Road Embankment Test Sections over Soft Peat Layer, Võõbu, Estonia

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Abstract. Various road embankment reinforcements on over a 2 to 4 meter thick peat deposit have been constructed in summer to autumn 2015 in the area of Kose-Võõbu in the northern part of Estonia. The test sections consist of five different reinforced road embankments: one layer of georeinforcement, two layers of georeinforcements, geocell mattress, light weight aggregate (LWA) and expanded polystyrene (EPS) light weight embankment structures with georeinforcement. An additional test section is a mass replacement. To accelerate the consolidation of the peat, reinforced test sections are loaded with surcharge. This paper presents information about peat field and laboratory tests, geodetic monitoring, settlement predictions and preliminary evaluation of the structures. The settlements of each test section are precisely measured with settlement plates installed over the peat layer, over e.g. EPS and LWA layers and surface dressing (bituminous layer). In addition, the surface treatment layer has been mapped by high-resolution laser scanning, also after surcharge removal the scanning will be conducted to obtain settlement profile due the surcharge. The intent of this test construction is to validate technical and economic feasibility of different reinforcement methods over designed road alignment (road E263).

Keywords: peat, reinforcement, light weight material, instrumentation, settlement, road construction.

Conference topic: Case histories.

Introduction

Various road embankment reinforcements on top of a 2 to 4 meter thick peat deposit have been constructed in summer and autumn 2015 in the area of Kose-Võõbu in Estonia. The test sections consist of six different road embankments.

The layout of test structures and longitudinal profile are presented in Figures 1–3. The test sections are numbered as follows: 0. mass replacement, 1. one-layer and, 2. two-layers of georeinforcement, 3. geocell mattress, 4. light weight aggregate and 5. EPS light weight embankment. The total length of test sections is ≈ 200 m and the length of each section is ≈ 30 m (6 sections). The width of the embankment is ≈ 30 m from toe to toe.

Site description and geology

The test site is located in Järvamaa, Paide Region alongside the road number E263 Tallinn–Tartu–Võru–Luhamaa road at km posts 67.076–67.256 (≈ 67 km from Tallinn). The test area is a part of Kõrvemaa swamp area. Based on the soundings and ground penetrating radar (GPR) results the thickness of the peat layer is approx. 1.8–3.4 m at the test area. The variation of the peat layer under the test sections are presented in Figures 1 and 2. The ground surface heights vary from +74.2 to +74.3 m above sea level. Between the section 5

and 0 there is a shallow ditch where the ground level is lower. Underlying the peat layer is clayey silt, fine sand and sand with gravel (moraine). The ground water levels vary from +74.1 to +74.3 beside test section 3.

Fig. 1. Three peat layers and natural water content of peat in the test sections 1 to 5

Most of the soundings and samples were taken in June 2015 but some soundings are older. In total 13 boreholes and 6 vane shear test were carried out and

≈130 disturbed and some undisturbed samples were collected.

According to soundings and samples there are three different layers of peat (Fig. 1). The presented shear strength are unreduced and from initial conditions.

- $z = 0\text{--}0.5$ m: low degree of decomposition, contains roots, branches and stumps.
- $z = 0.5\text{--}1.5$ m: medium to high degree of decomposition, $w \approx 400\text{--}600\%$, $\tau \approx 9$ kPa.
- $z = 1.5\text{--}3.5$ m: medium degree of decomposition, $w \approx 700\text{--}900\%$, $\tau \approx 4$ kPa.

Comprehensive oedometer compression tests were conducted on test section 4 borehole (Table 1). Tests were carried out according to standard CEN ISO/TS 17892-5.

Construction

Construction of the test structures took place from the June 2015 to the middle of October 2015 starting from the section 1 and ending with the construction of the surcharge. The contractor was Lemminkäinen Eesti AS. The structures and construction are presented more comprehensive in the article and report of Forsman *et al.* (2016, 2015a, 2015b). Surcharge is estimated to remain in place until autumn 2016. The construction is presented in the time lapse video in the following link: <https://onedrive.live.com/redir?resid=30E9DBABB750EB6F1183&authkey=!AJ7ke3VSUyp9s58&ithint=folder%2cdocx>

Test structures

Section 1 consisted of one layer reinforcement (woven polyester, strength 600/50 – warp/weft) on top of peat. *Section 2* consisted of 2-layer reinforcements. Bottom geotextile on top of the peat was 400/50 and the upper geotextile inside the embankment was 200/50. Vertical distance between the reinforcements was 0.5–0.8 m. *Section 3* consisted of 1 m high geocell mattress. Before installing the geocell mattress a nonwoven geotextile and geogrid (40/40) were placed on top of the topsoil. Geocell was filled with #0/64 mm limestone aggregate. *Section 4* consisted of light weight aggregate (LWA #10/20 mm, leca) layer. Before installing the LWA a woven reinforcement 400/50 was installed on top of topsoil. At the edges of the embankment 1 m thick aggregate barrier was build. LWA layer 1 to 1.5 m was installed between the barriers (1 m layer in the edges). *Section 5* consisted of EPS-block layer. Before installation of the EPS-blocks the peat layer was preloaded 14 days with 0.5 m thick sand embankment over a woven reinforcement 400/50 on top of topsoil. After preloading the surface was levelled and the EPS-blocks were installed on the sand surface.

To accelerate the consolidation of the peat layer the test sections were loaded with surcharge (pre and over loading embankments).

Instrumentation

Altogether 98 measurement points for settlement measurements were installed (locations are presented in the Fig. 3). Of this figure:

- 36 settlement plates were placed on top of the geotextile-covered peat layer (“R” plates).
- 6 settlement plates on top of the upper layer of geotextile in section 2 (≈1 m above the peat).
- 1 settlement plate on top of the EPS layers, in the centre of Section 5.
- 30+1 settlement plates on top of the uppermost (paved) road layer (“K” plates).
- 20 ceramic plates on top of the peat layer (1 m off from the lower edge of the road slope).
- 4 wooden plates on the Section 0 slopes.

The geometric levelling was conducted with precise digital instrument DiNi-03 and barcoded levelling staffs (Ellman 2015). The surface of the embankment has been measured by RPAS in several phases (Remotely Piloted Aircraft System, see Julge (2015)).

Settlement results (until 03/2016)

In the Figure 4 presented settlement points are located in the test section center alignment. The Figure also presents total load magnitude in each settlement point. The load does not take into account the effect of buoyancy when the embankment has settled below ground water. In the settlement calculations the buoyancy has been taken into account. The loading magnitude is an approximation based on construction site realised and designed embankment height.

In case the properties of the peat layer are homogeneous, the width of the embankments is the same and the ratio (embankment width) / (peat layer thickness) is big forming “an oedometer loading”, the settlement of peat layer under the centre line of the embankment is only dependent on the embankment load and the thickness of the peat layer.

The latest settlement results are from March 2016. Under the sections 1 / 2 / 3 / 4 / 5 the measured settlements of peat layer are 990 / 950 / 1720 / 1570 / 1140 mm and relative compressions of the peat layer 50 / 40 / 58 / 49 / 37%. The settlement results are also presented in Table 2 and in Figure 2. Those settlement results can be adjusted to the same “fictitious” peat thickness by “peat thickness factor” (PTF) in Eq. (1):

$$PTF = \frac{\text{peat thickness of section } n}{\text{peat thickness of section 5}} \quad (1)$$

That calculated PTF is 1.73 / 1.44 / 1.10 / 1.05 / 1.00 in sections 1 to 5. That way adjusted “fictitious” settlements are 1708 / 1366 / 1884 / 1641 / 1140 mm. The loading is clearly higher in the sections 1 to 3 than in sections 4 to 5 put the adjusted settlement is quite same. On the basis of that result it seems that the properties of the peat layer are not fully homogeneous but the peat seems to be softer under the sections 3–5 than under the sections 1–2. This is in line with the water-

content profile presented in Figure 1 where the most water layer 3 is much thinner in sections 1–2 than in sections 3–5.

On the basis of the measured settlements the settlement “profile” of the embankment cross-section has been formed during embankment construction phase before surcharge loading. The surface settlement plates

in the edges of the road embankment have only small difference in settlements compared to centre alignment settlements. It seems that the edges of the embankment are settling more than the centre line. So the surface drainage to the edges of the road is possible to work in future.

Table 1. Oedometer compression test results for the peat samples from borehole no. 13

Depth	w ₁	w ₂	ρ _d	C _c	C _α ⁽¹⁾	c _v ⁽¹⁾	k ⁽¹⁾	m _v ⁽¹⁾	e ⁽¹⁾
[m]	[%]	[%]	[t/m ³]	[-]	[-]	[m ² /a]	[m ⁻¹⁰ /s]	[MPa ⁻¹]	[-]
0.85–0.95	910	496	0.10	6.65	- / 0.31 / 0.47 / 0.16	- / 26.2 / 10.6 / -	- / 250 / 56 / -	- / 3.0 / 1.6 / -	15.2 / 8.6 / 7.1 / 6.7
1.35–1.45	1043	423	0.09	7.50	- / 0.39 / 0.38 / 0.11	- / 25.4 / 9.4 / -	- / 92 / 137 / -	- / 1.1 / 4.6 / -	17.2 / 8.8 / 7.5 / 6.8
2.15–2.25	800	437	0.11	5.70	- / 0.32 / 0.38 / 0.12	- / 6.0 / 11.0 / -	- / 54 / 30 / -	- / 2.8 / 0.9 / -	12.8 / 7.4 / 6.4 / 5.7
2.75–2.85	630	344	0.14	4.57	- / 0.32 / 0.31 / 0.37	- / 28.6 / 2.6 / -	- / 136 / 6.9 / -	- / 1.5 / 0.8 / -	10.2 / 6.6 / 5.9 / 5.2

Notes: (1) Loading and loading steps were σ = 10 (1 h); 25 (22 h); 50 (24 h); 75 (24 h); 100 kPa (24 h),

* Calculated σ = 25–50 kPa and σ = 50–75 kPa.

Fig. 2. Longitudinal profile of test sections 0–5 (March 2016 situation). The thin “red line” is the designed level of the road surface. The top and bottom level of embankment is presented with thick dashed red and black lines. The location of the mass replacement (MRP), EPS, LWA and Geocell are hatched to the profile. The original thicknesses of the peat before construction are: Section 1 – peat thickness 1.9–2.3 m, Section 2 1.9–2.4 m, Section 3 – 3.0–3.2 m, Section 4 – 3.2–3.6 m and Section 5 – 3.4–3.5 m

Fig. 3. Location of the levelling benchmarks: 0 – mass replacement; 1 – one layer and 2 – two layers of georeinforcement, 3 – geocell mattress, 4 – light weight aggregate and 5 – EPS light weight embankment structure (Ellmann 2015)

Table 2. Construction periods, loadings and settlements of the test sections 1 to 5 until March 2016. The load presented in the Table does not take into account the effect of buoyancy when the embankment has settled below ground water

Section	Construction time to "red line" level and to surcharge level	Load and measured settlement before surcharge construction 10/2015	Load with surcharge and measured settlement until 03/2016	Relative compression of peat layer until 03/16	Settlement difference between the centre alignment and the edges
1	11/81 days	~50 kN/m ² / 0.77 m	~90 kN/m ² / 0.89–0.99 m	~50%	20–50 mm
2	17/76 days	~50 kN/m ² / 0.71 m	~86 kN/m ² / 0.95 m	~40%	~40 mm
3	16/63 days	~50 kN/m ² / 1.44 m	~75 kN/m ² / 1.72 m	~58%	~30–60 mm
4	5/52 days	~45 kN/m ² / 1.06–1.23 m	~62 kN/m ² / 1.41–1.57 m	~49%	~10–40 mm
5	37/42 days	~35 kN/m ² / 0.75–0.90 m	~45 kN/m ² / 1.14–1.29 m	~37%	~0–40 mm

Fig. 4. Sections 1 to 5. Measured settlements of the peat and pavement benchmarks at the centre line (after Ellmann 2016). Measurements are until March 2016. The load presented in the upper Figure does not take into account the effect of buoyancy when the embankment has settled below ground water. Settlement plates R1 and K12 are at section 1, plates R24 and K25 are at section 2, plates R305 and K32 are from section 3, plates R45 and K42 are from section 4 and plates R55 and K55 are from section 5. "R" means that the plate is on the surface of the peat and "K" that the plate is on the level of red line

Settlement estimations

Preliminary settlement calculations were made using Novapoint GeoCalc 3.1-program (2013) with “Variable permeability” method and “Compressibility index (C_c)”. Ground water level was assumed to be at depth 0.3 m. below ground surface.

Three peat layers were used for settlement calculations. The calculation has been made with adjusted parameters (Fig. 5) which are originally based on the laboratory test results. The parameters are adjusted according to measured settlements of test section 4. The test section 4 was chosen for parameter adjustments because of the laboratory tests are conduct with soil samples from the borehole 13 (which is located at the area of section 4). Due to the consolidation of the peat

layer the road and surcharge embankment has settled near to the road alignment (“red line”). The difference between the top of surcharge load embankment and road alignment at 29.3.2016 is about 60 mm.

The settlement estimations are presented in Figure 5. According to calculations the settlement of section 4 after the surcharge removal is approximately 1530 mm. The settlement after 20 years is estimated to be approximately 1590 mm. The calculation estimates the settlements after removal of the surcharge loading to be quite small (<100 mm).

Further analysis of the settlements and a comparison of the different test sections performance is planned to be published during winter 2016 – summer 2017.

Fig. 5. Section 4. Measured (R44, R45, R46) and calculated settlements at period 0–1 year (upper Figure) and calculated (estimated) settlement after removal of surcharge loading (time 20 years). Settlement calculation parameters for Geocalc-program (Novapoint GeoCalc 2013) are presented on the right side. In the calculation the removing of the surcharge embankment is 1 year after construction

Conclusions

Analysis of measuring results and other observations will provide valuable results which can be used in the design of the road E263 (from Tallinn to Tartu) on its new alignment at peat area at Voobu-Mäo area. The construction and field-monitoring of the test sections are well documented and will aid further analysis of the test section in future.

All of the test sections 0 to 5 have some technical benefits and some technical or economical limitations. Which method is most suitable in different construction cases and place, must be considered case by case. All the methods described can be applied to constructing roads at peat areas.

The total settlement is important when considering the realized height of the embankment and the load affecting to peat layer, the amount of the aggregate needed and the stability of the structure during construction and as final structure during usage.

Preliminary estimation based on the measuring results and calculations is that the settlements at the centre line of the sections 1, 2, 3, 4 and 5 will be lower than 100 mm during 10 years after removing of surcharge which is lower than required in the guidelines of Estonian Road Administration.

For the effective drainage of the road surface it is important that the inclination of the road surface is remaining and the cross section shape of the road embankment and the surface is not flattening during usage. Based on these measurement results on March 2016 the final road cross-section profile will not settle unevenly. On the basis of the measured settlements the settlement "profile" of the embankment cross-section has been formed during embankment construction phase before surcharge loading. The surface settlement plates in the edges of the road embankment have only small difference in settlements compared to centre alignment settlements. It seems that the edges of the embankment are settling more than the centre line. Therefore the surface drainage to the edges of the road is possible to work in future.

The true safety factor of the embankment is not possible to estimate without new vane shear tests of peat layer under the embankment. The strength of the peat is

a "function" of the compression level and that "function" is not known with the peat of Võõbu. Additional vane soundings are designed to be done through the embankment during the autumn 2016.

The surcharge embankment is designed to be removed during autumn 2016 and the settlement measurements will be continuing.

Acknowledgements

Authors would like to thank Maanteeamet (Road Administration) for constructing the full-scale test section and for comprehensive field and laboratory survey.

Disclosure statement

Authors do not have any competing financial, professional, or personal interests from other parties.

References

- Forsman, J.; Dettenborn, T.; Skepast, P.; Mets, M.; Olep, M.; Ellmann, A.; Vallas, I.; Tõnts, T.; Kontson, K. 2015a. Full scale reinforced road embankment test sections over soft peat layer, Võõbu, Estonia, in *The 17th Nordic Geotechnical Meeting*, 25–28 May 2016, Reykjavik, Iceland. 10 p.
- Forsman, J.; Dettenborn, T.; Skepast, P. 2016. *Kose-Võõbu test embankment, preliminary technical analysis report* 04/2016. Ramboll Finland Oy. 36 p. + 276 app.
- Forsman, J.; Dettenborn, T.; Skepast, P. 2015b. *Kose-Võõbu test embankment construction report* 11/2015. Ramboll Finland Oy. 38 p.
- Ellmann, A. 2016. *Geodetic monitoring of the Võõbu test site in I-th quarter of 2016*. Tallinn University of Technology, Tallinn. 24 p. (in Estonian).
- Ellmann, A. 2015. *Mounting and monitoring of levelling benchmarks in the võõbu road construction test site*. Tallinn University of Technology, Tallinn. 23 p.
- Julge, K. 2015. 3D-model from aerial photos [online]. [cited 12 September 2016]. Available from Internet: <https://sketchfab.com/models/43081376e08f45c89eb5736ec9a4a975>
- Novapoint GeoCalc. 2013. *Novapoint GeoCalc 3.1 Vianova Systems* Finland Oy.