MacKays to Peka Peka Expressway: Road Embankment Construction on Peat Deposits

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ABSTRACT

The MacKays to Peka Peka Expressway Project comprises a 16km of new four lane expressway, to be constructed across sand dunes and peat swamps on the Kāpiti Coast, located 50km north of Wellington, New Zealand. Road embankments up to 7m high are to be constructed over peat deposits, ranging from heavily fibrous woody material through to amorphous silty peat, that are typically 0.5 to 4m deep. The NZ Transport Agency (NZTA) has selected an alliance to deliver the planned expressway from MacKays Crossing to Peka Peka, which is currently in the planning and consenting phase. A key aspect of the construction cost and long-term performance is the magnitude and duration of both construction and post construction peat settlements. This paper presents the findings of a trial embankment undertaken as part of this project, and compares the results of this trial with an historical trial embankment and construction records. The paper presents the peat compression parameters derived from this data for the preliminary design of the Expressway.

Keywords: peat, settlement, compression, permeability

1 INTRODUCTION

1.1 Project

The MacKays to Peka Peka Expressway Project is a proposed expressway on the Kāpiti Coast, 50km north of Wellington New Zealand. This project is part of The NZ Transport Agency's (NZTA) National Land Transport Programme and will form part of the Wellington Northern Corridor, one of the Roads of National Significance (RoNS).

A multi-disciplinary alliance, comprising of Beca Infrastructure, Fletcher Construction, Higgins, Kāpiti Coast District Council (KCDC) and the NZTA is delivering the Expressway. The Alliance is tasked with delivering the current consenting stage of the Project and will continue through the design and construction stages. The design is at a level of detail where a scheme cost estimate can be prepared and technical specialists can carry out their assessment of effects for resource consent.

The Expressway is approximately 16km in length and runs from south of Poplar Avenue to north of Peka Peka Road. It will provide for two lanes of traffic in each direction, with four grade separated interchanges. There are 18 bridges along the length of the expressway, to maintain local connectivity and provide crossings of rivers and streams. The Expressway is predominately on embankments, rising up to 7m at crossing points. The Expressway corridor traverses the dune sands and swamp deposits of the Kāpiti coastal lowlands, and is located in an area of relatively high seismicity.

1.2 Geological setting

The Expressway route traverses the Kāpiti coastal lowlands along their inland (eastern) margin. The sand dunes form areas of higher relief (up to around 20 m elevation) between low-lying interdunal areas. These are located within a relatively flat coastal plain, a few metres above sea level, and generally contain peat. Low alluvial terraces are associated with Waikanae River and streams. The geology along the route is reflected in the landforms and topography observed.

The Expressway route is bounded by the Tararua Ranges in the east; these are steep greywacke hills which have formed by the uplifting and tilting of basement rock along NE-SW oriented faults. The

Expressway crosses the coastal plain west of the Ranges, an area which has been shaped by repeated cycles of glaciation that have occurred in the past 2 million years.

During the Holocene (last 6500 years) the coast has then prograded (advanced seaward) by the deposition of sands and gravels from inland erosion, moving the coast westward by as much as 3.5km. These Holocene deposits include estuarine sands and gravels, dune sands (several successively younger phases, aging inland), peat, and river gravel. The Holocene Dune sands (Himatangi Group) and Interdune Deposits (Paraparaumu Peat) dominate the geology. The dune sands are often interfingered with peat deposits, and have in places advanced over the swampy ground. The shallow groundwater regime consists of unconfined aquifers in the Holocene sand and peat deposits. Typically the groundwater level within the peat deposits is within 1 m of the surface.

1.3 The influence of peat on the Expressway

Approximately 50% of the Expressway earthwork footprint is underlain by peat. The peat deposits are typically 0.5m to 4.0m thick and are characterised as very soft, highly organic and compressible. Challenges associated with construction of a road embankment over these weak peat deposits include large settlements, in particular post construction differential settlement, and temporary stability.

Ground improvements are required to address the potential settlements. Preload and Surcharge of the peat is proposed over a significant portion of the route. This involves constructing the embankment over peat and allowing the majority of the settlement to occur prior to pavement construction. The preload is equivalent to the predicted settlement and surcharge is the additional fill placed and removed. On-going secondary and creep settlements are anticipated, and these will impact the road. Excavation and Replacement of the peat is proposed where the peat extent and depth is limited and at critical locations such as at bridge abutments. These ground improvements have been selected to balance capital costs, on-going maintenance, the residual risk profile and constructability. The post construction performance of the Expressway, and an acceptable level of risk, has been agreed with the NZTA. The Preload and Surcharge design aims to limit settlement over the 10 year period to an acceptable operational level. The 10 year target coincides with the surfacing life cycle.

Construction settlements (primary consolidation) will be relatively large in magnitude, approximately 20 to 50% of the peat layer thickness. Key considerations are the settlement magnitude and duration, impacting the earthworks quantities and construction programme. Post construction settlements (secondary compression and creep) are smaller and occur at a slower rate. The key considerations are the settlement rate, and impact on operational performance of the Expressway.

The peat compression parameters used to assess the likely settlements have been developed based on laboratory test data, a number of field trials, previous construction records and observed performance of the existing roads. This paper presents the settlement data recorded during the Expressway field trial, a comparison with historic data, and the interpreted compression parameters.

2 PARAPARUMU PEAT

The Holocene interdune deposits encountered along the route are collectively known as Paraparaumu Peat. These deposits typically vary in thickness from 0.5 to 4m, and are locally up to 6m.

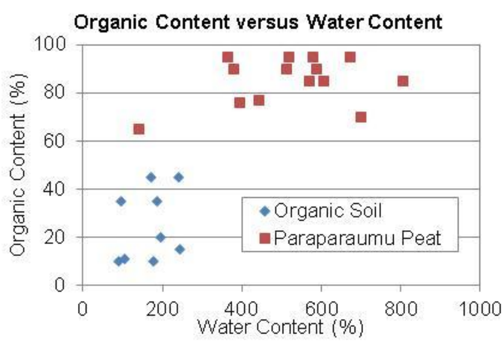

Figure 1. Organic content versus water content

These interdune deposits are predominantly classified as peat soils, with some organic soils present. For the purpose of this paper, peat type soils are defined as soils with an organic content of 50% or greater by dry mass. This is based on the NZ Geotechnical Society Soil and Rock Description Guidelines (2005) where peat soils consist predominately of plant remains. Where the interdune deposits are organic but not strictly classifiable as peat, the term organic is used. Figure 1 shows the clear difference in material properties between the peat and organic soils.

The peat typically comprises a sequence of fibrous woody material over amorphous, silty and silty to sandy peat. Application of the von Post (1926) peat classification yields a degree of humification ranging from H3 to H9. These swamp deposits are highly variable and include soft peat and loose peaty sand, as well as spongy vegetable matter. Woody peat with clay, silt and sand lenses are also common. The peat deposits are characterised by high water contents, up to 900%. The soil properties of peat deposits derived based on laboratory test data are presented in Table 1.

Table 1: Paraparaumu Peat characteristics

Soil Parameter	Peat
Natural Water Content (%)	250 - 900 (560[1])
Organic Content (%)	70 – 95
Initial Void Ratio [2]	5.5 - 11.0 (8.5[1])
Specific Gravity [2]	1.2 - 1.7 (1.4[1])

[1] Average value.
[2] Limited Specific Gravity data, value assumed where not available.

3 FIELD TRIALS AND SETTLEMENT DATA

A trial embankment has been undertaken for the Expressway design. The data from this trial, along with data from an historic trial embankment constructed for the Raumati Straight Widening Project (Opus 1999) and a summary of the construction records from the MacKays Crossing Project (Palmer 2010) are presented below. This data has been used to develop the peat compression parameters for the Expressway. Large scale trials are important for assessing the peat characteristics based on the variablity within the deposit, the difficulty in taking undistrubed representative samples, and the changing behaviour of peat on application of load.

3.1 Expressway trial embankment

A trial embankment has been constructed as part of the Expressway project to gain further understanding of the site ground conditions and performance. Surplus fill material was to be disposed of at a clean fill site located on the peat swamp south of Poplar Avenue. This provided an opportunity to simulate the construction of the Expressway, and gain further data from field based trials. The trial embankment was constructed adjacent to an existing clean fill area. The peat deposits vary in thickness across the footprint, typically from 1.5m to 2.9m, with 2.5m of peat considered to be a representative thickness. The trial embankment is approximately 20m long and 20m wide. The fill was placed in a number of lifts, up to a height of 2.75m, over a period of 3 months. The fill has remained in place for 10 months. The settlement monitoring equipment installed comprised of settlement plates and survey pins. The geometry of the trial embankment, along with the layout of the settlement monitoring equipment, is shown on Figure 2. The fill sequence is detailed on Figure 3.

The settlement monitoring results indicate up to 440mm settlement of the embankment has occurred. The settlement rate has reduced to approximately 5.5mm per month, 10 months after the final fill lift was placed. Lateral movements at the embankment toe were less than 20mm. These settlements are relatively low for peat. The low compressiblility of young woody peat and a groundwater level relatively deep in the peat layer are considered to be contributing factors. The data is provided on Figure 3.

The historic trial embankment and this Expressway embankment are comparable in both overall height and peat thickness. The magnitude of total settlement measured for the Expressway embankment is similar to that measured for the historic embankment. The Preload and Surcharge removal from the historic embankment has resulted in a reduced rate of secondary settlement, compared to the rate of secondary settlement observed for the Expressway trial embankment where no load has been removed. The reduced rate of secondary settlement resulting from load removal is expected (Mesri et al 1997).

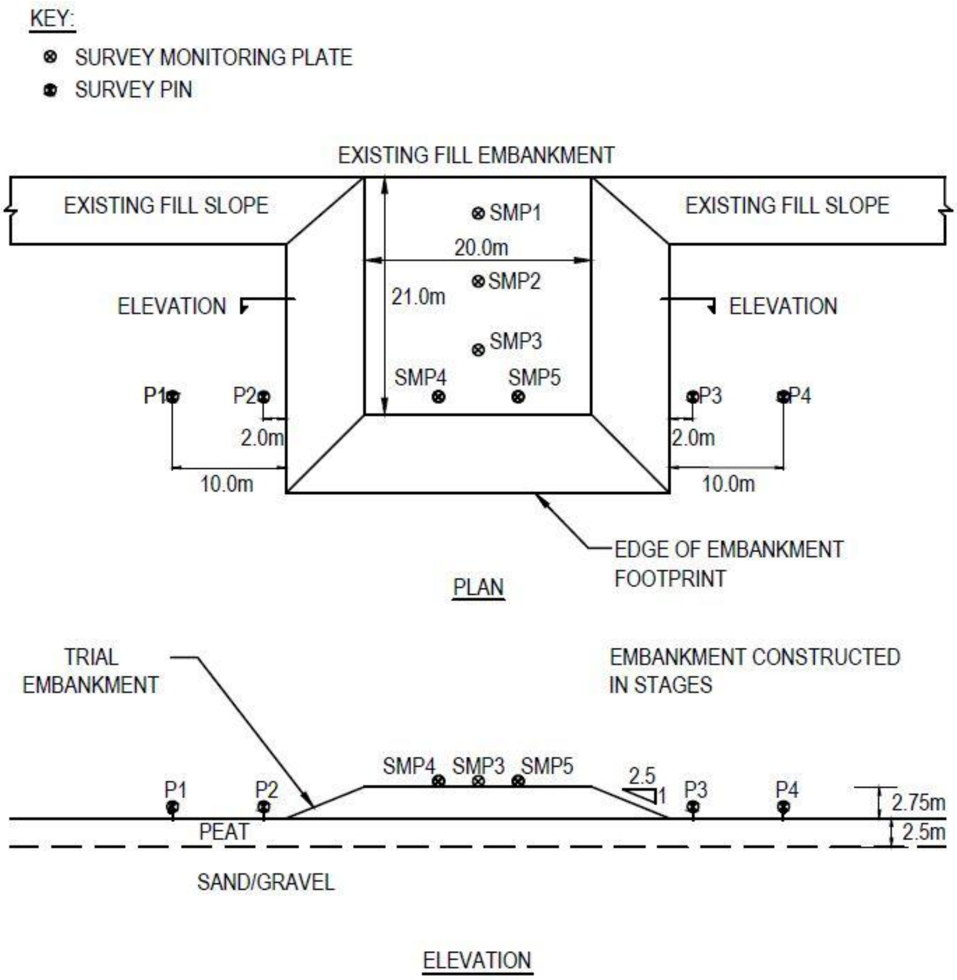

Figure 2. Expressway embankment trial layout

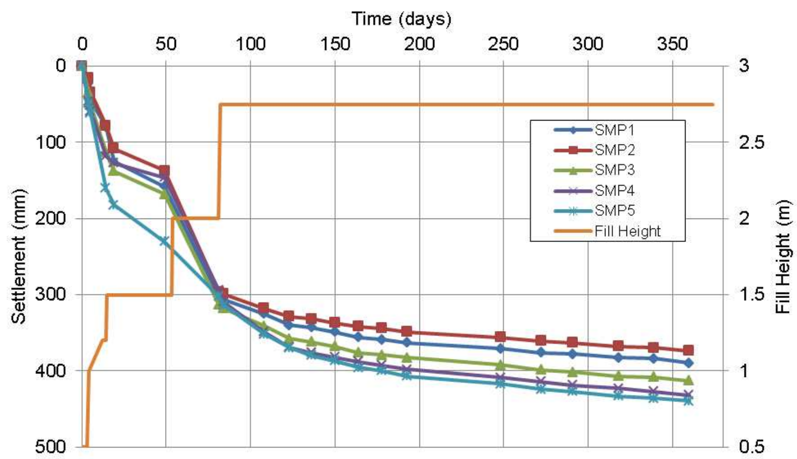

Figure 3. Expressway trial embankment settlement monitoring data

3.2 Raumati Straight widening

The existing State Highway (SH1) between MacKays Crossing and Poplar Avenue is known as Raumati Straight. This section of road embankment was constructed on peat deposits over 40 years ago, and was widened over the adjacent peat swamp during the early 2000's. The original road and subsequent widening has continued to settle, with settlements impacting the driver experience.

As part of the Raumati Straight Widening Project, a trial embankment was constructed to inform the widening design. The trial embankment was directed by Opus International Consultants (Opus) on behalf of the NZTA. Construction records and settlement monitoring data from the widening construction, along with the long-term performance, have also been reviewed.

3.2.1 Historical trial embankment

A trial embankment was constructed and monitored (Opus 1999) to confirm the settlement parameters for the Raumati Straight Widening Project. The existing SH1, south of Poplar Avenue, was widened over a short length to form the trial embankment.

The trial embankment was 30m long, and extended the existing road embankment by 3.5m. A 1.5m high fill, including the drainage blanket, was placed directly on the peat deposits. An additional 1.0m of surcharge fill was placed approximately 10 weeks after initial fill construction, and was subsequently removed after 5 months. The peat thickness at the trial location was 2.6 to 3.3m thick.

The settlement monitoring regime measured 480mm of settlement prior to the removal of the surcharge. The actual total settlement is expected to be slightly higher than this measured value as the settlement plates were installed following completion of the drainage blanket and therefore the initial settlement may not have been recorded. Following removal of the surcharge, the embankment continued to settle at a rate of 1.5mm per month. No swelling or rebound was identified as a result of the load removal.

Vertical wick drains were installed at 2.0m centres over part of the footprint. No vertical drains were installed over the remaining part of the embankment. The monitoring results indicated that the settlement behaviour of the two parts of the embankment were similar, with no discernible difference measured in the magnitude or rate of settlement.

3.2.2 Raumati Straight widening construction records

During construction the widening embankment height varied between 1.0 and 2.0m high, with an additional 0.5 to 0.8m placed and partially removed. The peat thickness varied between 2.0 to 4.5m. The measured construction settlement typically varied between 150 to 450mm. The load from the existing embankment is likely to have impacted the settlement magnitude and rate.

In the 10 years following construction, the crossfall across the widening has typically increased by 1 to 2%, and up to 3% in some locations, equivalent to 30 to 100mm of transverse differential settlement.

3.3 MacKays Crossing project

The new MacKays Crossing over bridge carrying SH1 over the North Island Main Trunk Rail Line was constructed between 2004 and 2007. As part of the project, a new fill approach embankment was constructed over peat. The MacKays Crossing case study has been published (Palmer 2010). A summary of the settlement monitoring data is provided within this paper.

The north embankment is 400m in length and is constructed on peat deposits varying from 0m to 6m thick, with up to 1.0m thick dune sands overlying the peat. Where the peat deposits are present, the embankment fill height varies from 3.0 to 8.0m high. The embankment was constructed in two stages, with a number of lifts per stage. A hold period was incorporated between stages to allow pore water pressures to dissipate. A 1.0m preload was placed above the final road level and was in place for 3 months. Vertical wick drains were installed over the embankment footprint to increase pore water dissipation, however these were not relied on during the design due to the uncertainty over performance of vertical wick drains in peat soils.

The new fill embankment settled 1.75m from the start of construction to sealing of the road pavement, over a two year period. While the road has been in service, and additional 0.15m of settlement occurred over the 2 years following completion. Although the magnitude of post construction settlement is relatively large, differential settlement is a small portion of the overall magnitude.

4 PARAMETER DERIVATION

The embankment heights vary from 2.0 to 7.0m high along the new Expressway route, and as such the parameters for peat needed to be applicable for varying height embankments.

Non-linear parameters, based on a compression index (Cc) approach, have been used to characterise the peat deposits. The non-linear approach provides a better fit for back analyses compared to a linear (Mv) approach, where a variety of embankment heights have been considered. The MacKays Crossing Project, with an 8.0m high embankment, was used to check the applicability of the parameters for large embankments. The interpreted compression parameters are provided in Table 2. The majority of this settlement will occur as a result of consolidation, with a component of immediate settlement. The immediate settlement has not been considered separately. Sand and gravel deposits are present below the peat and two way drainage has been assumed for the assessment.

Table 2: Interpreted peat compression characteristics

Compression Parameter	Symbol	Unit	Value
Unit weight	γ	kN/m^3	10.5
Compression Index Parameter[1]	C_c/ 1+e_0	-	0.35
Pre-consolidation Stress	σ_p'	kPa	15
Co-efficient of Consolidation (vertical)	C_v	m^2/year	3.0

[1] Cc is the Compression Index and e_0 is the Initial Void Ratio

The monitoring data currently available for the Expressway trial embankment is not considered sufficiently accurate to reliably determine secondary compression parameters over this relatively short time period.

5 CONCLUSIONS

Peat compression parameters have been developed based on back analyses of field data. The back analyses used available data from the Expressway Trial Embankment, Opus Trial Embankment (Opus 1999), as well as construction records from the MacKays Crossing Project (Palmer 2010).

The non-linear approach is considered to provide a better fit for back analyses of historic data and field trials when compared to a linear (Mv) approach, where a variety of embankment heights have been considered. The non-linear approach has been adopted as the primary tool for estimating settlement. A Compresion Index Parameter (Cc/1+e0) of 0.35 has been adopted based on consideration of all of the available data.

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