Undrained shear strength and stiffness of Irish glacial till from shear wave velocity

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Introduction

Much of the ground engineering work carried out in Ireland involves glacial tills. These tills were deposited beneath the ice sheet that covered much of Ireland during the Pleistocene period, some 18,000 years ago. For example, much of the city of Dublin it is underlain by a glacial deposit known colloquially as Dublin boulder clay (DBC).

It is known that the ice thickness in Dublin was approximately 1km and that several advances and retreats of the glaciers occurred in the area. The grinding action of this sheet as it eroded the underlying rocks coupled with its loading effect resulted in the formation of a hard lodgement till which in engineering terms is characterised by being very dense/hard, of very high stiffness and of low permeability.

A particular characteristic of the Irish tills, say when compared to similar material in the UK, is the presence of large cobbles and boulders. These make insitu investigation and sampling of the material extremely difficult. In particular the standard penetration test (SPT) can give erratic and unreliable results.

In addition, SPT tests are carried out in conjunction with cable percussive boring and there are significant limitations with this technique in relation to sample quality in tills and identification of thin horizons or layers.

In recent years there have been significant advances in techniques available to obtain high quality rotary core of glacial tills for example using the Geobor S or sonic drilling techniques (Long and Menkiti, 2007, Long et al, 2009, Quigley et al, 2011). However, these techniques are expensive and are only used on large or important projects. Geobor S coring is typically 25% more expensive than P size (85mm diameter) coring in glacial tills.

In parallel there has been rapid advances in some relatively cheap and practical geophysical methods, such as the multi-channel analysis of surface waves (MASW) technique (Donohue et al, 2003). MASW gives a profile of shear wave velocity (V_s) against depth from which the small strain stiffness (G_{max}) can be easily determined from the relationship with density (ϱ):

$$G_{max} = \varrho V_s^2$$

Currently MASW has been used widely in wind farm projects in upland areas, particularly during the preliminary geotechnical investigation phase, where remote sites mean that access is constrained.

In this paper the link between strength and stiffness from high quality laboratory tests on cores and MASW V_s measurements at a number of sites will be explored to investigate the potential of using MASW to generally profile the undrained shear strength and stiffness of Irish tills.

Initially the use of the SPT for this purpose will be examined using data from a recent case history.

Figure 1: A MASW survey was carried out for the Dublin Metro North project with a 2D Vs profile generated by towing a "streamer" of geophones along the route to collect data every 6m

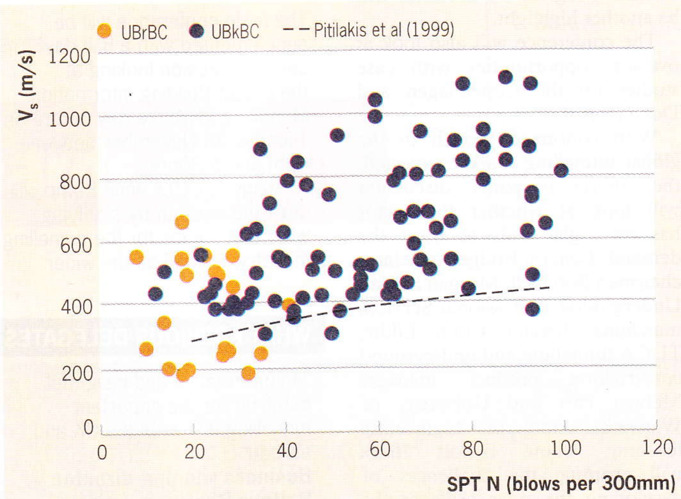

Figure 2: SPT N versus V_s for Dublin Metro North project

Standard penetration testing in DBC

Recently a ground investigation was carried out in Dublin for the proposed Metro North project and the focus is on work done towards the northern end of the line from Drumcondra to Lissenhall where the ground conditions comprise relatively homogenous DBC over limestone bedrock. A series of MASW profiles were carried out along the length of the proposed railway and SPT test data is also available for boreholes drilled immediately adjacent to the MASW surveys. These data have been chosen for this comparison as all the MASW testing was carried out by the same crew and the SPT tests were carried out with recently calibrated equipment (BSI, 2002).

A comparison between V_s and SPT N for this dataset is shown on Figure 2. Note the data have been sub-divided into tests on the upper brown boulder clay (UBrBC), which is typically 2m or so in thickness, and the underlying upper black boulder clay (UBkBC), see Skipper et al (2005) for details of the soils.

There is considerable scatter in the data. Although there is no doubt some variability in the V_s measurements it is felt that much of this scatter is due to the nature of the SPT testing in these very stony soils. The relationship between V_s and N for clays reported by Pitilakis et al (1999) is also shown on the plot. These authors combined data for various clays but it can be seen that the DBC is much stiffer than the other published data. Nonetheless, it is clear that use of SPT-based correlations for Irish glacial tills would be highly unreliable and a better technique is required.

Relationship between MASW and laboratory data

It is proposed instead to compare V_s from MASW and undrained shear strength (s_u) from triaxial tests on the high quality rotary cores of various Irish glacial tills. Data from 12 sites is presented. Eight of these are from the Dublin area, where V_s values are relatively high. These data are complemented by four others from throughout Ireland where, in general, lower V_s values were recorded.

Figure 3 shows a plot of s_u from the tests on the cores (mostly Geobor S) and V_s from MASW. As can be seen V_s values in the range 200m/s to 1,100m/s are encompassed. As shown, there is a reasonably strong relationship between s_u and V_s with s_u increasing with increasing V_s. The coefficient of correlation for the trend line shown is about 0.87. Beyond a V_s of about 400m/s the relationship appears to be more or less linear.

An important design parameter in geotechnical engineering is the ratio of G_{max} to s_u. For design the G_{max} value needs to be reduced to allow for strains around real structures. However, for structures in Irish glacial tills these strains are often very small. A value of 300 is typically used in design for stiff clays and tills; Stroud (1988). This value was, however, determined from testing and insitu observations of the behavior of British till and is felt by practising engineers to be conservative for Irish tills. A plot of G_{max}/s_u against V_s is shown on Figure 4. There is a clear pattern of increasing G_{max}/s_u with increasing V_s until a value of about 450m/s where the G_{max}/s_u values level off at about 2,250 on average, albeit there remains a reasonably large scatter in the data. However, all of the measured values are significantly higher than the traditionally adopted $G_{max}/s_u \approx 300$ from Stroud (1988).

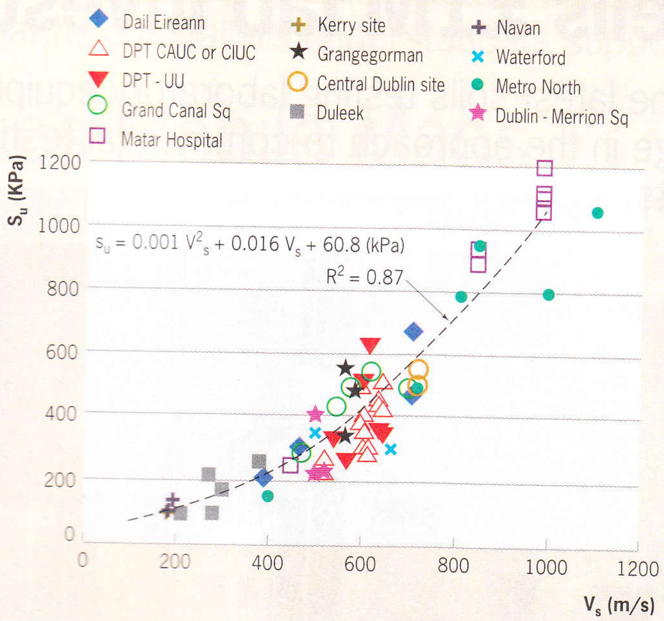

Figure 3: s_u from triaxial lab tests on cores versus V_s from MASW

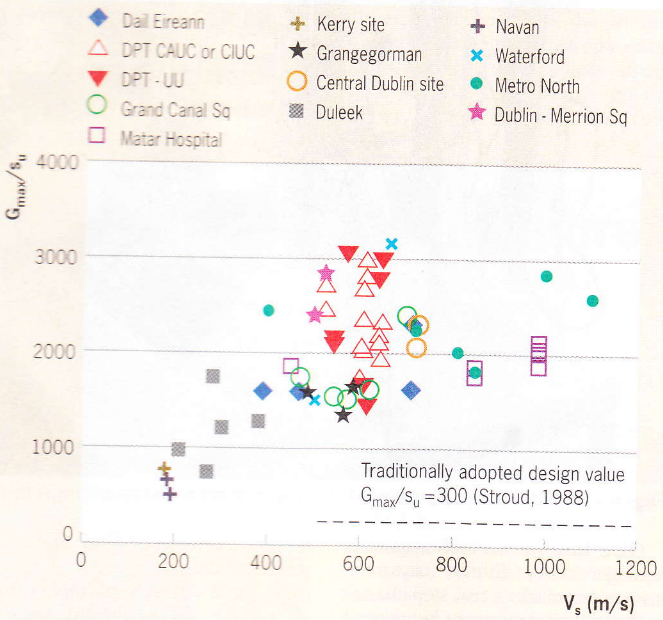

Figure 4: Gmax / s_u versus V_s (site designations as on Figure 2)

Conclusions

The main objective of this work was to explore the link between high quality laboratory strength tests on Geobor S and similar cores and MASW derived shear wave velocity measurements of Irish glacial till:

- A clear relationship was observed between V_s and s_u for the sites studies across a wide range in V_s values.
- Therefore it seems that savings can be made in ground investigations by utilising geophysical techniques in combination with a reduced number of boreholes.
- For preliminary design or for routine structures, in areas where the ground conditions are well known, perhaps geophysics can perhaps be used alone.
- The design parameter G_{max}/s_u appears to be significantly higher for Irish tills (particularly Dublin boulder clay) than for documented glacial tills from Britain. A value of 300, which is typically used in geotechnical design of glacial tills and stiff clays, appears to be highly conservative for Irish materials.

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