Embankments over blanket peat in Co. Donegal: Interpretation of piezometer data

EMBANKMENTS OVER BLANKET PEAT IN CO. DONEGAL: INTERPRETATION OF PIEZOMETER DATA

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ABSTRACT

A recent road improvement scheme on the N56 near Glenties, Co. Donegal, involved the staged construction of a surcharged embankment over blanket peat, enabling the peat to be left in place. This paper focusses on the interpretation of the pore pressure regime in the underlying peat during and after construction. The substantial peat strains induced by the embankment rendered buoyant the portion of the embankment that settled beneath the groundwater table and required assumptions to be made about piezometer positions. Additional assumptions necessary to arrive at coefficients of consolidation and permeabilities are presented. A hypothesis is proposed to explain the elevated long-term pore pressures noted at two of the instrument cluster locations.

Key words: *embankment, peat, pore water pressure, drainage*

INTRODUCTION

The Department of Transport has assigned ≈€8b to Transport Infrastructure Ireland (TII) this decade for our national road infrastructure. Given that 17.2% of the land area of Ireland consists of peat (Farrell 2012), it is inevitable that peat will be encountered on many future road schemes. Road projects in Ireland and elsewhere have traditionally involved substantial volumes of peat excavation, releasing carbon into the atmosphere, a driver of climate change.

Surcharging is a form of ground improvement that is often used on road construction projects to improve the engineering properties of underlying mineral soils. Surcharging entails the application of temporary overload (i.e. additional embankment height over and above final road level), thereby artificially increasing the peat's yield stress. This has the effect of front-loading the primary consolidation settlement (it occurs during construction rather than after the road surface is in place) and can also reduce long-term secondary/creep settlements. Importantly, the use of surcharged embankments on peat would enable the peat to remain *in situ*, thereby retaining its carbon store. However, surcharging is not currently permitted by Transport Infrastructure Ireland (TII Series 600, 2013) in highly organic soils including peat, nor is it widely used internationally in these soils.

The N56 Letterilly to Kilraine road improvement scheme (near Glenties, Co. Donegal), completed in 2022, afforded the opportunity to explore the potential of surcharging at a blanket peat site; excavate-and-replace was excluded due to ecological constraints and therefore a surcharging solution was permitted by TII on an exceptional basis. Given the novelty of the approach, a significant embankment monitoring programme was conducted as part of the scheme. An overview of the scheme is provided by Kissane *et al.* (2024), while Fattahi Masrour *et al*. (2024) focus on embankment primary consolidation performance at one location along the mainline. The focus of this paper is on pore water pressures in the peat during and after construction: the challenges in interpreting the pore pressures from piezometers given the large strains involved, and the likely effect of settlement on peat permeability.

N56 LETTERILLY TO KILRAINE IMPROVEMENT SCHEME

The project involved the redevelopment of a 4.5 km section of the N56 national secondary route, immediately north of Glenties, Co. Donegal. A multi-stage surcharged embankment (Figure 1a) was implemented along ≈1.5 km of the road. In order to inform the embankment staged-loading hold periods and assess embankment stability and peat settlements, six instrument clusters (ICs) were established along the road alignment; each IC incorporated a foundation settlement plate (FSP), a subsurface profile gauge (SSPG), a vibrating wire piezometer, and an inclinometer pair, one on each side of the road. An example cross-section (IC1), depicting the instruments, is shown in Figure 1b. A longitudinal section with relevant levels and IC locations is shown in Figure 2. To the west of the road alignment, a low-height unsurcharged control embankment (with three FSPs and a piezometer) was constructed to aid an assessment of the effect of surcharge magnitude on creep settlements. The peat properties at the site are provided elsewhere (Kissane *et al.* 2024, Fattahi Masrour *et al*. 2024).

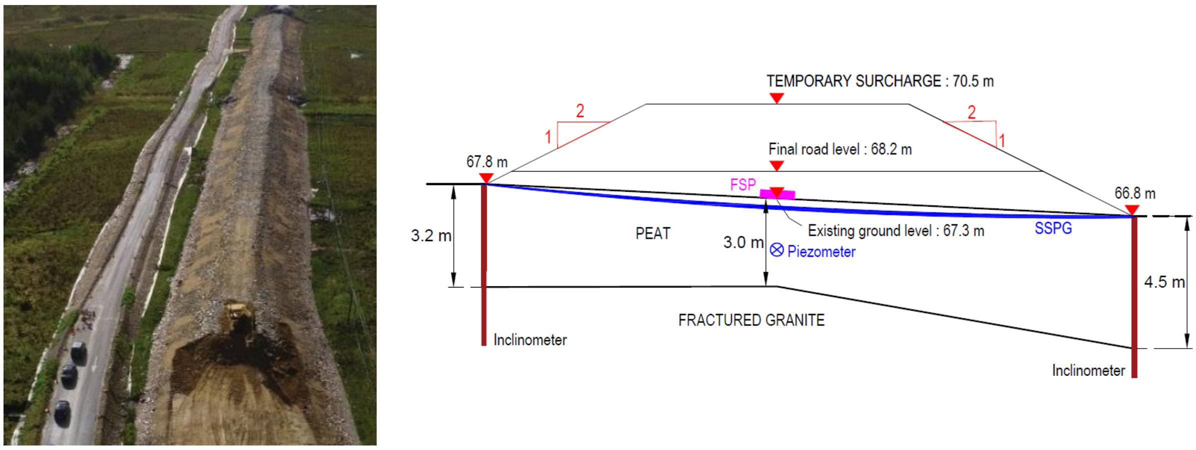

Figure 1: *(a) Surcharge removal at N56 Letterilly to Kilraine (Glenties) site, (b) Cross section at IC1 depicting embankment levels, peat thickness and instrumentation*

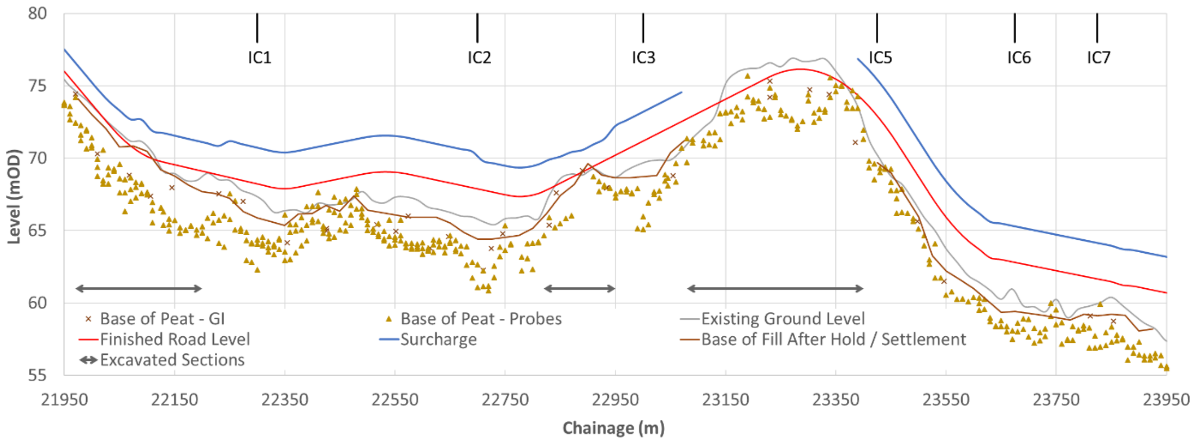

Figure 2: *Longitudinal section showing relevant levels and IC locations*

EXAMPLE SETTLEMENT AND PORE PRESSURE DATASET (IC1)

An example dataset (IC1) showing the evolution of total stress with time corresponding to staged embankment construction (eight stages in this case) is shown in Figure 3. The total stress is that corresponding to the level of the piezometer within the peat, initially 1.7 m below original ground level (for consistency with pore pressure data also plotted in Figure 3).

When a total stress increment (such as embankment loading) is applied to a saturated soil, the pore pressure in the underlying soil assumes all of this stress initially. This generates a hydraulic gradient between the underlying soil and that located more remotely, leading to pore pressure dissipation (and effective stress increase) over time. The rate of pore pressure dissipation reflects both the rate of total stress application and the permeability of the soil. The increases in excess pore pressures (i.e. over and above initial free-field values) within the peat and subsequent partial dissipation, in response to the eight loading stages, are apparent in Figure 3. Both corrected and uncorrected versions of total stress and pore pressures are included, which will be explained in the next section.

Primary settlement (Figure 3, IC1) occurs as a result of pore pressure dissipation; trends shown are based on the FSP and the SSPG reading closest to the embankment centre. Based on a peat thickness of 3 m, the settlements at the point of surcharge release correspond to vertical strains of ≈46% (FSP) and ≈41% (SSPG). These values may also include small amounts of creep settlement, which arises due to re-arrangement of particles upon reduction in water content (i.e. not related to changes in effective stress). Creep settlement continues long term and can be quantified more readily once primary consolidation is complete.

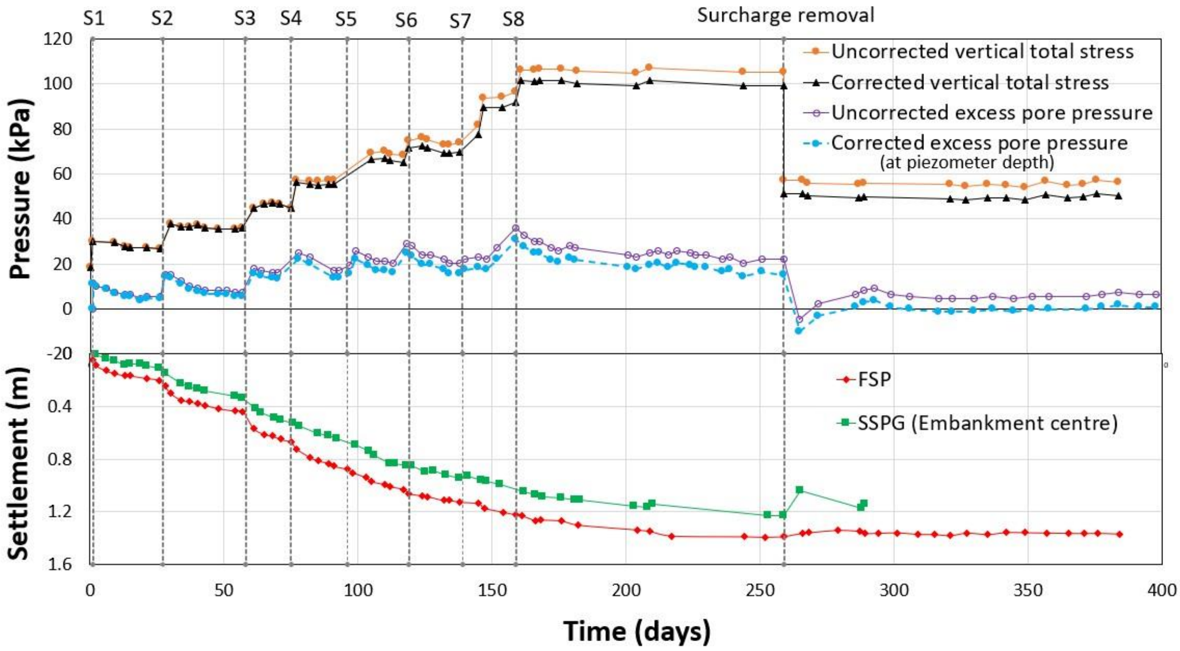

Figure 3: *Evolution of vertical total stress, excess pore pressure and settlement with time.*

PORE PRESSURE INTERPRETATION

The interpretation of the pore water pressure regime underneath the embankment was not straight-forward; key considerations are summarised in the following sections. Many of these relate to the large strain nature of the problem and have been highlighted by Arulrajah *et al.* (2004) in context of a trial embankment on soft marine clay in Singapore.

BUOYANCY

Once the settlement of the embankment exceeded the depth to the groundwater table, the portion of the embankment below the water table become buoyant, prompting a correction to the total stresses (see Figure 3, IC1). Submergence of the fill also caused a small reduction in external load during the consolidation process as settlement progresses.

PIEZOMETER SETTLEMENT

Piezometers settle in tandem with the soil in which they are installed and therefore the original datum (near the midpoint of the peat stratum) will change over time. This is particularly pronounced in large strain scenarios such as in embankments constructed on peat.

For example, the instrument at IC1 was initially 0.25 m below mid depth. Assuming (i) that the peat thickness is uniform, (ii) peat properties are consistent with depth (water contents and shear wave velocities indicate that this is the case; see Fattahi Masrour *et al.*, 2024) and (iii) little decay of the embankment total stress with depth within the peat, it is assumed that the piezometric datum reduced by (3 m - 1.75 m)/3 m or 42% of the surface settlement at any time. For IC1, the final excess pore pressure correction applied at the end of stage 8 is ≈6 kPa (i.e. an assumed 0.6 m settlement of the instrument), see Figure 3.

DEGREE OF DISSIPATION

The measurement of pore water pressure at a specific depth within a soil layer undergoing consolidation enables the progress of consolidation (and primary settlement) at that depth to be assessed. It does not reflect the average degree of consolidation in the layer, which is what dictates surface (and therefore embankment) settlement. A double drainage isochrone, based on Terzaghi's theory of consolidation, was used to infer the average degree of consolidation in the peat layer from the single piezometer reading. Double drainage was assumed based on the existence of fractured granite beneath the peat (Russian sampler log), and a thin sand layer 100 mm thick detected by the CPT ball.

Fattahi Masrour *et al.* (2024) concluded that the use of settlement measurements, interpreted in conjunction with the Asaoka (1978) method, is a better means of estimating the degree of dissipation, given the number of assumptions involved in interpreting pore pressure data.

COEFFICIENTS OF CONSOLIDATION

The coefficient of consolidation (c_v) is a parameter which dictates the rate of pore pressure dissipation and corresponding evolution of primary settlement. Values of c_v were computed from the degree of dissipation values in the peat along the mainline and under the control embankment. It was not possible to estimate c_v for most of individual stages along the mainline due to insufficient pore pressure dissipation, but a global estimate was possible, assuming that the maximum load was applied in a single increment at the midpoint of the staged construction process (see Fattahi Masrour *et al.* 2024 for full details). The values of c_v ranged between 0.45-2.1 m^2/year along the mainline (maximum vertical effective stresses in the range 40-97 kPa) and 115 m^2/year for stage 1 of the control embankment (maximum vertical effective stress of 27 kPa), showing the dramatic reduction in c_v with vertical effective stress known to occur in peat (e.g. Carlsten 1988). These values are lower than those derived using the Asaoka (1978) method, which are 2.0-8.6 m^2/year for the mainline and 121 m^2/year for stage 1 of the control embankment. Arulrajah *et al.* (2004) also concluded that the Asaoka (1978) method produced higher values of c_v than those deduced from pore pressures.

PERMEABILITY REDUCTION IN PEAT – A HYPOTHESIS

Corrected excess pore pressures for IC1, IC2, IC3, IC5, IC7 and the control embankment are shown in Figure 4 (no piezometer at IC6). For IC1, IC5, IC7 and the control embankment, the piezometer position correction results in zero excess pore pressures after surcharge removal, as expected. However, elevated excess pore pressures of 5-10 kPa were noted at IC2 and IC3 after surcharge removal. A mechanism is postulated below to explain how this might have occurred (see Figure 5, illustrated for IC1), requiring all of the following:

(i) Significant compression arose underneath the embankment at most of the IC positions. Based on the SSPG measurements at IC1 for example, peat strain was at least 30% within the central 12 m of the embankment width (Fattahi Masrour *et al,* 2024).

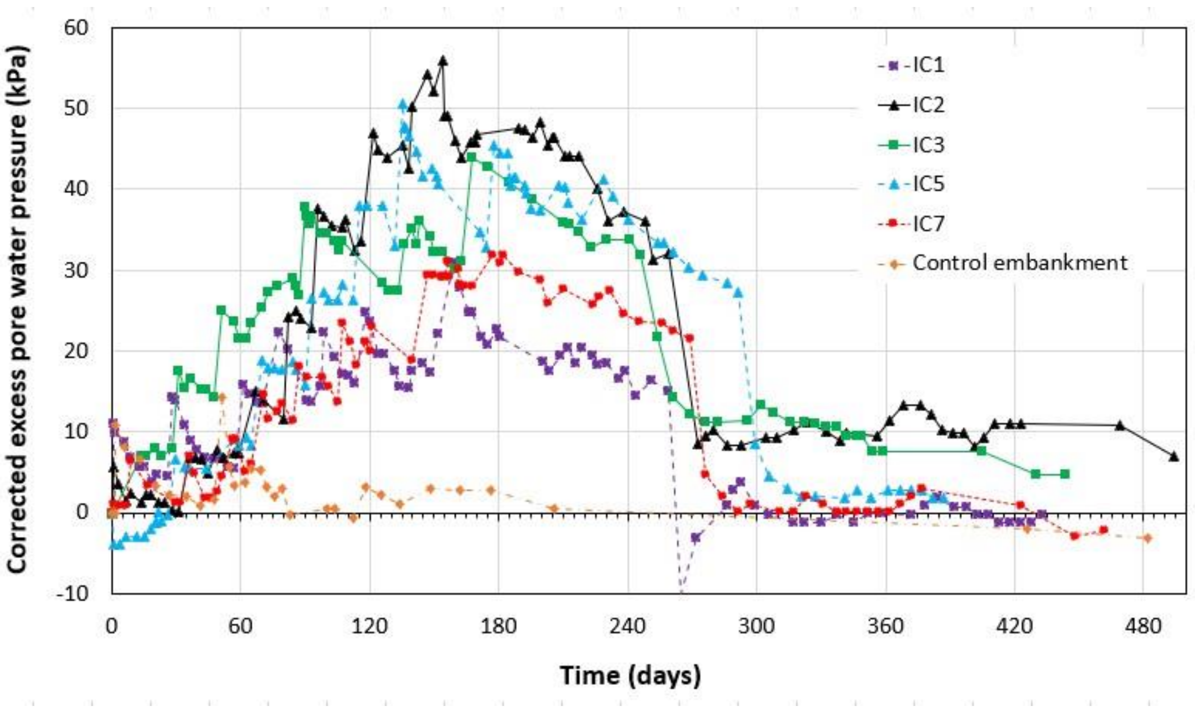

Figure 4: *Excess pore pressures at IC (mainline) and control embankment locations.*

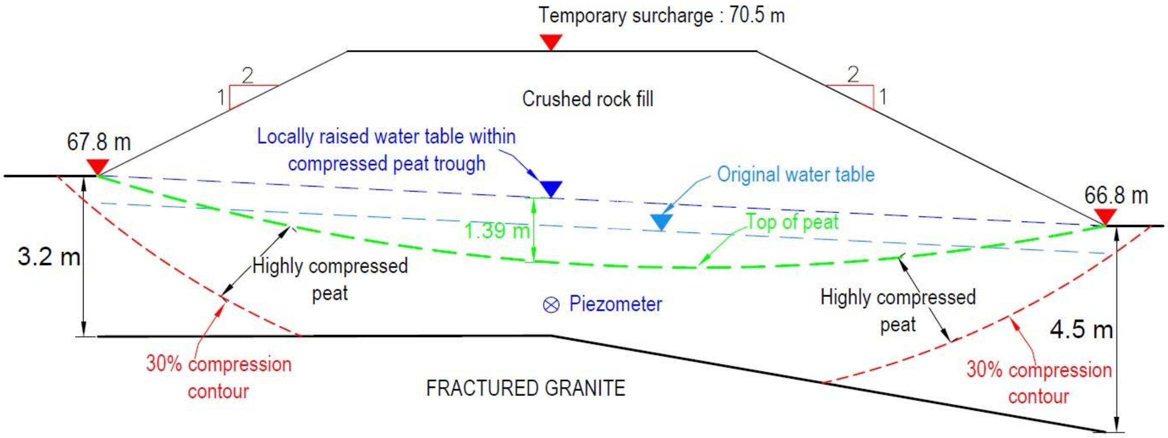

Figure 5: *Conjectured mechanism of locally raised water table within peat (IC1 shown)*

(ii) Hanrahan (1954) reported a reduction in permeability of ≈60 for Irish peat due to a void ratio reduction of 35%. Hobbs (1986), presenting an envelope of data from ≈100 tests from various countries, suggested a reduction in permeability of at least 10 for a void ratio reduction from 15 to 10. The initial void ratio at the N59 site averaged 15 (*in situ* moisture contents averaged ≈1000%) and a similar reduction in void ratio or strain level arose to those quoted above. Using the Asoaka-derived c_v values, the permeability for stage 1 of the control embankment was calculated as 2.3×10^{-7} m/s (27 kPa: low stress), falling within the limits quoted by Mesri and Ajlouni (2007) for a void ratio of 15 at *in situ* stress levels. The permeability range for the mainline was one to two orders of magnitude lower: 2.1×10^{-9}-1.1×10^{-8} m/s (40-97 kPa: higher stress), in keeping with the large reductions described above. These reductions, in addition to the deformed peat-fill interface, will create a shallow ‘trough’ of free-draining fill surrounded by relatively impermeable peat extending to the surface (and possibly above due to heave beyond the embankment toes).

(iii) A combination of rainfall infiltration and gravity groundwater flow can drain into this newly formed trough. Depending on the vertical alignment of the road and the depressed peat surface following surcharge application and removal, water can become trapped in this zone. Local low spots in the base of the fill at IC2 and IC3 (Figure 2) meet the requirements of the hypothesis. Water can outfall from this trough at either the existing ground surface near the embankment toe or at transverse cross ditches constructed at drainage culverts or sections where excavation and replacement was performed.

CONCLUSIONS

The interpretation of the pore pressure regime in a soil layer from a piezometer, and in turn the degree of dissipation and coefficients of consolidation, is complicated in large-strain scenarios, such as the construction of high embankments over peat. Issues identified in this paper include: (i) buoyancy of the portion of fill which has settled beneath the water table, (ii) uncertainty in relation to the piezometer position (and therefore the pore water pressure datum) within the settling mass, (iii) drainage boundary conditions, and (iv) extrapolation of the degree of dissipation at one level within a layer to an average degree of dissipation over an entire layer.

It is postulated that the large strains within the peat may give rise to a significant localised reduction in permeability near the top of the peat. This relatively low permeability settlement trough, filled with highly permeable rock fill, is conjectured to contribute to the elevated excess pore pressures once the surcharge was removed at two of the IC positions.

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