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Geotechnical aspects of tunnelling in soft ground in Ireland

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ABSTRACT: In this paper the geotechnical factors which affected the construction of a selection of medium size tunnels in overburden in Ireland are examined. These tunnels were constructed mostly in glacial till deposits or in alluvial soils. The paper discusses the experiences of tunnelling in these deposits, the problems encountered and the measures adopted to overcome the difficulties.

1. INTRODUCTION

Tunnelling in Ireland in recent years has primarily been carried out as part of water and sewerage improvement schemes. The country has no underground system and to date no tunnelling has been carried out for the construction of roads or motorways, although plans are being prepared for a motorway tunnel to be constructed in Dublin in the near future. However, significant information can be obtained from experiences gained during the construction of small and medium size tunnels which can be of assistance in the case of larger tunnel projects.

In this paper the geotechnical considerations which affected the construction of a selection of medium size tunnels around the major cities in Ireland, with diameters ranging from about 1.5m to 3.5m, are examined. These tunnels were constructed mostly in glacial till with varying particle size distributions or in alluvial soils. The experiences of tunnelling these deposits are discussed.

2 TUNNELLING IN GLACIAL TILL

The predominant glacial deposit in Dublin and the surrounding area comprises a very stiff/hard lodgement till, commonly referred to as the Dublin Black Boulder Clay (Farrell and Wall, 1990). Generally this deposit directly overlies the limestone bedrock and can be over 15m thick in places, although in many areas the rock is relatively close to the surface and consequently tunnelling is frequently in a mixed boulder clay/rock face. The glaciation of the Dublin area was not a single simple event. The till deposits are complex and the presence of fluvioglacial and glaciomarine sand and gravel sediments are indicative of either local withdrawals and re-advances of the ice sheet or a complex system beneath and around the ice itself (Eyles & McCabe, 1989). The complexity of the till deposits can give rise to problems in tunnelling as outlined by Bevan & Parkes(1976). Fissures have been noted in this till but to date these have not been considered to be of engineering significance. The upper 2m to 3m of the lodgement till in those areas which have been exposed to environmental and biological action have been weathered, resulting in a paler, generally brown colour with a consequential reduction in undrained strength (Farrell, Coxon et al., 1995).

The significant geotechnical parameters of the Dublin Black Boulder Clay with regard to tunnelling are its strength, stone and boulder content and the presence of permeable layers within the deposit. The grading curve of the material, after the cobbles and boulders have been removed, approximates to a straight line that is typical of Irish glacial tills - see Figure 1. The fines content, i.e. those particles whose size is less than 0.06mm, typically has a liquid limit, w_L of 20% to 35% and a plasticity index, I_p generally in the range 6% to 15% which indicate that this soil is a low plasticity clay. However, it is important to note that the fines content varies around 35%, sometimes

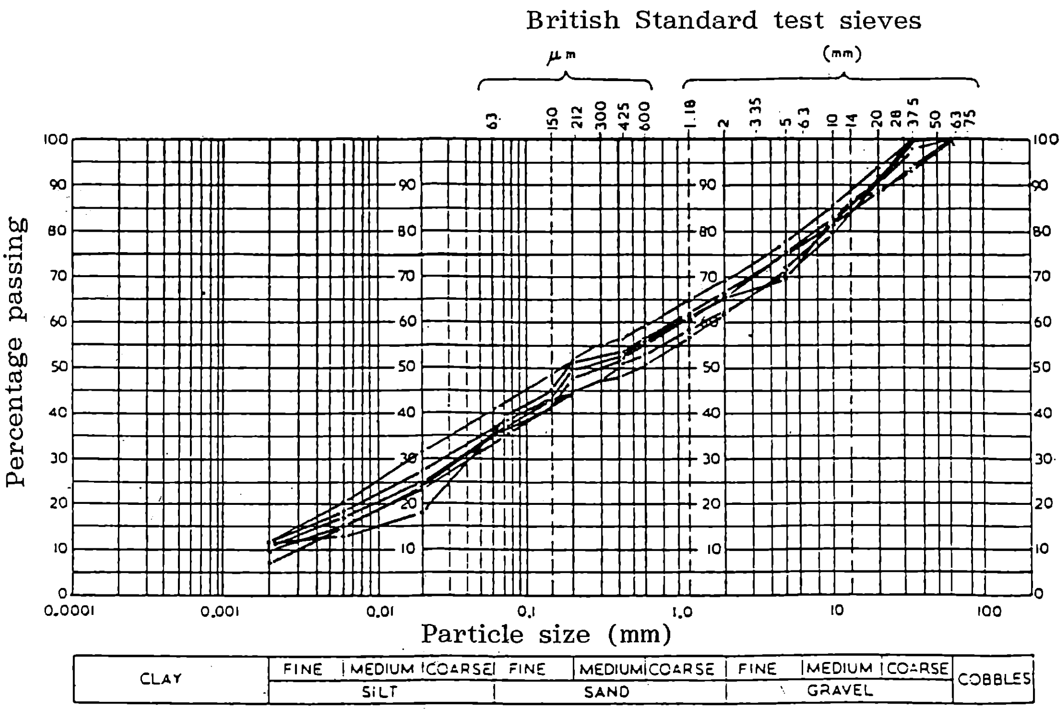

Figure 1. Typical grading curves for Irish glacial tills

being greater than 40% but sometimes being less than 30% which indicates that the behaviour of this material is not always that of a fine grained cohesive soil. The reduction in the fines content of the boulder clays below the typical value of 35% has significance for the stability of tunnel faces as this can result in lack of cohesion and face instability. This can be particularly significant when blasting is being used to excavate a tunnel through a mixed face of overburden and rock as the blasting can give rise to high pore water pressures and cause collapse of the face.

The Dublin Black Boulder Clay is generally dense and strong. The natural water content of this soil is typically between 8% and 15%, with little variation with depth, so that its density lies in the range 2.3 Mg/m^3 to 2.38 Mg/m^3. However, any comparison of the moisture content of this soil with the index properties must allow for differences in the gradings of the samples tested.

Sampling of the Dublin Black Boulder Clay is always difficult because of the high stone content and hence most previous research in the laboratory to investigate the strength and stiffness of this soil has been carried out on remoulded specimens. Recent laboratory tests on specimens sculptured from blocks of Black Boulder Clay have recorded undrained shear strengths of up to 580 kPa. This strength, together with the cobble and boulder content of the soil, makes for difficult tunnelling. Keyes & Kinirons(1992) reported relatively slow progress using clay spades on the 1.5m diameter Patrick Street Sewer Tunnel which was constructed in 1991 through this deposit under Christchurch Cathedral in the centre of Dublin - see Figure 2. In the case of this tunnel, with a relatively small face, the cobble and boulder content of the soil had a greater influence on the efficiency of the mining than it would probably have in the case of a larger diameter tunnel. During construction of the 3.66m diameter Grand Canal Drainage Tunnel in Dublin between 1972 and 1974, see Figure 2, O'Donoghue & White(1975) reported that the use of blasting was found to be the most efficient way to remove the Black Boulder Clay. Nicholls (1930) reported that, when the south shaft in Ringsend, Dublin was being excavated in 1926 for the tunnel to take electricity and water mains under the River Liffey, 'large boulders were met in the hard boulder clay.'

The nature and unpredictable variability of the Dublin Black Boulder Clay, with sand and gravel layers and lenses, can give rise to unstable tunnel faces. This is particularly so because, in Ireland, the water table is

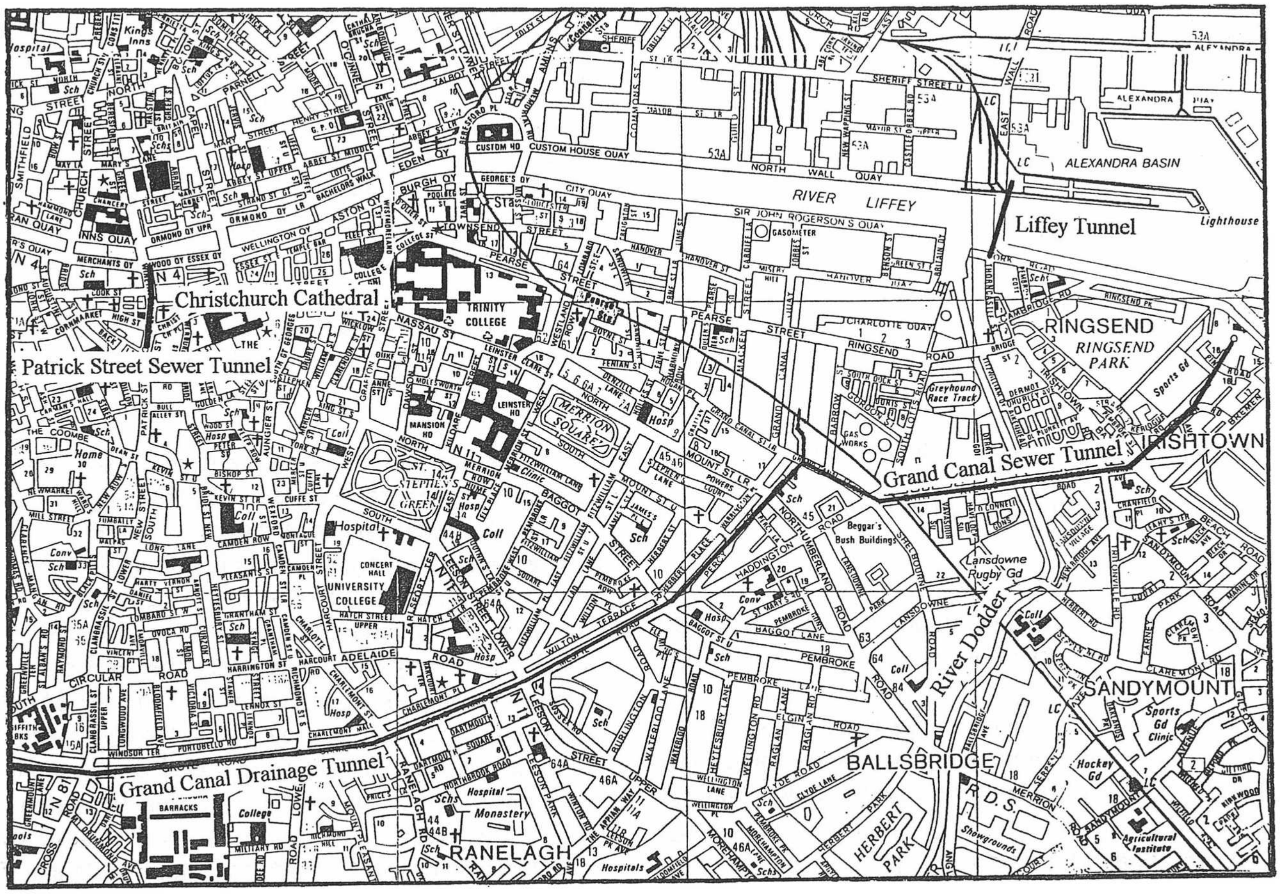

Figure 2. Location of tunnels in the Dublin area

generally close to the surface and since most tunnelling is at a depth of about 4m to 10 m below ground level it is below the general ground water table. The sand and gravel layers and lenses may or may not be connected to a water source. In some cases the water sources are essentially small water reservoirs which, when drained, are not replenished. Nicholls (1930) reported that, when the south shaft in Ringsend, Dublin was being excavated for the Liffey Tunnel, see Figure 2, 'veins of sand began to appear in the clay, and a heavy subsidence occurred between the shaft and the sea wall, an area of about 10 feet (3m) square suddenly sinking nearly 20 ft (6m).' During construction of the Grand Canal Drainage Tunnel it was found necessary to use compressed air to stabilise the face and prevent water ingress through sand and gravel layers (O'Donoghue & White, 1975).

A feature of the glacial deposits which is of relevance to tunnelling is that, as they overlie the preglacial land surface, they may in places have infilled preglacial river valleys. An example of this is the buried channel of an old river valley incised into the limestone bedrock beneath the centre of Dublin which was noted by Farrington (1929). In places the depth of this channel is over 40m below the existing ground level. Another example is provided by Grant et al. (1996) who reported that a buried valley filled with glacial sands and gravels encroached on the line of a water mains tunnel through granite near Sandyford, south of Dublin. The soft ground along this portion of the tunnel had to be grouted to enable construction to proceed using hand excavation.

The Dublin Black Boulder Clay can be very stiff, as has been shown by small strain measurements carried out by Tracy & Farrell(1996) in undrained triaxial tests on specimens sculptured from block samples of this soil. The results from these tests are plotted in Figure 3 and show that a secant shear modulus (G) value of about 200 MPa was recorded at 0.01% shear strain which reduced to about 20 MPa at 1% strain. Farrell, Lehane et al.(1995), back-analysing the measured settlements of piles and foundations to determine the stiffness of this soil, obtained average shear modulus values of about 50 MPa from the

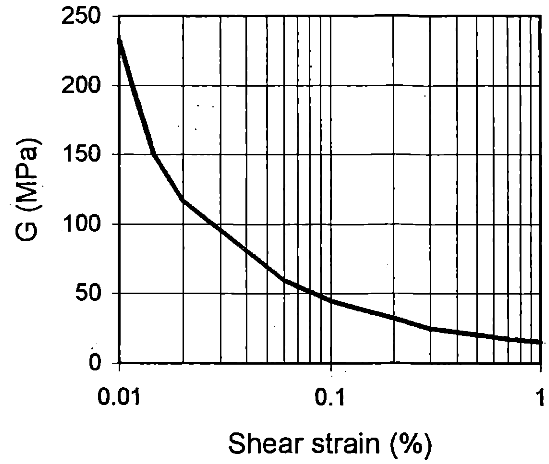

Figure 3. Graph of G plotted against shear strain

settlements of piles and about 35 MPa from the settlements of foundations.

On account of the high stiffness of Dublin Black Boulder Clay, no significant ground movements have been recorded to date around tunnels taken through this soil, other than those resulting from seepage through permeable layers and ground loss. Attempts were made by Keyes(1990) to measure the settlements above the Grand Canal Drainage Tunnel, but these were found to be too small to be measured. Recent advances in the precision of measuring ground movements may lead to more success in the future in the recording of ground movements due to tunnelling in the Dublin Black Boulder Clay.

The presence of sand and gravel layers and pockets within an otherwise clay or silt till has given rise to unstable faces on several projects. On the Tramore River Valley Sewage Scheme in Cork, attempts to intercept and drain such layers or pockets with wellpoints and deep wells proved to be unsuccessful and difficult mining conditions persisted over some portions of the tunnel. When pipe jacking through glacial till in Athlone, a low plasticity silty sandy gravel was encountered at a depth of about 4 m below the water table. The fines content of this soil was sufficient to limit the effectiveness of dewatering and chemical grouting.

3 TUNNELLING IN ALLUVIAL DEPOSITS

The Grand Canal Sewer Tunnel, which was the extension of the Grand Canal Drainage Tunnel into the alluvial deposits on the south bank of the River Liffey, see Figure 2, is the only major tunnel constructed in alluvial deposits in the Dublin area. This tunnel was constructed in the early 1980s as part of the Greater Dublin Drainage Scheme using a 3.8m diameter fullface tunnel boring machine (TBM) manufactured by Lovat of Canada. The cutting head had two flood doors which were kept open during cutting to allow the soil to pass the mucking-out auger and conveyor. This machine could cope with cobbles and small boulders which were anticipated and were encountered during the drive. It did not, however, deal with the water ingress.

The ground conditions along the route of the Grand Canal Sewer Tunnel comprised fill overlying alluvial gravels. The permeability of the latter was estimated from gradings and in situ borehole permeability tests to be high and about $5x10^{-4}$ m/s, the fill being above crown level. Compressed air was applied to the tunnel in the early stages, however the air loss was excessive. Compressed air tests were then carried out along the route by pumping air through sealed boreholes into the ground at the level of the tunnel and measuring the air pressures within the ground and the rate of flow. These tests indicated that the air loss would be excessive along the entire route and it was decided to proceed instead by dewatering inside the tunnel. This dewatering reduced the water level in the surrounding ground and a water level drop was recorded at a significant distance from the line of the tunnel. Some local settlement problems due to drawdown did arise adjacent to the tunnel where a silt pocket occurred within the alluvial deposits. The tunnel drives were under a roadway for almost the entire length of the tunnel. Some swallow holes did form from the crest of the tunnel to the underside of the road pavement and these were stabilised by grouting from the surface. Chemical grouting of the permeable soils was used around the shafts to enable the TBM to be started in the ground.

An interesting construction method was adopted by the contractor to enable the tunnel to pass under the River Dodder with only 1.5m of granular cover. The contractor laid steel sheet piles on the bed of the river above the tunnel as a safety precaution and then completed the drive with relative ease using the TBM.

The lining for this tunnel was formed by constructing rings using segments erected within the TBM. Whilst the main drive was carried out at atmospheric pressure, compressed air was used within the completed tunnel to enable a smooth concrete lining be constructed within special formwork. Leakage of the compressed air caused an unusual problem in that the overlying fill contained some organic material in places and the enriched air accelerated the decomposition which gave rise to significant temperature rise in the ground.

Pipe jacking was carried out beneath the quays in Cork to construct sewers as part of the Cork Main Drainage Scheme. Dwane(1990) reported that the pipe jacking was mostly through fill with some organic silt layers. Because the ground water level in the fill along the quays closely followed the level of the tides in the River Lee and because the invert of the pipes were below the low tide level, some form of ground water control was necessary to stabilise the ground and enable pipe jacking to be carried out at all stages of the tides. Stabilisation was achieved by injecting a grout consisting of a mixture of cement and bentonite. This grouting was generally successful and reduced the pumping requirement and hence the risk of soil removal due to pumping and drawdown of the ground water level causing settlement of adjacent buildings.

4 CONCLUSIONS

The geotechnical aspects which affected the construction of a number of tunnels in Ireland have been examined. This examination has demonstrated that the strength and stone content of the Dublin Black Boulder Clay, in which some of the larger tunnels have been constructed, has given rise to difficult tunnelling conditions, sometimes requiring blasting which is more often associated with tunnelling in rock. The complex geological history of this lodgement till can result in water bearing sand and gravel layers within the otherwise "cohesive" deposit which can, in some situations, be connected to a water recharge source. The presence of such layers in a tunnel face has required the use of special measures and sometimes compressed air has been adopted. The complexity of the glacial deposits has also caused difficulties during tunnelling in other parts of Ireland. The experiences of tunnelling in alluvial deposits in Dublin and Cork has shown that the permeability of the gravels, allied to their boulder content, can limit the underground construction options. The use of compressed air in a tunnel under fill caused an unusual problem in that it accelerated the decomposition of organic material and caused a significant rise in ground temperature.

REFERENCES

Bevan, O. M. & Parkes, D. B. (1975) Tunnelling in Glacial Materials in the British Isles. *The Engineering Properties of Glacial Materials*, University of Birmingham, 235-243.

Dwane, T. F. (1990) Cork Main Drainage Scheme: Aspects of the Design and Construction. *Transactions of the Institution of Engineers of Ireland*, 113,6-39.

Eyles, N. & McCabe, A. M. (1989) Glaciomarine facies within subglacial tunnel valleys: the sedimentary record of glacio-isostatic downwarping in the Irish Sea Basin. *Sedimentology*, 36, 677-710.

Farrell, E. R., Coxon P., Doff, D. H. & Pried'homme, L. (1995) The genesis of the brown boulder clay of Dublin. *Quarterly Journal of Engineering Geology*, 28, 143-152.

Farrell, E. R., Lehane, B, O'Brien, S. & Orr, T. (1995) *Stiffness of Dublin Black Boulder Clay*, Proc. XI ECSMFE, Copenhagen, DGF-Bulletin 11, 1, 109-112.

Farrell, E. R. and Wall, D. (1990) The soils of Dublin. *Transactions of the Institution of Engineers of Ireland*, 115, 78-97.

Farrington, A. (1929) The pre-glacial topography of the Liffey basin. *Proc. Royal Irish Academy*, 38, B, 148-170.

Grant, J., McCarthy, D. & Sharkey, J. (1996) Construction of water main tunnel at Brewery Road. *Transactions of the Institution of Engineers of Ireland*, To be published.

Keyes, J. (1990) Personal communication.

Keyes, J. & M. Kinirons, T. G. (1992) The Patrick Street Sewer: Design and Construction. *Transactions of the Institution of Engineers of Ireland*, 117, 97-109.

Nicholls, H. (1930) *The Construction of a Tunnel under the River Liffey*. Transactions of the Institution of Engineers of Ireland, 60, 85 - 230.

O'Donoghue, B. E. & White, P. R. (1976) Grand Canal Drainage Tunnel: Design Aspects, *Transactions of the Institution of Engineers of Ireland*, 99, 68-81.

Smith, W. (1983) Grand Canal sewer tunnel completes missing link in Dublin's drainage plan. *Tunnels and Tunnelling*, November, 32-34.

Tracy, P. & Farrell, E. R. (1996) Ground movements around excavations in Dublin Boulder Clay. To be published.