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Geophysical Characterisation of Glacio-fluvial Gravels - A Case Study from Cork, Ireland

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SUMMARY

Extensive glacio-fluvial deposits occur within Cork city and its surrounds. The glacio-fluvial gravels are of mixed provenance and thickness due to the complex geology of the area. In this paper, Electrical Resistivity Tomography (ERT) and Multichannel Analysis of Surface Waves (MASW) methods were tested simultaneously on a site with existing geotechnical and Standard Penetration Test (SPT) data. The combined use of both methods has potential, with ERT approximating material type recorded in boreholes and shear wave velocities from MASW predominantly corresponding to densities identified by SPT.

Introduction

Extensive glacio-fluvial deposits lie within Cork city and its surrounds. These are often capped with alluvium or made ground. In co-operation with UCC and Apex Geoservices, ERT and MASW surveys were concurrently conducted along the banks of the River Lee in Cork city. The aims were: to explore the applicability of both geophysical methods in the investigation of Irish ground conditions; to examine their combined use in conjunction with standard penetration testing (SPT) and rotary and cable percussive drilling methods; to establish correlations between geophysical and geotechnical datasets. Fieldwork was carried out by UCD and Apex Geoservices in November 2006.

Cork

The site is located in Cork city (Fig 1a) and consists of three locations adjacent to the North Channel of the River Lee (Fig 1b). R2 was conducted in a roughly E-W orientation along the riverbank in Fitzgerald’s Park. Whereas R1 and R3 were carried out in a NW-SE direction on the GAA pitch of UCC sports grounds and near the Mardyke Bridge respectively. Locations of survey lines are presented in Figure 1b, Borehole & Survey Line Location Map.

Sports and recreational grounds and parkland occupy the site, which lies at an elevation of 10m OD or less. The North Channel of the River Lee borders the site to the north, flowing in an eastern direction towards Lough Mahon Estuary, Cork Harbour and ultimately the Celtic Sea. The River Lee’s water level is approximately 5m OD. Please see Figure 1b), Site Map for more detail. Made ground and fill were anticipated (in the form of historical flood defences and floodplain reclamation) due to the urban surroundings. Deposits of sand and gravel are commercially quarried at Ballincollig, 10km west of the site. Information from the general area suggests depth to bedrock is approximately 30 metres.

Information published by the Geological Survey of Ireland indicates the site is underlain by Carboniferous limestone, sandstone and mudstone. The rock formations are part of a large E-W trending regional scale fold with younger rocks to the core. Devonian sandstones occur on the northern limbs of the fold to the north of the Lee’s Northern Channel.

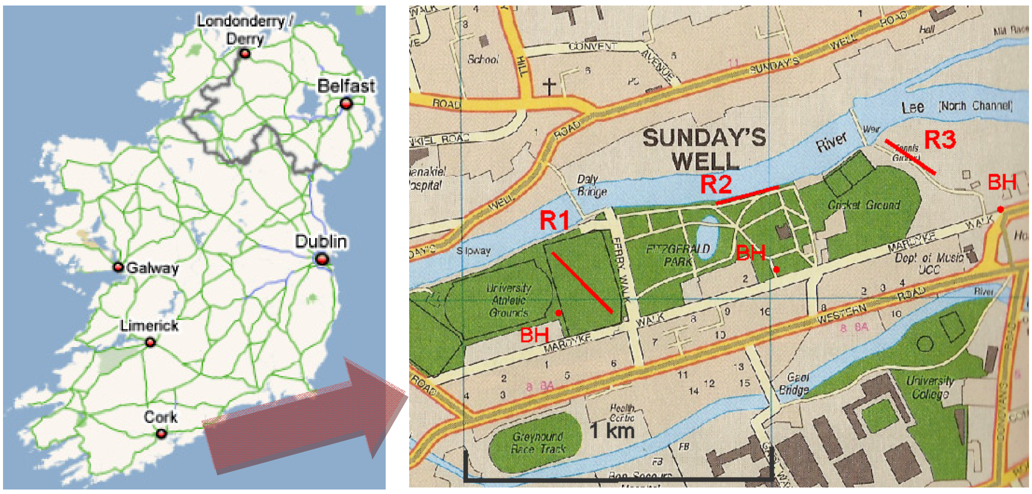

Figure 1:a) Location of Cork test site, b) Borehole & Survey Line Location map

Existing Geotechnical Information

Ground conditions at the three study sites are shown on Figure 2.

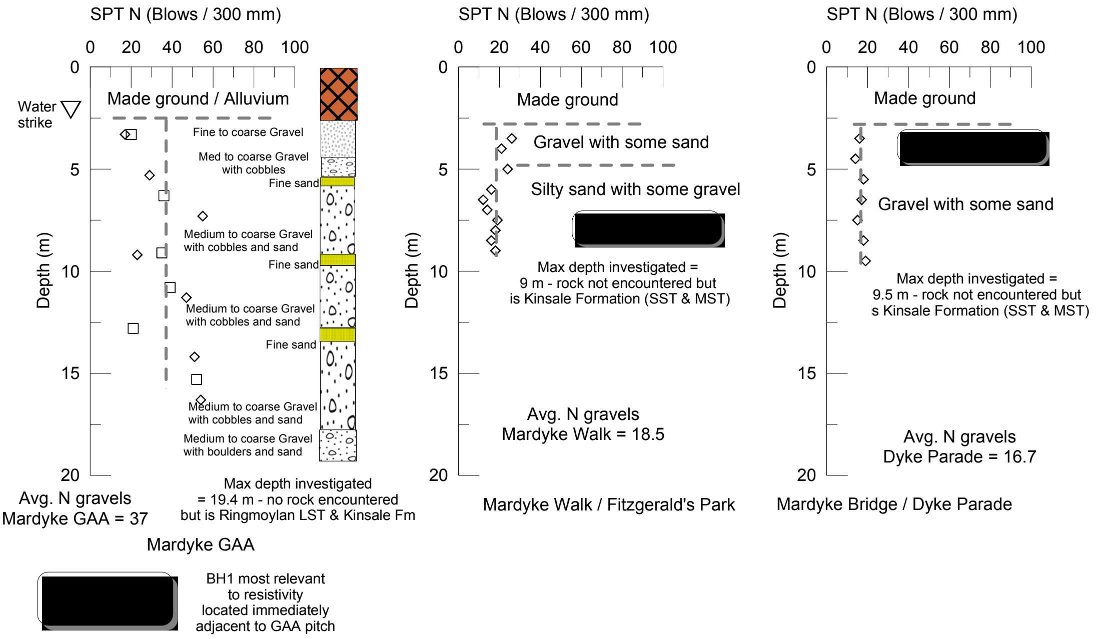

Figure 2. Ground conditions at a) Mardyke GAA, (b) Fitzgerald's Park and (c) Mardyke Bridge.

At the Mardyke GAA site, approximately 2.4 m of made ground and alluvium are underlain by a complex sequence of gravel soils. These soils generally comprise a coarse to medium gravel with some sand and cobbles but this material is interlayered with fine sand, as shown on Figure 2a. Towards the base of the borehole some boulders are encountered within the material. Standard penetration test (SPT) N values increase gradually from about 20 at the top of the sequence to about 50 at the base with an average value of about 37. At Fitzgerald's Park and Mardyke Bridge no alluvium was recorded in the boreholes (although they were located approximately 100 m from the river). However, in both cases, gravel soils were proven beneath about 2.6 m of made ground. At Mardyke Walk, near Fitzgerald's Park, about 2m of gravel with sand (comprising about 80% gravel and 18% sand) overlies silty sand with gravel (containing about 58% sand and 28% gravel). At Mardyke Bridge the silty sand material was not encountered. At these two sites SPT N values showed no increase with depth, were lower than those at Mardyke GAA and averaged about 18.5 and 16.7 respectively. Groundwater was generally encountered at the top of the gravel sequence and is tidal. Bedrock was not proven at the three locations but the bedrock type is noted on Figure 2.

Electrical Resistivity Tomography

Resistivity data was collected by means of surface survey, using the Wenner array and employing 32 stainless steel electrodes, a Geopulse Tigre resistivity meter, multicore cable and 'Imager Pro' data acquisition software. The acquired data files were read inverted by the least squares method using RES2Dinv, version 3.49e, (Loke & Barker, 2001). After several iterations, inverse model resistivity pseudo-sections were produced. Examples of these 2-D Resistivity sections are shown in Figures 3, with depths of 23.4, 29.3, and 11.7m bgl reached respectively, due to variation of electrode spacing employed. In general, there is broad agreement between the modelled resistivity sections and the borehole logs. As shown, the made ground and saturated gravels encountered at Fitzgerald's Park are clearly identified on R2 with deeper deposits of finer silty gravel being inferred and becoming cleaner and coarser towards the base of the section. A low resistivity anomaly to the east may represent urbanisation-affected material. Corresponding saturated gravels and made ground occurring at

Mardyke Bridge are again illustrated on R3 but as this profile was perpendicular to both the riverbank and R2, coarser cleaner deposits, expected at a channel edge, are additionally implied in the south eastern portion. Profile R1 at Mardyke GAA pitch also demonstrates the presence of saturated, albeit coarser, gravel material. Boreholes confirmed cobbly gravel. However, the thinner, inter-bedded sands encountered are not indicated on the resistivity section. Instead, the boundary between the cobbly gravel and overlying made ground and alluvium (and the coinciding water table) is sharply delineated. Overall, the highest resistivity is displayed by material occurring at the Mardyke GAA location, which SPT data suggests is twice as dense as the material at the other two locations. Since borehole logs indicated the presence of cobbles there and, consequently, higher overall particle size, it is the authors' opinion the ERT method appears to be more sensitive to material type than density.

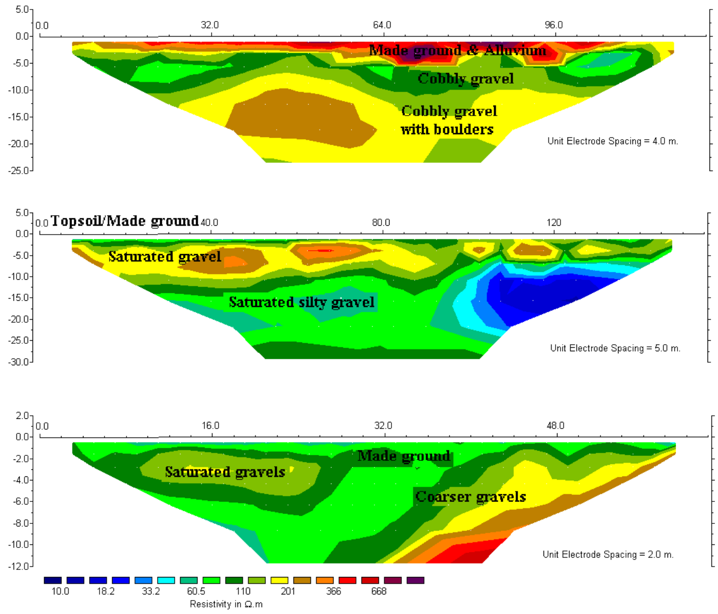

Figure 3. Modelled Resistivity Sections from (a) Mardyke GAA Pitch (b) Fitzgerald's Park and (c) Mardyke Bridge

Multichannel Analysis of Surface Waves (MASW)

The surface wave data was recorded using a Seistronix RAS-24 seismograph, with 24 geophones. A 10 kg sledgehammer was used to generate the surface waves which were in turn detected by 10Hz geophones. A number of different source and receiver locations were chosen for each MASW profile, to determine the optimum acquisition parameters. A receiver spacing of 2 m and a source-receiver offset of 6 m was deemed suitable for the sites under investigation, 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 wavefield transformation method (Park et al., 1998). 1-D shear wave velocity models were estimated by Surfseis using the Levenberg-Marquardt and single value decomposition inversion techniques detailed by Xia et al. (1999). MASW results for the three Cork sites are illustrated in Figure 4. Due to a lack of space only the final inverted shear wave velocity profiles are presented here, although it should be noted that each of the profiles presented converged to an RMS error of less than 4 m/s within 5 iterations. Interestingly the V_s profiles from Fitzgeralds Park and the Mardyke GAA pitch are similar, with the Mardyke bridge site exhibiting higher V_s below 5 m depth. This is inconsistent with SPT tests which suggested the materials at the Mardyke GAA site were approximately twice as dense as those at the other two locations. Small strain shear modulus (Gmax) is related to shear wave velocity (V_s) and density (ρ) by: $G = \rho V_s^2$. However Young's modulus $E = 2.4G$ (for Poisson's ratio = 0.2). Typically for gravel soils E_{max} is estimated from $E_{max} \approx 10\ N$ (MPa) (Stroud, 1988). Then for $\rho = 1.8$ Mg/m³: $V_s/\sqrt{N} \approx 48$.

Average Vs data for the three sites under consideration here, together with two others where MASW V_s and SPT N data are available (Long and Roberts, 2008), are summarised on Table 1. Excepting Mardyke Bridge, the average $V_s/\sqrt{N}$= 45, is very similar to the theoretical value of 48, thus suggesting some consistency between the SPT and MASW data.

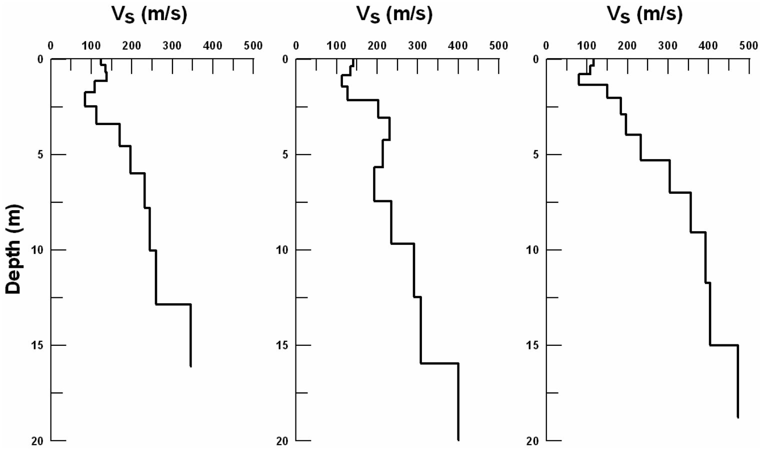

Figure 4. Inverted V_s from (a) Mardyke GAA pitch, (b) Fitzgeralds park and (c) Mardyke bridge

Site	Depth (m)	SPT N	V_s (m/s)	$\frac{V_s}{\sqrt{N}}$
Glucksman	5	30	200	37
	10	35	320	54
	15	40	400	63
ERI	5	31	220	40
Fitzgerald Park	7.5	18.5	200	46
Mardyke GAA	5	30	180	33
	10	37	220	36
	15	45	320	48
Mardyke Bridge	7.5	16.7	300	73

Table 1. Summary of SPT,V_s and $V_s/\sqrt{N}$ data from study area.

Conclusions

The combined use of ERT and MASW shows potential for the characterization of Irish glacio- fluvial gravels. SPT and MASW results from the test sites are generally consistent and can provide information on material density and stiffness. Whereas ERT can broadly identify material type but may not recognize fine layering of sediment.

References

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