“Relationship between shear wave velocity and undrained shear strength of Irish glacial tills”

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Summary

A large part of the city of Dublin it is underlain by a glacial deposit known as Dublin boulder clay (DBC). In engineering terms this lodgement till is characterised as being very dense / hard, of very high stiffness and of low permeability. The use of “Geobore S” rotary coring and Multichannel Analysis of Surface Waves (MASW) shear wave velocity profiling has improved our ability over recent years to adequately characterise this material. The main objective of this work was to explore the link between high quality laboratory strength tests on Geobore-S cores and MASW derived shear wave velocity measurements of Dublin boulder clay. A reasonably clear relationship was observed between these tests for three boulder clay sites.

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 was known that the ice thickness in Dublin was approximately 1 km 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 in situ investigation and sampling of the material extremely difficult. In recent years there have been two significant developments in Ireland with respect to investigation of the Irish glacial tills:

- The ability to obtain high quality rotary cores using the Geobore-S method or similar
- The use of MASW to accurately characterise the in situ stiffness of the material.

In this paper the link between high quality laboratory strength tests on Geobore-S cores and MASW testing at the same site will be explored to investigate the potential of using MASW to profile the undrained shear strength of Irish tills.

Geobore-S rotary coring

Current state of the art in Dublin is to recover high quality cored samples of DBC using "Geobore S" rotary coring. This is a wire-line, triple tube rotary coring technique with polymer flush to optimise sample recovery. The wire-line assembly allows the sample to be retrieved immediately after coring and minimises the duration the sample is in contact with the flushing medium. The drill bit is typically 102 mm ID and is equipped with face discharge, meaning the flushing agent is never in direct contact with the soil. The innermost tube is the plastic core liner. Drilling is carried out in a borehole of 140 mm to 150 mm in diameter. Typically drilling progresses at about 100 bar drill fluid pressure and 800 revolutions per minute (rpm) of the core barrel. Cores runs are usually 1.5 m. In general, 95% core recovery is achieved with experienced drilling crews. Cores are logged immediately on recovery and selected lengths are chosen for future laboratory testing. These sections are sealed with cling film and wax prior to transportation to the laboratory. As well as producing very high core recovery, which allows accurate geological logging, the quality of the cores is also very high from the point of view of testing for mechanical engineering properties. Long and Menkiti (2007) compared the engineering quality of Geobore S cores to hand carved block samples from the site of the Dublin Port Tunnel and found them to be very similar. An interesting finding from this work was that if high quality cores were available then the undrained shear strength (s_u) measured in sophisticated CIUC or CAUC (isotropically or anisotropically consolidated) triaxial tests was very similar to that obtained from relatively simple UU (unconsolidated) testing.

Figure 1: Geobore-S core of Dublin boulder clay showing distinct sand or silt lens within the largely clay matrix (Skipper et al., 2005)

Multichannel Analysis of Surface Waves (MASW)

The use of surface waves for the estimation of shear wave velocity (V_s) profiles has received considerable attention over the last number of years. The Multichannel Analysis of Surface Waves (MASW) method is one of the more recently developed techniques and makes use of multichannel recording techniques. As with the similar Spectral Analysis of Surface Waves (SASW) method, the MASW method is concerned with shallow depths that are of interest to civil engineers. The most significant difference between the SASW and the MASW techniques, involves the use of multiple receivers with the MASW method (usually 12 to 60) compared to the SASW technique, which is based on a two geophone approach. An advantage of the MASW approach is the ability of the technique to identify and separate fundamental and higher mode surface waves. The MASW field procedure is also not as time and labour intensive as the SASW method, which involves several measurements at different source-receiver configurations.

All of the surface wave data detailed here was recorded using a Seistronix RAS-24 seismograph, with 24 geophones. A number of different source and receiver locations were chosen for each MASW profile, to determine the optimum acquisition parameters, to take into account near field and far offset effects. Processing of the MASW data was performed using the software, Surfseis, which was used to select dispersion curves from a phase velocity-frequency spectra, generated using a wave field transformation method (Park et al., 1998). V_s models were estimated by Surfseis using the Levenberg-Marquardt and single value decomposition inversion techniques detailed by Xia et al. (1999).

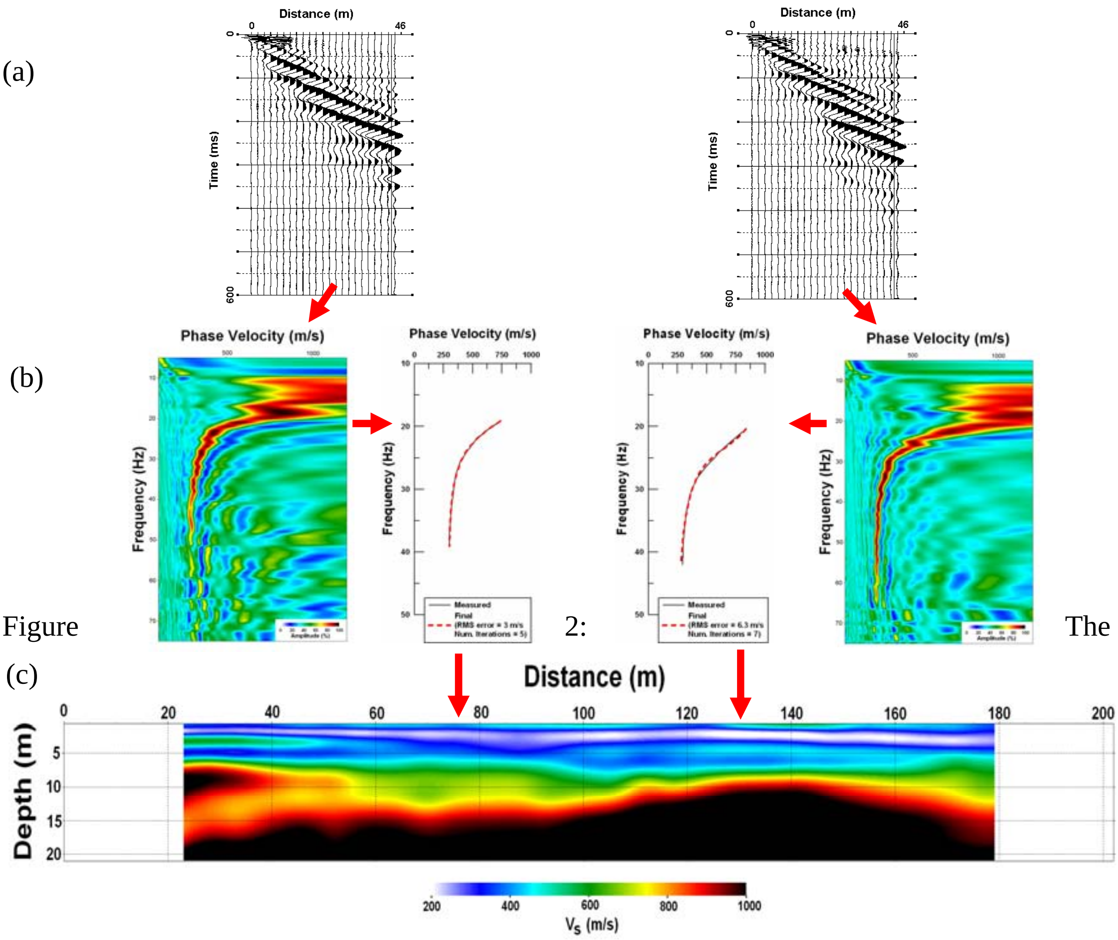

Figure 2: The various stages involved in producing a 2D MASW profile, in this case from a Dublin city centre site, south of the river Liffey: (a) raw seismic data, (b) dispersion curve image and inversion and (c) 2D V_s image combining inverted 1D V_s profiles.

An example of the 2D V_s distribution of a Dublin city centre site, located south of the river Liffey is shown in Figure 2, along with a summary of the various stages involved, necessary to produce such a plot. This data was acquired with a roll-along approach using a land streamer consisting of 24 plate coupled 4.5 Hz geophones. The source used to generate the seismic data was a tractor mounted weight drop (Fig. 3) and shots were acquired at 6 m intervals. As shown in Figure 2c, there is quite a large variation in the subsurface distribution of V_s at this site, with velocities of 200 – 700 m/s measured for the glacial till material (0 – 10 m approx). Donohue et al. (2003) observed similarly high velocities in their study of the small strain shear modulus ($G_{max}= \rho V_s^2$) of Dublin boulder clay. Below this depth the very high velocity material (V_s > 900 m/s) has been verified using boreholes as bedrock, the depth to which appears to be quite variable at this site. The large amplitude nature of surface waves relative to body waves makes them far more suitable for investigations in urban areas, such as Dublin, where first arrivals may be impossible to detect.

Figure 3: Acquisition of 2D roll-along MASW data in Dublin city centre.

Relationship between MASW and GeoBore-S

In this section the relationship between G_{max} and undrained shear strength (s_u) from triaxial tests on high quality Geobore S cores of Dublin boulder clay is discussed. Data is presented for three Dublin sites, Dáil Eireann, Dublin Port Tunnel and Grand Canal Square. Figure 4a shows a plot of s_u from the tests on the GeoboreS cores and V_s from MASW. As shown, there is a reasonably clear relationship between s_u and V_s for this material.

An important design parameter in geotechnical engineering is the ratio of small strain shear modulus (G_{max}) to s_u. A value of 300 is typically used in design for stiff clays and tills (Stroud, 1988). This value was, however, determined from testing and in situ observations of the behavior of British till and it felt by practicing engineers to be conservative for Irish tills. A plot of G_{max} / s_u against V_s is shown on Figure 4b. There is a reasonably large scatter in the data with G_{max} / s_u values varying between 1500 and 3000 with an average of about 2000. However all of the measured values are significantly higher than the traditionally adoped $G_{max}/s_u \approx 300$ from Stroud (1988). Attempts were also made in this study to relate G_{max} / s_u to water content or other index properties but no clear trends emerged.

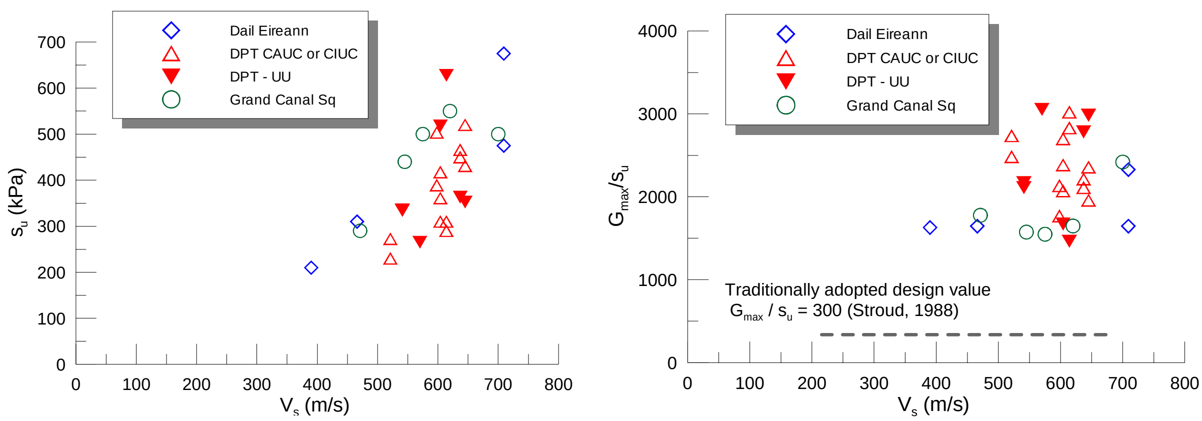

Figure 4: The variation of V_s with (a) s_u and (b) the design parameter G_{max}/s_u

Conclusions

The main objective of this work was to explore the link between high quality laboratory strength tests on Geobore-S cores and MASW derived shear wave velocity measurements of Dublin boulder clay. It was found that:

- A reasonably clear relationship was observed between V_s and s_u for three boulder clay sites.
- The design parameter G_{max}/s_u appears to be significantly higher for 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 this material.
- Measurement of the 2D distribution of V_s can be rapidly acquired using a roll-along MASW setup, which can provide important information for the design engineer in urban environments where other geotechnical and geophysical measurements may be unsuitable.

References

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