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Settlement trough parameters for tunnels in Irish glacial tills

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ABSTRACT

Glacial till (or boulder clay) is the most widespread sediment on the island of Ireland. The behaviour of these tills, especially Dublin Boulder Clay, is now better understood as a result of ground investigations and associated testing for major construction projects, particularly in the east of the country over the past decade. Despite an increase in tunnelling activity in the country over the same time period, there is very little documented evidence on the settlements induced by tunnelling operations in glacial till. In this paper, transverse surface settlement data from two glacial till sites are presented. Four profiles are presented for the 'soft ground' TBM-bored section of the Dublin Port Tunnel. Nine profiles are reported for pipe-jacked microtunnels constructed for a sewerage scheme in Mullingar in the Midlands; one of which was measured at the top of a railway embankment under which the pipeline passes. The measured settlements have been interpreted using a standard Gaussian error function, and trough width parameters show dependence on the fraction of the till, fine or coarse, that governs its behaviour. In addition, conservative design estimates of maximum trough settlement and volume loss have been provided, and the impact of boulders is discussed. This paper provides the first empirical guidance for predicting surface settlements above tunnels in Irish soils.

1. Introduction

Irish tunnelling experience has developed considerably since the Orr and Farrell (1996) report on tunnelling activity in the country 15 years ago, at which time tunnels had yet to be used to carry roads or motorways. The Jack Lynch Tunnel under Cork's River Lee was opened in May 1999; this submerged twin-bore tunnel is 610 m long and is estimated to have cost €133 m. The €752 m Dublin Port Tunnel (DPT), when opened in December 2006, became the longest urban tunnel in Europe (4.7 km twin bore) and the nation's largest ever civil engineering project. An important coupled outcome of the DPT project was the improved grasp of both the stratigraphy and engineering properties of Dublin Boulder Clay that arose from handling the extensive geotechnical data generated (e.g. Long and Menkiti, 2007). Another highly significant project, the €660 m and 675 m long twin-bore submerged Limerick tunnel under the River Shannon, was opened in September 2010. In parallel with the development of large scale tunnels, the application of pipe-jacking to the construction of pipelines for utilities such as water, sewage and gas in a variety of soil and rock types has escalated. Curran (2010) interprets jacking force data for slurry-shield pipe-jacked microtunnels at eleven Irish sites encompassing a variety of soil and rock types.

Lochaden et al. (2008) report on successful efforts to model settlements above the DPT using finite element software, with the predictions relatively insensitive to the constitutive soil model used. In practice, however, predictions of surface settlement troughs over tunnels in Irish soils have to date relied heavily on experience from the UK and beyond, such as the recommended Gaussian trough width parameters published by Mair and Taylor (1997) for tunnels in sands/gravels and clays with generally a small range of particle sizes, and the achievable volume losses suggested by Mair (1996) and others. Some Irish soils have particular characteristics that significantly affect their behaviour; for example, Irish boulder clays are often well-graded and composed of a wide range of particle sizes from clay-size to gravel-size, so that some of these soils are characterised as fine soils while others are characterised as coarse soils (Farrell, 2010). For this reason, it was deemed important to analyse tunnel-induced settlements in these soils, and also to consider the impact of boulders that are sometimes encountered. In this paper, settlement data is provided for (i) large diameter open-face shielded tunnels in glacial till for the DPT project, and (ii) small diameter closed-face pipe-jacked tunnels in a glacial till at Mullingar, Co. Westmeath; including data for a section of pipeline passing beneath a high railway embankment. The inferred Gaussian parameters are an important record of Irish tunnelling-induced settlement experience and also, in the case of the Dublin Port Tunnel, supplement the limited data published internationally for tunnels with low cover to diameter ratios. All of the aforemen-

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Nomenclature

AVN	remote control tunnelling machine with slurry material removal
c_u	undrained shear strength
D	tunnel diameter (including overcut)
DBC	Dublin Boulder Clay
DPT	Dublin Port Tunnel
i	value of y corresponding to point of inflection of Gaussian trough
k	Gaussian trough width parameter
MH	manhole
N	stability number
N_{Tc}	stability number at collapse
N_{60}	standard penetration test value
s_v	vertical settlement at any point in trough
s_{max}	vertical settlement over centreline of tunnel (at $y = 0$)
σ_t	tunnel internal support pressure
σ_v	vertical total stress at the depth of the tunnel axis
TBM	Tunnel Boring Machine
V_l	volume loss
V_s	volume of Gaussian settlement trough per metre length
V_t	volume of tunnel per metre length
y	transverse horizontal distance from tunnel centreline
z_0	depth to tunnel axis

tioned site locations are illustrated in Fig. 1; in addition to a Belfast site with older data which is referred to later in the paper.

2. Tunnelling projects at Dublin and Mullingar

2.1. Dublin Port Tunnel

The Dublin Port Tunnel is a 4.7 km long urban road transport twin-tunnel constructed to ease congestion in Dublin city centre by removing heavy vehicular traffic to and from Dublin Port and rerouting it from the centre of Ireland's capital to the outer orbital M50 motorway. Construction of the DPT began in 2001 and the tunnel was opened in 2006. Construction methods used included cut and cover, pipe jacking, hard rock TBM tunnelling and 'soft ground' TBM tunnelling. The section of the project considered in this paper is the 325 m section of twin tunnel bored in boulder clay at Whitehall, towards the northern end of the scheme (Fig. 2). An 11.77 m diameter Herrenknecht open-face shielded back-actor machine was used for this section. Summary information on the surface settlement profiles is provided in Table 1.

Fig. 1. Map showing locations of Irish tunnelling projects referred to in this paper.

The data published here, for four different chainages, relate to the southbound bore which was the first to be constructed. Interpretation of the settlement data measured during construction of the northbound bore will be the subject of a future publication. Goto et al. (2004) make general observations from settlement profiles in the Whitehall area as part of an overview paper on the DPT scheme. Additional data and a fuller interpretation is provided in this paper.

2.2. Mullingar

Approximately 750 m length of pipe-jacked tunnels were constructed in Mullingar between July and October 2009 as part of the Mullingar Sewerage Improvement Scheme. Herrenknecht AVN (remote-controlled slurry-shield tunnelling) machines deploying a 'mixed' head (incorporating both scraping teeth and cutting discs) of the type shown in Fig. 3 were used. Two different sized Tunnel Boring Machines (TBMs) were used, AVN 1200 and AVN 1800, with external diameters of 1505 mm and 2150 mm respectively. The relevant particulars of each are shown in Table 2a. The forces and penetration rates recorded during pipe-jacking in this contract have been interpreted elsewhere (Curran, 2010).

The settlement data reported here pertain to distinct areas of the scheme, hereafter referred to as Areas A–C (see Table 2b and Fig. 4):

- **Area A.** Area A includes the Supervalu car park and access road to it from Austin Friars Street in the town centre. In this area, transverse profiles 1–7 and 13–19 were situated between manholes MH22 and MH23, and transverse profiles 26–32, 36–43 and 47–53 were situated between manholes MH23 and MH24. The pavement in the area was typically 200 mm thick and the tunnel axis is at a depth of between 3.6 m and 5.4 m.
- **Area B.** Area B is immediately west of the River Brosna, near the Mullingar Greyhound Stadium. In this area, transverse profiles 117–123, 127–133 and 159–165 all lie to the southern end of the section of pipeline between manholes MH9 and MH11 and the tunnel axis is at a depth of between 3.5 m and 4.1 m. Profiles 127–133 and 159–165 were measured on a concrete slab.
- **Area C.** Area C is immediately north of the Mullingar Greyhound Stadium. In this area, the pipeline between manholes MH11 and MH13 passes approximately 4 m below an 8 m high embankment supporting the Dublin–Sligo railway line. Settlements were recorded on points marked on both rails of each of three railway tracks. Note that the direction of the pipeline is approximately 13° off perpendicular to the embankment centreline at that point.