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Rampart roads in the peat lands of Ireland: Genesis, development and current performance

Juan Pablo Osorio
Technological University Dublin, juan.osorio@tudublin.ie

Eric R. Farrell
Trinity College Dublin, Ireland

Brendan C. O'Kelly
Trinity College Dublin, Ireland

See next page for additional authors

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Authors
Juan Pablo Osorio, Eric R. Farrell, Brendan C. O'Kelly, and Tom Casey

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Rampart roads in the peat lands of Ireland: genesis, development and current performance

J.P. Osorio, E.R. Farrell & B.C. O'Kelly
Trinity College Dublin, Ireland

T. Casey
National Roads Authority, Dublin, Ireland

ABSTRACT: The construction and improvement of roads on peat lands has always been a challenging task in geotechnical engineering. Rampart roads, which are a particular feature of the bog roads in Ireland, are caused by the excavation of peat from the roadsides over many years for use as a domestic fuel. The historical development of rampart roads and current performance under the added traffic loading is discussed. Various road improvement methods have been applied to improve the road ability to carry traffic and the technical aspects and performance of the methods are discussed. In particular, the performance of the improvement methods is related to the geotechnical properties of the underlying bog foundation.

1 INTRODUCTION

According to Hobbs (1986), about 17.2% of the overall land surface of Ireland is covered with peat (Figure 1) although for some counties the peat coverage is significantly greater, for example, 36.1% in County Leitrim (Hammond, 1981). Hence, a significant part of the countries road network has been constructed across peat lands. In addition, peat harvesting for fuel in the vicinity of the bog roads has historically been common practice and has led to the creation of elevated roads, referred to as rampart roads.

This paper presents an historical overview of the genesis and development of rampart roads in Ireland. The geotechnical properties of the bog foundation are discussed along with the different improvement methods that have been used, albeit with different levels of success, over the years.

2 RAMPART ROADS: HISTORICAL BACKGROUND

2.1 *Ancient bog roads*

Bog reclamation and peat harvesting in Ireland can be closely related to the development of the first bog roads. References in the Old Irish law texts (Feehan & O'Donovan, 1996) trace peat harvesting for use instead of wood as a fuel back to the seventh and eighth centuries although peat harvesting is know to have been common practice during the late Bronze Age (centuries leading up to 1000 BC).

The first roads constructed across the bogs in Ireland are called toghers and comprised oak planks that had been laid on sleepers and pegged into the bog foundation using vertical stakes (O'Keeffe, 1973). Some toghers incorporated a stone or gravel layer above a brushwood base. The toghers were mainly used as foot roads, and where wide enough, were sometimes used for wheeled vehicles and animal traffic.

During the seventeenth century, the role of the toghers was replaced with the construction of new permanent roads after ten Acts for the improvement of the road network were passed by the Parliament of James I. Of these, the Highway Act for the Amendment of Bridges and Toghers had the biggest impact (O'Keeffe, 1973).

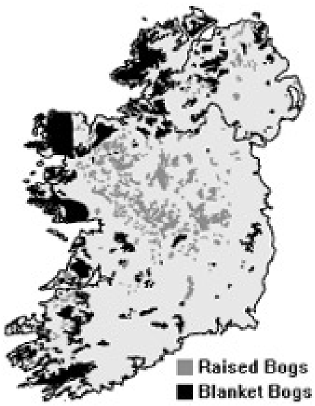

Figure 1. Peat land distribution in Ireland (Bord na Móna, 2001).

2.2 *Bog roads network beginnings*

However, it was in the eighteenth century that the network of bog roads in Ireland began to be properly developed by landowners and the Grand Jurys in order to gain commercial and military access to the remote rural areas. The advances and developments in bog road construction by the middle of the nineteenth century have been reported by Parnell (1833) and Mullins & Mullins (1846). The usual construction procedure was as follows:

- Mark the centreline of the road and form the base on which the road materials are to be placed. After the centreline had been traced, a system of parallel and transversal open drains was excavated allowing sufficient drainage to achieve adequate bearing capacity and stability of the bog foundation.
- Peat material that had been excavated in forming the drains was placed in the form of a ridge above the road surface and allowed to naturally air dry. The drying period, which varied between two summer months and two years, depended on the water content of the *insitu* peat material.
- A sub-grade layer of stiff clay was placed and compacted above the dried peat material followed by a cover of stone/gravel as the road surface.

The procedure described differed slightly from one place to another depending on the site conditions and the construction requirements.

2.3 *Genesis of the rampart roads*

The improved roads across the peat lands provided better access and made peat harvesting easier. Peat was the main domestic fuel in Ireland during the eighteenth and nineteenth centuries with up to five million tonnes being harvested annually (Feehan & O'Donovan, 1996). The rapid cut away of the peat material in the vicinity of the roadsides resulted in an elevated road surface that in some cases was many meters above the surrounding ground (Figure 2). These elevated bog roads are referred to as rampart roads.

Rampart roads often undergo considerable distortion (Figure 3) due to the low shear strength and high compressibility of the bog foundation, which may pose a significant safety hazard. High maintenance budgets are necessary to keep bog roads in service. For example, 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 was about ten times higher. According to Leebody (1911), the authorities started to address the rampart road problem by the middle of the nineteenth century. In 1851, it was prohibited to sink any pit or hole within 9.0 m of the centreline of carriageways and public roads.

2.4 *Previous works on rampart roads*

2.4.1 *Leebody (1911)*

Leebody (1911) reported rampart road of between 1.5 and 9.0 m in height and proposed different ways of tackling the problem during the Second Irish Roads Congress.

In general, the rampart roads only become dangerously out of shape after a period of time has elapsed following peat harvesting (Leebody, 1911) since some time must elapse before aerobic decay of the remaining peat material can restart. Aerobic decay leads to deformations due to volumetric shrinkage and disintegration of the organic material (Hobbs, 1986). Moreover, peat harvesting operations required that the land area adjoining the rampart roads had been drained thereby allowing deeper harvesting. In many cases, the open drains along the roadsides were excavated deeper on one side causing the rampart to tilt towards the deeper drain. Additionally, rabbits were able to dig burrows close to the road surface as the peat decayed.

Leebody (1911) proposed three different approaches to deal with the rampart road problem. Planting a light fence with young trees was recommended where the rampart had not yet undergone large deformations. The tree root growth was expected to prevent the weakening of the rampart sides. Cutting a few meters from the top of the rampart and using the excavated material to reinforce the rampart sides was recommended in situations where the rampart had already experienced large deformations but rabbits had not started digging burrows. Planting a light fence with young trees was also recommended. The road surface was then rebuilt following the procedure described earlier in section 2.2.

Three different solutions were proposed in situations where rabbits had already started digging burrows. Firstly, exterminate the rabbits and reinforce the roadsides with a clay berm. Next, break and fill the burrows with a mixture of brushwood and clay. Restore the road surface only where needed, which allowed the road to remain open during the repair works. Secondly, and the most commonly applied solution, was to excavate the entire rampart such that

Figure 2. Rampart road on the N62 national secondary road, County Offaly, Ireland.

Figure 3. Extreme undulations on N62 rampart road, County Offaly, Ireland.

the road surface was level with the surrounding ground, where possible. Otherwise, abandonment of the site and the construction of a new road on firm inorganic ground were recommended if the side slopes were too steep and heavy traffic was expected.

2.4.2 *Hanrahan (1953 & 1954)*

Hanrahan (1953 & 1954) presented research studies on bog roads, most of which were rampart roads of flexible construction (material ranging from clay to hand-placed pavement and with a varying layer thickness even within one cross-section). Nearly all of the sites had experienced some distortion, including: transverse or diagonal surface undulations; cracking or depressions due to poor drainage; lack of maintenance; thin road structure; large vegetation which increased the loads and rate of consolidation near the roadsides; humps and depressions at side road junctions and, in some cases, failure due to the low quality of the construction materials. An impervious road surface was cited as most importance since rapid degeneration appeared to occur following puncturing of the impermeable surface seal.

Hanrahan (1953) presented the following recommendations to improve the quality and safety of new and existing roads. Drainage should precede construction to increase the shear strength of the bog foundation (drainage after construction induces large consolidation settlements). Where possible, the construction or improvement of the bog roads should be carried out on pre-consolidated ground such as that produced on lowering the rampart road level. Trees and shrubs in the vicinity should be removed and replanted a safe distance away from the road. The road surface must be constructed using an impermeable material and should be regularly maintained in good condition. Uniform cross-sections along the length of the road are desirable and rapid changes in dimensions should be avoided. Cracks and depressions in the road surface may extend to such a depth that cavities may be found in the bog foundation. The cavities should be filled with an impermeable flexible material. Side drains should be piped, covered and located a safe distance from the roadside. Very steep vertical curves are undesirable due to the increase in applied loading caused by centrifugal force effects. The road material in contact with the bog foundation should be of uniform quality and impermeable, for example, a clay-sand mixture. Heavy static loads should be restricted on the road or verges.

2.4.3 *Hanrahan (1964, 1967 & 1976)*

The main road linking Edenderry and Rathangan, County Offaly, Ireland, was reconstructed between August 1953 and March 1954 following bearing and serviceability failures (road located on a bog foundation, 7.6 m in mean depth). Hanrahan (1964) reported that the failure occurred due to poor thickness control during the placement of the gravel base with excessive quantities placed at certain locations (anywhere between 0.30 and 0.76 m in thickness). Excessive loading caused overstressing of the bog foundation, slips, upheaval and lateral creep distortions along the road. The solution recommended was to replace part of the gravel layer with lightweight bales of compressed air-dried peat and thereby take advantage of the pre-consolidated bog foundation. Furthermore, Hanrahan (1967 & 1976) proposed a design method for road construction on bog foundations, considering three main requirements:

- The pavement must be adequately thick in order to reduce the stresses induced by traffic to a value that does not exceed the design shear strength of the underlying bog foundation.
- The bearing capacity of the bog foundation must not be exceeded by the combined weight of the pavement and traffic.
- Settlement or distortion of the road surface must not exceed values specified by local authorities.

The requirements listed above are very difficult to achieve on bog land due to its low shear strength and high compressibility. A gravel embankment that acts as a temporary surcharge was proposed to induce pre-consolidation in the bog foundation thereby increasing its shear strength and reducing its compressibility (Hanrahan 1967 & 1976). Sometimes the pre-consolidation period can be excessive and the permeability anisotropy may restrict the surcharge effect to a shallow depth. Hanrahan (1967 & 1976) suggested that the installation of vertical drains would accelerate the pre-consolidation process and produce a more uniform increase in the shear strength of the peat with depth. Part of the surcharge was removed to stop the pre-consolidation process when the required increase in shear strength had been achieved. A potential flooding problem may occur since the pre-consolidated area will most likely be depressed on removing the gravel surcharge. Hanrahan (1976) recommended placing the gravel layer over a lightweight fill to keep the road surface higher than the surrounding ground.

2.4.4 *Nerney (1985)*

A 2.0 km section of the R403 regional road (County Kildare, Ireland), which runs along a bog, had presented problems for decades requiring frequent and expensive repairs. Nerney (1985) conducted a study of the pavement layer and bog foundation. The work focused on three sections along the road that were representative of rampart, semi-rampart and level-profile cross-sections. A Dynaflect deflection survey using yielded Dynaflect maximum deflection (DMD) data – a measure of the overall strength of the road; surface curvature index (SCI) data – a measure of the strength of the upper road layers and Geophone 5 (G5) data – a measure of the strength of the sub-grade below a depth of about 1.0 m.

The high DMD values indicated a weak road structure overall. The SCI values indicated very strong and thick pavement structures, sometimes comparable with that of concrete slab values. However, the G5 values identified the bog foundation as the source of the structural weakness.

3 GEOTECHNICAL PROPERTIES

3.1 *Peat formation and drainage effect*

Peat deposits comprise partially decayed and fragmented plant remains that have accumulated under water (Mesri & Ajlouni, 2007). Two distinctive peat layers can be identified: (i) the uppermost layer known as the acrotelm which varies between 10 and 60 cm in thickness; (ii) the underlying catotelm layer permanently located below the groundwater table. In the acrotelm, the water contains sufficient oxygen from precipitation, flow and the atmosphere to support aerobic micro-flora, which maintains the aerobic decay process. As the oxygen concentration reduces with depth in the catotelm, the aerobic micro-flora population decreases and, conversely, the anaerobic micro-flora population increases. The anaerobic micro-flora have a slower metabolic activity, hence the decay process slows leading to the gradual accumulation of partially decayed plant material as peat (Hobbs, 1986).

Peat is a highly heterogeneous and anisotropic material and its geotechnical properties are generally extremely variable over small distances since peat is formed from different plant species and the decay process is not uniform throughout the bog mass. However, the geotechnical properties of peat (water content, unit weight, ignition loss, permeability, compressibility and shear strength, amongst others) are generally closely interrelated.

Land drainage for peat harvesting significantly alters the geotechnical properties inducing distortion and may potentially leading to instability in rampart roads. Further loading of the bog foundation by the road structure and traffic causes significant consolidation and may lead to shear failure of the ramparts. Drainage causes a lowering of the groundwater table increasing the thickness of the acrotelm layer (reduction in thickness of catotelm). Hence, zones that had been submerged (anaerobic state) regain oxygen and become repopulated with aerobic micro-flora, which significantly speeds up the decay process. Drainage has a significant impact on the geotechnical properties of both the acrotelm and catotelm layers. Several changes occur within the acrotelm, including: (i) the level of humification increases as the decay rate increases; (ii) volumetric shrinkage occurs due to air drying of the peat; (iii) the void ratio, water content and permeability values decrease while the unit weight, effective stress and shear strength values increase.

Meanwhile, the remaining peat in the catotelm layer is subjected to an increased state of effective stress that results in subsidence and may potentially lead to shear failure. Subsidence leads to the peat in the acrotelm re-submerging below the groundwater table and hence the loading situation changes on an ongoing basis (Cuddy, 1988). The dried out peat material undergoes a permanent material change due to oxidation and is unable to recover lost moisture on re-submergence (Hobbs, 1986).

3.2 *Water content*

Undrained peat from the Irish Midlands generally has water content values in the range of 650 to 1500% although values as low as 570% and as high as 4900% have been reported (Cuddy, 1988). The value of the water content can be reduced to about 1000% by shallow drainage or to about 700% by deep drainage (Hanrahan, 1954).

Clara bog in County Offaly, Ireland, is a raised bog and nature reserve that has no significant peat harvesting history. O'Loughlin (2001) reported water content values in the range of 1300 to 1500% with a mean water content value of 1400%. Hebib and Farrell (2003) studied the peat properties from Raheenmore and Ballydermot raised bogs in Ireland.

The Raheenmore bog also had no significant peat harvesting history and had a mean water content value of 1200%. The Ballydermot bog had over 50 years of peat harvesting history and had a mean water content value of 850%.

3.3 *Compressibility*

The exceptionally high water content values and porous nature make peat extremely compressible. However, pore water pressure dissipation occurs simultaneously with secondary compression, the latter involving structural rearrangement, viscous processes and micro-pore water expulsion (Hobbs, 1986).

A temporary surcharge is applied to pre-consolidate the bog foundation and the surcharge is later removed to reduce the post-construction settlements to acceptable values. Surcharging produces a pre-consolidation pressure that is greater than the final vertical effective stress (Mesri & Ajlouni, 2007). According to Hanrahan (1976), pre-consolidation of the bog foundation has been used in Ireland as early as 1951 in the improvement of rampart roads.

O'Loughlin (2001) reported a mean pre-consolidation stress of 3 kPa and an initial void ratio in the range of 16 to 32 for the Clara bog peat. The mean pre-consolidation stress was 17 kPa and the void ratio was in the range of 10 to 16 for the Ballydermot bog peat. Hebib & Farrell (2003) also reported pre-consolidation stress and initial void ratio values of 15 kPa and 12, respectively, for the Ballydermot bog peat. The pre-consolidation stress and initial void ratio values were 5 kPa and 18, respectively, for the Raheenmore bog peat.

3.4 *Shear strength*

The shear strength of the bog foundation is increased by drainage (Hanrahan, 1954). Nerney (1985) reported that *insitu* vane measurements indicated higher shear strength values in the consolidated peat material beneath the road centreline and in the drier peat located above the groundwater table. Peat is a frictional material with high friction angle values. Mesri & Ajlouni (2007) reported effective friction angle values for peat in the range of 40° to 60°. Farrell & Hebib (1998) reported an effective friction angle of 55° for the Raheenmore bog peat.

3.5 *Permeability*

Permeability is an important engineering property that controls the consolidation rate. The coefficient of permeability (k) of peat for flow in the horizontal direction is generally greater than for the vertical direction. Hobbs (1986) reported horizontal-to-vertical coefficient of permeability ratios in the range of 1.7 to 7.5. However, after vertical loading, the horizontal permeability can be up to 300 times greater than the vertical permeability due to the general horizontal alignment of the constituent fibres (Cuddy, 1988).

Table 1: Preferred maintenance techniques for bog roads used by County Councils in Ireland.

Maintenance technique	National roads	Regional roads	Local roads
Overlay existing pavement with hot-mix bituminous material or crushed stone.	First option	First option	First option
Reinforce the pavement incorporating geosynthetic with bituminous overlay.	Second option	Second option	Not used
Replace peat using granular fill.	Third Option	Not used	Not used

The rapid decrease in the k value under loading is another important feature. Hanrahan (1954) reported initial k values of 4 x 10^{-6} m/s for a peat material. However, under an applied stress of 55 kPa, the k value had reduced to 2 x 10^{-8} m/s after a period of two days, and to 8 x 10^{-11} m/s after seven months.

4 CURRENT PERFORMANCE AND IMPROVEMENT METHODS

4.1 *Maintenance techniques in Ireland*

Over the last 30 years, the construction and improvement of bog roads and rampart roads has radically changed with the introduction of new materials such as geosynthetics, super-lightweight fills and very flexible mixed-bituminous materials.

Davitt et al. (2000) carried out a survey on the current performance and maintenance techniques used on the bog roads in Ireland. The survey was carried out on national, regional and local roads and, in total, responses were received from 12 local authorities. A summary of the preferred maintenance techniques used to improve and widen bog roads is presented in Table 1.

4.2 *Crushed stone and bituminous overlay*

Overlaying the existing pavement with crushed stone, hot-mixed or cold-mixed bituminous materials are the most popular maintenance techniques. The main disadvantage of overlaying the existing pavement is the increase in weight applied to the compressible bog foundation so that the technique really only provides a temporary improvement. Most counties where hot-mixed bituminous materials are used reported higher unit costs and longer life spans than for crushed stone overlays. Cold-mixed bituminous materials were reported by four counties with the advantage of easier installation and similar unit costs than for hot-mixed bituminous materials. However, cold-mixed bituminous materials were relatively new to Ireland in 2000 (when survey was carried out) and hence no life span comparison was available.

Bituminous materials are stronger and structurally more efficient than crushed stone overlays and can be applied at about half the depth to achieve a similar structural contribution. Hence, the bituminous layer applies less weight to the bog foundation and most likely cause less settlement (Davitt et al., 2000).

4.3 *Geosynthetic combined with unbound or bituminous overlay materials*

In Ireland, geosynthetic reinforcement of the pavement over the last 15 years has proven to be successful and cost efficient giving longer life spans compared to crushed stone and bituminous overlays. All of the survey counties that had used geosynthetics reinforcement reported an increase in the pavement strength without adding any appreciable weight. The technique has succeeded in maintaining lightly trafficked roads over bog land for more than 10 years whereas crushed stone or bituminous overlays have had to be reapplied at intervals of between three and four years (Davitt et al., 2000).

4.4 *Lightweight and super-lightweight materials*

Lightweight materials (e.g. pulverized fuel ash, PFA) have been used to reduce the weight when improving bog roads that have become excessively deformed or critically unstable due to successive overlays of gravel/stone. The unit weight of PFA is about 16 kN/m^3 compared to that of crushed stone of about 22 kN/m^3 (Davitt & Killen, 1996). Nevertheless, research for new materials has increased due to the relatively high unit costs of PFA.

Super-lightweight materials including expanded polystyrene (EPS) have also been used due to its lower unit weight compared to traditional materials or lightweight fills. The unit weight of EPS is between 0.2 and 0.3 kN/m^3. Each EPS block (typically 3x1.2x0.6 m) can be handled by a single person making the installation process much faster and easier. However, EPS is the most costly of the super-lightweight fills although it gives the maximum advantage in load reduction. A granular fill is usually placed on top to prevent floatation of the EPS blocks (Davitt & Killen, 1996).

5 SUMMARY AND CONCLUSIONS

Rampart roads, a particular feature of bog roads in Ireland, pose a significant safety hazard to road users. Drainage and peat harvesting have lead to changes in the geotechnical properties of the bog foundation inducing distortion and instability of the rampart roads. The authorities started to first address the problem in the mid 1800's. The existing rampart road network has to be improved and widened in accordance with the present traffic demand and economical growth.

An extensive research program on the current performance and geotechnical properties of rampart roads must be conducted since no large scale research on the subject has been undertaken since Hanrahan (1953 & 1954). In particular, the effectiveness of the maintenance, improvement and construction methods used for bog and rampart roads have to be assessed.

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