Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0211

Determining the extent and material effects of a buried pre-glacial channel on underground construction in Dublin, Ireland

Détermination de l'étendue et des effets matériels d'un canal pré-glaciaire enfoui sur la construction souterraine à Dublin, Irlande

M Friedman
Transport Infrastructure Ireland, Dublin, Ireland

E O'Connor, M Fleming
Arup, Dublin, Ireland

S Kealy
Ground Investigations Ireland Ltd, Dublin, Ireland

M Long
University Colllege Dublin, Dublin, Ireland

ABSTRACT: A buried pre-glacial channel carved into the underlying limestone bedrock is located to the north of the River Liffey in Dublin, Ireland. The channel has been infilled with fluvio-glacial sands and gravels and lenses of stiff till to a depth of up to 45m. A metro scheme is proposed to run from north - south from Sandyford in South Dublin, through the city centre and north to Dublin Airport and the town of Swords. It will be underground in the city mostly within the bedrock, but will encounter the buried channel for approximately 1km. An earlier variant of the scheme was described by Friedman et al (2015) who also gave a general distribution of the materials within the channel. Recent work has been carried out to map in three dimensions the extents of the channel and sequence of the infill materials; to collect high quality samples of the granular material; and to utilise a suite of conventional and advanced tests to determine their abrasive effect on tunnel boring machines (TBMs). This paper summarises the work to date.

RÉSUMÉ: Un chenal pré-glaciaire enfoui dans le substrat rocheux calcaire sous-jacent est situé au nord de la rivière Liffey, à Dublin, en Irlande. Le chenal a été rempli de sables fluvio-glaciaires, de graviers et de lentilles rigides jusqu'à une profondeur de 45 m. Il est proposé de mettre en place un système de métro du nord au sud depuis Sandyford au sud de Dublin, en passant par le centre-ville et au nord de l'aéroport de Dublin et de la ville de Swords. Ce sera sous terre dans la ville principalement dans le substrat rocheux, mais rencontrera le canal enfoui sur environ 1 km. Friedman et al (2015) ont décrit une variante antérieure du schéma, qui a également donné une répartition générale des matériaux dans le canal. Des travaux récents ont été menés pour cartographier en trois dimensions l'étendue du canal et la séquence des matériaux de remplissage; recueillir des échantillons de haute qualité du matériau granulaire; et à utiliser une série de tests conventionnels et avancés pour déterminer leur effet abrasif sur les tunneliers (TBM). Cet article résume le travail accompli à ce jour.

Keywords: Abrasivity; TBM; Dublin; sands and gravels

1 INTRODUCTION

Dublin is well known for its competent boulder clay deposits which underlie much of the city (Long and Menkiti 2007). These deposits pose few geotechnical problems due to their high strength and stiffness and very low permeability. However glacial gravel deposits are also found within the city. For example Farrington (1929) identified the existence of a pre-glacial channel just north of the River Liffey (Figure 1).

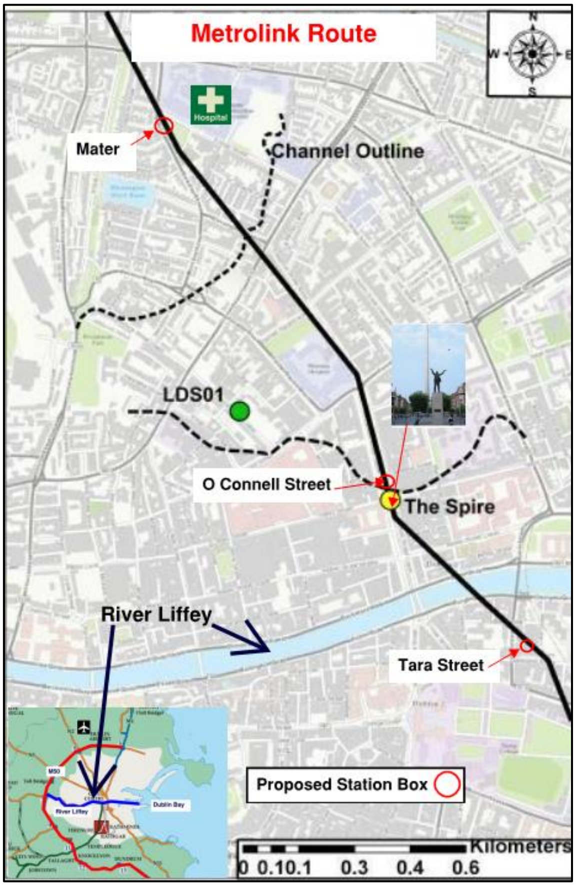

Figure 1. Location plan showing the outline of the buried channel, the proposed Metrolink route, Dublin Spire and borehole LDS01.

It is most dominant towards the north of the present channel of the River Liffey near the city centre and returns near the current mouth of the river. Near Heuston Station on the west side of the city the channel crosses over the present river course to the south forming a more localised deeper zone. It is unclear whether widely varying sea levels, tectonic movements or some weakness in the underlying rock gave rise to the channel. However from an engineering point of view, it has significant importance in that is it generally filled with deposits of glacial and fluvio-glacial gravels.

The mode of formation of the gravel deposits within the channel has not been studied in detail. It is likely however that the deeper deposits were formed by drainage channels either beneath or within the Pleistocene glacial ice. More recent deposits closer to the surface may be river gravels or river terrace gravels.

A metro scheme as shown in Figure 1 is proposed to run north south through the city centre in tunnel, intercepting the channel. Although there have been extensive geotechnical investigations into the channel and its materials, to the authors' knowledge little research work on this topic has been done since the original publication of Farrington (1929).

1.1 *Recent work*

Long et al. (2012) gave a brief description of the channel and infill materials (sand and gravel) in the context of retaining wall design, construction and monitoring. The authors gave design parameters for the gravels, described the control of groundwater and recommended a suite of geophysical techniques including multichannel analysis of surface waves (MASW), S/P waves and resisitivity to distinguish granular materials from Boulder Clay.

Friedman et al. (2015) gave a cross-section of the channel, showing the complexity of the infill materials, based on ground investigation data for earlier variants of the current metro scheme.

1.2 *Current research*

This paper attempts to address this lack of information by summarising the work by Kealy (2017) and O'Connor (2018).

Kealy (2017) has taken available ground investigation information and developed a three dimensional model of the channel and its infill constituents along the metro corridor. He also postulated as to the mode and sequence of deposition of the materials.

O'Connor (2018) collected high quality samples of the granular materials within the channel and subjected them to a suite of tests to give their engineering properties and abrasivity.

2 GEOLOGICAL BACKGROUND AND LOCATION OF THE CHANNEL

The fluvio-glacial sands and gravels related to this paper are understood to have been deposited during the Last Glacial Maximum of the Irish Ice Sheet (IIS). Clark et al (2009) have indicated that the duration of the maximum extent of the global ice sheets occurred between 26,500 to 19,000 years ago. The climatic conditions in Ireland during this time were variable with significant fluctuations between warm and cold periods. In response to the fluctuations in temperatures the IIS went through periods of glacial retreat and advancement. In direct response to these cycles there was variation in eustatic (sea) and isostatic (ground) level resulting in a complex history with regards to the movement of the IIS and it's associated geological deposits.

Kealy (2017) has described four main phases of deposition related to the pre-glacial channel.

Phase 1: The last Glacial Maximum takes place in Ireland 26,500 years (BP).

Phase 2: The pre-glacial channel serves as a conduit for subglacial water flow during glaciation. This results in an esker type (sand and gravel) deposit within the channel. Where the ice is contact with rock at the channel edges, lodgement tills are deposited.

Phase 3: This phase has been interpreted to have occurred during a period of glacial retreat where the mass balance within the glacial system is negative, leading to higher water pressure at the base of the glacier and the glacier becoming decoupled with the underlying bed. It is understood that this can lead to higher flows of basal water resulting in more widespread deposition of sands and gravels.

Phase 4: This has been interpreted to have taken place during another period of glacial advance where the glacier is coupled with the underlying deposits filling the channel, causing them to be overconsolidated and depositing lodgement till on top. The cover of the later till may not be constant over the area due to local fluctuations of meltwater having washied the till away.

3 DUBLIN METROLINK PROJECT

The Metrolink Project is a proposed north-south metro line running from the town of Swords in North Dublin via Dubin Airport and terminating at Charlemont, south of the city centre. There are connections with Luas light rail and commuter rail sevices throughout the route.

It is proposed to be in tunnel through the city centre and at Dublin airport where tunnels will encounter glacial tills and associated water bearing granular lenses, bedrock, and the soil rock interface.

4 DESCRIPTION OF THE PRE-GLACIAL CHANNEL

Kealy (2017) generated a 3D geological model of the section of the pre-glacial Channel associated with the Metrolink Project in the north inner city. Figure 2 gives a rockhead contour plan of the area. It can be seen at the edge of the channel, rockhead is -7 to -10m above ordnance datum (AOD) and at in the centre of the channel within the alignment of the metro, rockhead is -20 to -24m AOD.

The area modelled by Kealy (2017) represented a complicated fluvio-glacial environment. The result of which, is a complex stratigraphy comprising of sands, gravels, slightly clayey

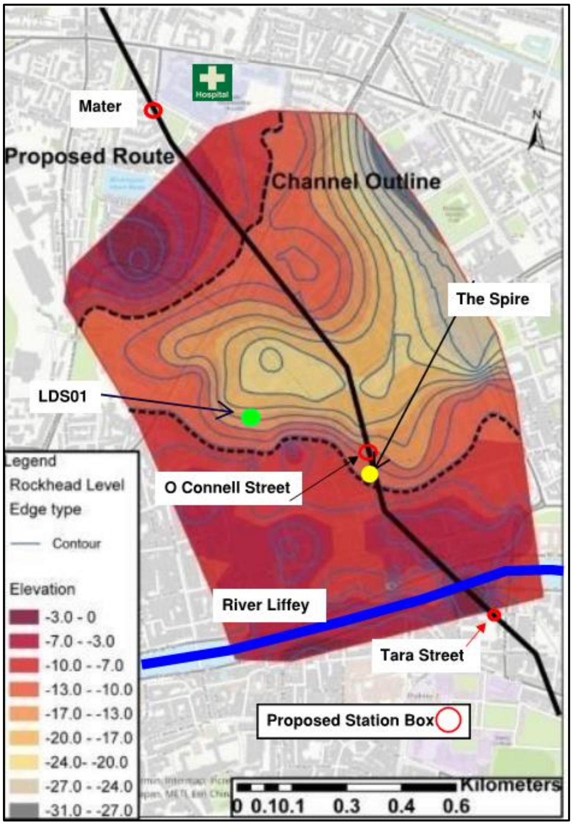

Figure 2. Rockhead contour plan at location of pre-glacial trench (Kealy 2017)

gravelly sands, clayey sandy gravels and glacial till. The model focuses on the areas where the bedrock is the deepest, has the greatest cover of fluvio-glacial sands and gravels and where the Metrolink tunnels are proposed to run.

Due to the complexity of the sand and gravel deposits found in the pre-glacial channel Kealy (2017) simplified them to one unit termed Fluvio-glacial deposits. The area modelled presented four main geological units:

1. Limestone/Mudstone Bedrock 2. Lower Glacial till deposit 3. Fluvio- glacial deposit and 4. an Upper Glacial till deposit.

Figures 3 and 4 present the 3D models for rockhead and the fluvial-glacial deposits showing the same area as the contour plan in Figure 2.

For the rockhead profile, Figure 3, it is clear from the model that the rock dips quite dramatically moving north from the Spire, outlining the most southerly part of the trench The deepest part of the trench is near to the Rotunda Hospital where the rock then begins to rise gradually towards the Mater Hospital.

Figure 4 shows the bedrock profile, the lower glacial till deposit and the fluvio-glacial deposit. The fluvio glacial deposit is seen to be continuous across the area from the most southerly flank close to the Spire to the Mater Hospital.

5 LIKELY TUNELLING TECHNIQUES

The likely geology calls for the use of a TBM that can operate in rock in open mode, but also have a closed face at all other times. An earth pressure balance machine (EPBM) would be most suited to the ground conditions.

The exact design will be developed by the manufacturer, but it is likely the cutter head will have a combination of disc cutters for rock, scrapers for soil, and a rock crusher for any boulders.

Closed face tunnelling, by its very nature, makes interventions to repair and replace worn cutters other than in shafts or station boxes very problematic. Thus it is important for manufacturers to have information as to the strength and abrasivity of the materials the EPBM will encounter.

6 GROUND INVESTIGATION / SAMPLING AND TESTING

Four ground investigations have been carried out for metro schemes in the area.

Recovery of these fluvio-glacial gravels is challenging. Cable percussion drilling can be used for their recovery but the method has proved extremely difficult, time consuming and not with out problems. The main issue being retaining fines and meeting refusal on cobbles/boulders. O' Connor (2018) has suggested that rotary-sonic drilling may prove useful for the recovery of such gravels.

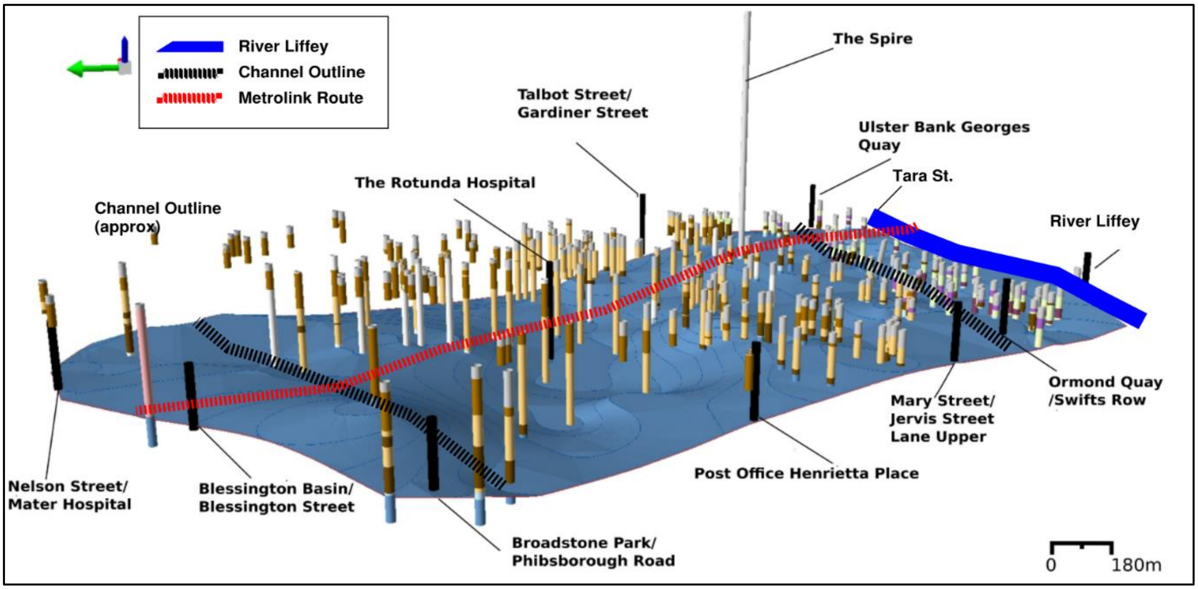

Figure 3. 3D image of ground model showing bedrock profile (blue)

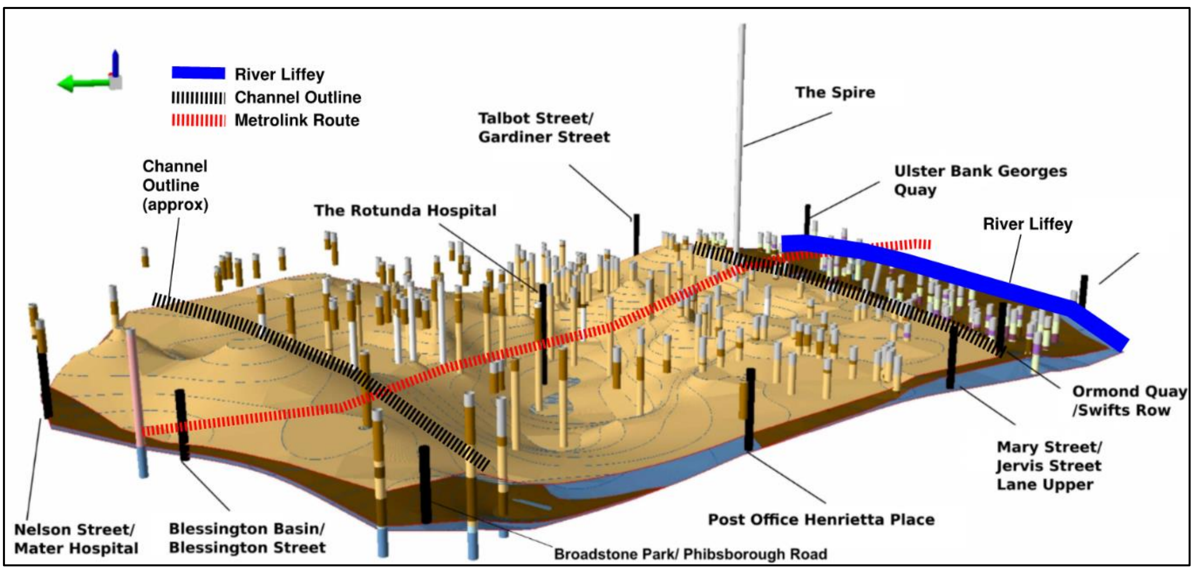

Figure 4. 3D image of ground model showing distribution of fluvio-glacial materials (yellow) and glacial till on the flanks (brown)

Standard penetration test (SPT) N values are shown on Figure 5a. It can be seen that there is considerable scatter in the data and there are many refusals (denoted by N = 50). The presence of cobbles and boulders in the material would have contributed to these refusals. In the fluvio-glacial gravels most of the tests refused. The material can be classified as dense to very dense.

The density of the material was also studied using the multi-channel analysis of surface wave techniques (MASW). This technique has been shown to give reliable shear wave velocity (V_s) values for Dublin glacial deposits when

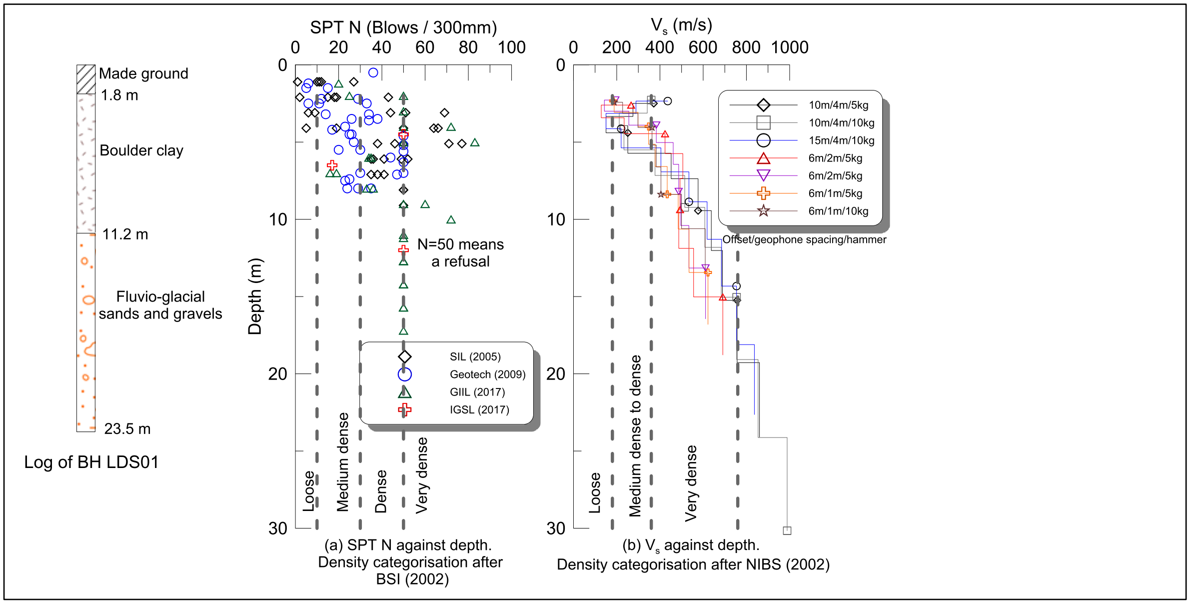

Figure 5 Standard penetration test (SPT) and MASW surface wave test results

compared with a number of other techniques (eg Donohue et al. 2003). The technique allows the geophone spacing, the striking hammer offset distance and the mass of the striking hammer to be altered. By varying these parameters a V_s profile for a site can be obtained over a range of depths. An example at the location of BH LDS01 is shown on Figure 5b. A full profile for the site with depth varying between about 2 m and 30 m was obtained.

The V_s values suggest the material is generally very dense (NIBS 2003) with its density increasing with depth. It is clear that the MASW data provides a much better characterisation of the material density when compared to the SPT.

Particle size distribution curves for the fluvio-glacial gravels confirm the material to be a sandy gravel with cobbles. The dominant lithologies are limestone, greywacke sandstone, siltstones with occasional granite and basic igneous rocks.

7 ABRASIVITY TESTING

A material specific abrasivity test suite was developed for the gravels. The suite comprised a number of well known abrasivity test methods which included the LCPC and Cerchar scratch test. The suite also included some newly developed abrasion test methods such as the soil abrasion test (SAT) and the soft ground abrasion test (SGAT) which is currently under development at the SINTEF Laboratory, Trondheim, Norway. Other tests included geotechnical classification testing (PSD, water content), the Sievers J' (SJ) Miniature Drill test and a petrographic and mineralogical analysis of the gravel.

Obtaining an abrasivity value for these gravels provided a particular challenge as the material required assesment from both a soil and rock testing perspective. The values derived from the SAT, as shown on Figure 6a, indicate that the gravel is of low/medium abrasion according to Jacobsen et al (2013)**.** This test represents abrasion caused by crushing. These values appear to agree with the SGAT results shown on Figure 6b. SGAT testing indicates that thematerial is of low abrasion (personal communication SINTEF, 2017). This test attempts to replicate the contact between the TBM cutter tool under in situ conditions such as moisture content and density. These low to

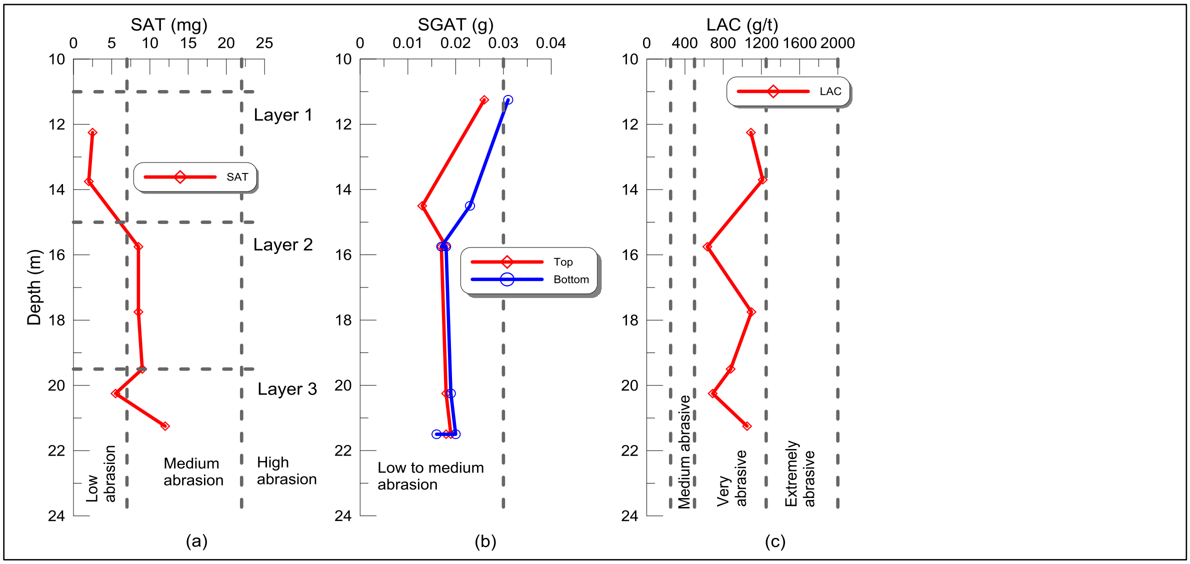

Figure 6. Results of (a) SAT, (b) SGAT and (c) LCPC abrasion testing

medium abrasivity results are conflicted by the LCPC test results as shown on Figure 6cwhich indicate the material is very abrasive (Thuro et al, 2007). However the LCPC test refers to a different form of abrasion and is a measure of impact abrasion (material degradation due o particle impact).

Cerchar and SJ minature drill testing was carried out on individual cobbles types considered to be lithologically dominant throughout the gravels. Cobbles up to 21cm in diameter were recovered during the drilling of LDS 01.

The Cerchar test results indicate that the cobbles are very abrasive (Thuro & Käsling 2009). Yet the SJ minature drill test results suggest that the cobbles have a very low surface hardness (Dahl et al, 2007). Both of these test methods suggest that the greywacke sandstone present in abundance in these gravels is the most abrasive.

The mineralogical and thin section analyses have shown that the gravel has potential to contain cryptocrystalline quartz, an abrasive microscopic quartz, potentially derived from the Dublin limestones and/or Lower Palaeozioc siltstones both of which are abundant in the gravel.

8 CONCLUSIONS

This paper presents a summary of recent work into the nature and geotechnical engineering properties of the fluvio-glacial gravels of central Dublin. These materials are likely to be encountered by Metrolink tunnels. A significant feature of the current research was focused on the abrasivity of the gravels.

The main body of the material was shown to be dense to very dense sandy gravel with cobbles. Geophysical techniques proved useful in the characterisation of the material.

The extent both vertically and laterally of the channel was well defined with 3D modelling.

An extensive suite of abrasivity testing was carried out on the bulk material and individual cobbles. These tests included both those in common usage and currently under development.

It is clear that predicting the abrasivity of such gravel material is extremely complex and therefore no single test method is sufficient to derive such an abrasivity value. A range of testing methods for abrasion must be undertaken to fully understand its abrasion potential. A clear understanding of the geological and geotechnical properties of the gravels is also necessary to provide an adequate assessment of the gravels abrasion potential.

Future work should include a trial of rotary-sonic drilling techniques to enhance gravel recovery.

9 ACKNOWLEDGEMENTS

The authors are grateful for assistance in the field work by Irish Geotechnical Services Ltd. (IGSL) who drilled the borehole at Lower Dominick Street and to Andy Trafford, geophysical consultant, who undertook the MASW surface wave testing.

Much of the soil abrasion testing was carried out at the laboratories of SINTEF and at the Norwegian University for Science and Technology (NTNU), Trondheim, Norway In particular the authors are grateful for the assistance of Filip Dahl at SINTEF and Pål Jacobsen at NTNU.

The work described was funded by the Geological Survey of Ireland Short Call Scheme (2016) and Transport Infrastructure Ireland.

10 REFERENCES

Clark, P.U., Dyke, A. S., Shakun, J, D., Anders, C, E., Clark, J., Wohlfarth, B., Mitrovica, J, X., Hostetler, S, W. & McCabe A, M., 2009. The Last Glacial Maximum. *Science*, 325(5941), pp.710–714.

Donohue, S, et al. (2003) G_{max} from multichannel analysis of surface waves for Dublin Boulder Clay In: Vanicek, and et al, Eds., *Proceedings XIIIth European Conference on Soil Mechanics and Geotechnical Engineering*: CGtS, Prague pp 515 - 520.

Dahl, F., Grøv, E., & Breivik, T. (2007). Development of a new direct test method for estimating cutter life, based on the Sievers' J miniature drill test. *Tunnelling and Underground Space Technology, 22*(1), 106–116.

Farrington, A. (1929) The pre-glacial topography of the Liffey basin, *Proc. Royal Irish Academy*, Vol. 38, No. B, pp 148 - 170.

Friedman, M., et al. (2015) The geotechnics of infrastructure development in Dublin, Ireland, *XVIth European Conference on Soil Mechanics and Geotechnical Engineering (ECSMGE)* Edinburgh, Scotland: Thomas Telford Ltd., pp 265 - 270.

Jakobsen, P. Lohne, J.. Challenges of methods and approaches for estimating soil abrasivity in soft ground TBM tunnelling. Wear. (ISSN 0043-1648). 308(1-2): 166-173, 2013

Kealy, S. (2017) Three dimensional geological and geotechnical model of the pre-glacial channel central Dublin, MEngSc Thesis, School of Civil Engineering, University College Dublin, April.

Long, M., et al. (2012) Retaining wall behaviour in Dublin's fluvio-glacial gravel, Ireland, *Institution of Civil Engineers Journal of Geotechnical Engineering*, Vol. 165, No. GE5, October pp 289 - 307.

Long, M., and C.O. Menkiti (2007) Geotechnical properties of Dublin Boulder Clay, *Géotechnique*, Vol. 57, (7), pp 595-611.

NIBS (2003) National Institute of Building Sciences - Recommended provisions for seismic regulations for new buildings and other structures Part 1: Provisions. Washington, DC: Building Seismic Safety Council.

O'Connor, E. (2018) The pre-glacial channel central Dublin, a geotechnical investigation of material abrasivity and its influence on TBM tool selection, MEngSc Thesis, School of Civil Engineering, University College Dublin, October.

Thuro, K. & Käsling, H. (2009). Classification of the abrasiveness of soil and rock. *Geomechanics & Tunnelling 2*: 179–188.

Thuro K, Singer J, Käsling, H & Bauer M (2007). Determinig abrasivity with the LCPC test, *Proc 1st Canada-US Rock Mechanics Symposium, 2-7, pp827 – 834*