Sample preparation effects on the compaction properties of Swedish fine-grained tills

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Abstract

Fine-grained tills are a dominant feature of the drift geology of Sweden. Until recently their use in earthworks applications has been limited due to the plentiful supply of naturally occurring gravel and crushed rock, and their high sensitivity to moisture content change which often leads to the view that fine-grained tills are problem soils. Environmental and economic factors are, however, leading to pressure to increase the use of site-won materials, including fine-grained tills, in earthworks applications. This paper sets out the case for the increased use of fine-grained tills in such applications and examines the Moisture Condition Value test, for the determination of potential soil acceptability for earthworks, in the context of standards developed over 20 years in Britain and the emerging practice in Sweden. One of the key differences between Swedish practice and the approach followed in the British Standard is in terms of the sample preparation method employed. In Britain samples are air-dried prior to wetting to a range of moisture contents and testing while in Sweden an initially wet sample is selectively air-dried to achieve the desired range of moisture contents. The results of a detailed laboratory testing programme to investigate the influence of these sample preparation methods on the test results are presented. It is concluded that the Swedish method of selective air-drying is suitable for use in areas of high precipitation and associated high natural moisture contents. However, in areas where natural moisture contents are not consistently high the British Standard method is preferred. It is important to recognize that the sample preparation method employed will influence the test results and that the methods are not interchangeable. It is further found that, for the limited range of soils tested, there is no appreciable difference between the air-drying employed in the British Standard and oven-drying. However, it is recognized that further research is required in this area, not least on British soils.

Keywords: compaction, earthworks, laboratory studies, till

Fine-grained glacial tills are a predominant soil type in Sweden. However, the plentiful supply of naturally occurring gravel and crushed rock has limited their use in earthworks applications. As both economic and environmental pressures are brought to bear on such operations site-won materials, such as fine-grained tills, will become a more attractive alternative to gravel and crushed rock.

Fine-grained tills tend to be highly sensitive to moisture content change. In a high precipitation environment, such as Sweden where natural moisture contents are also high, this means that great care is required in their testing and handling. The Moisture Condition Apparatus (MCA) is widely used to determine the acceptability of soils, and particularly glacial tills, in the UK. However, differences have evolved between practice in the UK and Sweden, in particular in relation to the test sample preparation method employed.

This paper examines the case for the increased use of fine-grained tills in Swedish earthworks. It also examines the main issues in respect of the use of the Moisture Condition Apparatus (MCA) (Parsons 1976) to determine the acceptability of such materials and presents the results of a laboratory study into the effects of the sample preparation method employed on the resulting measured compaction properties. Three methods are examined; these involve air-drying, oven-drying and partial-drying of samples.

Swedish earthworks practice

In Sweden approximately 70% of the land area is covered by tills. One of the most common types is fine-grained till, which may include up to 60% of silt and clay sized particles. Fine-grained tills are often regarded as problem soils due to their high sensitivity to moisture content change, their frost susceptibility and variability.

The high sensitivity of fine-grained tills to changes in moisture content means that in earthworks they are often replaced with gravel or crushed rock, which are in plentiful supply in most parts of Sweden, to achieve the required bearing capacity at formation level. This replacement requires materials to be transported, often over long distances, for both the disposal of the fine-grained material and also to bring the replacement material to site. An increase in the use of fine-grained tills will result in much lower environmental impacts. For comparison, in one instance the reuse of around 26 000 m^3 of site-won pavement materials led to a reduction of 115 000 vehicle-kilometres, compared to more conventional dispose-and-replace operations (Milton & Earland 1999).

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Economic incentives for the reuse of site-won materials are in place in many European countries. In the UK, for example, a tax on landfill and a levy on primary aggregate use are in operation.

In Sweden earthworks materials have traditionally comprised naturally occurring gravel and crushed rock. The supply of gravel and bedrock has been considered effectively unlimited. However, during the last twenty years the environmental impact of such activities has been increasingly more stringently addressed. In 1996 the Swedish authorities introduced a new tax to reduce the usage on natural gravel (SFS 1995). The total annual production of aggregates was 79 million tonnes in 1999. This was divided into natural gravel (29 million tonnes), crushed bedrock (38 million tonnes), tills (1.2 million tonnes) and other materials (10.7 million tonnes). The tills represent just 1.6% of all aggregates used during 1999 (SGU 2000). The main environmental focus has been on recycling material not to increase the use of site-won materials such as fine-grained tills.

A tax on the disposal of material to landfill was also introduced in 1999 (SFS 1999). However, it is not clear whether the tax is being applied to the disposal of fine-grained tills or if such materials are being utilized in associated works such as noise bunds, which may or may not be subject to the tax.

A fine-grained till could be utilized in two ways: as a raw material for producing sand and gravel or in its natural state.

In some areas tills have been used as raw materials from which sand and gravel have been extracted, albeit only to a limited extent. A Swedish study has shown that the waste from this type of operation constituted between 20% and 60% of the original excavated mass when producing road material with sufficient quality (SNRA 1996). The borrow pit will then contain the remaining material which may consist of fine-grained material, cobbles and boulders. This could locally produce undesirable environmental impacts such as problems with the re-establishment of vegetation and also of the creation of areas with low bearing capacity during wet conditions.

The most important factor in increasing the bearing capacity of a fine-grained soil is compaction. Soil compaction also reduces the compressibility and enhances the shear strength of the soil. However, the use of different laboratory practices in different countries has led to some debate (Jones & Greenwood 1993) on the effects of different sample preparation procedures on the resulting measured compaction properties.

Test methods

In this study two different laboratory methods have been used to evaluate the compaction properties of the soils.

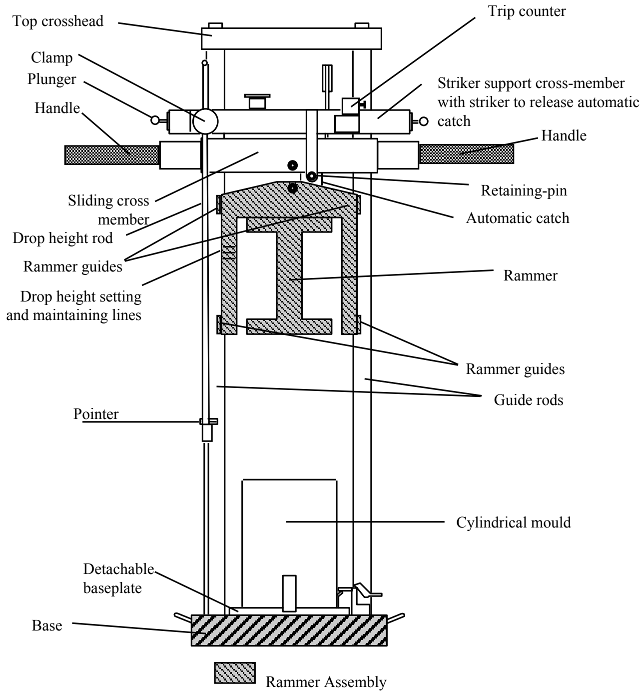

Fig. 1. The moisture condition apparatus.

The methods used were the Proctor compaction method and MCA compaction (Parsons 1976).

The Proctor compaction test was introduced in 1933 (Proctor 1933; Rodriguez *et al.* 1988). Modified Proctor is the most frequently used Proctor method in Sweden and was therefore chosen for this suite of tests. The modified Proctor method was performed according to Swedish Standard (SS 1994*a*). The only difference between Swedish and the British Standard methods is the number of blows. The Swedish method uses 25 blows on each of the five layers while the British Standard (BSI 1990*a*) uses 27 blows. The applied energy in the modified Proctor method according to the Swedish method is 2482 kJ/m^3. This should be compared to 2682 kJ/m^3 according to BSI (1990*a*) and 2693 kJ/m^3 according to ASTM (1986).

Parsons (1976) developed the Moisture Condition Value (MCV) test method at the Transport Research Laboratory (TRL). The test is a rapid measurement of the moisture condition of earthworks material. It is aimed at construction control to assess the acceptability of materials in relation to the specified upper limit of the moisture content (Parsons 1976). In MCV testing a special moisture condition apparatus (MCA) is used (Fig. 1). The apparatus has a mould with a detachable base and an inner diameter of 100 mm. A free falling rammer with a mass of 7 kg and a diameter of 97 mm is attached to an automatic release mechanism. Normally a soil sample of 1.5 kg is used together with a drop height of 250 mm. A lightweight disk is placed on top of the soil to avoid extrusion of soil between the rammer and the sides of the mould. The disk also prevents smearing of the soil onto the rammer sides.

Parsons developed the method for use exclusively with cohesive (or fine-grained) materials. However, the methodology was later adapted to enable its use with many granular (coarse-grained) materials, particularly tills with a wide particle size range commonly encountered in the UK (Matheson & Oliphant 1991; Matheson & Winter 1997).

The MCV of a soil sample is defined as the lowest compaction energy required to obtain maximum compaction at a specific moisture content. To calculate the MCV, the penetration of the rammer at any given numbers of blows is compared to the penetration at four times as many blows and the difference is determined. This difference in penetration is plotted against the logarithm of the lower number of blows. The straight line extension of the steepest part of the curve then usually defines the point at which the 5 mm line is crossed (BSI 1990*a*) for cohesive soils and the best-fit method for granular soils. (Fig. 2). Matheson & Winter (1997) make a strong case for the exclusive use of the best-fit line. The MCV is defined as 10 times the logarithm of the number of blows corresponding to a difference in penetration of 5 mm on the plotted curve.

A determination of the MCV versus moisture content for the soil is performed by several tests at different moisture contents. From the results a linear regression is performed. This regression forms an equation:

$$w = a - b(MCV) \quad (1)$$

where w is the moisture content (%); a is the intercept with the moisture content axis (%); and b is the regression coefficient or the slope of the line (% moisture content change per MCV).

From the parameters a and b certain conclusions can be drawn about the compaction properties of the soil. The parameter a is an arbitrary low-strength moisture content value, which could be used, in similar circumstance to the liquid limit of the soil as a crude index value. The b parameter indicates the sensitivity of the soil to change in moisture content, a small b value indicating high sensitivity. The idealized regression, or calibration line, is illustrated in Figure 3.

The applicability of the MCV test is defined by the position of the plotted particle size distribution on the ternary diagram (Oliphant & Winter 1997) shown in Figure 4. The MCA test has been in routine operation since 1983 in Scotland (Matheson & Oliphant 1991; Matheson & Winter 1997), an area which, like Sweden, is dominated by glacial tills.

In contrast to the Proctor method the MCV method applies different amounts of compaction energy dependent on soil type and actual moisture content. Another major difference is the way of applying the compaction energy. The Proctor method applies the compaction energy with a 50 mm diameter rammer and the position of the rammer is changed during the test in order to ensure an even distribution of energy to the upper face of the sample. In contrast, the MCV method applies the compaction energy to the entire area of the test sample.

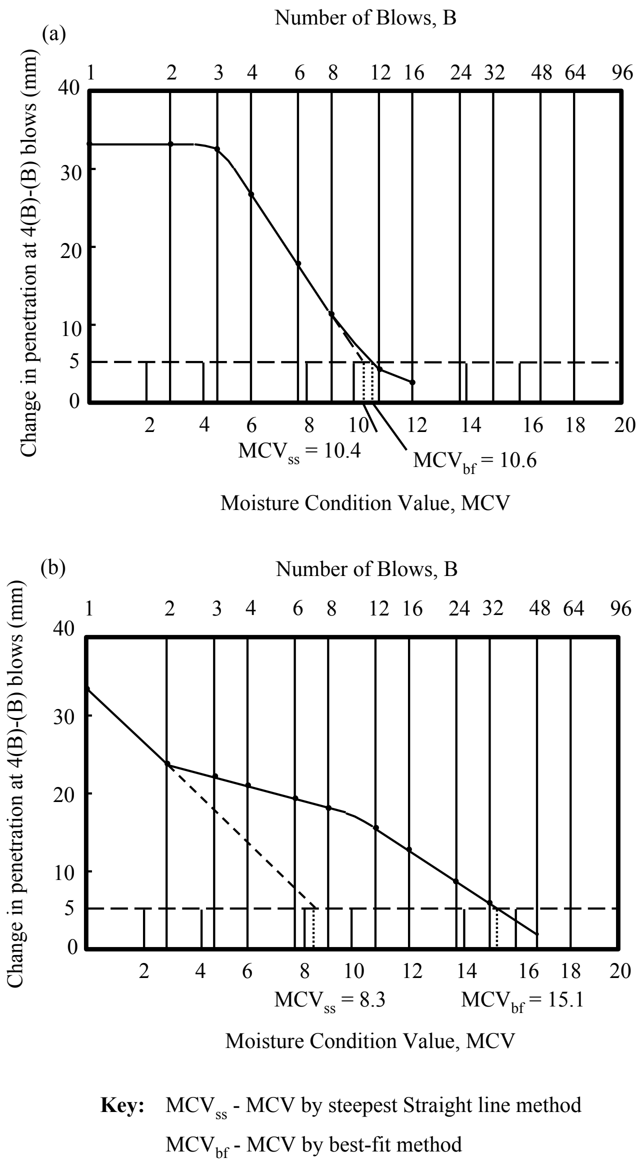

Fig. 2. Determination of MCV (**a**) cohesive (fine-grained) materials; and (**b**) granular (coarse-grained) materials.

Soils tested

Three different Swedish soils were tested and denoted after their geographical location: E22 Flyinge North (E22.F.N.), Sturup PG9 and Östra Torn. The particle size distributions are shown in Figure 4 and presented in Figure 5. The E22 material and Sturup PG9 are both classified as clayey sand tills and the soil from Östra Torn is classified as a sandy silty clay till. Liquid limit, plasticity limit and plasticity index for the different soils are presented in Table 1 and plotted in Figure 6. The results of chemical analyses are presented in Table 2.

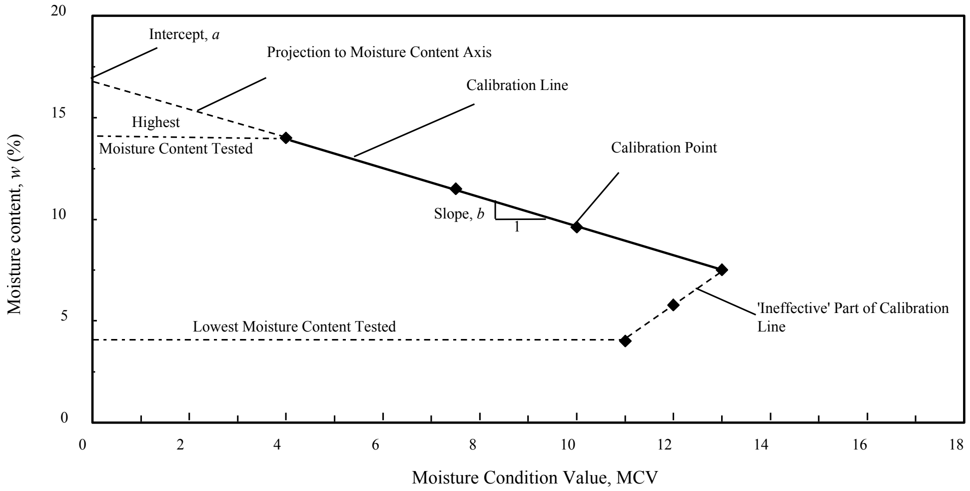

Fig. 3. Typical calibration line.

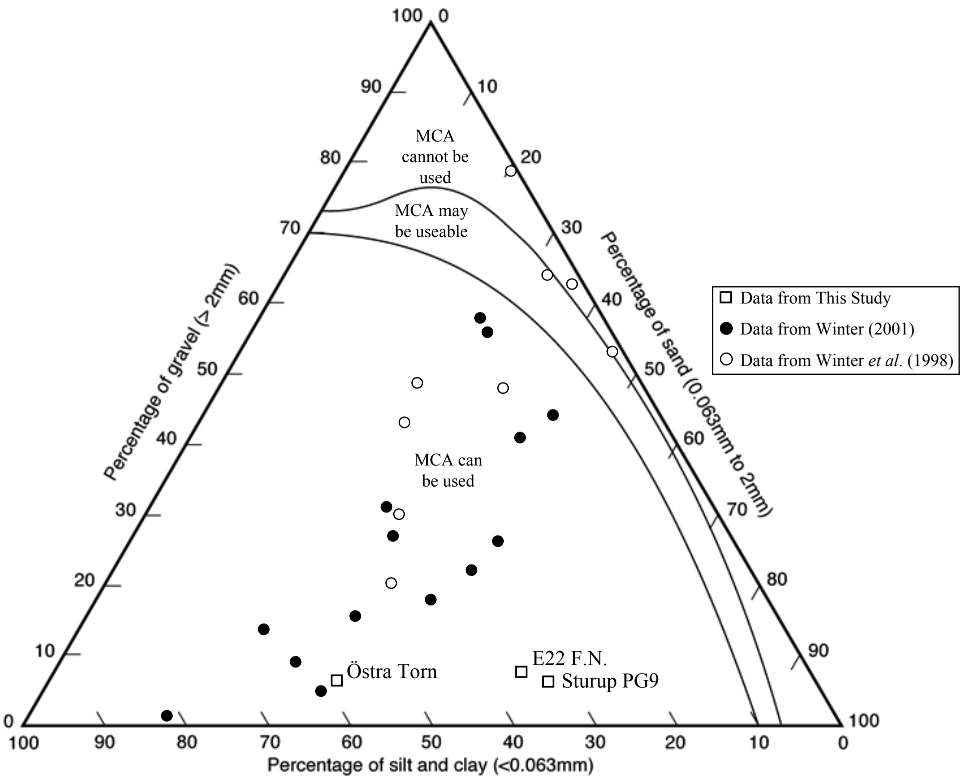

Fig. 4. Limits of use if the MCA (after Oliphant & Winter 1997; Matheson & Winter 1997) showing typical particle size distributions tills from Scotland, Northern England and southern Sweden.

Sample preparation

The differences between sample preparation in Sweden and Britain mainly entail the methods used to achieve the range of moisture contents required to achieve an MCV calibration line. In Sweden, full drying of clayey soils before any type of testing is generally avoided whenever possible since drying and re-wetting is considered to significantly alter the structure of the soil. Swedish practice thus requires drying a soil from its natural moisture content to achieve the desired range of moisture contents. The British Standard method (BSI 1990*a*) uses an air-dried soil that is wetted to achieve the desired range of moisture contents. Both methods are developed to deal with the hysteresis effect between drying and wetting of a soil (i.e. the soil properties are different between the drying phase and the wetting phase), albeit using diametrically opposed approaches; one starts with a wet soil and the other with a dry soil. For both the Swedish and the British Standard method the soil needs to rest for some time to achieve homogeneous conditions in the soil samples (i.e. even distribution of the water within the soil). In BSI (1990*a*) the minimum storage time for cohesive soils

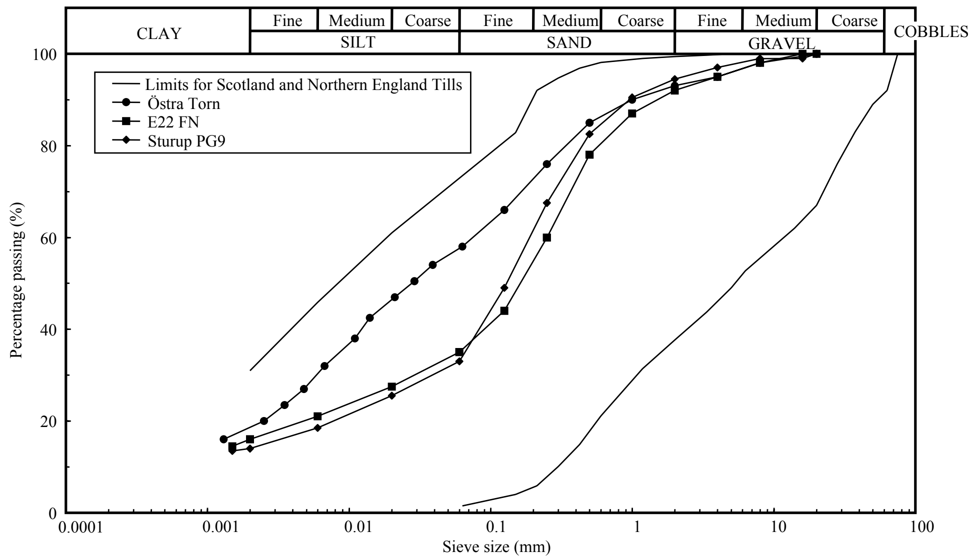

Fig. 5. Particle size distributions for the soils used in this study. The envelope for selected tills from Scotland and Northern England is shown comparison (after Winter *et al.* 1998 and Winter 2001).

Table 1. *Index properties of the soils tested.*

Soil	Liquid Limit, *LL* (%)	Plastic Limit, *PL* (%)	Plasticity Index, *PI* (%)
Östra Torn	25	16	9
E22 FN	17	10	7
Sturup PG9	21	12	9

is 24 hours in an airtight container. In the tests reported here, the minimum storage time was one week for both partially dried soil and wetted soil. To compare the effect of different drying methods both air-dried and oven-dried soils were prepared. The oven-dried soils were dried for at least 24 hours and then cooled to room temperature before re-wetting.

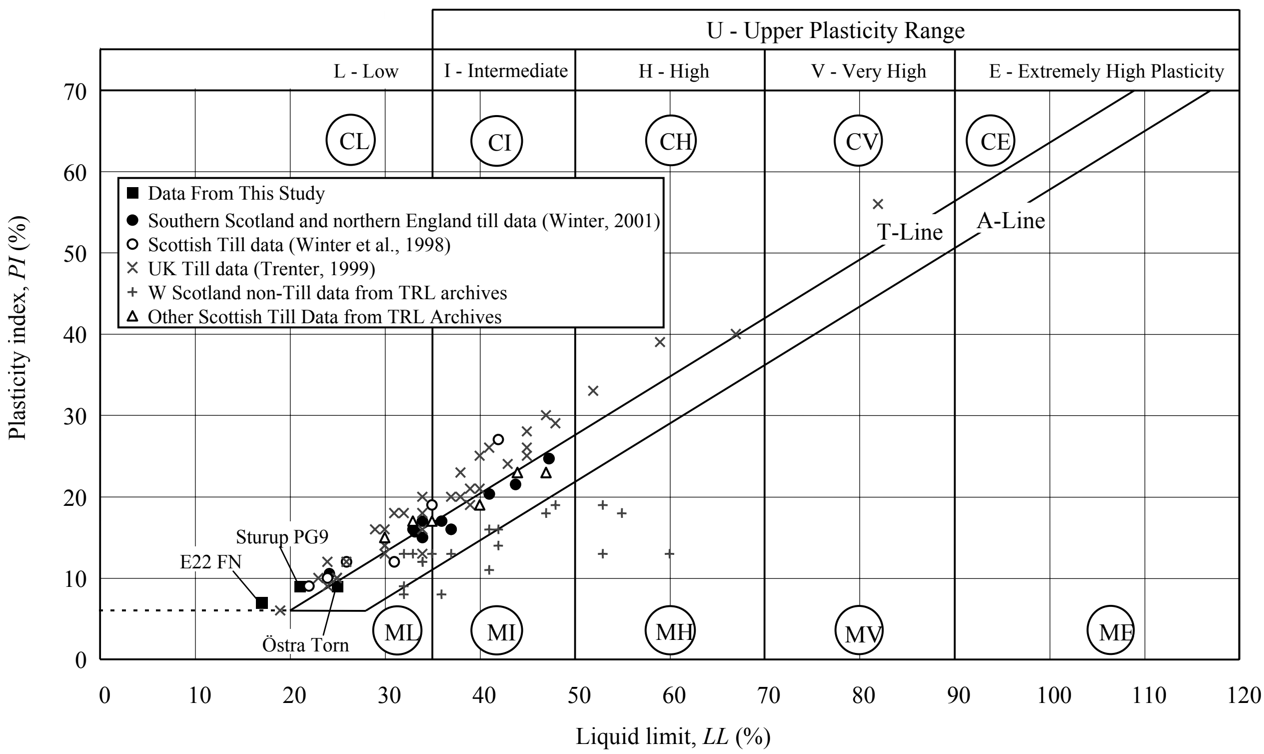

Fig. 6. Plasticity chart showing data from this study. Data from other sources is shown for comparison.

Table 2. *Chemical analysis of the tested soils.*

Soil	PH–H_2O Swedish Standard (SS 1991)	Organic content (%) Swedish Standard (SS 1994*b*)	$CaCO_3$ (%) Larsson *et al.* (1987)	Free lime (%) Swedish Standard (SS 1998).	CaO (%) British Standard Institution (BSI 1990*b*)
Östra Torn	8.6	<0.2	13.5	<0.1	8.8
E22 FN	8.4	<0.2	20.1	<0.1	12.8
Sturup	8.2	<0.2	3.1	<0.1	2.2

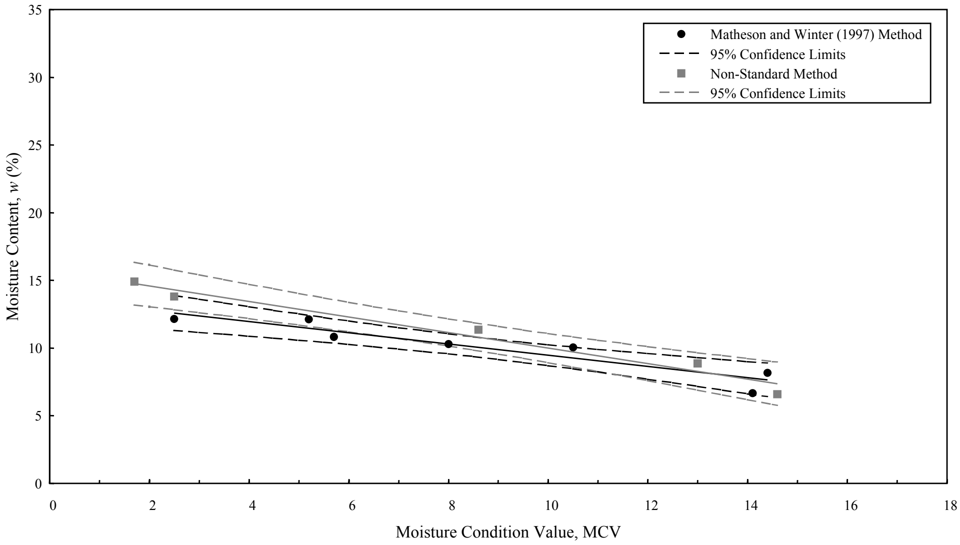

Fig. 7. MCV calibration lines obtained using the standard and non-standard methods (after Winter 2001).

The Swedish method is similar to that proposed by Jones & Greenwood (1993). Their method essentially involves one test at the natural moisture content and further tests on samples that have been wetted-up or partially dried to higher and lower moisture contents respectively. Winter (2001) reported the results of an extensive testing programme to compare the standard method, as presented by Matheson & Winter (1997), and that proposed by Jones & Greenwood (1993). Even though no large and statistically significant differences were found in the results obtained from the two methods (e.g. Fig. 7), operational difficulties were experienced with the Jones & Greenwood (1993) method and this was not recommended for further routine use. There are, however, two key differences between the Jones & Greenwood (1993) method and the Swedish method. These are as follows:

(1) Natural moisture content MCV data are not incorporated into determinations of the calibration line using the Swedish method. Winter (2001) found the incorporation of these data to be particularly difficult with fine-grained soils due to the differences in the residual soil structure created by the different sample preparation methods (see Matheson & Winter 1997).
(2) In Sweden the high natural moisture contents of the soils mean that all tests are carried out on samples selectively air-dried to the required moisture contents and none have their moisture content increased. This effectively minimizes the effects of hysteresis on the wetting-drying curve. It does, however, rely upon encountering wet soils in the field. While this could be compensated for in the laboratory by wetting the soil sample, this further increases the sample preparation time and potentially increases the effects of hysteresis.

Results and differences between Sweden and UK

MCV calibration lines for each of the soils are presented in Figure 8. These were determined using the Swedish method of sample preparation. There are substantial differences between the MCV calibrations for the Östra Torn material and E22 materials. These were expected due to the differences in clay content between the two materials. However, the differences between the E22 material and the Sturup material was not expected since the grading of the soils was similar. The Proctor results as well as the dry density versus moisture content for the MCA compacted samples are presented in Figure 9 for the E22 and Östra Torn materials. The results show a very similar behaviour between modified Proctor

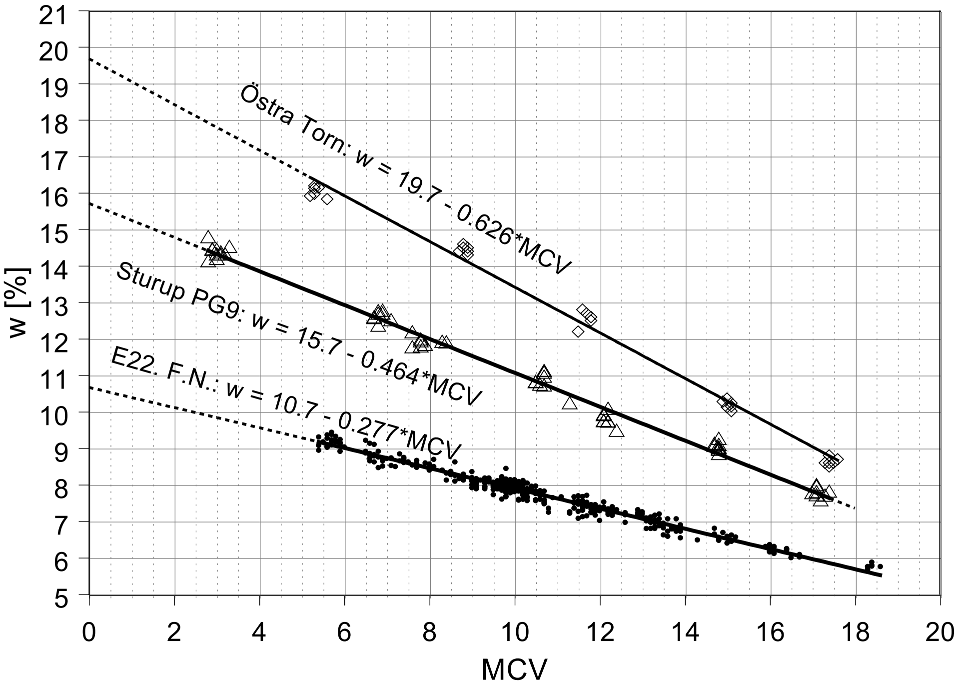

Fig. 8. MCV calibration lines for the three different soils.

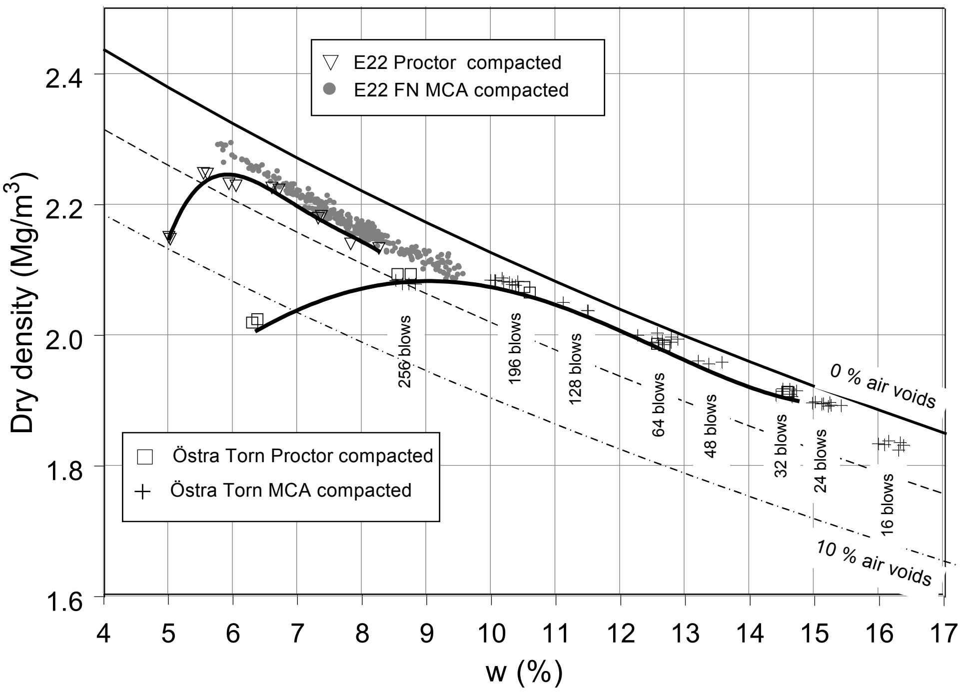

Fig. 9. Dry density determined with modified Proctor versus dry density determined with MCA.

compacted samples and MCV compacted samples. However, for the material from Östra Torn the Proctor compaction results in a slightly higher dry density compared to MCV compaction at the dry side. The soil from E22 shows another pattern where the MCV compaction gives a higher dry density across the full range of moisture contents compared to Proctor compaction. These results should be compared with results from similar tests presented by Murray *et al.* (1992). In the results presented by Murray *et al.* (1992) the dry density of the MCV compacted samples is in between the dry density that is achieved with Proctor and modified Proctor compaction respectively. Further Murray *et al.* (1992) discuss the difference in air voids and that the MCV compaction gives an optimum moisture content closer to full saturation. The results in Figure 9 also illustrate a higher degree of saturation for the MCV compacted samples compared to the Proctor compacted

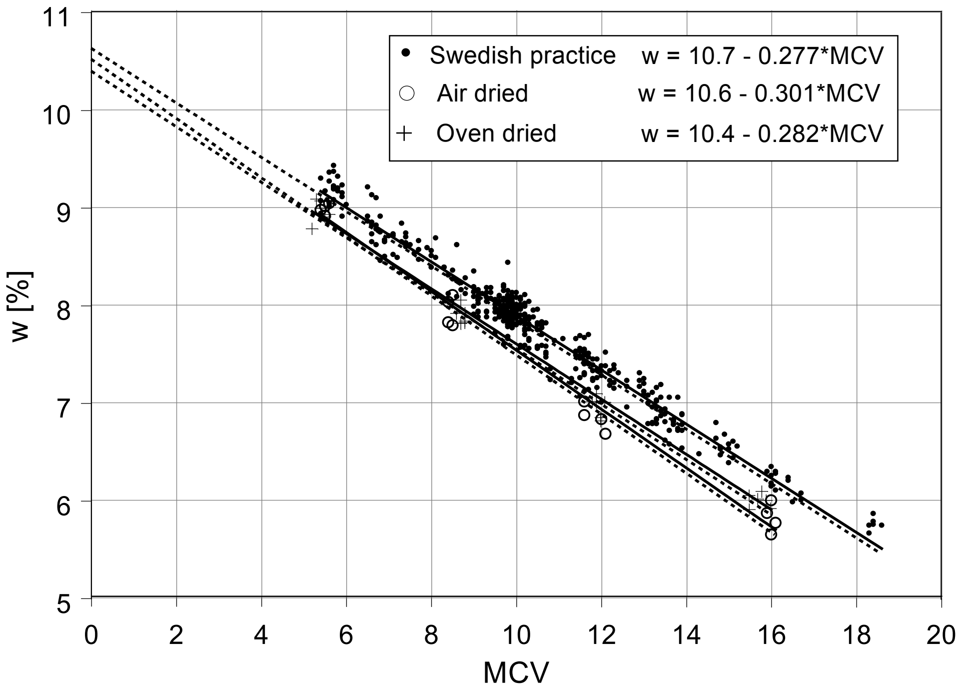

Fig. 10. MCV calibration lines for the E22 material treated in three different ways.

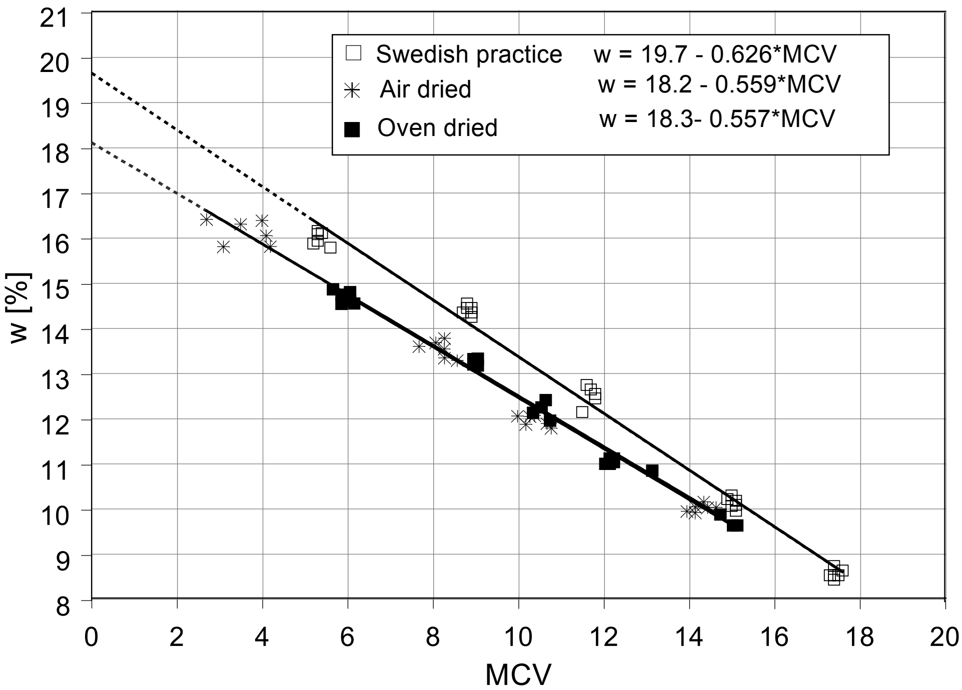

Fig. 11. MCV calibration lines for the Östra Torn material treated in three different ways.

samples. A plausible explanation for the differences in the results could be the differences in the soil types and the differences between the applied compaction energy between the Swedish and the British Standard methods.

Sherwood (1970) showed that the reproducibility of the Proctor test was reasonable as expressed in terms of the resulting optimum moisture content and maximum dry density.

The results presented in Figures 10 (E22) and 11 (Östra Torn) show that the differences in sample preparation affect the MCV calibration lines to a greater degree for soils with a higher clay and silt content (i.e. Östra Torn). This indicates that the clay and silt particles are most affected by drying and wetting. The results also indicate that it is the drying of the soils that makes the main difference and it is not dependent upon how the soils are dried (i.e. air-drying or oven-drying).

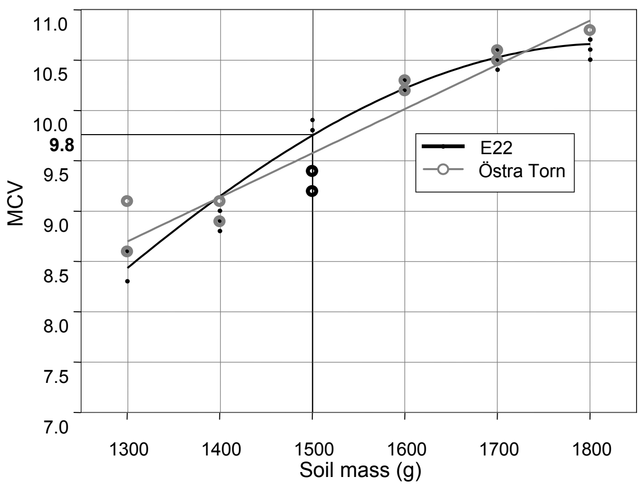

Fig. 12. MCV as a result of soil mass in compaction for two different soils.

The differences in soil preparation between Sweden and Britain do affect the MCV calibration line. However, the Swedish method can be very time consuming due to the need for controlled drying. To achieve the best quality in MCV calibration the differences in moisture content between samples in the calibration should be equidistant. To obtain this with the Swedish method, the drying procedure needs to be carefully controlled. Since the agglomerations of soil dry from the surface there is a wet core surrounded by a drier shell. This difference in moisture content between the surface and core could affect the MCV calibration due to high suction on the surface of the soil agglomerations. To overcome this, the soil must achieve equilibrium and this could take several days for a clayey soil. The problem with uneven distribution of moisture in the soil could also arise when the soil is wetted. However, for the completely air-dried and oven-dried soil most of the bonds in the agglomerations are broken and the moisture appears to be more evenly distributed when wetted.

Since both contractors and consultants as well as the Swedish National Road Administration (SNRA 1996) have adopted the MCV method as a test method for fine grained soils it is likely that Sweden will adopt the proposed European Standard prEn 13286-46 (ES 2000). The MCV method gained its first acceptance during the construction of Yttre Ringvägen in Malmö, the connection road to the Öresund fixed link. However, due to the lack of a Swedish standard some of the consultant companies involved in the road and railway design used their own MCV calibration methods. Some consultants used 1.8 kg soil samples in the MCV mould instead of the standard 1.5 kg sample. This 0.3 kg of extra soil resulted in a higher MCV compared to the correct value, see Figure 12. This illustrates the need for a standard. However, the proposed European Standard does not deal with soil preparation for MCV calibration, although it does specify both the maximum particle size of the soil and the sample size.

According to the particle size distributions (see Figs. 4 & 5) the MCV calibration lines for E22 and Sturup should be very similar. However, the calibration lines for these materials are markedly different; the *a* and *b* parameters both being greater for Sturup than E22 (Fig. 8). One plausible explanation for this difference could be found in the chemical composition, see Table 2. The major difference between the soils could be as a result of the natural lime content. The effects of such chemical differences are the subjects of ongoing investigation.

Conclusions

The case for the increased use of Swedish fine-grained tills has been made. Economic and environmental pressures for the use of such site-won materials are likely to increase and as such their use is likely to increase.

In this case some means of rapidly assessing the acceptability of a soil at a given point in time and at a given location is required. The MCV test seems to be entirely fit for this purpose. However, there is some conflict between the methods of sample preparation used in Sweden and elsewhere, particularly in the UK.

The Swedish method relies heavily upon the existence of high moisture content soils in the field or extensive laboratory work. This allows all of the different moisture contents required to determine a MCV calibration line to be achieved by partially drying the soil. This effectively eliminates the effects of hysteresis that can create problems if soils must be both dried and wetted from the naturally occurring moisture content, as has been previously observed for the method proposed by Jones & Greenwood (1993). However, it should be noted that this approach is only likely to be appropriate for very wet climates, where natural moisture contents are high.

The Swedish method of determining the calibration line better reflects the field condition. However, the MCV calibration line is not intended to necessarily reflect the field condition. It is primarily intended to highlight the sensitivity of a soil to changes in moisture content, highly sensitive soils being more likely to be rendered unacceptable by rainfall than less sensitive soils. Similarly, highly sensitive unacceptable soils require smaller decreases in moisture content to be rendered acceptable than do less sensitive soils. Indeed software has been developed that allows the likely acceptability of a soil to be forecast ahead of time (Smith *et al.* 1998; Winter 2001). It is most important that the field condition is reflected in tests conducted at the construction stage. In this case tests are taken at the natural moisture content and no air-drying is allowed.

Whilst the Swedish method of MCV sample preparation is entirely appropriate to wet naturally occurring soils it is viewed as inappropriate to other locations. In these latter instances the British Standard method as further developed by Matheson & Winter (1997) is recommended. With these considerations in mind, both methods could be used although they may give somewhat different results. The choice of method should be based on the local conditions. It is important to recognize that the sample preparation method employed will influence the test results and that the methods are not interchangeable.

It is further found that, for the limited range of soils tested, there is no appreciable difference between the air-drying employed in the British Standard and oven-drying. However, it is recognized that further research is required in this area, not least on British soils.

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