2010-09-02

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Recommended Citation

Osorio, Juan Pablo, Farrell, Eric Raymond, O'Kelly, Brendan Christopher. (2010). Peat improvement under vacuum preloading: a novel approach for bog roads in Ireland. In: *Joint Symposium Proceedings, Bridge & Infrastructure Research Ireland and Concrete Research Ireland.* Eds: Ní Nualláin, Nóra Áine; Walsh, Des; West, Roger; Cannon, Eamonn; Caprani, Colin and McCabe, Bryan. Ireland 2-3 September 2010. Cork: Cork Institute of Technology, 255-262.

Funder: National Roads Authority, Ireland

PEAT IMPROVEMENT UNDER VACUUM PRELOADING: A NOVEL APPROACH FOR BOG ROADS IN IRELAND

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Abstract
This paper presents the preliminary findings of a TCD/NRA vacuum preloading field trial that is part of a research project into the construction options for improving rampart roads. Vacuum preloading is a construction method used to accelerate settlement and the increase shear strength by applying a vacuum pressure to the ground by means of prefabricated vertical drains, an impervious tight sheet and a vacuum pump. Consolidating the ground by applying a vacuum load has several advantages over other techniques, for example; no fill material is required; construction periods are generally shorter; and there is no need for chemical admixtures. This paper presents a review of the literature and describes the setup and initial stage of the TCD/NRA vacuum preloading field trial, that is currently being carried out at Ballydermot bog.

Keywords: Ground improvement, peat, bog rampart roads, vacuum preloading

1. Introduction

In Ireland, there is a need to improve bog roads and rampart roads to meet modern traffic demands and safety requirements and also to reduce maintenance costs. Rampart roads are bog roads in which the peat has been harvested for fuel from one or both sides, leaving the road surface, in some cases, many meters above the surrounding ground surface. Rampart roads often undergo considerable distortion due to the low shear strength and high compressibility of the bog foundation, which may pose a significant safety hazard (Osorio et al., 2008). Cuddy (1988) reported that the cost of maintaining a bog road at a similar performance level to that of a road constructed on a firm ground foundation differed by about a factor of ten. The most commonly used techniques in Ireland to improve bog roads are overlaying the existing pavement with crushed stone, hot-mixed or cold-mixed bituminous materials; reinforcement of pavement with geosynthetics and the use of lightweight or super-lightweight fills (Davitt et al., 2000). Currently, there is no consistent methodology for the design of such road improvements.

Peat ground-improvement techniques such as surcharging and chemical stabilisation have been researched in Ireland. Hanrahan (1954, 1964, 1976) presented research studies in peat pre-consolidation using a gravel embankment as a temporary surcharge and the installation of vertical drains to accelerate the consolidation process and produce a more uniform increase in the shear strength of the peat with depth. Hebib (2001) and Hebib and Farrell (2003) presented a study into methods of stabilising peats by the addition of binders, although this approach has not proven to be cost effective in practice. This paper presents vacuum preloading as a novel and viable technique for improving bog roads and describes the setup and initial stage of the TCD/NRA vacuum preloading field trial.

2. Background on vacuum preloading

Vacuum preloading is a construction method used to accelerate ground settlement by reducing the air pressure at the ground surface, thereby accelerating the consolidation process. In vacuum preloading applications, the ground surface is sealed with an impervious membrane and through a vacuum pump a negative pressure (with respect to atmospheric pressure) is created in a sand cushion beneath the sealing membrane and in prefabricated vertical drains installed in the ground (Mohamedelhassan and Shang, 2002). The vacuum preloading technique was initially proposed by Kjellman (1952) as a mean of improving clayey soils. Vacuum preloading has several advantages over embankment loading, for example; no fill material is required; construction periods are usually shorter; and there is no need for heavy machinery. In addition, the vacuum pressure method is an environmentally friendly methodology since it does not put any chemical admixtures into the ground (Chai et al., 2005).

The vacuum preloading technique has been used extensively in several countries in Europe, Asia and North America since the 1980s (Dam et al., 2006) to improve the ground for the construction of ports, airport runways, roads and an oil storage station (Chu et al., 2000, Tang and Shang, 2000, Masse et al., 2001, Hayashi et al., 2002, Gao, 2004, Qiu et al., 2007, Chai et al., 2008). The ground conditions are usually highly compressible clayey soils and hydraulic fills used for land reclamation projects.

3. TCD/NRA vacuum preloading field trial

The TCD/NRA vacuum preloading field trial is currently being undertaken at Ballydermot bog. The main objective is to evaluate vacuum preloading as a technique for improving peat ground and its feasibility for improving the conditions and reducing the maintenance costs for bog roads and rampart roads.

3.1 Ground conditions

Ballydermot bog is a raised bog located to the north of Rathangan, Co. Offaly. Milled peat production commenced at Ballydermot bog in the mid-1940s and is currently being exploited by Bord na Móna (Hebib, 2001). A typical soil profile at the test area is presented in Table 1. In March 2009, 24 stand pipes were installed at the test area to monitor the ground water table depth. During the initial recording period, summer and autumn 2009, the water table was generally at a depth of between 0.25m and 0.90m, with extreme values as deep as 1.05m and as high as 0.02m above the ground surface.

Table 1 - Simplified soil profile

Layer	Depth (m)	Description	Observations and properties
1	0 – 0.7	Man-made fill	Black peat; occasional plastic bags, gravel, pieces of geotextile, machine parts.
2	0.7 – 4.0	Pseudo-fibrous peat	w = 660 – 1085% G_S = 1.39 – 1.54 LOI = 96 – 99% pH = 4.5 – 6.2 Von Post = H_4 – H_7
3	4.0 – 7.0	Boulder clay	The clay fraction reduces with depth until only boulders are found.

3.2 Summary of TCD/NRA field trial construction

The vacuum preloading field trial test covers a 10x10m surface area. Initially, 0.4m depth of the fill layer was excavated over a 12x12m area and levelled. It is important to note that for this paper, all depths are taken from the original ground level. Ninety-eight prefabricated vertical drains (PVD) were pushed vertically into the peat to a depth of 2.65m using the bucket of a bog digger and an aluminium box section as the lance. This left approximately 1.35m depth of peat between the base of the PVDs and the peat-clay interface to prevent the escape of the vacuum (Figure 1). According to Hayashi et al. (2002), when using PVDs, no improvement effect is achieved unless the drain spacing is 0.90m or shorter. In order to evaluate how the difference in the spacing of the PVDs affects the improvement method, the test area is subdivided in two, one in which the drain spacing is 0.85m and a second one with a spacing of 1.20m (Figure 2). The instrumentation system, which was pushed into the ground after the installation of the PVDs, will be discussed later.

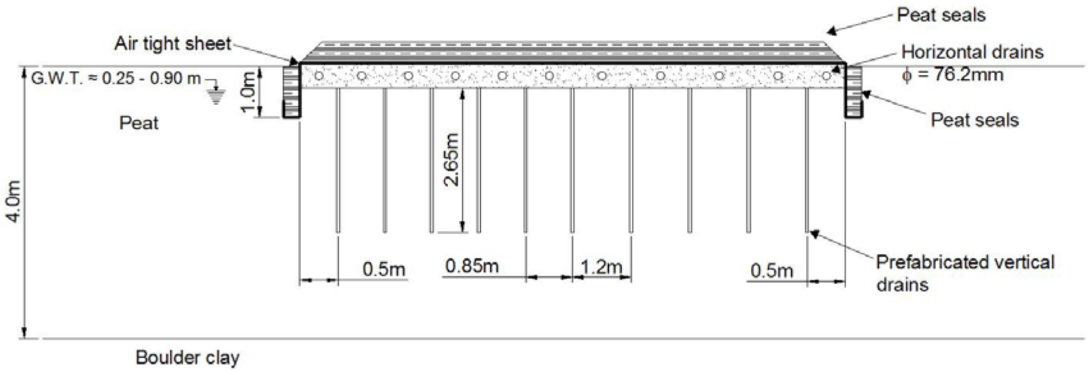

Figure 1 - Cross section of TCD/NRA vacuum preloading field trial

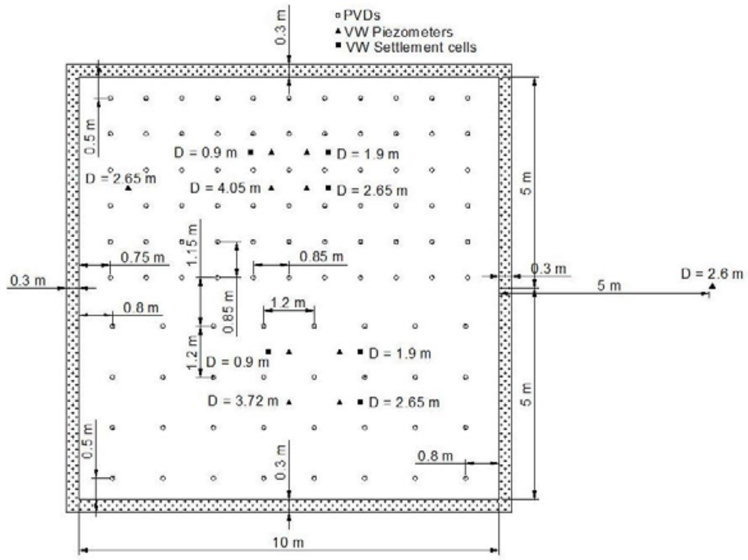

Figure 2 - PVD and subsurface instrumentation arrangement

A 0.15m deep sand bed was placed on the ground surface and a 0.30m deep gravel bed was placed above the sand bed. Corrugated and perforated flexible pipes, 76.2mm in diameter, were embedded horizontally within the gravel bed. The granular surface bed and the horizontal drains act as a drainage layer, transmitting the vacuum to the underlying peat as well as discharging pore water and air out of the treated soil mass (Figure 3). A 0.3m wide and 1.0m deep trench was then dug around the 10x10m test area and an airtight polythene membrane was laid over the test area. The membrane was keyed at the bottom of the trench by backfilling the trench and covering the top with peat in order to help maintain the seal and protect the membrane (Figure 1). Afterwards, the surface instrumentation was installed and the pumping system was connected. The vacuum is applied using a 38mm diameter jetpump connected to a 1.5kW centrifugal pump that can generate an 80kPa design preload vacuum pressure.

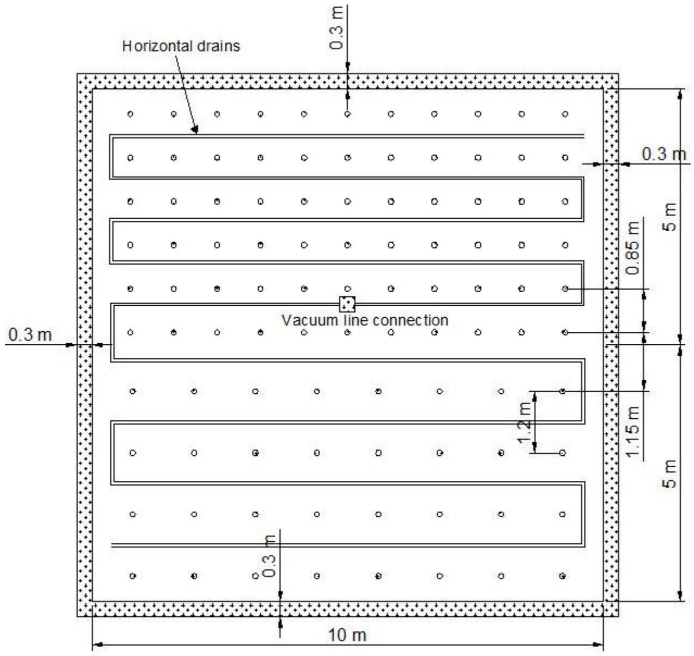

Figure 3 - Horizontal drains arragement

3.3 Instrumentation

The instrumentation system is designed to measure the settlement at different depths; positive and negative pore-water pressures at different depths; barometric pressure; surface and ground temperatures; water flow; ground water table and rainfall. The instrumentation system includes six push-in vibrating wire settlement cells; ten push-in vibrating wire piezometers (calibrated for both positive and negative pressures); a surface barometer/thermometer; 26 surface settlement plates; 17 stand pipes to monitor the ground water table level; a water meter and a rain gauge (Figures 2 and 4).

Due to the difference in PVD spacings, the two subareas required independent monitoring of settlement and pore pressures. Hence, three settlement cells and four piezometers were pushed in at the centre of each subarea at different depths (Figure 2). One of the remaining piezometers was located at the inner edge of the test area to study boundary effects, while the other was placed outside to observe if the vacuum pressure has any significant effect beyond the studied area. The surface barometer/thermometer and one of the settlement cells are connected to dataloggers allowing hourly monitoring of the test.

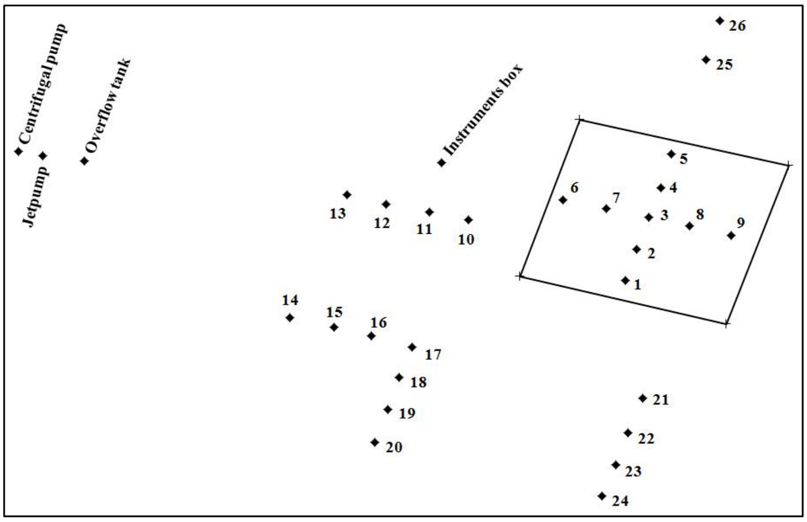

Figure 4 – Surface settlement plates and stand pipes distribution

Figure 4 shows that nine settlement plates are located inside the test area, with another 17 settlement plates located around it. A stand pipe was also pushed in next to each plate outside the test area allowing the ground water table depth measurement. These stand pipes replaced the ones installed before the test area was constructed, since most were lost during the construction.

A water meter was placed at the end of the water discharge pipe to measure the amount of ground water expelled from the soil mass which could be correlated with the settlement measures. The rain gauge was placed to record precipitation and to correlate it with the variations on the ground water table.

3.4 Test start and initial results

The TCD/NRA vacuum preloading field trial commenced on the 30th November 2009. The results from the first month are presented in this paper during which an average vacuum of 50kPa was achieved in the gravel layer. Figure 5 presents the settlements at different depths for both subareas. Figures 6 and 7 show the pore-water pressures recorded at different depths in both subareas.

Figure 5 shows that a surface settlement of 0.85m was recorded in the subarea of 0.85m spacing, and a surface settlement of 0.65m was recorded for the 1.20m spacing within a month.

Figure 6 shows that for the 0.85m spacing subarea there is a similar reduction in piezometric pressure at all depths within the peat layer of between 27.2kPa and 31.9kPa. However, the full 50kPa reduction in piezometric pressure was not transmitted to the monitor points in the peat layer. The piezometer located at 4.05m depth in the peat-clay interface presented a reduction of only 10.4kPa. It is important to remember that the PVDs were only installed to a depth of 2.65m. The piezometer located 5.0m outside the treated area did not show any reduction in the pore-water pressure, indicating that the vacuum does not affect the pressures outside the test area.

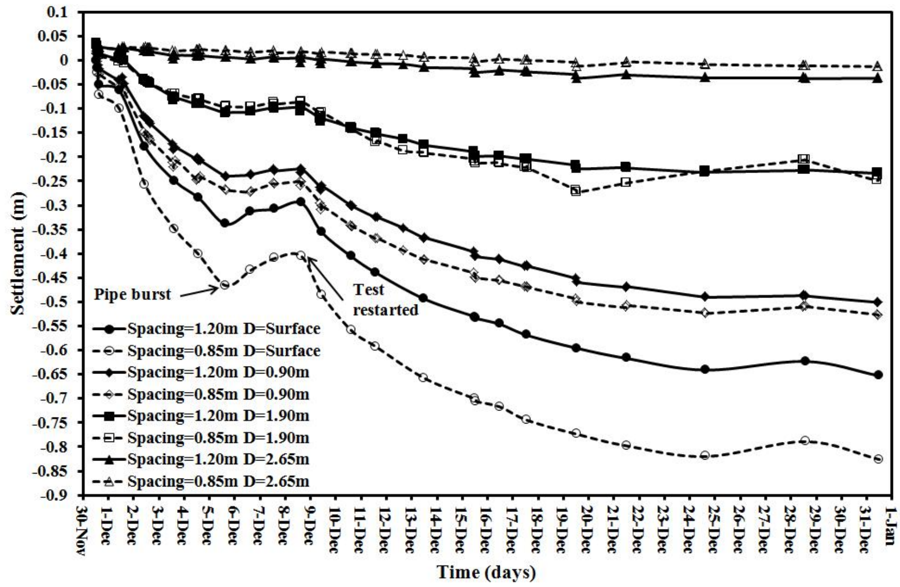

Figure 5 – Ground settlement at different depths for both spacing subareas

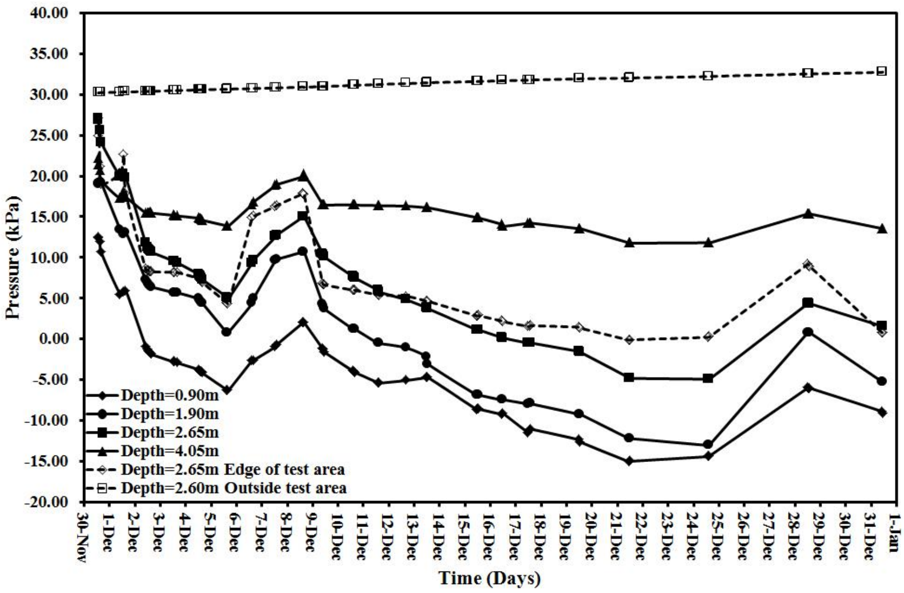

Figure 6 – Pore-water pressure variation for 0.85m PVD spacing subarea

Figure 7, obtained for the 1.20m spacing subarea, shows a similar trend with a piezometric drop of between 18.7kPa and 23.0kPa recorded at all depths, although lower in value, which can be explained due to the greater spacing between the PVDs. Note that at this subarea, the piezometric reduction with depth recorded by the instruments was similar, including the deepest piezometer which is located at a depth of 3.72m, i.e. 1.0m under the bottom of the PVDs and 0.30m above the peat-clay interface.

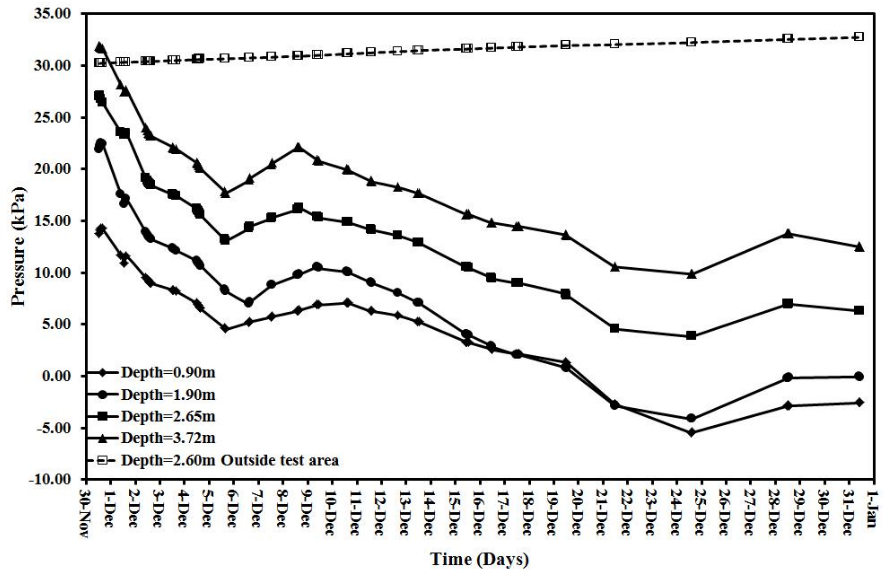

Figure 7 – Pore-water pressure variation for 1.20m PVD spacing subarea

4. Conclusions

The TCD/NRA vacuum preloading field trial was implemented and showed that this technique can be successfully used in peat soils. The average 50kPa vacuum level recorded at the ground surface in this trial is less than the maximum vacuum pressure achievable, which according to literature is generally considered to be about 80kPa, and additional measures are to be taken onsite to improve this. The vacuum distribution and drainage system comprising PVDs, horizontal drains and a granular bed, was effective in distributing the applied vacuum pressure and collecting the drained water. A surface settlement of about 0.85m was achieved under the average vacuum pressure of 50kPa within the first month where the PVD spacing was 0.85m. There was a noticeable difference in the time settlement plots, the pore pressure reduction, and the magnitude of settlement between the areas of different drain spacing. A uniform reduction in piezometric pressure with depth was observed, even 1.0m under the bottom of the PVDs. The findings indicate that a drain spacing of 1.2m can be effectively used to achieve significant ground improvement, albeit less than that achieved for a closer spacing. The main differences recorded were in the surface settlement readings and the reasons for this require further investigation. Further analysis will be carried out after the trial is over with the full set of data collected.

5. Acknowledgements

The research project ‘Design Approach for Improving Rampart Roads’ is funded by a Research Programme Fellowship (2007) from the National Roads Authority (Ireland). The authors would like to thank Bord na Móna for the use of the facilities at Ballydermot bog. The first author would like to kindly acknowledge Universidad de Antioquia for the leave of absence granted to work on this project and research awards in the form of an Ussher Award from Trinity College Dublin and the Geotechnical Trust Fund award from Institution of Engineers of Ireland.

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