# Optimum use of material: selection of limits for suitable earthworks fill: Irish experience


P. C. Rutty[1,2]* & T. P. Johnston[3]

[1] Mott Macdonald Group Ltd, 8–10 Sydenham Road, Croydon CR0 2EE, UK
[2] Previous address: AGEC Ltd, The Grainstore, Singletons Lane, Bagenalstown, Co. Carlow, Ireland
[3] AGEC Ltd, The Grainstore, Singletons Lane, Bagenalstown, Co. Carlow, Ireland

*Corresponding author (e-mail: peter.rutty@mottmac.com)



**Abstract:** Most Irish earthworks fills consist of glacially derived soils with some excavated rock. Excavated rock and granular glacial soils will nearly always provide acceptable fill. Cohesive glacial soils are generally well-graded tills, characterized by low plasticity and relatively high undrained strength. These cohesive tills provide acceptable fills providing they can be placed and compacted to provide sufficient strength and stiffness, and achieve low air voids.

In standard earthworks specifications, acceptability limits for cohesive fills may be specified by moisture content, moisture condition value or undrained shear strength. The lower limit of strength or moisture content adopted ensures acceptable trafficability, compressibility and stability. Laboratory relationship testing is carried out to establish the relationship between the various test properties.

Experience has shown that simple measurements and descriptions of strength derived from data collected routinely during ground investigations are adequate for estimation at tender. For construction control, moisture condition value testing has been widely adopted, is suitable for the range of soils encountered and provides quick results allowing timely decision-making. Irish tills are moisture susceptible and on-site results allow marginal materials to be processed on site for re-use, providing care is taken to work only in dry weather and protect placed fill.


Over the past ten years or so there has been substantial road building activity in Ireland to improve highway infrastructure with motorways or high-quality dual carriageways connecting the major commercial centres of the Republic of Ireland to Dublin, Dublin to Northern Ireland, and also Belfast to other parts of the north. Generally these projects have been procured using design and build or design, build, finance and operate (Public–Private Partnership or PPP) contracts. The contracts have placed most of the ground risk with the contractors but also encouraged value engineering by way of using excavated marginal material for earthworks construction where appropriate.

Most Irish earthworks fills consist of glacially derived soils with some excavated rock. Excavated rock and granular glacial soils will nearly always provide acceptable fill. The cohesive glacial soils generally are over-consolidated well-graded tills, characterized by low or medium plasticity, and with relatively high strengths (e.g. Clarke *et al.* 2001). These cohesive tills normally meet the classification of general cohesive fill under the National Roads Authority (2000) of Ireland Specification for Road Works (NRA SRW) and UK Highways Agency Specification for Highway Works (HA SHW). Acceptability of cohesive till for use as general earthworks fill depends on its strength. However, due to their low plasticity, Irish cohesive tills are extremely sensitive to minor changes in moisture content, with a significant strength reduction resulting from a small increase in moisture content. This sensitivity often makes the use of criteria based on moisture content limits difficult in the assessment and classification of earthworks materials for general fill. Over time the material properties used to assess and specify earthworks acceptability have changed and developed allowing better use to be made of site arisings.

Within the published specifications, grading limits are predetermined, and for general cohesive fills the designer has the option of specifying acceptability limits by moisture content or moisture condition value (MCV) or undrained shear strength. These limits are decided based on factors such as earthworks trafficability, fill compressibility and slope stability. Originally moisture content was used, later in combination with plastic limit (PL), to set the acceptability limits of fill. For some cohesive materials, including cohesive glacial soils, moisture content alone or with PL has been found to provide poor guidance to acceptability and other tests have been employed.

For monitoring construction acceptability of cohesive tills, the MCV test (Matheson & Winter 1997) has gained


*From*: Radford T. A. (ed.) 2012. *Earthworks in Europe*. Geological Society, London,
Engineering Geology Special Publications, **26**, 79–92, http://dx.doi.org/10.1144/EGSP26.10

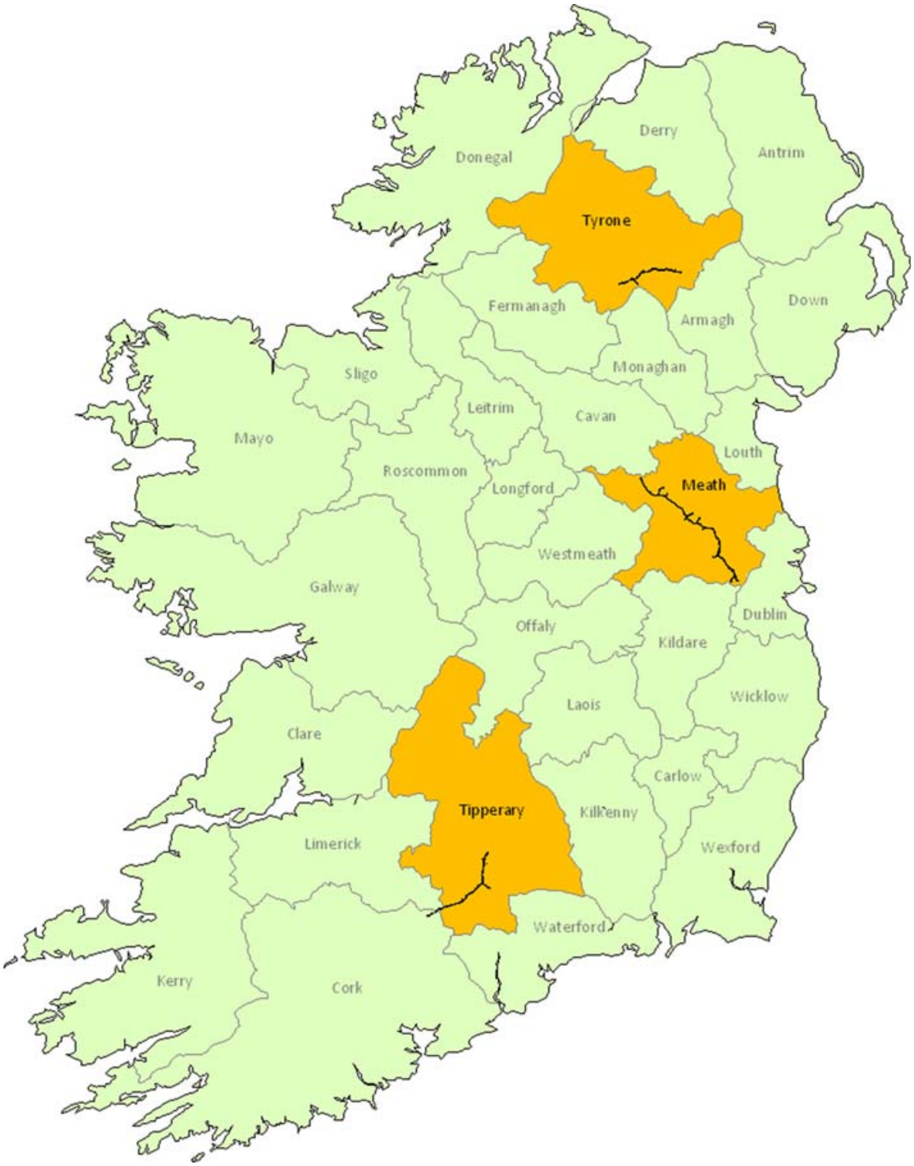


**Fig. 1.** Ireland showing locations of case history projects.

wide acceptance; however, MCV testing is not always carried out as part of ground investigation work, and when testing has been undertaken, results have commonly correlated poorly with other material acceptability parameters. The paper describes other means of assessing the strength of cohesive tills, particularly for design, and presents summary case studies from three road construction contracts in Ireland (Fig. 1).

## Specifications and acceptability limits

### Specifications

The earthworks specification used for road construction in the Republic of Ireland is the National Roads Authority (2000) (NRA) Specification for Road Works (SRW). The

SRW has been adapted for use in Ireland from the UK Highways Agency Specification for Highway Works (SHW). The SHW is employed for projects in Northern Ireland with amendments incorporated by the Roads Service of Northern Ireland. Throughout Ireland, available materials for earthworks typically comprise soils that have resulted from glacial activity, together with excavated rock. Series 600 is the section within both the SRW and the SHW that specifically deals with earthworks and appendix 1/5 is used to specify the frequency of testing during construction for classification purposes.

Earthworks materials are classified in table 6/1 of Series 600, with grading requirements set in table 6/2. Class 1 general granular materials are defined as those with less than 15% fine material (i.e. clay and silt size particles, $<63$ μm). The specifications further sub-divide Class 1 materials into well-graded and uniformly-graded materials on the basis of uniformity coefficient, and to coarse granular material which may include particle sizes up to 500 mm and for which a minimum 10% fines value is required. Unlike UK SHW, there is no requirement in SRW to specify other acceptability limits, such as moisture content, for Class 1 materials.

Class 2 general cohesive materials as those with more than 15% fine material. The specification sub-divides Class 2 into four sub-classes: Class 2A and 2B, wet and dry cohesive materials respectively, comprise predominantly fine material with no more than 20% $>2$ mm, and are differentiated on the basis of moisture content relative to plastic limit; Class 2C, stony cohesive material, has a wider grading allowing up to 80% $>2$ mm which generally includes most excavated cohesive tills; and Class 2D, silty cohesive material occurs rarely in Ireland. Using the Irish SRW (and similar to UK SHW) it is the responsibility of the earthworks designer to decide which acceptability limits to use and to set the limits of acceptability.

### Granular fills

Most Irish glacial sands and gravels, are well-graded, containing a wide range of particle sizes and are classified as Class 1A. In the Republic of Ireland it has been found that these fills drain readily and there is no need to specify moisture contents to achieve adequate compaction, though the requirement is retained in UK SHW. Generally as-dug rock fill material also will be well-graded and is classified as either Class 1A or Class 1C and is rarely processed unless required to be used as a 'selected fill'.

Uniformly graded silty fine sands, that could be classified as Class 1B material, occur more rarely and these can be more difficult to work as earthworks materials as they require careful management of water content, placement, compaction and subsequent trafficking. Selection of acceptability limits for granular materials for earthworks is covered in the literature and reference might be made to for example Trenter (2001) or UK HA44/91. Use of granular fills in earthworks is not considered further in this paper.

### Cohesive fills

Typically Class 2A or 2B materials are rarely found in excavations on Irish roads projects and are not considered further.

Generally most cohesive tills meet the grading requirements for Class 2C 'Stony cohesive material' and provide the majority of earthworks fill material in Ireland. To employ such materials, a design should ensure that they are capable of being excavated, placed, compacted by appropriate roller, and subsequently trafficked (but only by earthmoving plant not as a general haul route) to allow succeeding layers to be placed and compacted. Earthworks management should avoid over-trafficking of placed material as this will cause rutting and material deterioration, perhaps leaving shear surfaces within the fill. To allow these materials to provide an adequate road pavement foundation, it will usually be necessary to employ a capping layer of good quality granular material. In the long term, design should ensure no undue settlement of the fill and stable slopes.

To achieve these requirements the fill requires appropriate strength and stiffness, both during construction and long term. The long term requirement for stability depends on the effective friction strength and requires the designer to select a safe slope angle using conventional design methods (see e.g. Trenter 2001 or UK HA44/91). Adequate construction and long term stiffness are achieved by proper earthworks management including compaction to achieve low air voids. Note that over-compaction should be avoided as this can lead to 'mattressing' when high pore pressures are generated in lower layers of wet clay fill, preventing proper compaction of subsequent layers. Short term strength is required to enable earthmoving and compaction plant to traffic the newly placed layers and construct further layers of fill. This strength might be ensured by different means; traditionally in the Ireland moisture content was used; however more recently, more direct measurements of short term strength have been used. The strength requirement for earthworks fills is no more than this and for most Class 2C fill it will be necessary to form bespoke haul roads to allow more intensive trafficking.

Class 2D material is not commonly encountered in Ireland and is not considered further.

## Moisture content: historical use, limitations, suitability and relationship testing

### Historical use

Early methods of assessing soil acceptability were based on either visual recognition of unsuitable soil types or by the establishment of an upper limit of moisture content beyond which the soil was deemed to be unworkable (see

e.g. Winter 2001). Over the last fifty years, the earthworks specification (in both the UK and Ireland) has been altered several times, partly reflecting the difficulties in adequately specifying cohesive fills.

In the 3rd edition of UK *Specification for Road and Bridge Works* (HMSO 1963) all excavated material was classified as either suitable or unsuitable, with suitable material defined as that which was acceptable for use in the works. For the purpose of use in earthworks all excavated material was classified as either plastic or non-plastic. Non-plastic materials were defined as those on which it was impossible to carry out a plasticity index test. Plastic materials were defined as all other acceptable materials described in CP 2001 as 'fine grained cohesive materials'. The amount of compaction used was decided by the contractor and confirmed by site trials, to achieve an end product dry density corresponding to an air voids content not greater than 10% at the measured moisture content (5% in topmost 2 feet below formation). For 'plastic materials', compaction was only permitted when the moisture content was not greater than 2% above the PL, though the accompanying notes for guidance indicated that higher values could be used for some clays. These specification requirements would appear to exclude most Irish tills as, although they are typically cohesive (i.e. have a plasticity index) they could not be described as fine grained cohesive material as defined in CP 2001 because of their gravel content.

The 4th edition of *UK Specification for Road and Bridge Works* (HMSO 1969) implemented method compaction. Suitable excavated soil materials acceptable for use in earthworks, capable of compaction and of forming stable specified slopes were classified as either:

- 'Cohesive soil', included clays and marls with up to 20% gravel and moisture content not less than PL–4;
- 'Well-graded granular and dry cohesive soils', includes clays and marls with more than 20% gravel and/or having a moisture content less than PL–4; this would include typical Irish cohesive tills together with most sands and gravels;
- 'Uniformly-graded material', includes sands and gravels with uniformity coefficient less than 10, and silts and pulverised fuel ash (PFA).

In this 4th edition, the upper moisture content limit was to be decided by the designer, and the notes for guidance suggested a value of $1.2 \times$ PL.

The 5th edition of UK *Specification for Road and Bridge Works* (HMSO 1976, 1978), generally referred to as the 'Blue Book', used similar classifications for material suitability and compaction methods. The accompanying notes for guidance stated that to achieve maximum economy, the specification had been drawn up to encourage best use of all materials on the site and that the design principle should be that if materials can be excavated, transported, and compacted they were suitable for most earthworks. The notes reported the TRRL Report LR 406 conclusion that in certain instances cohesive soils can be used with moisture content up to $1.3 \times$ PL, although this may depend on the final design requirements for the earthworks, and also may restrict the plant deployed by the contractor. In practice, moisture content limits between 0.9 and $1.3 \times$ PL were selected by designers based on trials and experience. The Irish Department of the Environment adapted this specification for Irish conditions and published the *Specification for Road Works* in 1978 (Davitt 2001). It was commonly referred to as the 'Green Book'.

The 6th edition of the *UK Specification for Highway Works* was published in 1986 and was referred to as the 'Brown Book'. This edition introduced a change to the system for classifying excavated materials, introduced a wider range of definitions of suitable materials that would be acceptable for use in earthworks and moved away from reliance on moisture content to specify acceptability by allowing the designer to adopt other measures, such as strength. Typical Irish tills will fall into Class 2C stony cohesive material.

The 7th edition of the *UK Specification for Highway Works* (SHW, Highways Agency) was published in 1998 and continued the classification system adopted in the 'Brown Book'. To advise designers on the design and preparation of contract documents, the UK Highways Agency produced advice note HA44/91 (1991). This provided advice on selecting appropriate strength limits to define acceptability of the various earthworks classes and for Class 2 general cohesive fill it suggested that a lower limit could be 35–50 kPa and an upper limit 150–200 kPa. The option of establishing equivalent values of moisture content or MCV to these strength limits was suggested.

In 2000, the NRA published a new *Specification for Road Works* (NRA SRW), based on UK HA SHW 7th edition (1991), and this has been used for all trunk road and motorway projects constructed more recently in Ireland. The UK specifications are used in Northern Ireland.

## Limitations

Traditionally, moisture content has been employed as a measure of acceptability for cohesive soils, as it is simple and relatively quick to measure; however it cannot easily be measured in the field, and usually requires laboratory testing. The use of a moisture content relationship with PL to determine earthworks suitability is based on the change in consistency of a cohesive material as its moisture content increases. The PL is the point at which the soil changes from a 'semi-solid' state to a 'plastic' state. At PL undrained shear strength has been assessed variously as 110 kPa to 170 kPa (Wroth & Wood 1978; Whyte 1982). The liquid limit (LL) is the point at which the material becomes liquid. As the moisture content of a cohesive material approaches its LL, the undrained shear strength of the soil reduces until the strength is approximately 1.5 kPa. Typically, moisture content of soils encountered in earthworks ranges from below PL to less than LL, generally in the 'plastic' range.

Relationships with PL require PL to be determined for each sample, increasing the number of tests for each sample and the time taken. PL is measured on the fraction of soil less than 425 μm and includes some sand in the sample, while moisture content is measured on that part of the sample with sizes less than 20 mm (BS1377 1990). Hence there is a discrepancy between the material used to measure PL (particle sizes less than 425 μm) and the fraction used for moisture content determination (less than 20 mm). If a moisture content relationship with PL (or liquid limit) is used then the moisture content should be adjusted to give a 'matrix moisture content' that represents the moisture content of the fraction less than 425 μm. Dumbleton & West (1966) showed PL varies with the granular content of the sample and the nature of the sand (shape, grading, etc). A number of workers have shown that determination of PL is subject to operator skill and may not be repeatable (Sherwood 1970; Arrowsmith 1979; Whyte 1982), perhaps partly because there is a subjective element in rolling the clay sample. Barnes & Staples (1988) showed that as the stone content of a till increases then the multiplicand applied to PL should decrease to maintain constant minimum shear strength. For these reasons moisture content, and its relationship to PL, are no longer widely used to assess acceptability of cohesive soils.

## Acceptability

Materials that are acceptable for use in earthworks must be capable of being placed, compacted, and subsequently trafficked by earth-moving plant to allow succeeding layers to be placed and compacted. Overtrafficking must be avoided by earthworks/site management and any short-term slopes in the fill should be stable. Providing an adequate road pavement foundation is not a necessary requirement, a capping layer of good quality granular material can be provided. In the long term the fill should not settle unduly and its slopes should be stable. These criteria determine the lower strength limits for acceptable fill material.

Experience in Ireland has shown that the critical requirements are that compacted fill material will be stable, not settle and be trafficable. During construction these requirements are largely determined by the short term or undrained strength of the compacted fill. Slope stability can be assessed using the method described by Taylor (1948). Acceptable settlement of the fill is produced by proper compaction, which can only be achieved if the material is trafficable.

Over the years a number of attempts have been made to assess the trafficability of compacted cohesive fills and relate trafficability by different plant to a measure of soil strength. Arrowsmith (1979) reported on experience with boulder clay/glacial till in NW England and observed that caterpillar tractors and scrapers required a minimum shear strength of 35 kPa to operate but for large rubber-tyred scrapers the minimum strength was 50 kPa. Dennehy (1979) described observations and *in-situ* strength testing carried out at a number of sites where 'wet cohesive fill' was being placed. He concluded that for light scrapers with low tyre pressures the lower limit of soil strength was between 40 kPa and 60 kPa, while for medium to heavy scrapers at high tyre pressures the limiting strength was between 60 kPa and 80 kPa. Kennard *et al.* (1979) reviewing construction of a series of embankment dams with clay cores, observed that using a specification based on shear strength had advantages compared to one based on moisture content and that the lower strength limit is usually governed by plant trafficability rather than fill stability. They found that the lower strength limit varied from 42 kPa to 70 kPa.

Parsons & Darley (1982) carried out an extensive study including observations at 25 motorway and all-purpose road construction sites in the UK. They recorded the performance of different types of earthmoving plant in terms of various factors affecting productivity compared to soil conditions measured using MCV. The work showed that heavier plant required soil with a higher MCV to operate and that even the most lightly loaded plant would not operate with an MCV lower than 6, while most plant would operate with MCV of 10 or more. Their results showed that a high proportion of twin-engined scrapers could operate on soils at MCVs less than 8, equivalent to the usual criterion of suitability then adopted.

Advice note HA44/91 recommends relationship testing. It indicates that a minimum strength limit of 30–50 kPa would be typical and that the lower limit would depend on trafficability and stability. It is suggested that lower MCVs of between 7 and 9 could be used as a basis for deriving alternative lower limits of acceptability in terms of 'an equivalent value' of moisture content, California Bearing Ratio test (CBR) or undrained shear strength. To apply an equivalent value, calibration testing is critical as both the lower and upper bound limits vary for differing 'fines' contents and differing plasticity index (PI) values. This applies particularly to the more moisture sensitive materials such as Class 2C. HA44/91 references work carried out the Transport Research Laboratory, Arrowsmith (1979), Al Shaikh-Ali (1979) and Snedker (1973). HA44/91 also provides useful information on working with glacial till and notes that behaviour depends on the amount of fines and that high silt content makes till very weather susceptible.

The lower strength limit for acceptable cohesive fill controls trafficability and short-term stability of fills. A low strength fill with undrained strength of 30 kPa and a slope of 1:2 will be acceptably stable up to more than 8 m height. Trafficability will therefore govern highway embankment construction, and this will depend on the type of plant deployed for the bulk earthworks operations. Although this might be difficult to predict for a traditional contract, for the 'design and construct' contract the designer should be able to select an appropriate value based on discussion with the constructor subsequent to site specific calibration tests and optional site trials. In Ireland, material is typically hauled using large pneumatic-tyred dumpers, placed by

tracked excavators and dozers, and compacted using heavy smooth-wheeled, often vibratory, rollers.

## Relationship testing

Parsons & Boden (1979) showed that MCV was related to undrained strength of a soil, and they presented a series of correlations for different types of clays and silts (Fig. 2). They published relationships for low, intermediate and high plasticity soils – for low plasticity clays, Log $S_u = 0.91 + 0.112$ MCV and for low plasticity silts, Log $S_u = 0.91 + 0.120$ MCV. The relationships show that for any given soil strength the MCV is higher for high and intermediate plasticity clays and silts, when compared to low

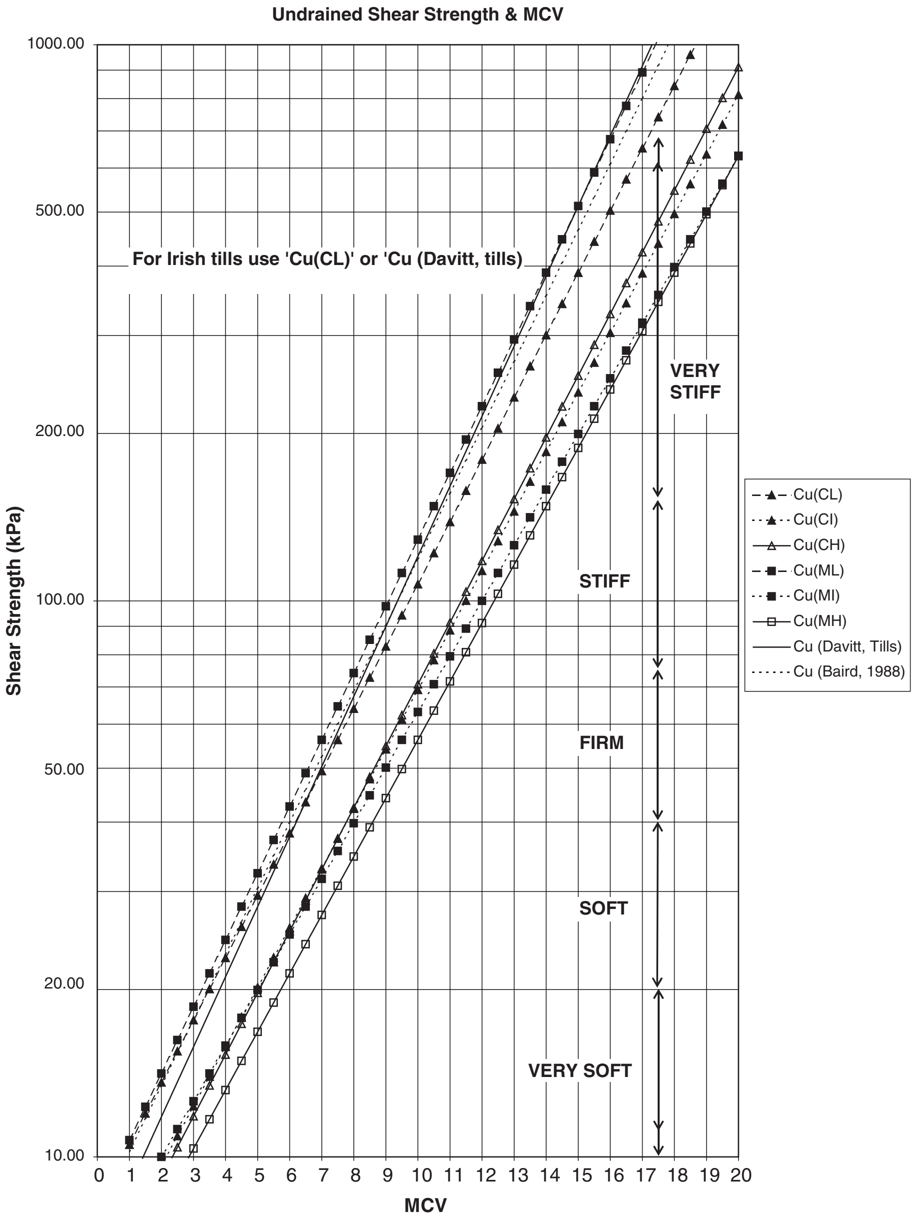


**Fig. 2.** Correlation between undrained strength and MCV for different soil types.

plasticity clays and silts. The correlations are straight line relationships when undrained strength is plotted on a logarithmic scale.

Baird (1988) contended that suitable fill will have stable side slopes, support construction plant and allow construction of the pavement layers, and that for cohesive soils this depended only on the compacted fill's undrained shear strength. The experience was based on testing ten samples of glacial clay from Northumberland (with PI values typically between 11 and 15) and a relationship between undrained shear strength and MCV was derived (Log $S_u = 0.891 + 0.1148$ MCV). This correlation is similar to that produced by Parsons & Boden (1979) for low plasticity cohesive clays and silts.

Davitt (1984) reviewed published work from the UK, and undertook studies of the relationship between MCV and undrained strength for Irish glacial tills (with PI values of 11–14) from three roadwork sites. Soil strength was measured using quick undrained triaxial tests on remoulded samples of 100 mm diameter by 200 mm high and by laboratory CBR tests, and these results were compared to MCVs. The correlation between MCV and shear strength for Irish tills (Log $S_u = 0.82 + 0.126$ MCV) is similar to that produced by Baird for Northumberland tills, and to Parsons & Boden (1979) for low plasticity cohesive materials (Fig. 2).

For many years the relationship between the moisture content of a cohesive material and its shear strength was considered to be one of the most important for earthworks. However, the shear strength of low plasticity clay soils is very sensitive to change in moisture content, whereas the moisture content for a given strength is dependent on the clay mineral range and can therefore cover a wide range of values (Baird 1988). For tills, the situation is further complicated by the common intermixing of cohesive tills with layers or lenses of water bearing granular material, which has the twin adverse effects of reducing PL (by the addition of sand to the matrix) and typically releasing pore water to soften the fines matrix. Relationship testing has demonstrated that moisture content typically provides a poor indicator of strength.

Unambiguous relationships between undrained strength, CBR and MCV have been established by the referenced workers for cohesive tills, and together with the earthworks experience with these soils it is possible to:

- Use a range of data from ground investigation including laboratory undrained strength, undrained strength derived from Standard Penetration Test (SPT) N-values, site and laboratory MCV testing, site and laboratory CBR testing, and soil strength descriptions following BS 5930 1999 (and now BS EN ISO 14688-2:2004), to assess the proportion of excavated soils likely to be acceptable for use in earthworks; and
- Reliably select an acceptable lower strength criterion, as undrained strength or MCV, as required by SRW/SHW, for Class 2C material based on the proposed earthworks plant and continued monitoring of the trafficability of the engineered fill during construction.

## Irish experience

### Assessment of acceptability

There are two basic activities which require assessment of acceptability for design of earthworks:

(1) Assessment of available volume of acceptable material from proposed excavations (cuts) that will be available for use as fill in embankments. This is essential to plan the works, to design a vertical alignment that balances cut and fill and consider the logistics of the earthworks operations. This activity is carried out relatively early in the design process – indeed a preliminary assessment would usually be required as part of the design used as the basis for pricing and tendering the works. The assessment will be based on the ground investigation and other geotechnical information available at the time together with any additional local knowledge. The process should consider all of the data available, identify anomalous results and warn the constructor of any geotechnical risks associated with the assessment. To undertake this assessment the earthworks designer and the constructor can agree acceptability limits based on the proposed earthmoving plant. For cohesive materials these limits might be any, or all, of the various properties: moisture content, shear strength, CBR, MCV, as mentioned above.

(2) Compilation of a specification of acceptability criteria for the works in line with the appropriate specification (SRW or SHW). Both specifications require acceptability limits for cohesive fills and these should be one of moisture content, undrained shear strength or MCV. For design and construct contracts, the specified limits should suit the constructor's proposed earthworks plant but this can only be established properly with calibration tests and site trials, or from experience with similar materials.

Typically Irish cohesive tills have a vertical profile comprising a near surface layer of 1–3 m thickness with variable moisture content controlled by rainfall. This zone has low confining stresses and in wet conditions without soil suction, can sustain only low strengths although in dry conditions soils may become stiff or very stiff. As depth and confining stresses increase, soil strength typically is greater and exceeds 'stiff' consistency.

Data readily available from most ground investigations includes strength descriptions to BS5930 and SPT N-values. These can both be readily correlated with *in situ* undrained shear strength and have been found to provide good guidance to acceptability for use as fill. From BS5930, 1999, a description of soft or very soft indicates a strength of less than 40 kPa and will always represent

unacceptably weak clay soil, while stiff or very stiff indicates a strength of 75 kPa or more, which will be acceptable. Cohesive soils described as 'firm' (BS EN ISO 14688-2:2004 'medium') should have strength in the range 40–75 kPa and can be considered marginal, dependent on the plant and experience of the constructor; the descriptor firm to stiff can be particularly useful as an indicator that strength is towards the upper end of the range and more likely to be acceptable. (N.B. BS5930 1999 has been amended subsequently to its use for these projects and Amendment No. 1 (2007) incorporates changes from BS N ISO 14688-2:2004. Values of undrained strength are no longer associated with the consistency descriptions very soft through to very stiff. Where undrained strength has been measured in the field then descriptors extremely low, through to extremely high can be used. 'Low' represents strength of 20–40 kPa, 'medium' 40–75 kPa and 'high' 75–150 kPa.) In Ireland, to assess undrained strength, it has been found that using Stroud's correlation a value of $f_1 = 6.0$ is generally applicable to low plasticity tills, hence $c_u = 6 \times N$ (see e.g. Clayton 1995). Hence an SPT N value of 10, indicating strength of 60 kPa, can often provide a useful indicator of the lower acceptable shear strength.

The remainder of the paper describes earthworks design and construction using cohesive till soils on three road projects in Ireland. In each case the materials were low plasticity cohesive tills and ground investigation used traditional methods of sampling and testing. The case histories illustrate how simple assessments of strength from tactile tests and SPTs can be used as a basis for quantifying available volumes of acceptable materials. Anomalous results from some other tests are described. Low plasticity cohesive tills are very moisture sensitive and Ireland can be a wet place to carry out earthworks construction. The importance of following specified construction procedures to maintain material properties during the works is noted, and strength measurement during construction by MCV is shown to provide a quick, reliable basis for assessing acceptability.

## Case studies

### N8 Cashel to Mitchelstown

The N8 Cashel to Mitchelstown road improvement was the first early contractor involvement (ECI) road scheme in Ireland. The route runs for some 37 km SW of Cashel to west of Mitchelstown. A series of ground investigations were carried out over a period of three years prior to construction. These investigations were designed and supervised by the NRA's consultant. The ECI contract was awarded to Roadbridge-Sisk JV, and design was carried out by their consultants McCarthy-Hyder-CarlBro with AGEC Ltd as sub-consultant responsible for geotechnical design. Construction started in March 2006 and was completed in July 2008.

The ground investigations showed that most of the cohesive till tested was well-graded with a range of particle sizes from clay to cobbles. Generally more than 15% of the material was fines (clay and silt sized) and hence meeting the SRW requirements for Class 2C material (Fig. 3a). Descriptions from trial pits, and reports of refusal in cable tool boreholes indicated the presence of boulders. Plasticity testing shows that the fines have low plasticity (mostly low plasticity clay soils, CL) with liquid limit (LL) = 20 to 35 and PL = 12–20 (Fig. 3b). Test data shows little variation of plasticity with depth and that natural moisture content was higher in the upper 1–2 m (Fig. 3c).

The ground investigations data revealed poor correlation between laboratory MCVs and natural moisture content (Fig. 4), and poor correlation between laboratory MCVs and likely *in-situ* strengths as described in borehole and trial pit records and revealed by SPTs. The correlation between laboratory CBR testing and *in-situ* strength was also poor. More than 50% of MCV results were less than 8, indicating more than half of the excavated material would likely be unacceptable for re-use as fill; there were few values of MCV $\geq 9$ (Figs 4 & 5). Review of the SPT values and shear strength descriptions indicated that most of the material (around 75%) would be suitable for re-use (Fig. 6).

As a check, the relationship between plasticity and natural moisture content was considered for individual soil samples of cohesive till. Generally the results indicated that natural moisture content was less than or close to the PL of soil samples, which would suggest that generally samples of cohesive till would have a strength descriptor of 'stiff' or stronger (Fig. 3c). These results correlated reasonably well with strength descriptions and strength derived from *in-situ* SPT N-values.

It was agreed with the constructor that a minimum MCV of 7, equivalent to strength of *c*. 50 kPa, would be specified for recompacted cohesive till (SRW Class 2C material) bearing in mind the moisture sensitive nature of the material and this value was used to assess quantities for earthworks planning. Approximately 90% of material was consequently determined as acceptable. MCV was selected as the on-site control, with a lower acceptability limit of 7 noted above. This is at the lower end of the range suggested in HA44, by correlation with undrained strength short term embankment stability could be demonstrated, and the contractor was happy that the value would suit his plant and methods. In particular, the contractor did not intend to use compacted fills for construction traffic. Higher strength fill with MCV = 9 was specified immediately beneath capping to limit capping depth.

Recognizing the moisture sensitivity of the cohesive till material, the particular specification was varied to allow acceptability testing at the point of deposition (as compared to point of excavation generally in a traditional contract). This enabled any near surface wetter, weaker soils to be processed, for example by air drying, to render them acceptable for re-use as general fill. Trials had indicated air drying

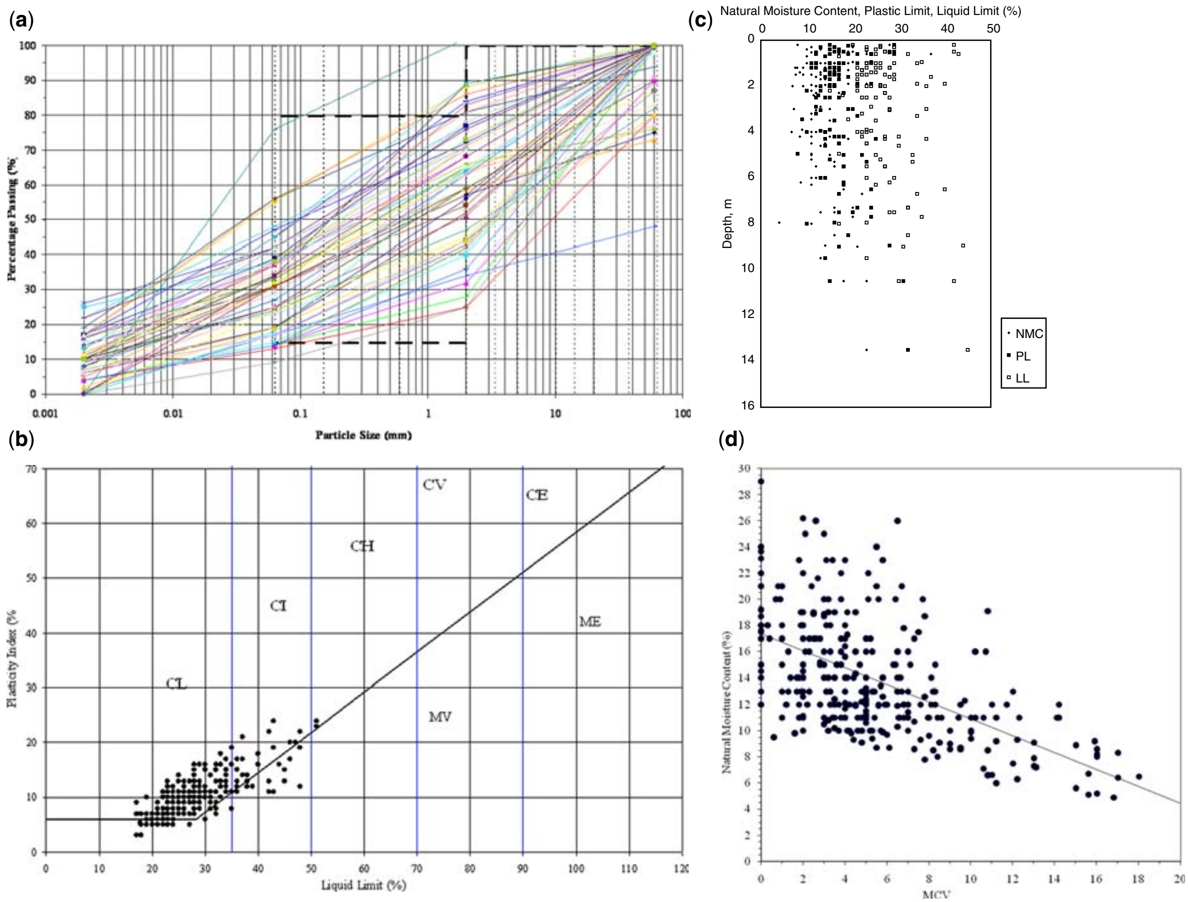


**Fig. 3.** N8 Cashel to Mitchelstown. (**a**) Typical cohesive till gradings; (**b**) plasticity data for cohesive till; (**c**) natural moisture content, plastic limit and liquid limit for cohesive till; and (**d**) natural moisture content and MCV for cohesive till.

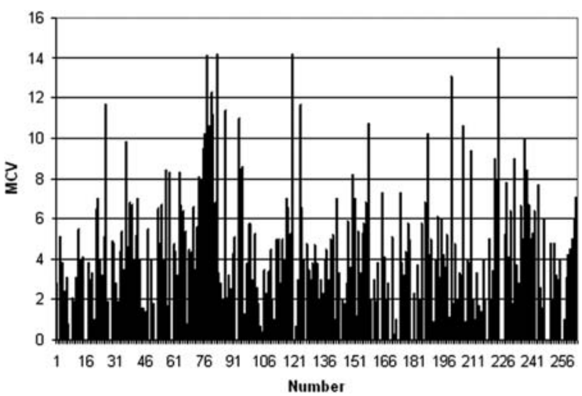


**Fig. 4.** Number of MCV results from ground investigations: N8 Cashel to Mitchelstown.

could allow low plasticity till soils to gain strength from MCV of 5 or 6 to more than 9 in around 6 hours.

During construction more than 95% of excavated cohesive till soils were used for earthworks construction confirming the assessment based on strength description and SPT was cautious. Earthworks required excavation and placing of around four million cubic metres of fill and this was continued throughout the year. It is considered that this was possible because the contractor paid attention to the details specified in SHW (clause 602) requiring him to keep earthworks free from water and protect constructed fills by sealing and shaping to falls. He also had extensive Irish experience. Typically, he refrained from bulk earthworks operations during periods of wet weather when it would be difficult to maintain the condition of moisture-sensitive materials and did not traffic constructed fills but made use of well-constructed haul roads to maintain productivity; he

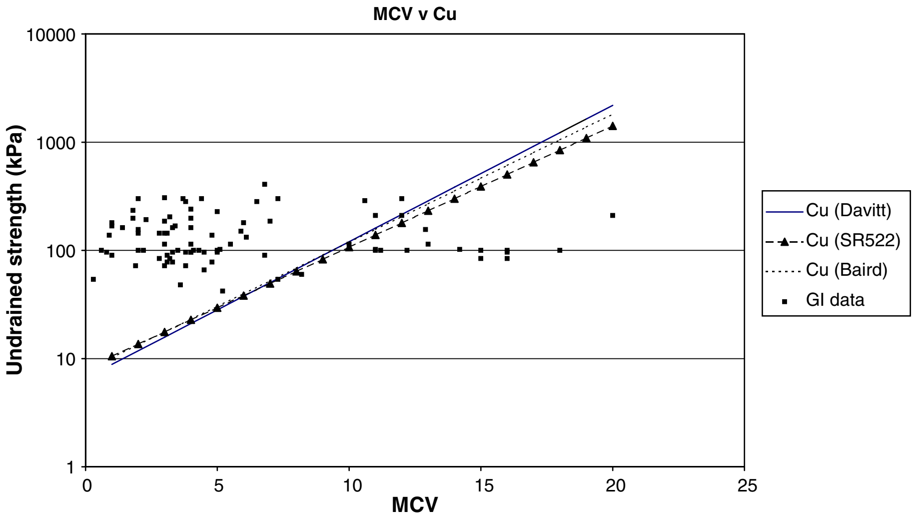


**Fig. 5.** Undrained strength and MCV from ground investigations: N8 Cashel to Mitchelstown.

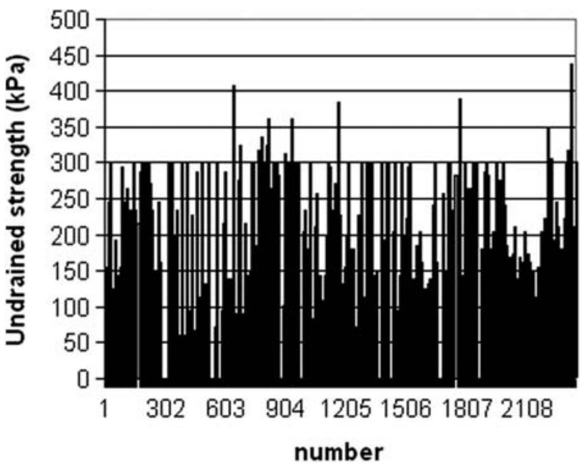


**Fig. 6.** Number of undrained strength results from ground investigations: N8 Cashel to Mitchelstown.

exploited periods of dry weather to progress the works. The lower MCV limit of 7 allowed economical use of site-won fill and was successful.

## M3 Clonee to north of Kells

In March 2007, Eurolink Motorway Operations (M3) Ltd, a consortium formed by Cintra Concesiones de Infraestructuras de Transporte, S.A. ('Cintra') and SIAC Construction Ltd. ('SIAC'), was awarded the contract to develop the M3 Clonee to North of Kells Scheme in Ireland. This project in County Meath is part of the NRA's plans to improve road links to Dublin from the regions and the consortium entered into a PPP (Public Private Partnership) contract with M3 Motorway JV (M3 JV), a Joint Venture contracting entity formed by Ferrovial-Agroman, S.A. (through Ferrovial-Agroman Ireland Ltd) and SIAC Construction Ltd for the design and construction of the new motorway.

Prior to the award of the construction contract a series of ground investigations were carried out for the NRA, which were designed and supervised by their consultants. Detailed design was by McCarthy-Hyder-CarlBro, with geotechnical design by AGEC Ltd, Eptisa (Spain) and Webber Associates (UK) all acting as sub-consultants to McCarthy-Hyder-CarlBro. AGEC Ltd was engaged as geotechnical project design manager for the whole route. Detailed design was carried out between November 2006 and December 2007, allowing construction to start in April 2007.

Ground investigation data showed a typical Irish cohesive till grading, with a substantial proportion of coarse material, but in most cases more than 20% fines. The material generally meets the grading requirements for Class 2C stony cohesive material (Fig. 7a). Plasticity of the matrix material is low (CL) with typically LL = 20–35 and PL = 12–25 (Fig. 7b). Test data showed little variation of plasticity with depth, and again revealed that natural moisture content was higher in the upper 1–2 m (Fig. 7c).

Data from the ground investigations showed a general correlation between moisture content and MCV (Fig. 7d), but the laboratory results indicated that, based on MCV testing, up to 40% of samples tested would be unsuitable for re-use. By comparison, examination of SPT results and soil

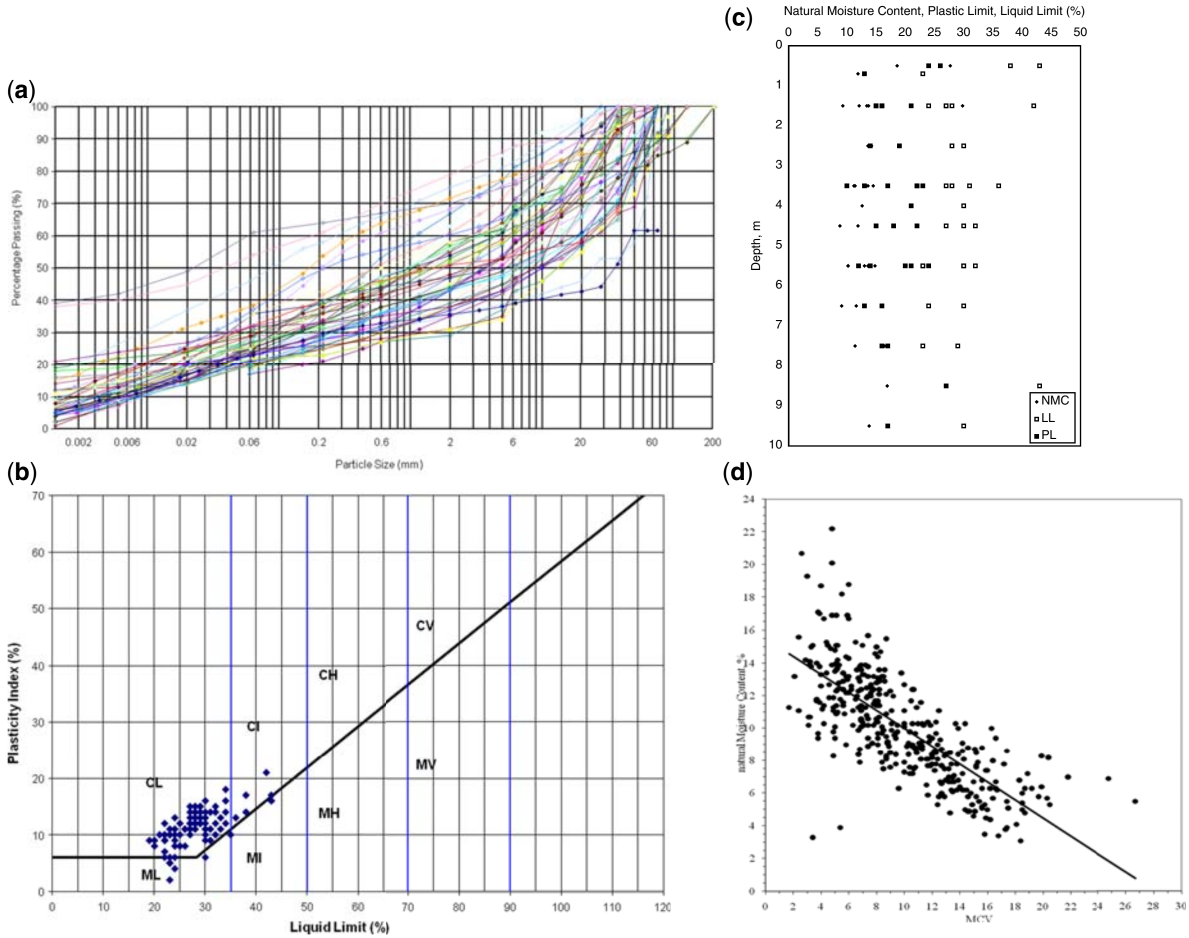


**Fig. 7.** M3 Clonee to Kells. (**a**) Typical cohesive till gradings; (**b**) plasticity data for cohesive till; (**c**) natural moisture content, plastic limit and liquid limit for cohesive till; and (**d**) natural moisture content and MCV for cohesive till.

strength descriptions indicated that most of the material would be acceptable. Natural moisture content data was generally less than or equal to the PL, which confirmed the *in situ* SPT and strength descriptions were likely to be correct. Similarly to the N8 project, the volume of acceptable site-won fill was estimated based largely on SPT and strength descriptions. MCV results from the ground investigation were not consistent with this data or other data, and would have severely underestimated the acceptable material quantity.

MCV limits of 7 (lower) and 15 (upper) were specified for construction. The Irish partner in the consortium was experienced at working with moisture sensitive cohesive tills in Irish weather conditions and this enabled earthworks to progress without a seasonal break. Ireland might be considered relatively rainy with from 750–1500 mm rainfall and 150–225 rain days per year. Rainfall is spread throughout the year with no obvious wet or dry seasons, though spring and summer are commonly drier than autumn and winter. There can be substantial variations from one year to another. However it does not rain all the time and good drying conditions are frequent as there is often a breeze or stronger wind.

## A4/A5 Dungannon to Ballygawley

The 27 km long A4/A5 Dungannon to Ballygawley DBFO (Design, Build, Finance and Operate) Scheme 3, in County Tyrone, Northern Ireland, was constructed by joint venture contractor, Lagan Ferrovial-Agroman JV, for Amey Lagan Roads Limited on behalf of the Roads Service of Northern Ireland (RSNI). Ground investigation was procured for RSNI and designed by its consultants. Detailed design for

the project was carried out by Arup between January 2008 and June 2009, with AGEC Ltd as geotechnical subconsultant, responsible for earthworks and other geotechnical design. Construction started in February 2008 and the road was opened in December 2010.

Cohesive till material available from proposed excavations along the route typically was well-graded and includes more than 20% fines (Fig. 8a). The matrix has low plasticity, LL = 25– 40; PL = 12–20 (Fig. 8b), with some variation with depth, and again moisture content is more variable in the upper 1–2 m of the ground profile (Fig. 8c). The material available for fill was generally described as stiff gravelly clay, with a poor correlation between moisture content and MCV from laboratory testing (Fig. 8d). MCV results indicated that a substantial percentage (around 40%) of material would not be acceptable, despite descriptions of material as stiff and very stiff.

Strength derived from SPT results along with strength descriptions were examined and indicated that around 80% of material in cuttings would be acceptable for re-use, and again this is significantly different from an assessment based on MCV results. From Figure 8c it can be seen that the natural moisture content results are typically less than or equal to the PL, and are consistent with the SPT results and descriptions indicating stiff and better strength. Again, and reflecting the relative consistency of the low plasticity tills, MCV limits of 7 and 15 were specified for construction.

The joint venture included an Irish partner, and Ferrovial had Irish experience from a series of road construction projects. Through the implementation of the specified

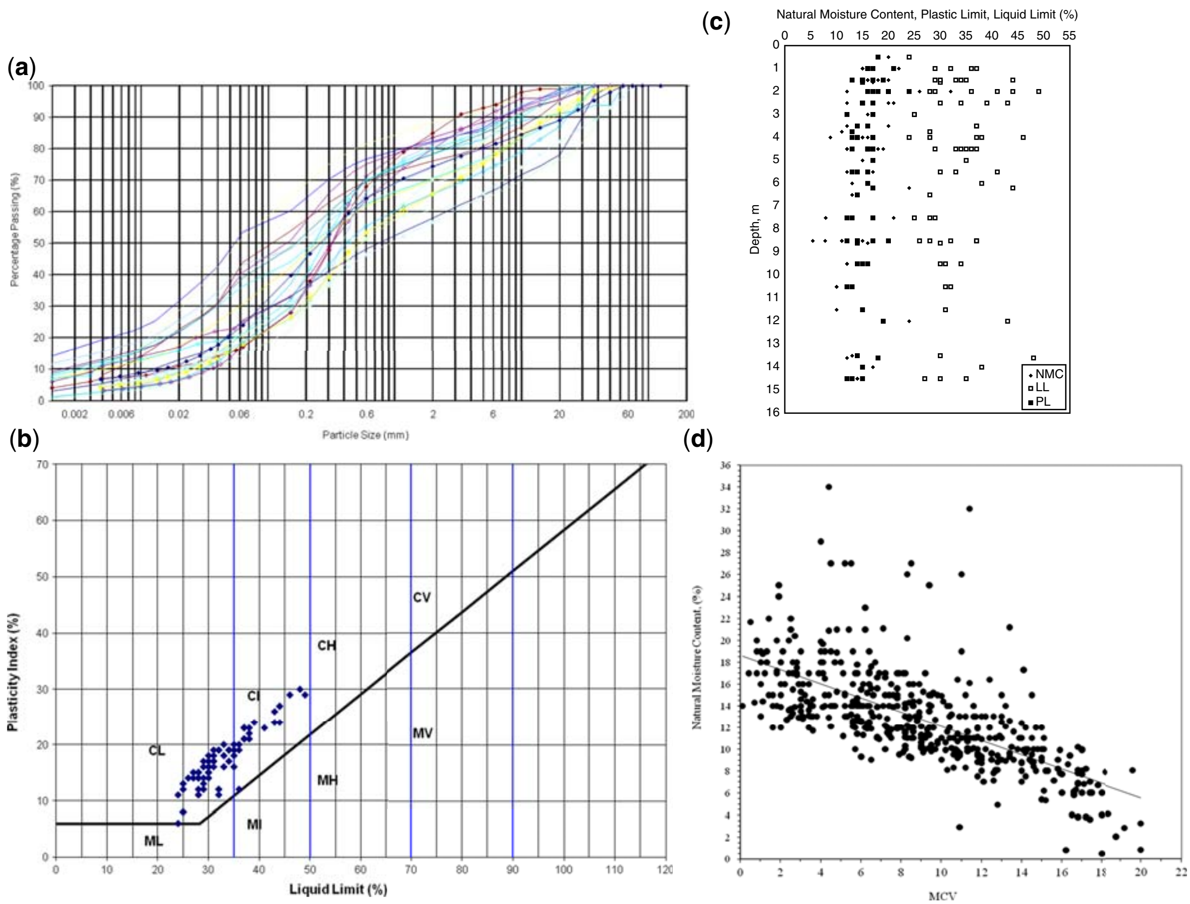


**Fig. 8. A4/A5** Dungannon to Ballygawley. (**a**) Typical cohesive till gradings; (**b**) plasticity data for cohesive till; (**c**)natural moisture content, plastic limit and liquid limit for cohesive till; and (**d**) natural moisture content and MCV for cohesive till.

requirements and adoption of good construction practice, the contractor was able to work throughout the year.

## Summary

In Ireland, the NRA SRW allows all Class 1A well-graded granular material to be used regardless of the moisture content as experience has shown these soils generally are free-draining. This practice contrasts with that adopted in Northern Ireland, where moisture content limits are generally specified. The majority of earthworks fill in Ireland is Class 2C stony cohesive material, derived from glacial cohesive tills, and both NRA and HA earthworks specifications require the designer to choose lower limits of acceptability from one of moisture content, undrained strength or MCV. Work in the UK has established that a lower limit based on trafficability of earthworks plant generally governs this selection, and correlations between MCV and strength have been established, both in general terms (with variations for different plasticity soils) and specifically for glacial clay soils. Work by Davitt has confirmed that a similar relationship to that for UK glacial clay soils and those for low plasticity silts and clays is valid for low plasticity cohesive tills in Ireland.

Irish experience with cohesive tills soils has shown that strength is a good indicator of acceptability for use in earthworks construction. In design a range of measures of strength are available from ground investigations and include field material description, moisture content, SPT N-value, CBR value, MCV value and laboratory undrained strength triaxial testing. Of these, moisture content (and matrix moisture content) did not provide good indicators of likely material strength. Results from laboratory CBR testing and MCV testing did not correlate well with other tests and appeared to underestimate the *in-situ* strength of soils. It is unclear why laboratory MCV and CBR testing provide unrepresentative indicators of field strength of cohesive tills. Field descriptions and strength derived from SPT, assuming $c_u = 6 \times N$, provided the most reliable and consistent indicators of strength, and these have been the most useful guide to assessing the likely volumes of acceptable fill material from sections of highway cut. For most contractors and generally for short term stability an acceptable lower limit of strength is 50 kPa. This strength value can be compared with MCV using published work on similar low plasticity tills and will usually correlate with MCV = 7. For construction acceptability limits the MCV test is an appropriate test and provides results quickly and straightforwardly.

Critically the susceptibility of earthworks materials to moisture must be recognized and managed in order to ensure optimum use of site arisings for bulk earthworks operations. In this regard implementation of the requirement to keep earthworks free of water described in SRW 602.15 is critical, and measures such as proper drainage, shaping placed fills to provide falls and ensuring fills are sealed against water ingress make a significant difference. Cohesive tills of only medium (firm) strength are generally unsuited to general construction traffic and proper haul routes should be provided.

This work is based on experience of design and construction of roads in Ireland and the authors would like to thank their colleagues at Applied Ground Engineering Consultants Limited for their help over the years when this work was underway. They would also like to extend their thanks to the contractors who constructed the three schemes described in the case studies: Roadbridge-Sisk JV, M3 Motorway JV and Lagan Ferrovial-Agroman JV.

## References

Al Shaikh-Ali, M. M. H. 1979. The behaviour of Cheshire Basin lodgement till in motorway construction. *Proceedings of the Conference on Clay Fills*, 14–15 November 1978, Institution of Civil Engineers, London. Institution of Civil Engineers, London, 15–24.

Arrowsmith, E. J. 1979. Roadwork fills – a materials engineer's viewpoint. *Proceedings of the Conference on Clay Fills*. Institution of Civil Engineers, London, 25–36.

Baird, H. G. 1998. Earthworks control – assessment of 'suitability'. *Ground Engineering*, May, 21–28.

Barnes, G. E. & Staples, S. G. 1988. The acceptability of clay fill as affected by stone content. *Ground Engineering*, January, 22–30.

BS1377. 1990. *British Standard Methods of Test for Soils for Civil Engineering Purposes, Parts 1 to 9*. British Standards Institution, 1990.

BS5930. 1999. *Code of Practice for Site Investigations*. British Standards Institution, 1999.

Clarke, B. G., Hughes, D. B. & Hashemi, S. 2001. Characteristic parameters of tills in relation to earthworks, *Proceedings on the Seminar on Earthworks*, 12 December 2001, Institution of Engineers of Ireland/Geotechnical Society of Ireland, Paper 6.

Clayton, C. R. I. 1995 The Standard Penetration Test (SPT): Methods and Use. CIRIA Report 143. CIRIA, London.

CP. 2001 *Code of practice on site investigations*. British Standards Institution, 1957.

Davitt, S. 1984. The use of the moisture condition test in assessing soils for roadworks, Report RC.278. Environmental Research Unit, November.

Davitt, S. 2001. Comparison of Specification of Earthworks – NRA Specification for Road Works (2000) and DOE Specification for Road Works (1978). *Proceedings of the Seminar on Earthworks*, 12 December 2001, Institution of Engineers of Ireland/Geotechnical Society of Ireland, Paper 6.

Dennehy, J. P. 1979. The remoulded undrained shear strength of cohesive soils and its influence on the suitability of embankment fill. *Proceedings of the Conference on Clay Fills*, 14–15 November 1978. Institution of Civil Engineers, London, 87–94.

Dumbleton, M. J. & West, G. 1966. Some factors affecting the relation between the clay minerals in soils and their plasticity. *Clay Minerals*, **6**, 179–193.

HMSO. 1963. *Specification for Road and Bridge Works*. 3rd edn.

HMSO. 1969. *Specification for Road and Bridge Works*. 4th edn. Ministry of Transport, Scottish Development Department & Welsh Office. HMSO, London.

HMSO. 1976. *Specification for Road and Bridge Works*. 5th edn. Department of Transport, Scottish Development Department & Welsh Office. HMSO, London.

HMSO. 1978. *Specification for Road and Bridge Works, Supplement no 1*. Department of Transport, Scottish Development Department & Welsh Office. HMSO, London.

HIGHWAYS AGENCY. 1986. *Specification for Highway Works*. 6th edn.

HIGHWAYS AGENCY. 1991. *Design Manual for Roads and Bridges*, Volume 4, Section 1, HA44/91 Design and Preparation of Contract Documents [Incorporating Amendment No. 1 dated April 1995] (http://www.standardsforhighways.co.uk/dmrb/vol4/section1.htm)

HIGHWAYS AGENCY. 1998. *Manual of Contract Documents for Highway Works*, Volume 1, Specification for Highway Works. 7th edn (http://www.standardsforhighways.co.uk/mchw/vol1/index.htm)

KENNARD, M. F., LOVENBURY, H. T., CHARTRES, F. R. D. & HOSKINS, C. G. 1979. Shear strength specification for clay fills. *Proceedings of the Conference on Clay Fills*, 14–15 November 1978. Institution of Civil Engineers, London, 143–147.

MATHESON, G. D. & WINTER, M. G. 1997. *Use and Application of the MCA with particular reference to Glacial Tills*. TRL Report 273, Transport Research Laboratory.

NATIONAL ROADS AUTHORITY. 2001/2002*. Manual of Contract Documents for Road Works, Volume 1 Specification for Road Works.

PARSONS, A. W. & BODEN, J. B. 1979. *The Moisture Condition Test and its Potential Applications in Earthworks*, Report SR522, Transport and Road Research Laboratory.

PARSONS, A. W. & DARLEY, P. 1982. *The Effect of Soil Conditions on the Operation of Earthmoving Plant. Report* LR1034, Transport and Road Research Laboratory.

SHERWOOD, P. T. 1970. *The Reproducibility of the Results of Soil Classification and Compaction Tests*. Report LR 339. Road Research Laboratory.

SNEDKER, E. A. 1973. Choice of an upper limit of moisture content for highway earthworks. *Highways Design and Construction*, January 1973, 2–5.

TAYLOR, D. W. 1948. *Fundamentals of Soil Mechanics*. John Wiley & Sons, New York.

TRENTER, N. A. 2001. *Earthworks: A Guide*. Thomas Telford Limited, London.

WINTER, M. G. 2001. Earthworks acceptability for glacial tills. *Proceedings of the Seminar on Earthworks*, 12 December 2001. Institution of Engineers of Ireland/Geotechnical Society of Ireland, Paper 5.

WHYTE, I. L. 1982. Soil plasticity and strength – a new approach using extrusion. *Ground Engineering,* **15**, 16–24.

WROTH, C. P. & WOOD, D. M. 1978. The correlation of index properties with some basic engineering properties of soils. *Canadian Geotechnical Journal*, **15**, 137–145.