Application of soil acceptability forecasts

Prepared for Scottish Executive

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Executive Summary

Computer-based models for the forecast of the acceptability of soils for earthworks in both the long-term and the short-term have been developed.

A field trial to evaluate the performance of the models has been undertaken. The results of the field trials broadly confirm those reported for a previous exercise and confirm the efficacy of the model for moisture content predictions. Forecasts of MCV are, however, considered to be insufficiently accurate for practical use. This is considered to be due to two factors:

- uncertainties that remain in respect of the precise relationship between calibration and natural moisture content line data; and
- the natural tendency of the process of conversion from moisture content to MCV to accentuate any inherent errors in the data.

A detailed experimental study of a non-standard sample preparation procedure has been carried out. It is recommended that the non-standard procedure should not be taken forward as either a ‘standard’ or ‘alternative’ test procedure.

Detailed experimental studies of the offsets between the calibration line and the natural moisture content line have been carried out. It was concluded that, for fine-grained soils only, if a single natural moisture content MCV test confirmed the existence of an offset then a prediction method for the natural moisture content line could be used. The natural moisture content prediction method was validated as part of the studies presented here.

1 Introduction

In order to construct earthworks features, such as embankments, it is necessary first to conduct tests to determine the acceptability of the soil to be used as a construction material. In general terms the requirement is that the soil should be neither too wet nor too dry to compact to its optimum condition.

The Moisture Condition Apparatus (MCA) was developed by TRL Limited for the assessment of soil acceptability for earthworks compaction (Parsons, 1976, 1978, 1981). Subsequently, Moisture Condition Value (MCV) testing was introduced to routine use on Scottish trunk road projects, in 1983, after a series of field trials and a controlled introduction on selected contracts (Matheson and Oliphant, 1991).

There are two aspects to MCV testing. First, the calibration line (Figure 1), determined at the ground investigation stage, indicates the sensitivity of the soil to moisture content change. Thus, from an initial condition and meteorological data, the likelihood of acceptable soil conditions being encountered at the construction stage can be evaluated and used in earthworks planning. Second, tests conducted on samples at the in-situ moisture content indicate the actual acceptability potential at a point in time (Figure 1). Such tests are especially useful at the construction stage.

The range of soils that can be tested using the MCA is defined by means of the ternary diagram in Figure 2 and its derivation is described by Oliphant and Winter (1997). Test procedures are given in the current British Standard (British Standards Institution, BSI, 1990) and implemented by the Specification for Highway Works and the associated Notes for Guidance (MCHW 1 and 2, Clauses 632 and NG632). More detailed procedures for MCA testing on Scottish road contracts are given by Matheson and Winter (1997) and are implemented by MCHW 1 and 2 (Clauses 632SO and NG632SO).

2 Moisture condition testing

The calibration line is determined from tests on samples which are first air-dried before water is added to achieve a range of moisture contents representative of the full range of material states (Matheson and Winter, 1997). A typical MCA calibration line is illustrated in Figure 1. The high end of the range corresponds to a moisture content close to that at which seepage from the mould will commence during the test. The low end of the range corresponds to dry conditions under which compaction becomes difficult and the onset of the ineffective part of the calibration line occurs. The effect of air-drying is to destroy the fabric (or structure) of the soil. Samples for testing at the natural moisture content are not air-dried prior to testing and the fabric is thus left relatively undisturbed. This potentially can lead to differences between the MCVs determined for the calibration line and those determined on samples, at the same moisture content, at the construction stage.

The differences between the calibration line and results from tests conducted on samples at the natural moisture content are variable. The micro-fabric in granular soils is easily destroyed and the effect of air-drying is minimal and thus the offset will be close to zero. The micro-fabric in cohesive soils is much more robust and the effect of air-drying is much greater and may lead to offsets of the order of 3% of moisture content (Figure 1). In addition, when several tests are conducted at different natural moisture contents and the results combined to form a line, then it may not be parallel to the calibration line.

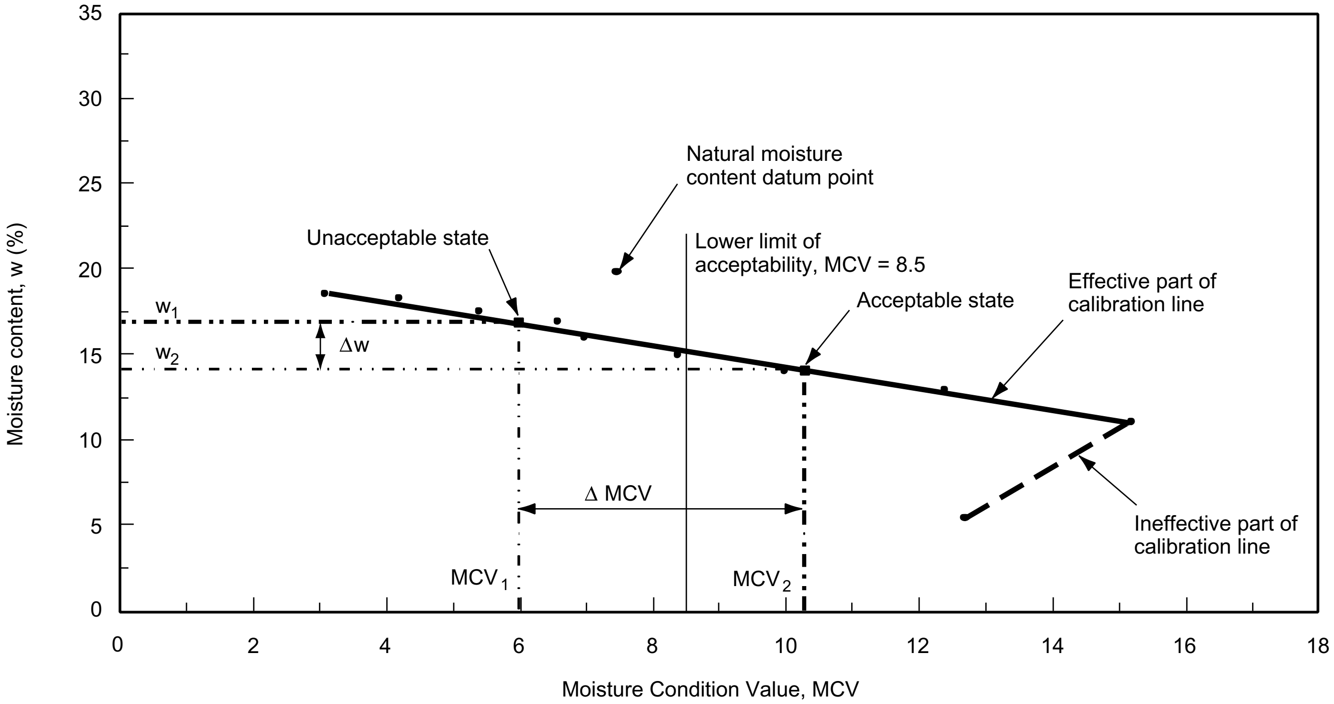


Figure 1 MCV calibration line showing the effect of moisture content change on MCV and acceptability for earthworks compaction. Also shown is a natural moisture content point for a typical fine-grained soil

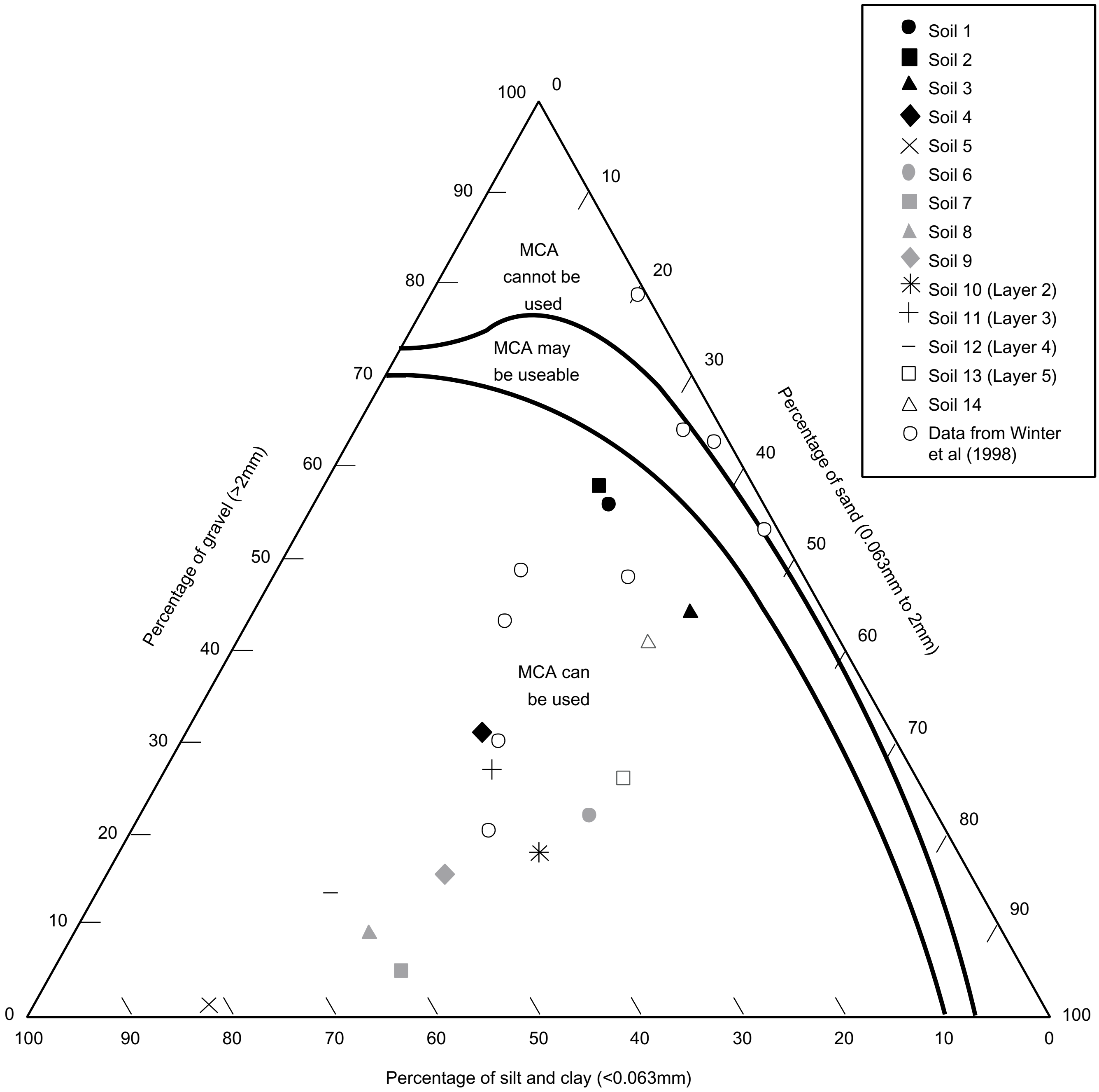


Figure 2 Limits of use of the MCA (after Oliphant and Winter, 1997; Matheson and Winter, 1997) showing particle size distributions for Soils 1 to 14. Particle size distributions are also shown for data from Winter *et al*. (1998)

3 Forecasting MCV

A model for forecasting MCV was developed as part of a previous research project, as an extra-mural contract placed on Heriot-Watt University by TRL (Smith *et al.*, 1993, 1998). Two computer programs were developed to facilitate forecasts in both the long-term (FORESALT) and the short-term (FORESAST).

The programs are both based on the SWATRER (Soil Water Actual Transpiration Rate - Extended, Revised) model, originally developed for use in agricultural applications and available as public domain software (Belmans *et al.*, 1983; Dierckx *et al.*, 1986). A user interface has been added to SWATRER for each of the long-term and short-term models, allowing the input of data required for analysis. The input data includes:

1 Ground investigation data:
   a Natural moisture content.
   b Dry density.
   c MCV calibration line, and
   d Natural moisture content MCV.
2 Saturated hydraulic conductivity.
3 Suction data.
4 Vegetation details.
5 Meteorological data.

Data output is in the form of on-screen graphics and data tables that may be sent to a printer.

The long-term model is for use following ground investigation and is intended to assist the designer in forecasting the likely acceptability immediately prior to and during the construction period. The information obtained from this model can be used in assessing the proportions of excavated acceptable and excavated unacceptable materials and thus the likely quantities of imported fill.

The short-term model is intended to assist estimation of soil acceptability during the construction period. Foreknowledge of likely soil acceptability will allow improved planning of earthworks operations, avoiding the excavation and trafficking of unacceptable materials, and more cost-effective use of construction plant.

Following success with a limited field trial (Smith *et al.*, 1993), an extensive field trial was conducted jointly by TRL and Heriot-Watt University, to assess the effectiveness of the model. This involved the use of state-of-the-art field measuring equipment, including a capacitance device for the measurement of soil moisture content, an automatic weather station and the TRL suction device. The last mentioned shows potential for use in future ground investigations to provide suction data input for both models.

Results indicated that the model showed considerable promise for forecasting soil acceptability. In general, predictions of soil moisture content, in high sensitivity soil, were within 5% (by volume) and approximately 3% (by weight). Forecasts were generally within 2 to 3 MCV of the values measured. The predictions and forecasts have been tested under more rigorous conditions as part of the current project.

3.1 Refinements and problems

After development of the software it was felt that it was in a useable form and could be released. However a number of issues, not contained within the original specification for the work, could provide improvements to the model:

1 The use of non-standard MCA test sample preparation procedures is increasingly common. The results of a study of this issue are described in Section 3.1.1.

2 In converting moisture content predictions to MCV forecasts, the assumption is made that the calibration line and the trend of natural moisture contents are parallel. The results of a study of this issue are described in Section 3.1.2.

3 The TRL suction probe returns in-situ suction curve data which may be more representative than laboratory test data or data input from standard suction curves (see Section 3.1.3).

4 Further refinements to the computer programs have been made to ensure year 2000 compliance and to account for changes to the format in which the Meteorological Office Rainfall and Evaporation Calculation System (MORECS) data required by the programs is supplied (see Section 3.1.4).

3.1.1 Non-standard MCA test sample preparation procedure

Some testing companies are currently deviating from standard MCA test specifications (Matheson and Winter, 1997; BSI, 1990) by using a non-standard sample preparation technique proposed by Jones and Greenwood (1993). Their procedure involves taking a bulk natural moisture content sample and dividing it into separate samples for testing. One such sample is tested at the natural moisture content. Some samples are partially air-dried to lower moisture contents prior to testing, while others have their moisture contents raised by the addition of varying amounts of water. By this process it is claimed that an equivalent of the natural moisture content line is determined (Figure 3). This approach is becoming increasingly common in England where relationship testing has gained favour (e.g., Jones and Greenwood, 1993). The approach is claimed to allow the MCV to be related directly to parameters such as moisture content and shear strength, for earthworks design purposes, without the usual problem of the natural moisture content data being offset from the calibration line (Figure 3).

An extensive testing programme was carried out to determine the difference in MCV calibration lines determined using the standard and non-standard sample preparation procedure. The tests were carried out on 14 samples of glacial tills and associated deposits from the Edinburgh area, Southern Scotland, and Northern England. Index and classification data are given in Table 1 and the particle size distributions illustrated in Figures 2 and 4.

MCV calibration lines were determined for each of the standard and non-standard calibration lines. An additional line was determined from a series of tests at different natural moisture contents. For each line the 95% confidence limits were calculated. These define the area in which, statistically 95% of the data may be expected to lie. These are shown for Soil 3, for example, in Figure 5.

A visual examination of the data indicated that 12 of the 14 standard and non-standard calibration line confidence limits overlapped throughout the full MCV range. The remaining two overlapped for most of the range, where they did not they lay close together.

For four of the 14 non-standard calibration line and natural moisture content line confidence limit pairs a comparison was not possible, as there was insufficient data to determine the natural moisture content line limits. However for the remaining 10 data sets, eight of the confidence limits overlapped throughout the full range of MCV tested while for one the limits overlapped over part of the range and for the final one there was no overlap. The results of this informal analysis are somewhat distorted by the broad confidence limits calculated for the natural moisture content line.

A more rigorous statistical analysis has been undertaken using the method given by Till (1974). This allows the comparison of both the intercept and slope of both the non-standard and standard calibration lines, and the natural moisture content line and the non-standard calibration line for each soil. This form of analysis circumvents the effects of broad confidence limits on the natural moisture content

Table 1 Sample descriptions and index properties

Sample number (layer number)	Standard descriptions to BS5930 (1981)	Description to MCHW 1 (Table 6/1)	*Particle Sizes*			*Atterberg Limits*			
			Fines	*Sand*	*Gravel*	*PL (%)*	*LL (%)*	*PI (%)*	*<425mm*
1	Light to mid brown slightly clayey SAND with some fine to coarse subangular gravel (occasional subrounded gravel).	Class 1A/2C - Well graded granular material/Stony cohesive material.	15	29	56	NP	NP	NP	30
2	Very soft saturated mid reddish brown very sandy CLAY, friable, containing abundant fine to subangular to subrounded gravel and occasional cobbles (Till derived).	Class 1A/2C - Well graded granular material/Stony cohesive material	16	27	58	NP	NP	NP	30
3	Very soft saturated mid reddish brown very sandy CLAY, friable, containing some fine to coarse subangular to subrounded gravel (Till derived).	Class 1A/2C - Well graded granular material/Stony cohesive material	13	43	44	NP	NP	NP	34
4	Very soft saturated light to mid reddish brown sandy CLAY containing some fine to coarse sub angular to subrounded gravel and occasional cobbles (Till derived).	Class 2C - Stony cohesive material	40	29	31	13.7	24.2	10.5	61
5	Very soft to soft mid brownish grey laminated CLAY with intermittent bands of light brown clay and coarse sand (Lacustrine?).	Class 2D - Silty cohesive material	82	17	1	20.7	41.0	20.3	98
6	Irregular lumps of light to mid brownish grey slightly weathered MUDSTONE, moderately strong with many irregular polished surfaces and carbonaceous fossil roots - “soapy” feel (Seat earth?).	Class 2A/2B - Wet/Dry cohesive material	34	44	22	22.3	43.8	21.5	44
7	Firm to stiff and stiff mid to dark grey fissured sandy CLAY some orange brown mottling, containing a little fine to coarse subangular to subrounded gravel, including micaceous sandstone and occasional coal fragments (Till).	Class 2A/2B - Wet/Dry cohesive material	61	34	5	17.0	34.0	17.0	90
8	Stiff mid to dark grey slightly sandy CLAY containing some fine to coarse subangular to subrounded gravel, including sandstone and occasional coal fragments (Till).	Class 2A/2B - Wet/Dry cohesive material	62	29	9	22.6	47.3	24.7	85
9	Soft to firm mid to dark grey slightly sandy CLAY containing some fine to coarse subangular and subrounded gravel and occasional cobbles, including sandstone, carbonaceous mudstone, occasional coal fragments (Till).	Class 2A/2B - Wet/Dry cohesive material	51	33	15	17.5	33.2	15.7	77
10 (2)	Soft to firm with some very soft inclusions mottled yellow orange grey brown slightly sandy CLAY with light grey lamiinations, with a little sub-angular to sub-rounded fine to coarse gravel and some medium to fine pieces of weak light grey mudstone.	Class 2C - Stony cohesive material	41	41	18	19.0	36.0	17.0	73
11 (3)	Firm mottled yellow orange grey brown slightly sandy CLAY with light grey laminations, with some medium to coarse angular to sub-rounded gravel, some fine pieces of weak light grey mudstone and some small pieces of coal and some fine roots.	Class 2C - Stony cohesive material	41	32	27	17.0	33.0	16.0	62
12 (4)	Firm mottled yellow orange grey brown slightly sandy CLAY with light grey laminations, with a little fine sub-angular to sub-rounded gravel and many fine pieces of weak dark grey mudstone.	Class 2A/2B - Wet/Dry cohesive material	64	23	13	21.0	37.0	16.0	76
13 (5)	Firm grey brown slightly sandy CLAY with a little fine to coarse sub-angular to sub-rounded gravel and many fine to coarse pieces of weak dark grey mudstone.	Class 2C - Stony cohesive material	29	45	26	19.0	34.0	15.0	47
14	Firm grey brown slightly sandy CLAY with a little fine sub-rounded gravel and many fine to coarse pieces of weak dark grey and some purple orange mudstone.	Class 2C - Stony cohesive material	18	41	41	21.0	37.0	16.0	28

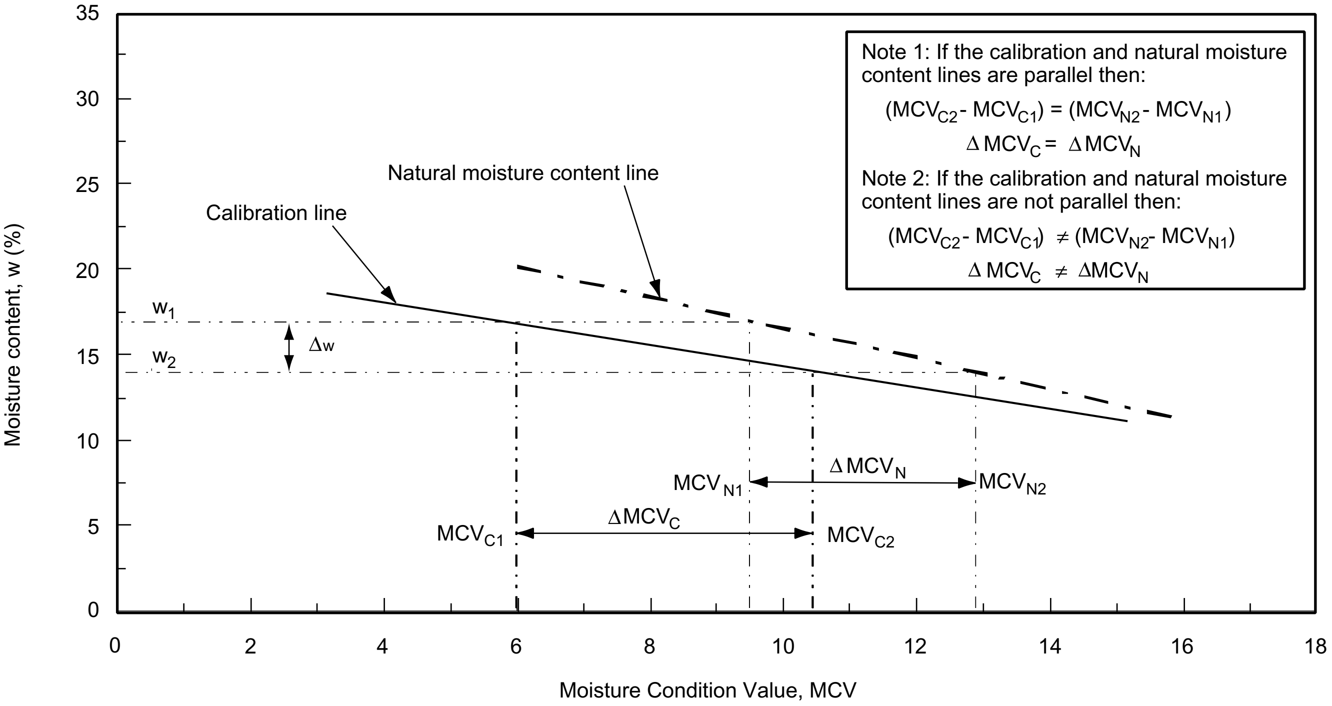


Figure 3 MCV calibration line and natural moisture content lines showing the potential errors in forecasting MCV from moisture content when the two lines are not parallel

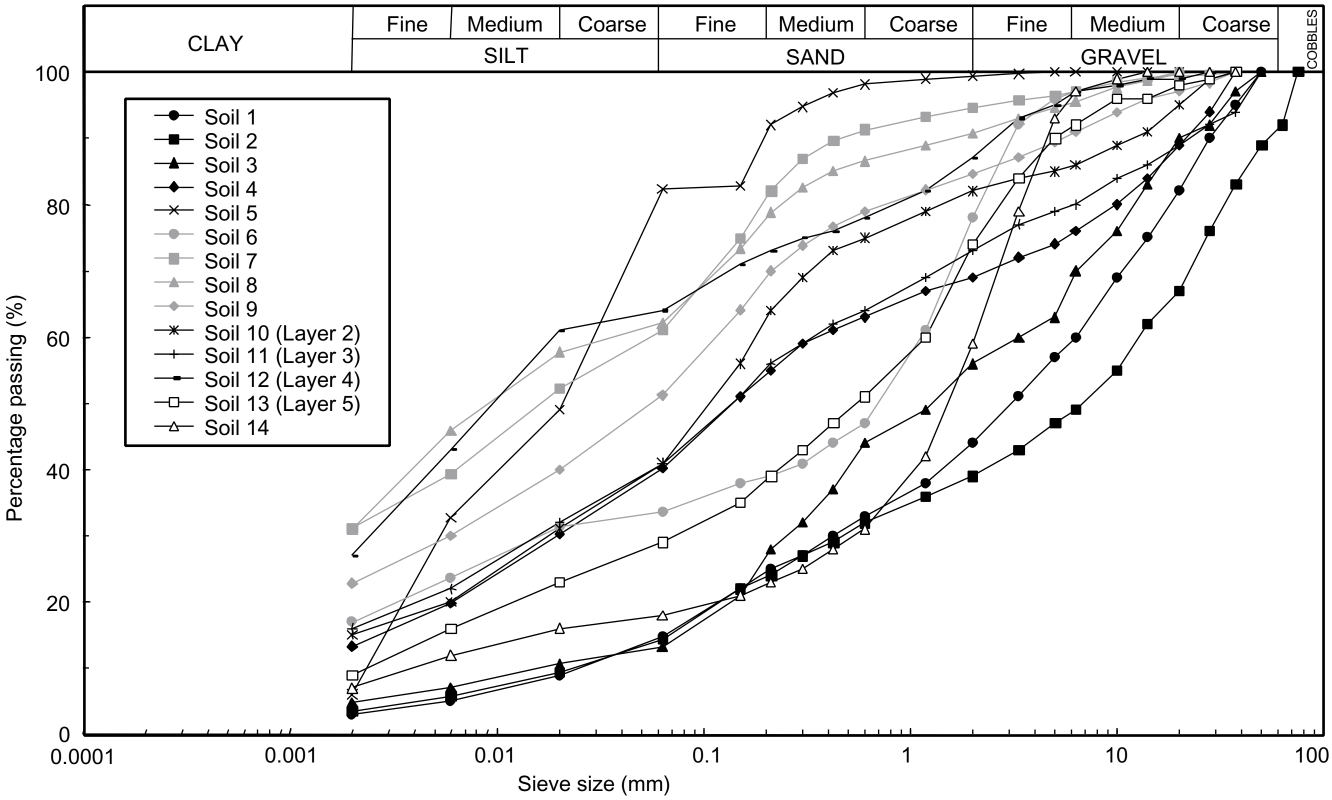


Figure 4 Particle size distributions for Soils 1 to 14

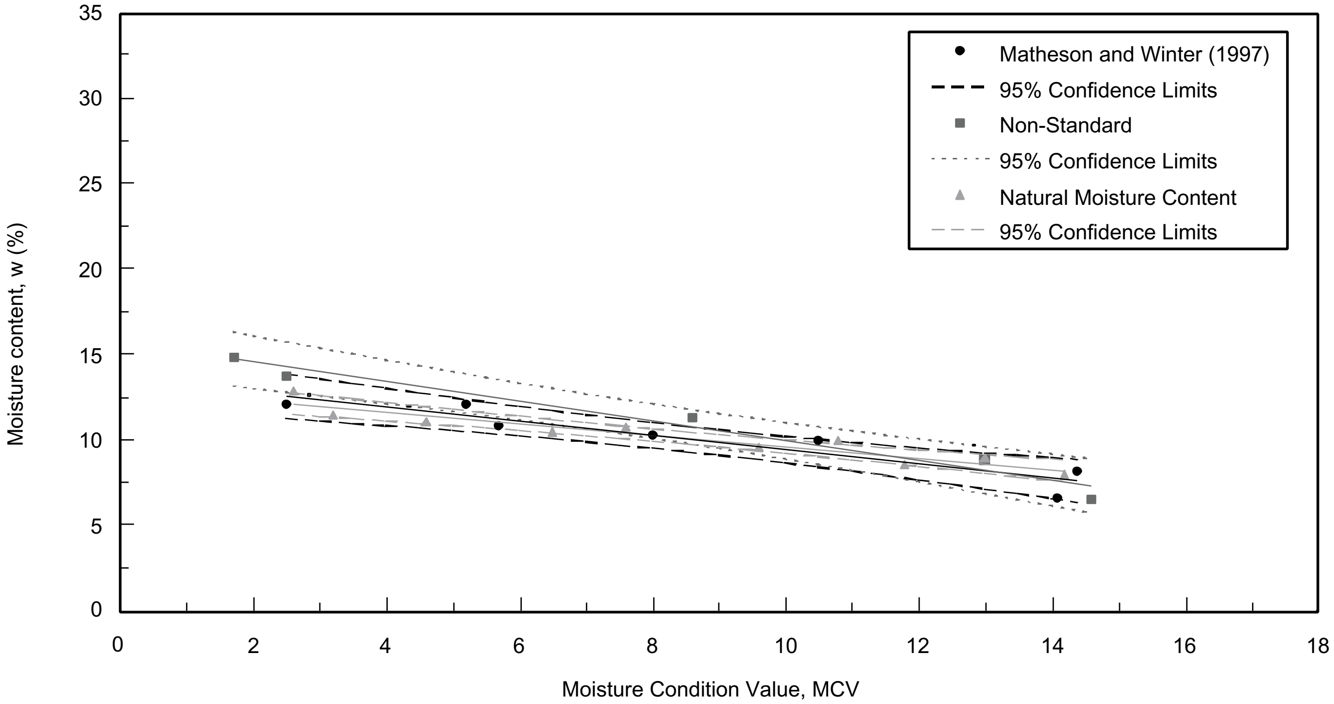


Figure 5 MCV calibration lines obtained using the standard and non-standard methods, and the natural moisture content line

line by comparing the natural moisture content line slope and intercept values with the confidence limits on the non-standard calibration line.

Essentially, where the intercept and slope are both judged to be similar then there are 95 in 100 chances that both calibration lines come from the same population. It is therefore correct to state that the lines are the same at the 95% confidence level. Similarly where only the slopes are judged to be similar then there are 95 in 100 chances that the two slopes come from the same population of slopes and that the two lines are therefore parallel. In this case it is correct to state that the lines are parallel at the 95% confidence level.

In contrast, if neither the intercept nor slope, or just the intercept, are judged to be similar then there are only 5 chances in 100 of them coming from the same population of lines. It is thus correct to state that the lines are not the same at the 95% confidence level.

For 10 of the 14 soils tested the standard and non-standard calibration lines may be considered the same at the 95% confidence level, while a further two may be considered parallel. The remaining two are considered not to be the same. It is therefore reasonable, on a statistical basis, to conclude that the non-standard procedure returns test results that are the same as those achieved using the standard procedure.

A comparison of the natural moisture content line and the non-standard calibration line is possible for only 12 of the 14 soils tested. Of these five may be considered the same at the 95% confidence level. Of the remainder, three may be considered parallel while the remaining four are not the same. The results for this comparison are somewhat less conclusive than that between the non-standard and standard calibration lines. On a statistical basis, the similarity of the natural moisture content line and the non-standard calibration line is not proven.

It was concluded above that the standard and non-standard calibration lines are statistically similar. In addition, the standard calibration line and the natural moisture content lines are not statistically similar (see also Section 3.1.2). It can thus be deduced that the non-standard calibration lines and the natural moisture content lines ought not to be statistically similar.

Discussions with the testing contractor indicated that considerable difficulty had been experienced with the non-standard procedure. This related to the successful drying and wetting samples to moisture contents within the testable range. Ultimately results from the standard calibration line were used to determine a target mass representing a particular moisture content and the drying sample was repeatedly weighed until this was reached. However, while this approach is possible with the testing regime conducted here it is unlikely to be a viable proposition, on cost and time grounds, in a commercial testing environment. It should be noted that a simpler approach, involving measurement of the sample moisture content and calculation of a target mass for a desired moisture content (Winter, 1989), is possible.

With the non-standard test sample preparation procedure difficulty was experienced in defining the full calibration line, especially the dry end without access to the standard calibration line data or resort to calculation. It is also clear that if the extremes of the MCV line (high or low moisture content) are not fully defined then due to the inherent scatter in the data errors in the determination of slope, sensitivity and intercept values are accentuated.

The adoption of the non-standard sample preparation procedure is not recommended for inclusion in the relevant Specifications and Standards either as a ‘standard’ method or an ‘alternative’ method.

3.1.2 Differences between laboratory and natural moisture content MCVs

Until recently, the difference between the laboratory and natural moisture content lines has not proved problematic as the reciprocal of the slope of the calibration line has been used simply to assess the likely magnitude of change in MCV due to indicative weather conditions. More recently it has proved possible to predict changes in moisture content, taking account of factors such as rainfall, evapotranspiration, ground conditions, surface cover and hydrological conditions (Smith *et al*., 1998). Forecasts of acceptability, in terms of MCV, may thus prove possible. An initial state of (MCV_1, w_1) at the ground investigation stage will not necessarily prevail at the construction stage (Figure 3); a state of (MCV_2, w_2) is more likely. The sign and magnitude of the change, Δw, will depend on the factors used to predict changes in moisture content.

The effect of the existence of an offset between the calibration and natural moisture content lines is shown in Figure 3. If the two lines are either coincident or parallel then for a given change in moisture content (Δw) then the change in MCV due to the calibration line ($MCV_{C2} - MCV_{C1} = \Delta MCV_C$) will be the same as that due to the natural moisture content line ($MCV_{N2} - MCV_{N1} = \Delta MCV_N$) and $\Delta MCV_C = \Delta MCV_N$. As the technique deals with changes in moisture content and MCV, rather than absolute values, the MCV may be determined directly from the calibration line. However, if the two lines are not parallel (Figure 3) and $\Delta MCV_C \neq \Delta MCV_N$, then this operation must be performed on the natural moisture content line.

The natural moisture content line can be determined from the results of a series of tests on a soil at different natural moisture contents which will, in most cases, require several samples to be taken at different times of the year. Alternatively, it may prove possible to predict the natural moisture content line based on analysis of historical calibration line and natural moisture content data.

An extensive testing programme was carried out to determine the difference between standard MCV calibration lines and the line determined from a number of tests carried out on the soil at different natural moisture contents. Lines determined from an equation developed by Howe (1993) to estimate the natural moisture content were also included in the comparison. These are shown for Soil 3, for example, in Figure 6. The soils tested are described in Section 3.1.1 as are the procedures used to compare the lines.

A visual examination of the data showed that seven of the 14 MCV calibration line and natural moisture content line confidence limits overlapped throughout the full range of MCV. Two overlapped for most of the MCV range and where they did not overlap they lay close together. The natural moisture content line exhibits a markedly different slope to the calibration line for Soil 8, and this was taken account of in the more rigorous analysis below. In one case (Soil 12) the confidence limits did not overlap at all.

The successful determination of a full-range natural moisture content line is heavily dependent upon the ability to return to, and sample from, the same formation at different times of the year. By this means samples at different in-situ moisture contents should be obtained. In the case of Soils 1 to 4 this was achieved by retrieving data from construction site records.

In the case of Soils 5 to 9, which were taken from opencast colliery sites, severe difficulties were encountered in returning to the same formation. Frequently the formation was either excavated or backfilled between site visits and, although the nearest available equivalent was sampled, this is reflected in the results. In only two cases has a natural moisture content line with more than two data points been obtained. Indeed, in one instance the opencast site was unexpectedly closed following the first site visit for sampling.

For Soils 10 to 14 trial pits were excavated at intervals at the same site and samples retrieved from each strata. This approach was largely successful. It was, however, complicated by the need to space the trial pit excavated during each site visit sufficiently far apart to ensure that the ground water regime was not affected by previous sampling activities. This may have led to minor local variations in the samples taken from each strata, this is particularly likely for Soil 10 and a natural moisture content line could not be constructed.

Similarly, for four of the 14 natural moisture content line and predicted natural moisture content line confidence limits a comparison was not possible. However for the remaining 10 data sets, eight of the confidence limits overlapped throughout the full range of MCV tested while for one (Soil 13) the limits overlap over part of the range and for the final one (Soil 12) there was no overlap.

The results of this informal analysis were somewhat distorted by the broad confidence limits calculated for the natural moisture content line. This reflected the wide margin of error in the determination of the natural moisture content line.

A more rigorous statistical analysis has been undertaken as described in Section 3.1.1.

It was evident from the results that for four soils (Soils 5, 6, 7 and 10) less than two data points form the natural moisture content line; these results were not considered further. Of the remaining ten both the intercept and slope were statistically similar for Soils 1 to 4, while just the slope was statistically similar for Soils 11 and 12. The remaining four soils yielded results that were not statistically similar. Examination of the data indicates that those deemed similar were the more coarse-grained soils for which an offset between the calibration line and the natural moisture content line would not be expected. This confirms assumptions made in the past. That is, there can be a difference between the calibration line and the natural moisture content data, especially in fine-grained soils.

It was also evident from the results that the method of predicting the natural moisture content line takes good account of the differences between the calibration line and natural moisture content data. In only two of the data sets (Soils 13 and 14) the natural moisture content and predicted natural moisture content lines were not parallel, and most indicated that the lines were statistically similar in terms of both intercept and slope. The equation developed by Howe (1993) for the prediction of the natural moisture content

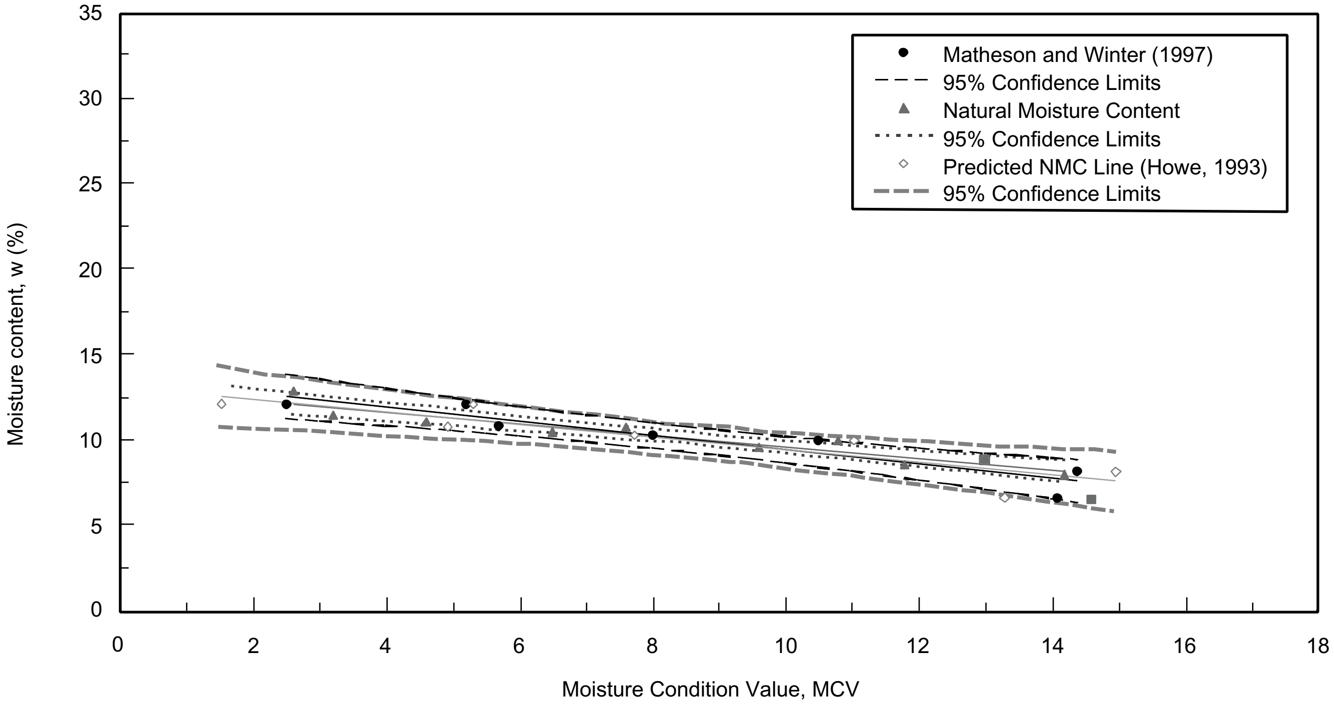


Figure 6 MCV calibration line, natural moisture content line and predicted natural moisture content line

line, has thus been incorporated into the system for forecasting soil acceptability for earthworking developed by Smith *et al.* (1998) as a separate Excel spreadsheet utility.

3.1.3 Incorporation of suction probe data

At present suction data is input either as the results of laboratory tests or by selection of a standard suction curve from a suite offered within the software.

Both the laboratory data and the standard curves give a suction curve of sample moisture content against the suction pressure $pF=\log_{10}h$ (where h is the height of a column of water in centimetres yielding an equivalent pressure). Typically the laboratory data is derived from tests using suction plate apparatus which can only test relatively small samples of soil. Thus the data may be unrepresentative of the bulk soil under consideration. In addition, the test is rarely performed as part of a ground investigation in the UK and is difficult to perform successfully. The standard suction curves contained in the program are taken from the published literature together with the soil descriptions given by the authors. The curves can be assigned to the individual layers of soil being analysed by selecting the appropriate curve number within the computer programs. The curves were generally obtained from tests using suction plate-type devices and all of the comments made above can be applied to the standard suction curves. In addition, some difficulty may be experienced in matching the curves to the soil type under consideration. However, by a careful process of trial and error Smith *et al.* (1998) conducted a successful analysis and forecast using the curves.

The TRL suction probe returns in-situ data that may give greater confidence in the output from the computer models. However, the suction probe gives results in terms of the filter paper moisture content as opposed to the soil moisture content. Nonetheless, this is generally analogous to soil moisture content and such data can be readily input to the software in the place of suction plate data.

The major disadvantage of the suction probe is that numerous measurements are required in order fully to define the suction curve. As soil moisture contents, and therefore soil suctions, tend to vary on an annual basis from dry in the summer to wet in the winter it is likely that measurements taken over the course of a year would be necessary. The probe was excluded from the field trial in order to provide a realistic test of the capabilities of the computer program (see Section 4). However, the probe could be considered for inclusion in future ground investigations to allow the input of data to the two computer programs.

3.1.4 Further refinements to the computer programs

Further refinements have been made to the computer programs to ensure year 2000 compliance. A testing regime has been carried out as detailed in BSI DISC PD2000-1, encompassing all of the date-related issues for software compliance.

In the period between the original development of the software and the current software some radical changes have been made to the format of the MORECS data. A great deal of effort has been expended in both modifications to the software and liaison with the Meteorological Office to ensure that the data can be read in and analysed successfully.

4 Field trial

A field trial to assess the accuracy of the MCV forecast using the FORESALT software has been carried out.

The trial involved the sinking of four capacitance moisture probe tubes (Dean *et al*., 1987; Bell *et al*., 1987) to allow the determination of moisture content profiles on a weekly basis without repeated soil sampling. These measurements allow comparison with the data obtained from predictions of the moisture content and from forecasts of the MCV using the FORESALT computer program. In addition, samples were recovered during the installation of the probe holes and tested for moisture content.

Weekly measurements of the volumetric moisture content using the capacitance probe were begun immediately following installation (Measurement Week 1). A period of 17 weeks was allowed to elapse before a ground investigation was carried out to establish start-point parameters for input to the computer program. This approach was taken to ensure that installation effects did not distort the trial results as was observed previously in the early stages of the trial carried out by Smith *et al*. (1998). A further ground investigation was carried out in Measurement Week 45 to establish physical end-point data for comparison with predicted moisture content and forecast MCV. The probe measurements were continued until Measurement Week 52 to give a post-trial measurement period to enable interpretation of any anomalies in the results obtained. The mean volumetric moisture content measured using the capacitance probe for Measurement Weeks 1 to 52 is plotted with depth in Figure 7.

Particles size distributions of the soil forming the layers are given in Figure 4. The data are also plotted on the ternary diagram describing limits of use of the MCA in Figure 2.

4.1 Input data

The ground, suction and surface vegetation input data for the FORESALT program were determined from physical investigation and observation. The MORECS input data is illustrated in Figure 8 showing the 30-year weekly average rainfall and potential evapotranspiration (PE). It is important to note that the seasonal variation in PE is significantly greater than that of rainfall, indicating the PE has a potentially marked effect on seasonal soil moisture content variations. A typical FORESALT program data input screen is illustrated in Figure 9.

4.2 Model results

The FORESALT program was used to provide both predictions of moisture content and forecasts of MCV.

Figure 10 uses the data from the first ground investigation as a start point for moisture content predictions using the FORESALT model. The solid lines represent the predicted changes in moisture content and the measured data from the second ground investigation are shown for comparison. In general, the variation from predicted to measured, at this date, is less than 1.4% of moisture content. The one exception is for Layer 4, for which the difference is close to 3.8%. The reason for the latter remains obscure. However, the overall picture for moisture content prediction is exceptionally promising and broadly similar to that reported by Smith *et al*. (1998), who reported predictions to be within 3% of moisture content over a 52-week period.

Figure 11 reports the measured and forecast MCV data. The differences at the time of the second ground investigation are 0.25, 2.6, 3.2 and 4.2 units of MCV for Layers 4, 2, 5 and 4, respectively. Interestingly Layer 4 returns the largest error for moisture content prediction and

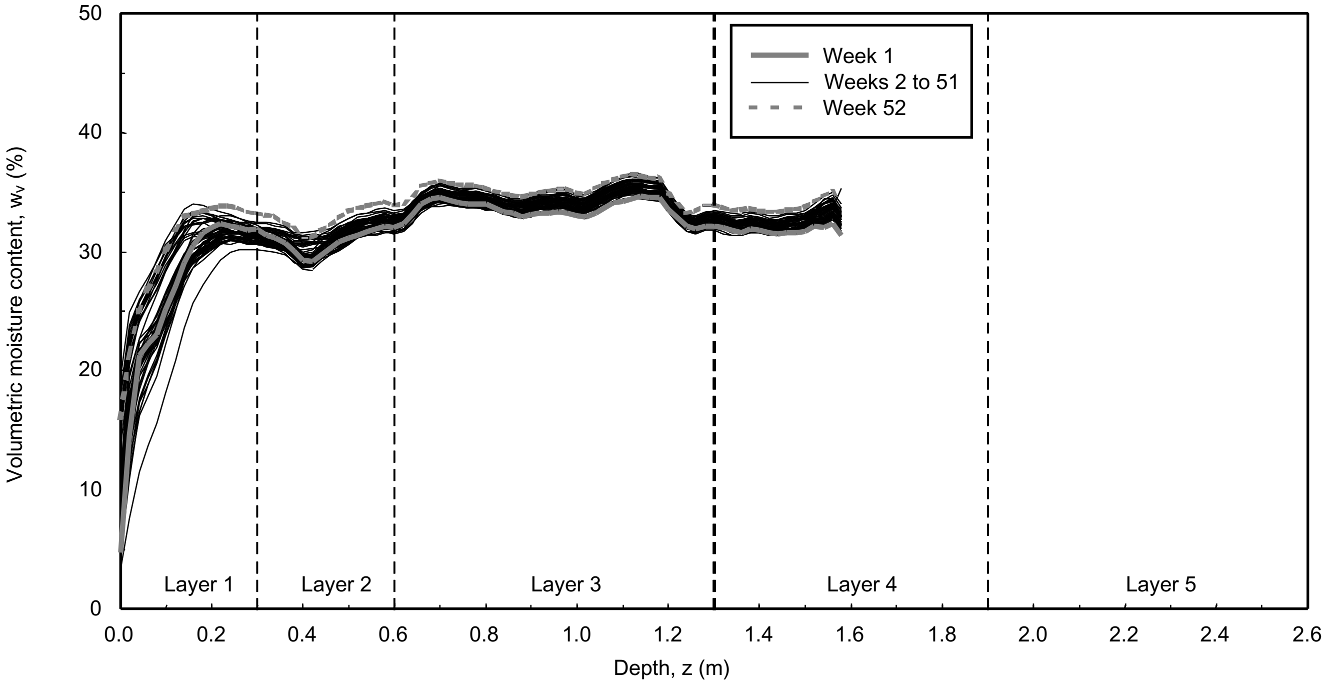
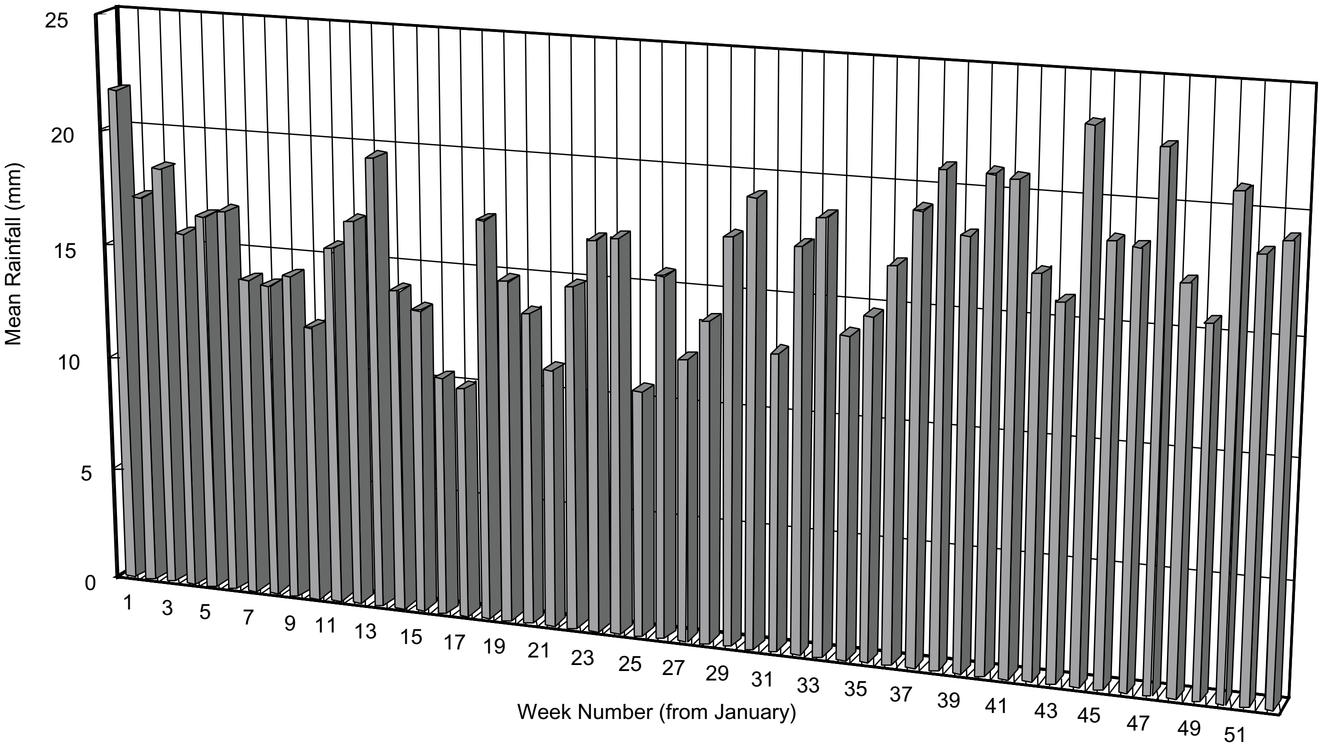


Figure 7 Mean volumetric moisture content with depth (Weeks 1 to 52



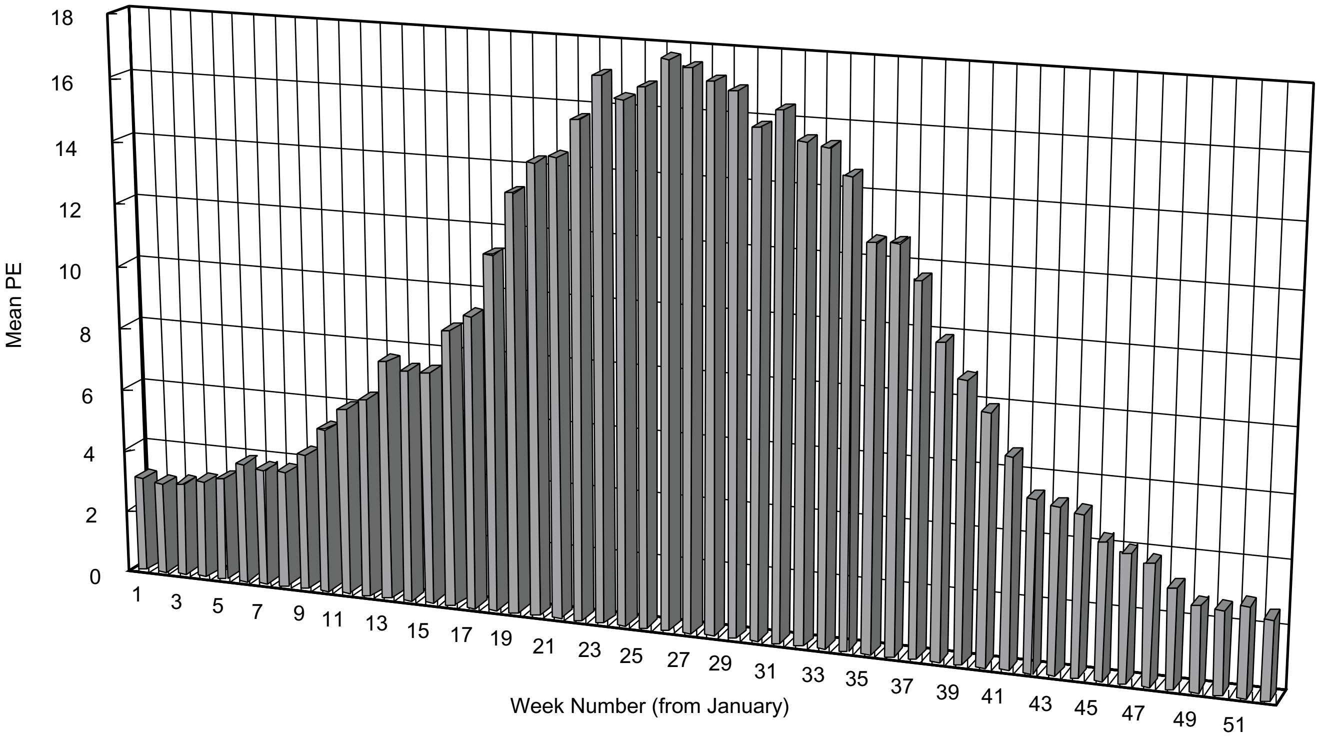
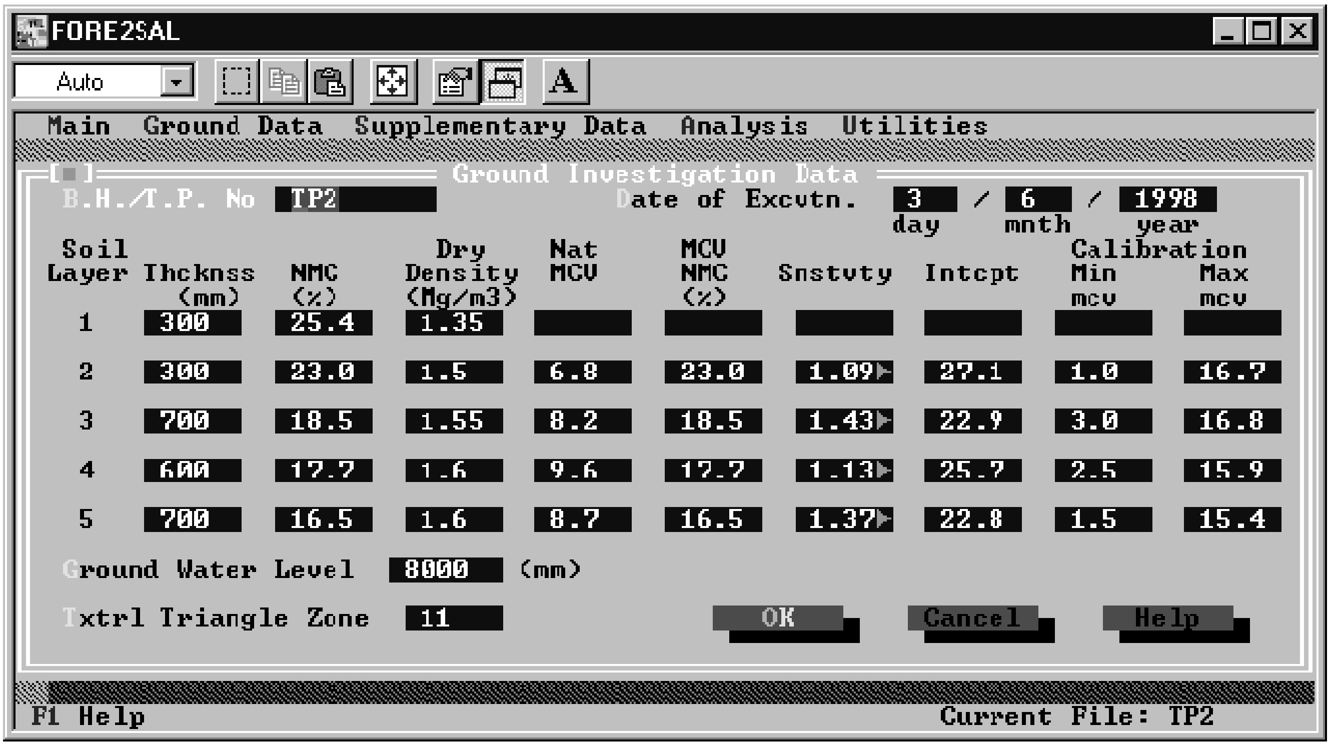


Figure 8 Mean 30-year weekly rainfall (top) and PE (bottom) data for MORECS grid square 57



Ground Investigation Data

B.H./T.P. No TP2

Date of Excvtn. 3 / 6 / 1998
day mnth year

Soil Layer	Thcknss (mm)	NMC (%)	Dry Density (Mg/m3)	Nat MCV	MCV NMC (%)	Snstvty	Intcpt	Calibration Min mcv	Calibration Max mcv
1	300	25.4	1.35						
2	300	23.0	1.5	6.8	23.0	1.09	27.1	1.0	16.7
3	700	18.5	1.55	8.2	18.5	1.43	22.9	3.0	16.8
4	600	17.7	1.6	9.6	17.7	1.13	25.7	2.5	15.9
5	700	16.5	1.6	8.7	16.5	1.37	22.8	1.5	15.4

Ground Water Level 8000 (mm)

Txtrl Triangle Zone 11

F1 Help Current File: TP2

Figure 9 FORESALT ground investigation data input screen

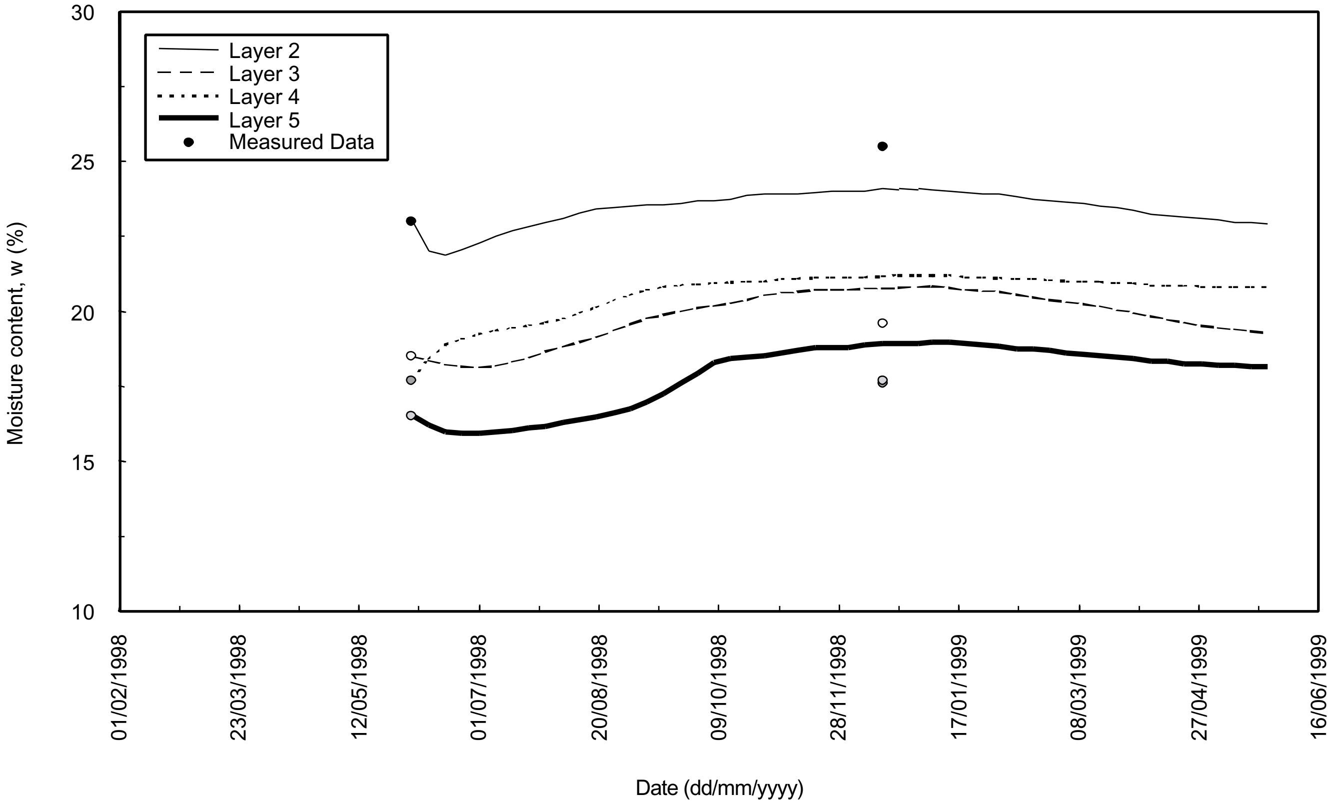


Figure 10 Predicted moisture content against time

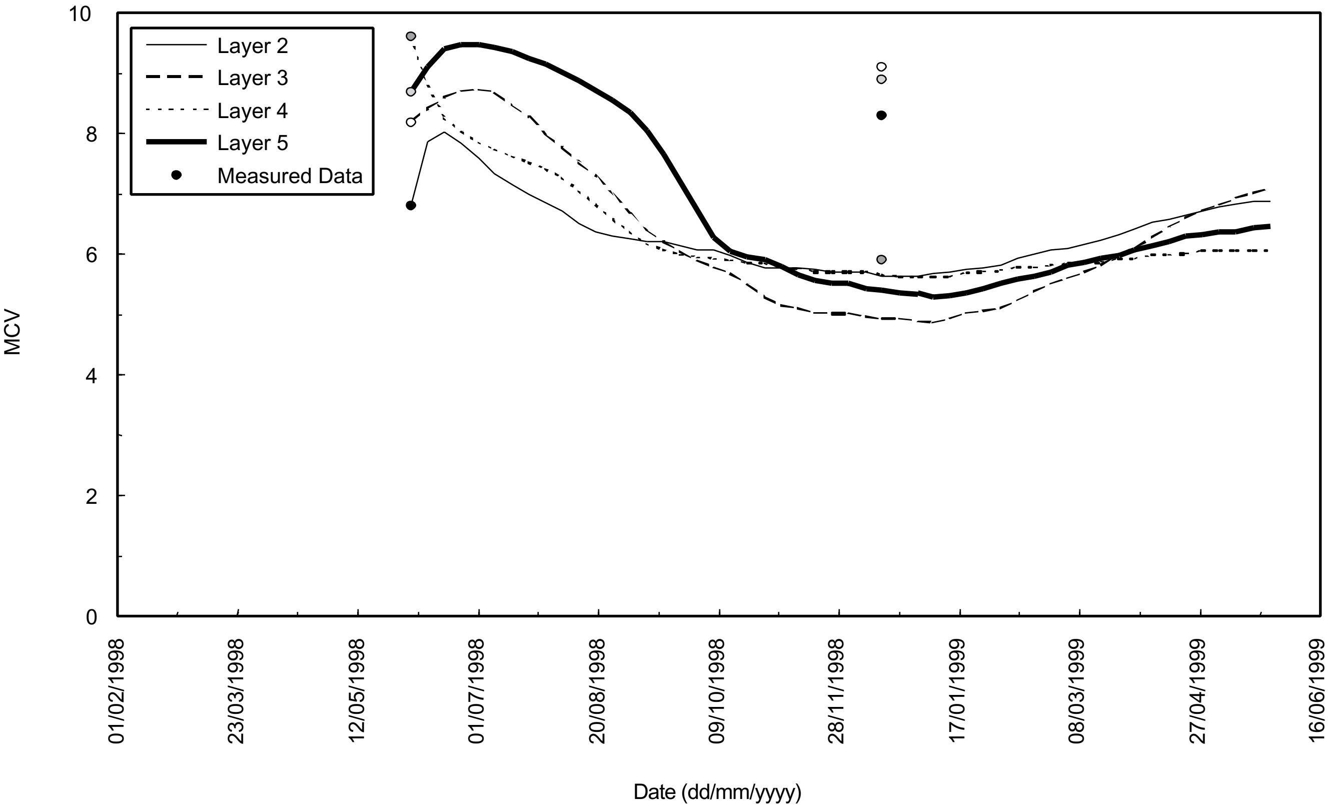


Figure 11 Forecast MCV against time

the smallest for MCV forecast. This appears to be an artefact of the conversion from moisture content to MCV, implicit within the software, with the associated doubts as to differences between the calibration and natural moisture content lines (see Section 3.1.2). (Figure 12 shows weekly forecasts of MCV for Layer 5 in the form of FORESALT program output screens.)

While the accuracy of MCV forecast is probably unacceptable for practical purposes it does bear a striking resemblance to that reported by Smith *et al.* (1998), who reported forecast to be within 3 units of MCV over a 52 week period. The soils considered in this trial are of moderate sensitivity (Matheson and Winter, 1997), while those reported on for the earlier trial were of high sensitivity. This gives a strong indication that forecasts of MCV are unlikely to be of practical use other than for soils of low sensitivity. Low sensitivity soils are relatively rare among the glacial tills that dominate Scottish surface deposits.

5 Summary and recommendations

Computer models for the forecast of the acceptability of soils for earthworks in both the long-term and the short-term have been developed. Modifications to the model have been undertaken to ensure full year 2000 compliance and a separate Excel® spreadsheet utility produced to allow the prediction of the natural moisture content MCV line from the calibration line for input to the model in appropriate instances.

A field trial to evaluate the performance of the models has been undertaken. The results of the field trials are broadly similar to those reported for a previous exercise and confirm the efficacy of the model for moisture content predictions. Forecasts of MCV are, however, considered to be insufficiently accurate for practical use. This is considered to be due to two factors:

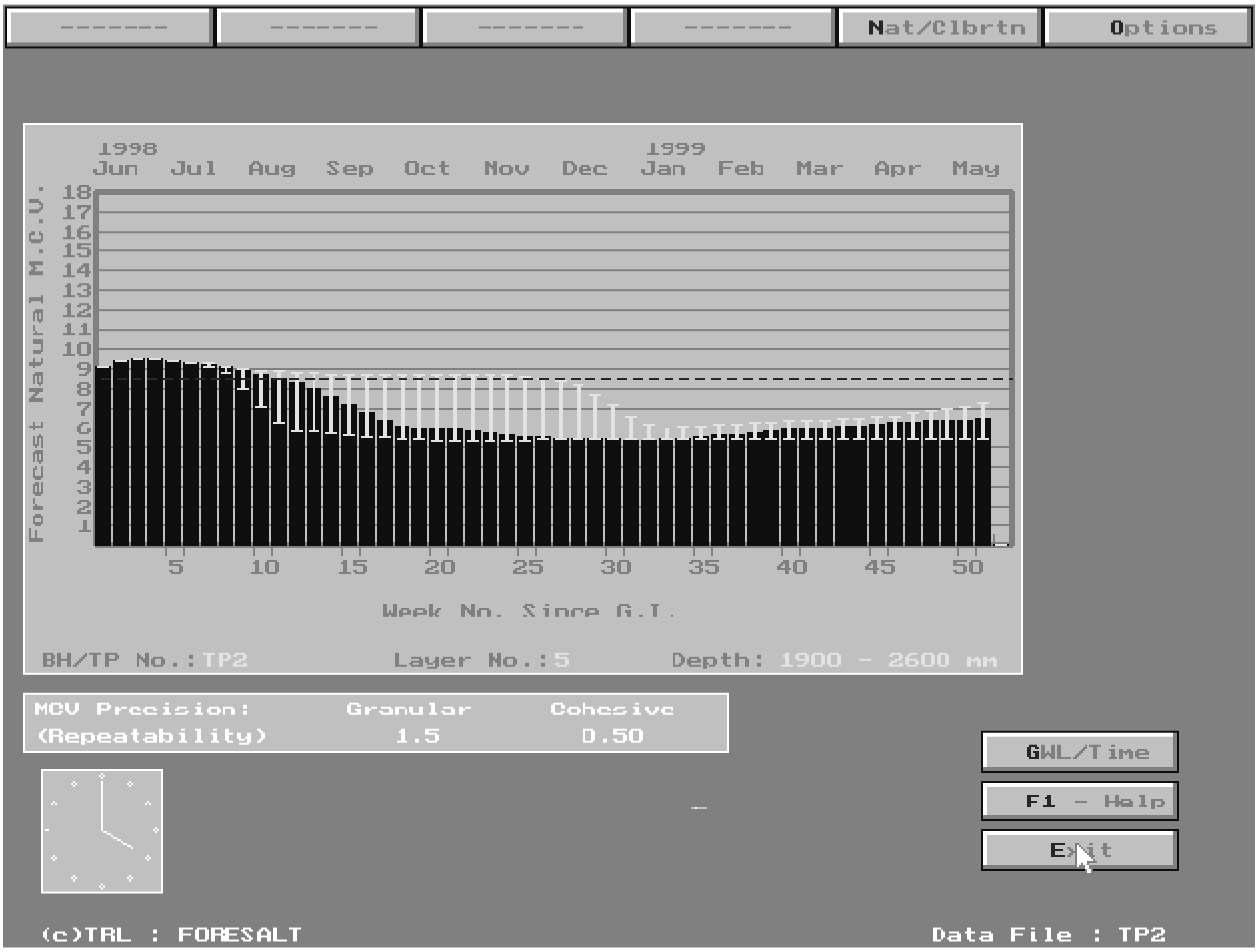
- uncertainties that remain in respect of the precise relationship between calibration and natural moisture content line data; and
- the natural tendency of the process of conversion from moisture content to MCV to accentuate any inherent errors in the data.

A detailed experimental study of a non-standard sample preparation procedure has been carried out. It is recommended that the non-standard procedure should not be taken forward as either a ‘standard’ or ‘alternative’ test procedure.

Detailed experimental studies of the offsets between the calibration line and the natural moisture content line have been carried out. It was concluded that, for fine-grained soils only, if a single natural moisture content MCV test confirmed the existence of an offset then a prediction method for the natural moisture content line could be used.

6 Acknowledgements

The technical and quality audits for this report were performed by RA Snowdon and P McMillan respectively; the author is grateful for their helpful suggestions and advice.



BH/TP No.: TP2 Layer No.: 5 Depth: 1900 - 2600 mm

MCV Precision:	Granular	Cohesive
(Repeatability)	1.5	0.50

(c)TRL : FORESALT

Data File : TP2

Figure 12 Output screen for weekly variation in MCV for TP2 Layer 5

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Abstract

Computer models for the forecast of the acceptability of soils for earthworks in both the long-term and the short-term have been developed. A number of issues pertinent to the efficient use of the models are addressed in this report; not least, the software has been revised to ensure year 2000 compliance. In addition, a field trial has been carried out. The results indicate that predictions can generally be achieved within 2% of moisture content. The accuracy of MCV forecasts is much more dependent on the moisture sensitivity of the modelled soil. Consequently care is required in interpreting such forecasts.

Related publications

TRL273	*Use and application of the MCA with particular reference to glacial tills* by G D Matheson and M G Winter. 1997 (price £35, code H)
TRL308	*The determination of the acceptability of selected fragmenting materials for earthworks compaction* by M G Winter. 1998 (price £25, code E)
RR361	*Compaction monitoring devices for earthworks* by R A Snowdon.1992 (price £25, code E)
RR208	*The compaction of soil using lightweight vibrating plate compactors* by A F Toombs. 1989 (price £20, code B)
RR90	*The precision of the moisture condition test* by A W Parsons and A F Toombs. 1987 (price £20, code B)
LR750	*The rapid measurement of the moisture condition of earthwork material* by A W Parsons. 1976 (price £20)

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