-C))*100	5.4	6.7	7.0	8.0	9.2	11.2

3. MOISTURE CONDITION VALUES AND MOISTURE CONTENTS

MCV (from Form MCA 1.3)	14.3	12.0	10.8	10.2	6.8	3.6
MOISTURE CONTENT (from Form MCA 2.2)	5.4	6.7	7.0	8.0	9.2	11.2

4. CALIBRATION LINE



6. CHARACTERISTICS OF CALIBRATION LINE

INTERCEPT (extrapolation to moisture content axis) in %	13.1
SLOPE (tangent of the angle between calibration line and MCV axis) in % w /MCV	-0.533
SENSITIVITY (1/Slope) in MCV/%w	1.877
CORRELATION COEFFICIENT	0.992

7. COMMENTS

Sample 6 MCV obtained by short extrapolation to 5mm line. No 'ineffective' part of calibration line.

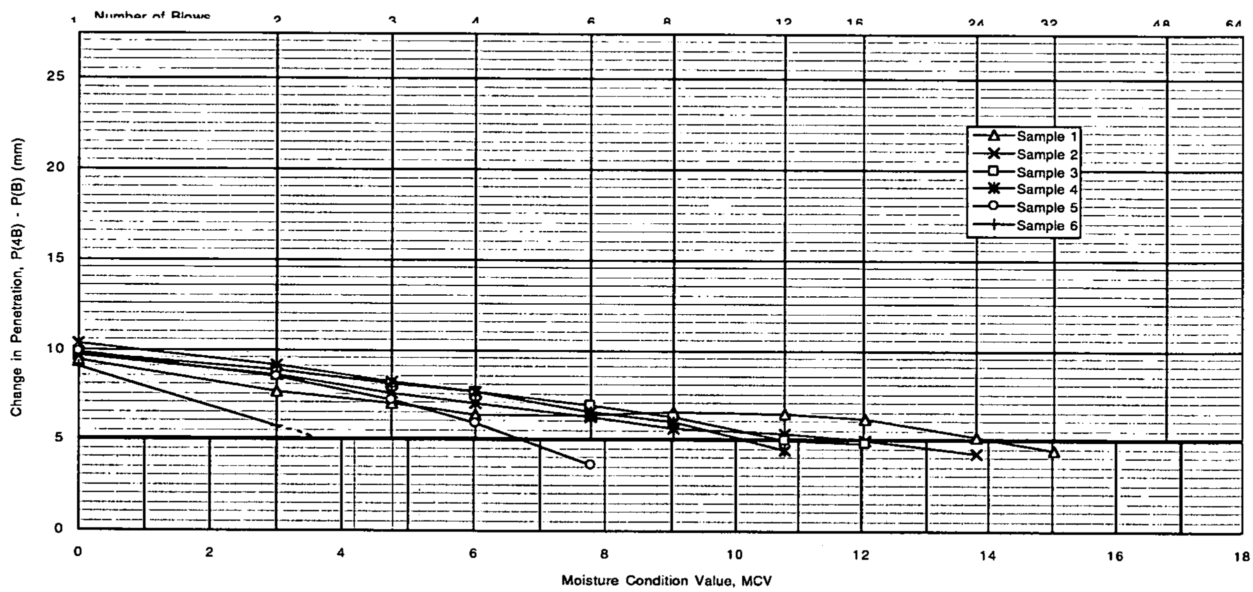
MCV TESTING **SITE** A9 Calvine - County Boundary **Form MCA 1**

1. PENETRATION MEASUREMENTS

DATE 18/5/78

SAMPLE NO.	1		2		3		4		5		6	
SOIL TYPE	Silty sandy TILL		As 1		As 1		As 1		As 1		As 1	
NUMBER OF BLOWS, B	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)
1	85.0	9.4	87.0	9.7	88.2	9.8	87.0	10.3	91.2	9.9	97.6	9.0
2	89.9	7.7	92.0	8.6	93.2	8.9	92.5	9.1	96.4	8.5	102.3	5.8
3	92.7	7.0	94.9	7.6	96.1	8.1	95.4	8.2	99.2	7.2	105.0	
4	94.4	6.4	96.7	7.0	98.0	7.7	97.3	7.7	101.1	5.9	106.6	
6	96.5	6.4	99.1	6.3	100.5	6.9	100.0	6.6	103.5	3.7	107.9	
8	97.6	6.6	100.6	5.7	102.1	6.3	101.6	6.0	104.9		108.1	
12	99.7	6.5	102.5	5.4	104.2	5.0	103.6	4.5	106.4		Water Seepage	
16	100.8	6.2	103.7	5.0	105.7	4.8	105.0		107.0			
24	102.9	5.2	105.4	4.3	107.4		106.6		107.2			
32	104.2	4.5	106.3		108.4		107.6					
48	106.2		107.9		109.2		108.1					
64	107.0		108.7		110.5							
96	108.1		109.7									
128	108.7											
192												
256												

2. CHANGE IN PENETRATION PLOTS



3. EVALUATION

SAMPLE NO.	MCV	ACCEPTABLE/UNACCEPTABLE	FINES CONTENT	COMMENTS
1	14.1		20%	
2	12.0		20%	
3	10.8		20%	
4	10.2		20%	
5	6.7		20%	
6	3.7		20%	Water Seepage at 10 Blows. Line extrapolated.

C3 CALIBRATION TEST ON SANDY TILL UNDER RELATIVELY DRY CONDITIONS

MCV TESTING

Form MCA 2

SITE A9 Avielochan-Slochd Bulk Location Ch73+00 Fines Content 18%

Soil Type Sandy TILL DATE 21/6/78

1. SAMPLE DETAILS

SAMPLE NO.	1	2	3	4	5	6
ESTIMATED MOISTURE CONTENT	5%	6%	7.5%	8%	8.5%	9%

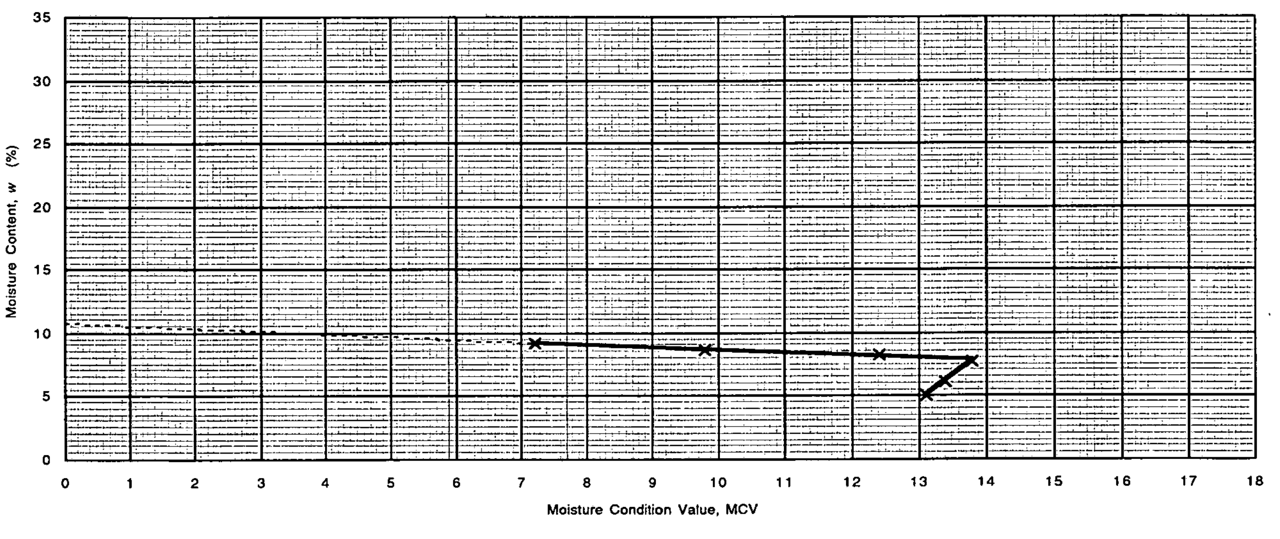
2. MOISTURE CONTENT DETERMINATION (after MCV testing)

CONTAINER NO.	10	11	12	13	14	15
CONTAINER MASS (C)	500g	501g	500g	502g	501g	500g
MASS OF WET SOIL AND CONTAINER (W)	2073g	2082g	2108g	2119g	2118g	2139g
MASS OF DRY SOIL AND CONTAINER (D)	1998g	1990g	1991g	1996g	1989g	2001g
MOISTURE CONTENT, $w = ((W-D)/(D-C))*100$	5.0	6.2	7.7	8.2	8.7	9.2

3. MOISTURE CONDITION VALUES AND MOISTURE CONTENTS

MCV (from Form MCA 1.3)	13.1	13.4	13.8	12.4	9.8	7.2
MOISTURE CONTENT (from Form MCA 2.2)	5.0	6.2	7.7	8.2	8.7	9.2

4. CALIBRATION LINE



6. CHARACTERISTICS OF CALIBRATION LINE

INTERCEPT (extrapolation to moisture content axis) in %	10.8
SLOPE (tangent of the angle between calibration line and MCV axis) in % w /MCV	-0.214
SENSITIVITY (1/Slope) in MCV/%w	4.677
CORRELATION COEFFICIENT	0.989

7. COMMENTS

Note: 'Ineffective' part to calibration line.

MCV TESTING

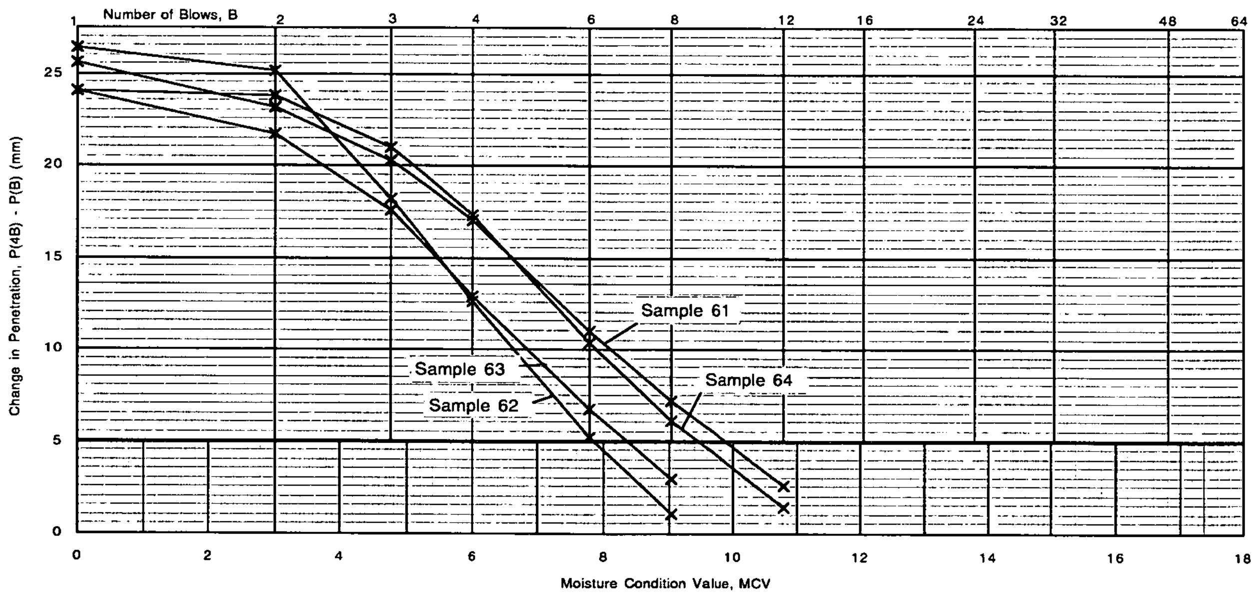
SITE M876 Ch4+80 **Form MCA 1**

1. PENETRATION MEASUREMENTS

DATE 5/4/78

SAMPLE NO.	61		62		63		64					
SOIL TYPE	Sandy silty CLAY with gravel		As 61		As 61		As 61					
NUMBER OF BLOWS, B	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)
1	63.6	25.6	56.8	26.4	68.5	24.1	59.7	24.1				
2	76.6	23.2	69.5	25.2	80.8	21.7	71.2	23.8				
3	84.1	20.3	77.5	18.2	87.9	17.6	78.7	21.0				
4	89.2	17.0	83.2	12.6	92.6	12.9	83.8	17.3				
6	95.8	11.0	90.7	5.2	98.7	6.8	90.7	10.4				
8	99.8	7.2	94.7	1.1	102.5	3.0	95.0	6.1				
12	104.4	2.6	95.7		105.5		99.7	1.4				
16	106.2		95.8		105.5		101.1					
24	106.8		95.9		105.5		101.1					
32	107.0		95.8		105.5		101.1					
48	107.0						101.1					
64												
96												
128												
192												
256												

2. CHANGE IN PENETRATION PLOTS



3. EVALUATION

SAMPLE NO.	MCV	ACCEPTABLE/UNACCEPTABLE	FINES CONTENT	COMMENTS
61	9.9	Acceptable	26%	Calibration is given as Example 1
62	7.8	Unacceptable	26%	Ditto
63	8.4	Acceptable	26%	Ditto
64	9.4	Acceptable	26%	Ditto

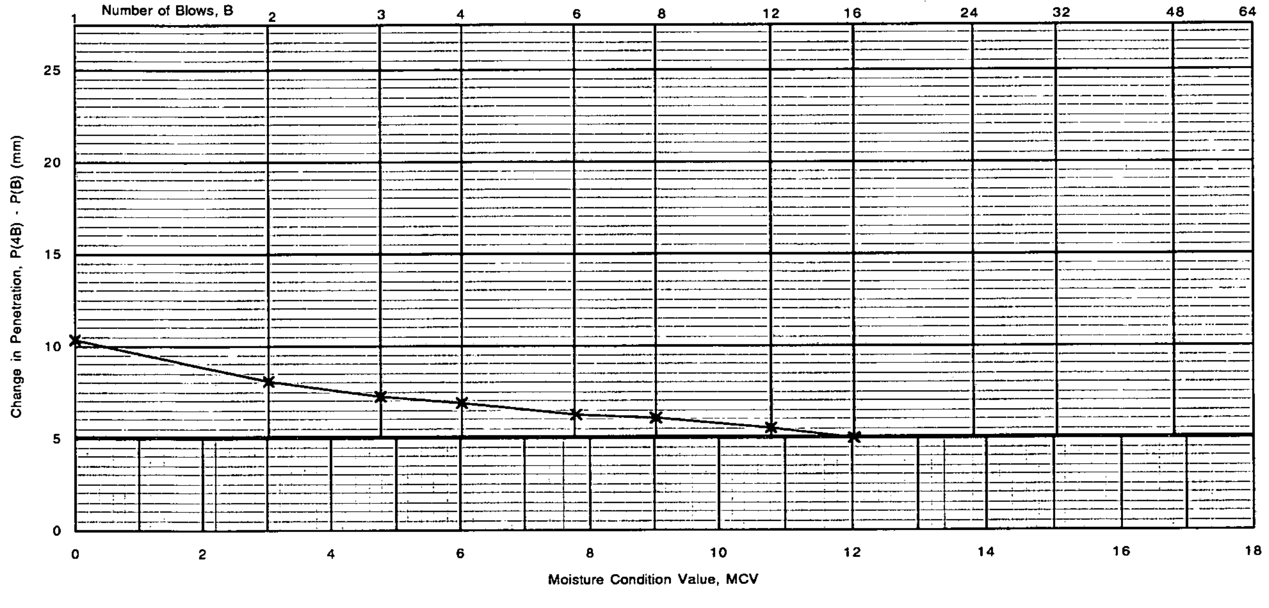
C5 MCV TESTS ON GRANULAR TILLS AFTER SATURATION

MCV TESTING SITE Evanton Form MCA 1

1. PENETRATION MEASUREMENTS DATE 8/9/82

SAMPLE NO.	1											
SOIL TYPE	Light brown SAND and GRAVEL											
NUMBER OF BLOWS, B	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)
1	71.8	10.4										
2	77.6	8.1										
3	80.3	7.3										
4	82.2	6.9										
6	84.4	6.3										
8	85.7	6.1										
12	87.6	5.6										
16	89.1	5.0										
24	90.7											
32	91.8											
48	93.2											
64	94.1											
96												
128												
192												
256												

2. CHANGE IN PENETRATION PLOTS



3. EVALUATION

SAMPLE NO.	MCV	ACCEPTABLE/UNACCEPTABLE	FINES CONTENT	COMMENTS
1	12.0	Acceptable	8%	Test on saturated material gives MCV>8.5.
				Therefore, no further MCV tests required, "all weather"
				material.
				Material retained on 20mm test sieve is 25%.

MCV TESTING

SITE Aviemore

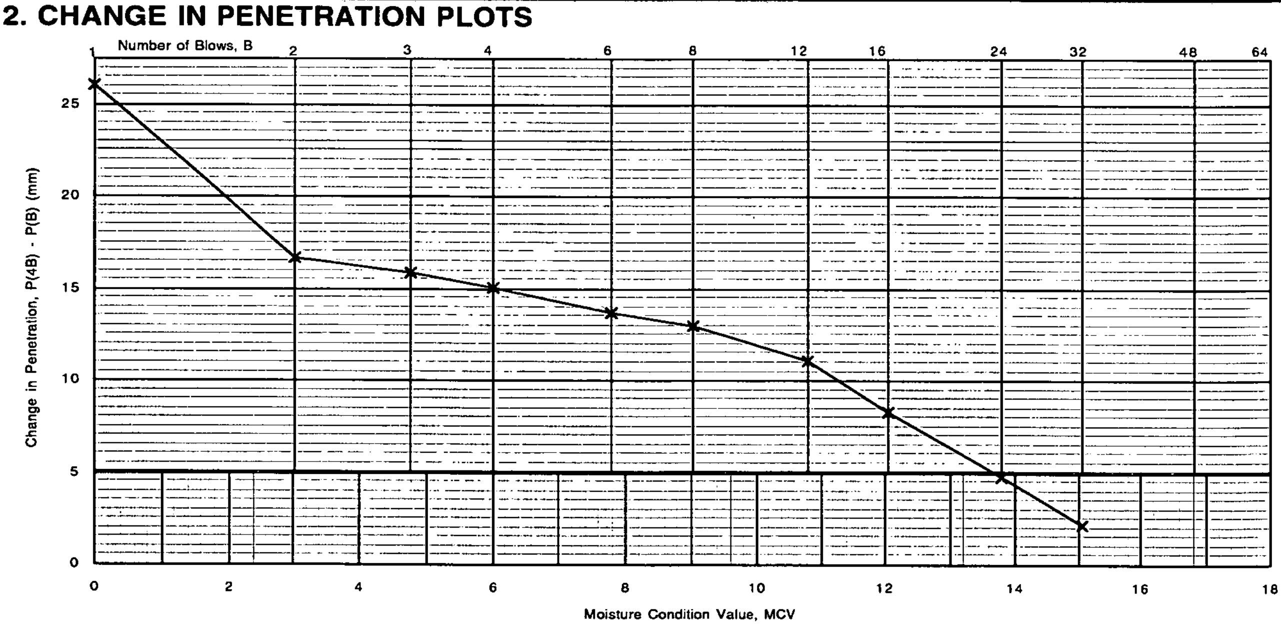
Form MCA 1

1. PENETRATION MEASUREMENTS

DATE 16/11/79

SAMPLE NO.	1											
SOIL TYPE	Silty SAND											
NUMBER OF BLOWS, B	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)	Penetration, P (mm)	Change in Penetration, P(4B) - P(B) (mm)
1	62.0	26.1										
2	79.6	16.7										
3	84.5	15.9										
4	88.1	15.1										
6	93.0	13.7										
8	96.3	13.0										
12	100.4	11.1										
16	103.2	8.3										
24	106.7	4.8										
32	109.3	2.2										
48	111.5											
64	111.5											
96	111.5											
128	111.5											
192												
256												

2. CHANGE IN PENETRATION PLOTS



3. EVALUATION

SAMPLE NO.	MCV	ACCEPTABLE/UNACCEPTABLE	FINES CONTENT	COMMENTS
1	13.7	Acceptable		Test on saturated material gives MCV>8.5.
				Therefore, no further MCV tests required. "all weather"
				material.
				Material retained on 20mm test sieve is 0%.

APPENDIX D: CERTIFICATION PROCEDURE FOR THE MCA

D1 INTRODUCTION

1.1. Certification is a requirement on Scottish trunk road and motorway contracts and should be carried out prior to the use of a MCA on a project and at regular intervals (generally six monthly) thereafter (see Form MCA3, Appendix B).

1.2. There are four areas of MCA operation which must be addressed as part of the certification procedure. These are as follows:

- i Mass of the rammer assembly.
- ii Tightness of all fittings.
- iii Fouling between the rammer assembly, during free-fall, and the mould.
- iv Speed of drop of the rammer assembly during free-fall.

1.3. This appendix describes the requirement and procedure for MCA machine certification as part of an approved, accredited quality assurance scheme.

1.4. All measuring instruments used in the certification procedure should be registered as part of an approved, accredited quality assurance scheme and be traceable to National Standards. The laboratory must be quality assured for the certification of the MCA as part of an approved, accredited scheme.

1.5. The British Standard (British Standards Institution, 1990a) requires that the inner surface of the MCA mould cylinder (see Figure 4) shall have a protective coating at least 0.05mm thick. It should be noted that this is a manufacturing requirement and it is not implied that individual moulds should be checked for this feature as part of a quality assurance scheme.

1.6. British Standards Institution (1990a) also requires that MCA moulds shall be permeable at the base, such that water discharges from the mould at a rate of between 4L/min and 7L/min when a constant head of 175mm is maintained above the mould base. It should be noted that this is a manufacturing requirement and it is not implied that individual moulds should be checked for this feature as part of a quality assurance scheme.

D2 MASS OF RAMMER ASSEMBLY

2.1. The rammer assembly is defined as the rammer together with the guidance and lifting attachments (Figure 4).

2.2. The total mass of the rammer assembly shall be 7kg$\pm$50g.

2.3. It is recommended that a digital balance, such as those normally found in a soils laboratory, be used for the purpose of measuring the mass of the rammer assembly. Such balances generally measure to $\pm$1g or better.

2.4. The results of this test should be recorded on Form MCA3, Part 1 (Appendix B).

D3 TIGHTNESS OF FITTINGS

3.1. In order to ensure the correct operation of the MCA (Figure 4), all fittings (screws, nuts and bolts) must be tightened in accordance with the manufacturer's recommendations.

3.2. If one or more of the fittings cannot be tightened correctly then either the faulty parts shall be replaced or the apparatus shall be rejected.

3.3. The decision to accept or reject the apparatus shall be recorded on MCA3, Part 2 (Appendix B).

D4 FOULING BETWEEN RAMMER ASSEMBLY AND MOULD

4.1. Fouling between the rammer assembly and mould (Figure 4) during free-fall will reduce the compactive effort applied to the soil sample. Consequently, the number of blows to achieve the required state of compaction will be overestimated, as will the MCV.

4.2. The apparatus should be checked to ensure that such fouling does not occur in normal operation.

4.3. Particular care should be paid to the following features

- i Cleanliness of the mould recess in the MCA base.
- ii Fit of the mould to the mould base.
- iii Functioning of the clips which attach the mould to the mould base.
- iv Functioning of the clips which attach the mould to the MCA base.

4.4. If the condition of any of the above items (Paragraph 4.3) is such that fouling of the rammer assembly and mould will occur during correct use of the MCA, then either the faulty components shall be replaced or the apparatus shall be rejected.

4.5. The decision to accept or reject the apparatus shall be recorded on Form MCA3, Part 3 (Appendix B).

D5 SPEED OF DROP OF RAMMER

D5.1 General principles

5.1. The MCA employs a heavy rammer, falling under the action of gravity, to compact soil samples. If the apparatus is poorly maintained, or poorly constructed, then frictional forces, exerted by the guide rails, may be large enough to significantly retard the rammer. This will lead to an over-estimate of the number of blows required to achieve the required state of compaction. Alternatively, the frictional forces may be intermittent, resulting in a wider range in estimates of MCV than would be achieved from correctly functioning MCAs.

5.2. The maximum speed of drop is always obtained when there is no friction. The effect of friction is to reduce the speed of drop from this maximum value. Thus, variability in the speed of drop is always accompanied by a reduction in the mean speed of drop. Statistical analysis shows that, for all practical purposes, the inherent variability of the speed of drop of the rammer assembly need not be considered.

5.3. The MCV is defined as $10.\log_{10}N$, where N is the number of blows required to achieve the required state of compaction. This state of compaction is determined by the amount of energy delivered to the soil sample by the rammer. Thus, the total kinetic energy ($0.5N.m.V^2$, where m is the mass of the rammer assembly and V is the mean speed of drop) can be assumed to be constant. The number of blows required to achieve the required state of compaction is thus inversely proportional to the square of the speed of drop of the rammer; $N = K/V^2$, where K is a constant. The expression for MCV can thus be rewritten in these terms:

$$MCV = 10 \log_{10}(K/V^2), \text{ or}$$

$$MCV = 10 \log_{10}K - 20 \log_{10}V \quad \text{...(D1)}$$

5.4. If the speed of drop deviates from the true value by an amount dV, by differentiating with respect to V, Equation (D1) becomes:

$$d(MCV) = -20(dV/V)\log_{10}e \text{ for small values of } dV \quad \text{...(D2)}$$

5.5. Errors of ± 0.5 in MCV are tolerable. Thus, the procedure for determining the speed of drop of the rammer

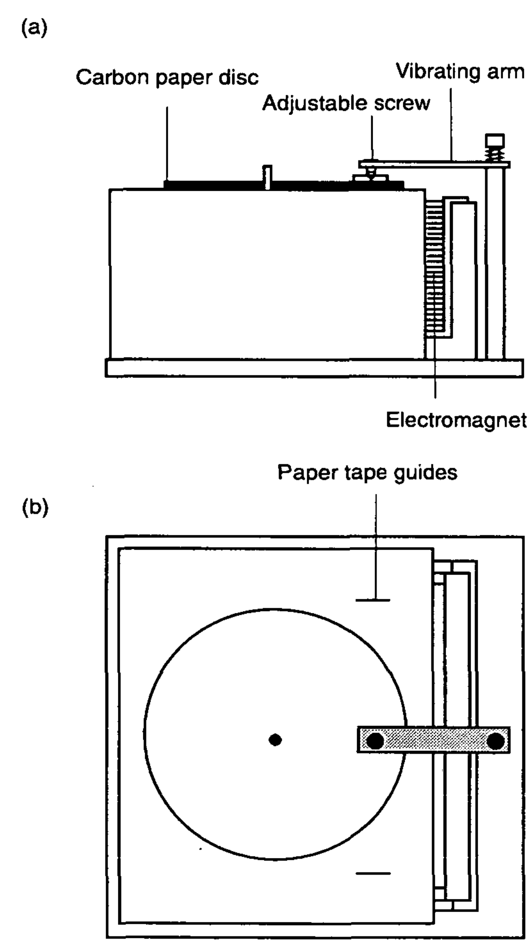


Fig. D1 Ticker tape timer: (a) side elevation; and (b) plan

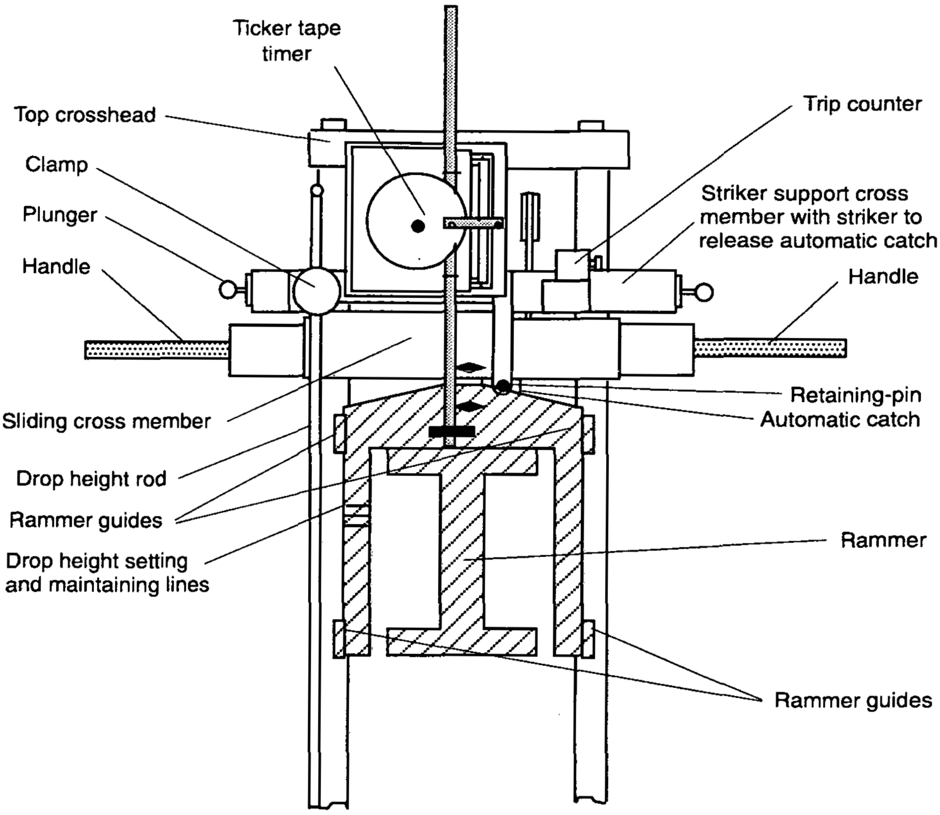


Fig. D2 Experimental set-up for use of the ticker tape timer

assembly must only occasionally accept an MCA which is biased by more than 0.5 MCV. This corresponds to a relative error in speed of drop of

$|dV/V| < 0.5/\log_{10}e^{20} = 0.058$ or, approximately, 6% ...(D3)

5.6. This error is less than the variation expected from experimental error (see Paragraph 5.9). Thus, it is not possible to base a test upon a single observation.

D5.2 Ticker timer

5.7. The ticker timer is normally used to determine the speed of drop of the MCA rammer assembly (Figure D1). Sources of ticker timers are given in Section D5.5. (Alternative devices may be used provided that they are capable of accuracy at least equivalent to that of the ticker timer - see Section D5.)

5.8. The ticker timer operates in a similar manner to a solid state electric doorbell, except that instead of striking a bell, a pointed screw set in the end of the arm strikes a disc of carbon paper mounted above the paper tape. A dot is thus imprinted on the paper tape at fixed time intervals of 1/50 second, derived from the frequency of the mains power supply (i.e., 50Hz). One end of the paper tape is connected to a moving object, and a record of the distance travelled in each time interval is obtained. When used with the MCA the ticker timer is mounted vertically, the paper tape passing through the device in the direction of fall of the rammer.

5.9. The accuracy of the ticker timer device depends upon the dots being imprinted on the tape at regular intervals. The ticker timer is subject to random errors in the timing of each dot with a standard deviation (SD) of about 1ms (compared with a time of drop of approximately 20ms). This corresponds to relative errors in the estimate of the speed of drop which have an SD of approximately '10% about the true value. (Note that improved accuracy in the variable mains power supply frequency can be achieved by the use of a controlled frequency power supply.)

5.10. A calibrated steel rule is required to measure the distance between successive imprinted dots on the paper tape.

D5.3 Procedure

5.11. The experimental set up for use of the ticker timer with the MCA is shown in Figure D2.

5.12. The ticker timer shall be clamped to the MCA striker support cross member. In this position the ticker tape guide holes are directly above the vertical side of the rammer.

5.13. The paper tape shall be attached to the front of the rammer with a piece of insulating tape.

5.14. The rammer shall be lifted, by means of the sliding cross-member, until the paper tape can be fed through the ticker timer guide holes.

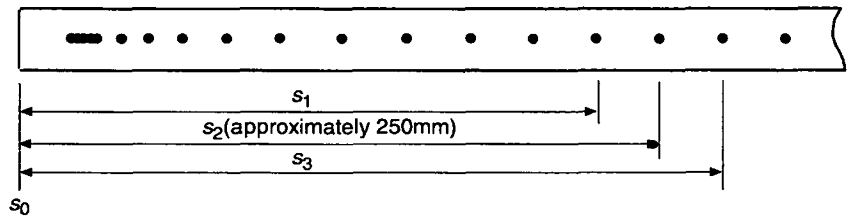


Fig. D3 Measurements to be taken from the paper tape

5.15. The rammer shall be raised to the release position. The timer is started and further upward pressure on the handles releases the rammer, pulling the paper tape through the timer as it falls.

5.16. The paper tape with the imprinted dots, representing the speed of drop of the rammer assembly, shall be retained for analysis.

5.17. The procedure given in Paragraphs 5.13 to 5.16 shall be repeated a further four times.

5.18. Four trials are required to reduce the relative error in the speed of drop such that it corresponds with a SD of approximately 4%.

5.19. This allows a simple test for MCA performance; if the measured speed of drop corresponds to the theoretical ±6% value then the apparatus is accepted, otherwise the apparatus is rejected.

D5.4 Calculation of results

5.20. The starting position of the rammer assembly shall first be estimated from the imprinted dots on the paper tape (distance of free-fall, s_0=0).

5.21. The distance from s_0 of three successive imprinted dots shall be measured as s_1, s_2 and s_3. These shall be selected such that the distance s_2 is as close as possible to 250mm. This corresponds to the drop height of the rammer assembly and therefore a point at which the rammer will be falling at its velocity at impact after 250mm drop. This arrangement is illustrated in Figure D3. The values of s_1, s_2 and s_3 shall be recorded on Form MCA3, Part 4 (Appendix B).

5.22. The theoretical (V_T) and actual (V_A) speeds of drop shall be calculated as shown on Form MCA3 (Appendix B) and recorded as indicated. The actual speed of drop (V_A) is calculated from the distance between the two imprinted dots either side of the dot closest 250mm from s_0 (Figure D3) divided by the time interval between the two imprinted dots at s_1 and s_3 (i.e., 2/50 second, or 0.04 second).

5.23. The percentage difference between V_T and V_A (V_P) shall be calculated and recorded on Form MCA3, Part 5 (Appendix B).

5.24. If $V_P < 6\%$ then the MCA shall be accepted. If $V_P > 6\%$ then the MCA shall be rejected. Acceptance/rejection of the MCA shall be recorded on Form MCA3, Part 5 (Appendix B).

5.25. Evaluations of this test assume that MCAs are either acceptable, with changes in the speed of drop less than 6% compared to the theoretical value, or unacceptable, with changes in the speed of drop of greater than 6%.

5.26. The probability of an acceptable MCA being rejected by the test is 8%. The probability of an unacceptable MCA being accepted by the test depends on the magnitude of the frictional forces. For example, if the bias in the speed of drop is sufficient to cause an error in the MCV of 1.0, the probability of an unacceptable machine being accepted is 9%.

D5.5 Sources of ticker timers

Nottingham Educational Supplies
Ludlow Hill Road
West Bridgeford
NOTTINGHAM NG12 6HD
Tel: 0115 945 2200

Griffen and George
Bishops Meadow
Loughborough
LEICESTERSHIRE LE11 0RG
Tel: 01509 233344

D5.6 Alternative methods

5.27. Any alternative method to the ticker timer method may be used to determine the speed of drop of the MCA rammer assembly provided that the equipment meets the following requirements:

- The equipment provides at least equivalent accuracy and precision to the ticker timer.
- The laboratory is quality assured for that test as part of an approved, accredited scheme.
- All equipment used is part of an approved, accredited quality assurance scheme and is traceable to National Standards.

5.28. One method which shows potential uses a pair of transmitting and a pair of receiving photo-electric cells.

5.29. The photo-electric cells are mounted either side of the MCA machine such that the transmitting and receiving pairs are facing. The upper and lower pairs should be spaced between 50mm and 200mm vertically apart. This distance is recorded as d_1.

5.30. The height of either the photo-electric cells or the MCA machine striker support cross member (Figure 4) are then adjusted such that the distance between the base of the MCA rammer and the centre of the upper and lower pairs of photo-electric cells is 250mm ±5mm. This distance is recorded as d_2.

5.31. The MCA rammer is then released and the times at which the upper and lower transmitting/receiving light beams are broken recorded as t_1 and t_2 respectively.

5.32. The theoretical velocity is calculated from

$$V_T = \sqrt{2 \times 9.81 d_2} \qquad \text{.... (D4)}$$

and the actual velocity from:

$$V_A = \frac{d_1}{t_2 - t_1} \qquad \text{....(D5)}$$

5.33. The percentage difference between V_T and V_A (V_P) can then be calculated (see Form MCA3, Part 5, Appendix B).

MORE INFORMATION

The Transport Research Laboratory has published the following other reports on this area of research:

1. RR361 Compaction monitoring devices for earthworks by R A Snowdon. (price code E)
2. TRL192 Sources of information for site investigations in Britain (revision of TRL Report LR 403) by J Perry and G West 1996. (price code L)
3. TRL206 In situ states of compaction of structural backfill by D P Steele and R A Snowdon 1996. (price code E)
4. TRL244 Behaviour of a cantilever contiguous bored pile wall in boulder clay at Finchley by A H Brookes and D R Carder 1997. (price code E)
5. TRL187 Behaviour of the diaphragm walls of a cut-and-cover tunnel constructed in boulder clay at Finchley by A H Brookes and D R Carder. 1996 (price code E)

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