Full scale reinforced road embankment test sections over soft peat layer, Võõbu, Estonia

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ABSTRACT
Various road embankment reinforcements on over of a 2 to 4 meter thick peat deposit have been constructed in 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 traditional mass replacement. To accelerate the consolidation of the peat, reinforced test sections are loaded with surcharge. This paper presents information about peat laboratory tests, construction and field monitoring. 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 the research is to validate technical and economic feasibility of different reinforcement methods over designed road alignment (road E263).

Keywords: test embankment, reinforcement, peat, instrumentation, light weight material

1 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 (Fig. 1). The test sections consist of six different road embankments. Test sections are numbered as follows (Fig. 2):

0. mass replacement
1. one layer of georeinforcement
2. two layers of georeinforcements
3. geocell mattress
4. light weight aggregate and
5. EPS light-weight embankment.

Figure 1. Location of the Võõbu test area.

Some details of the project:

- total length of test sections: ≈200 m
- number of test sections: 6 (sections 0 - 5)
- length of each section: 30 m
- width of embankment: 23 m (from toe to toe) and
- 98 measurement points for determining settlements.

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

2 SITE DESCRIPTION

2.1 Geology

The test site is located in Järvamaa, Paide Region alongside the Tallinn–Tartu–Võru–Luhamaa road at km posts 67.076–67.256. 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 appeared to be 1.8-3.4 m at the test area. The ground surface level varies from +74.2 to +74.3. 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).

2.2 Soundings and laboratory tests

The test area layout and the location of sounding points are presented in Fig. 4. 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.

The thickness of the peat layer is approx. 1.8-3.4 m. According to soundings and samplings there are three different layers of peat (Fig 2). The presented shear strength are unreduced and from initial conditions.

- z=0-0.5 m: low degree of decomposition, contains roots, branches and stumps
- z=0.5-1.5 m: medium to high degree of decomposition, w≈400-600 %, τ≈9 kPa
- z=1.5-3.5 m: medium degree of decomposition, w≈700-900 % τ≈4 kPa

Comprehensive oedometer compression tests were conducted on samples from borehole no. 13. Tests were carried out according to standard CEN ISO/TS 17892-5.

The ground investigation results from borehole no. 13 are presented in Fig. 2 and results of oedometer tests in Table 1.

Table 1. Oedometer compression test results for the peat samples from borehole no. 13. Used loading steps were σ=10 (1 h); 25 (22 h); 50(24 h); 75 (24 h); 100 kPa (24 h).

Depth	σ	w	ρ_d	C_c	C_α	c_v *	k *	m_v *	e
[m]	[MPa]	[%]	[t/m^3]	[-]	[-]	[m^2/a]	[m^{-10}/s]	[MPa^{-1}]	[-]
0.85 - 0.95	0	910	0.10	6.65	-	-	-	-	15.2
	0.05				0.31	26.2	250	3.0	8.6
	0.075				0.47	10.64	56	1.6	7.1
	0.1				0.16	-	-	-	6.7
1.35 - 1.45	0	1043	0.09	7.50	-	-	-	-	17.2
	0.05				0.39	25.4	92	1.1	8.8
	0.075				0.38	9.4	137	4.6	7.5
	0.1				0.11	-	-	-	6.8
2.15 – 2.25	0	800	0.11	5.70	-	-	-	-	12.8
	0.05				0.32	6.0	54	2.8	7.4
	0.075				0.38	11.0	30	0.9	6.4
	0.1				0.12	-	-	-	5.7
2.75 – 2.85	0	630	0.14	4.57	-	-	-	-	10.2
	0.05				0.32	28.6	136	1.5	6.6
	0.075				0.31	2.6	6.9	0.8	5.9
	0.1				0.37	-	-	-	5.2

* Calculated σ = 0.25-0.05 Mpa; σ = 0.05-0.075 MPa

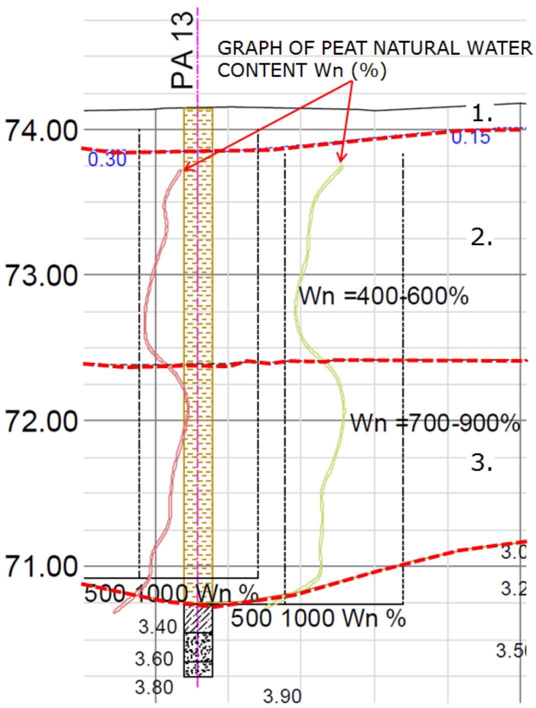


Figure 2. Bore hole 13. Three peat layers and natural water content of peat in two points.

2.3 Ground penetrating radar (GPR)

Before construction works the thickness of peat layer in test area was measured (June 2015) with ground penetrating radar (GPR).

The used GPR antennas were: 400 MHz and 100 MHz GSSI antennas and also 500 Hz MALA antenna. The GPR-measurement results were calibrated with borehole data. The average measured dielectric constant was E_r=44 which indicates that peat has a high water content. Because of the high water content only 100 MHz antenna data was used for the thickness analysis.

3 CONSTRUCTION OF TEST SECTIONS

Construction of the test structures took place from June to October 2015 starting from the section 1 and ending with the construction of the surcharge (surcharge is estimated to remain in place until autumn 2016).

The contractor was Lemminkäinen Eesti AS. The construction is presented in the time lapse construction video, presented in the following link: https://onedrive.live.com/redir?resid=30E9DBABB750EB6F!183&authkey=!AJ7ke3VSUyp9s58&ithint=folder%2cdocx.

The longitudinal profile of test sections and peat layer thickness is presented in Fig. 5. The realized construction timetable for embankment height and loading on the peat layer is presented in Table 2.

This paper presents the designed heights of the constructed embankments. The effect of the settlements during construction and its affect to embankment height and load magnitude of the peat layer will be analysed with settlement follow-up measurements and reported in later reports and articles during 2016-2017.

Figure 3. Test sections. 0. mass replacement, 1. one layer and 2. two layers of georeinforcements, 3. geocell mattress, 4.light weight aggregate and 5. EPS light weight embankment structure. Tallinn is on the left.

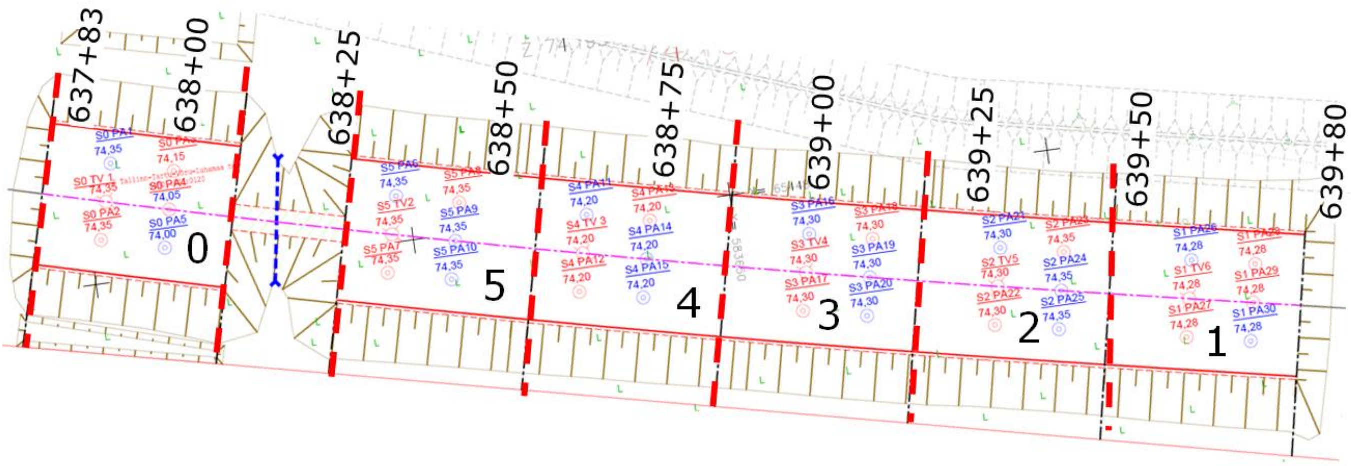
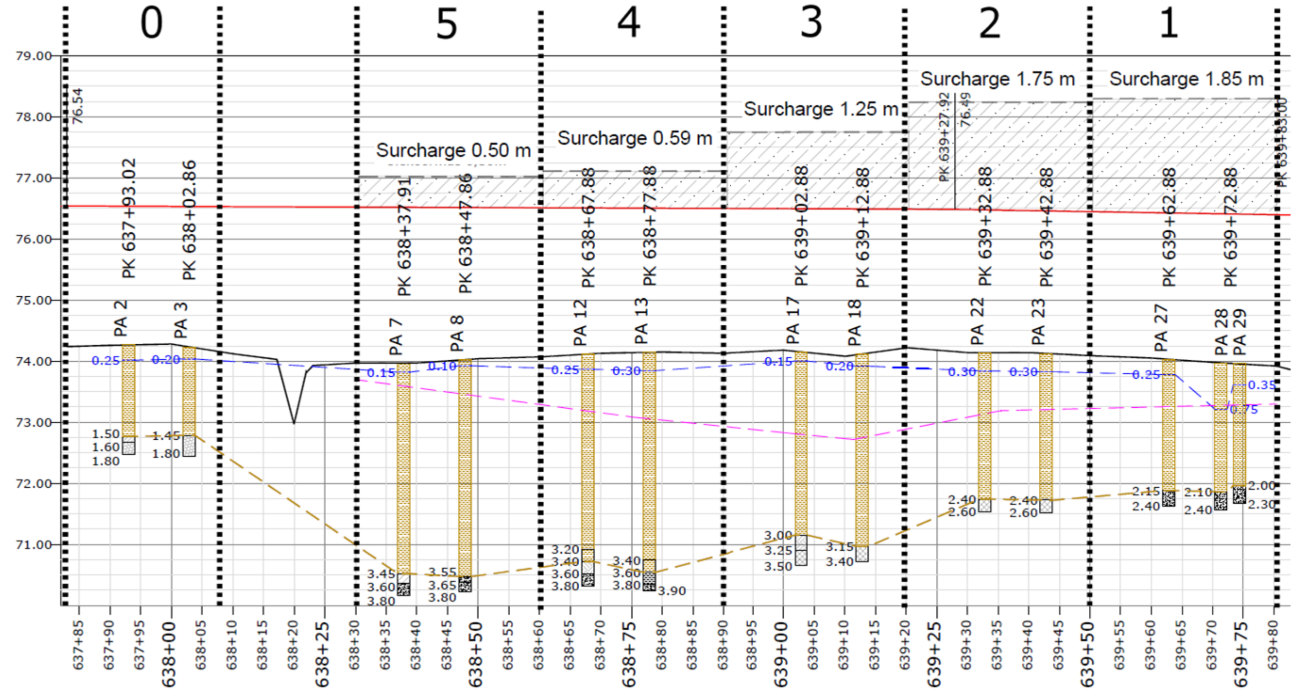


Figure 4. Location of ground investigations points. Distance between posts 639+80 -637+83 is ≈200 m.

a)



b)

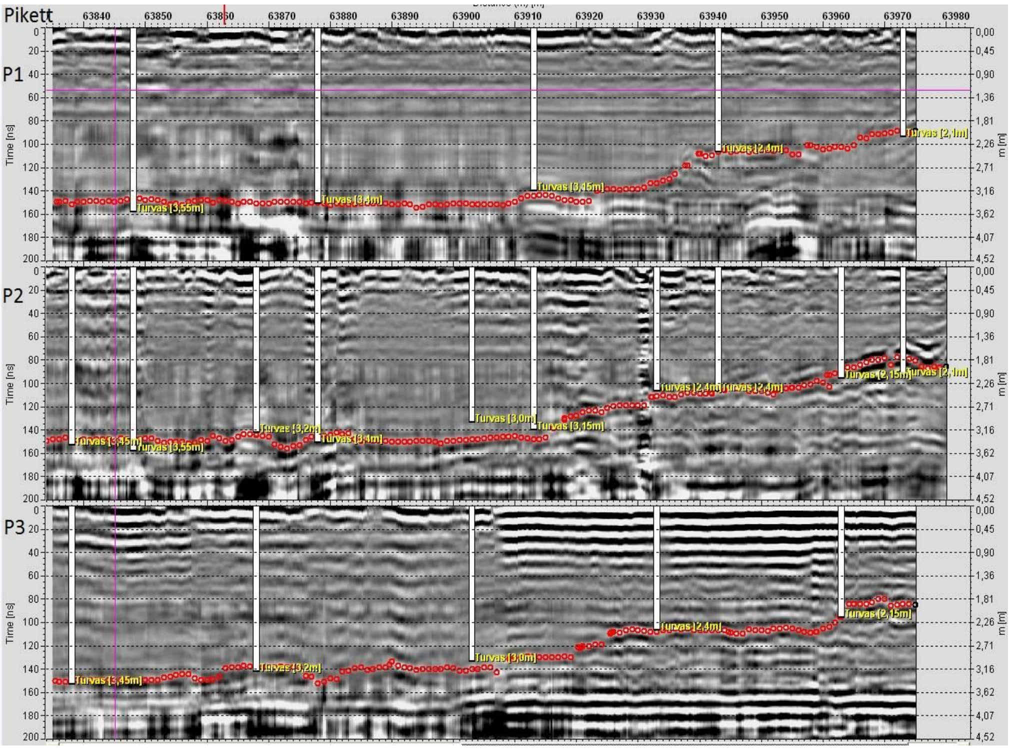


Figure 5. a) Longitudinal profile of test area. The red line is the designed level of the road surface. b) soundings and georadar results from 3 lines (red dotted line is the interpreted bottom of the peat layer).

3.1 Preparation works

The preparation works in the test area including cutting the trees and milling the stumps, sticks, small branches, grass etc. on top of peat layer (Fig. 6). By milling, a uniform and load-bearing working platform was created.

Typically, topsoil is removed before construction. In this case, removal of the topsoil would have exposed a very soft peat, which would have been easily disturbed and the construction site would had been hard or impossible to operate as a result.

Figure 6. Milling the topsoil (stumps, roots, small sticks, grass etc.) for working platform.

3.2 Test section 0

Section 0 consisted of mass replacement. The excavated peat was replaced with a sand and gravel embankment. The top of embankment (0.15 m) was constructed with crushed limestone #2/64 mm and after that surfaced with a layer of crushed limestone # 8/12 mm.

3.3 Test section 1 (Fig. 7, and 12)

The section 1 consisted of 1-layer reinforcement (woven polyester strength 600/50 - warp/weft) on top of peat. In the edges of the embankment reinforcement was wrapped around at least 5.7 m towards the centre line. The designed height of final designed road embankment was ≈2.5 m (from red line to initial peat surface). On top of the road embankment the surcharge layer with thickness of ≈1.85 m was loaded. In total the designed embankment height (including surcharge) over the peat is ≈4.35 m. However, due to the settlements during construction works the height of the constructed embankment is in reality greater (≈5 m).

3.4 Test section 2 (Fig. 12)

The 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. In the edges of the embankment reinforcements were wrapped around at least 5.0 m towards centre line. The height of the final designed road embankment was ≈2.5 m. In total the designed embankment height (including surcharge) over the peat is ≈4.25 m and in reality ≈5 m.

3.5 Test section 3 (Fig. 7 and 12)

Section 3 consisted of geocell mattress. Before installing the geocell mattress a nonwoven geotextile and geogrid (40/40) were placed on top of the topsoil. The height of the geocell was 1 m and it was filled with # 0/64 mm limestone aggregates. The filling was not compacted inside the geocells. The height of the final designed road embankment was ≈2.5 m. On the top of the road embankment was installed surcharge of ≈1.25 m. In total the designed embankment height (including surcharge) over the peat is ≈3.75 m and in reality ≈5 m.

Table 2. Table presents time after beginning of construction the section, loading magnitude of the peat layer and designed heights of embankment in each stage.

Section	Load [kN/m]	Height [m]	Construction duration [d]	Type
1	48	2.40	0-4	Embankment
1	51	2.55	11-13	Surface dres.
1	88	4.40	81-89	Surcharge
2	48	2.40	0-17	Embankment
2	51	2.55	26-28	Surface dres.
2	86	4.30	76-84	Surcharge
3	20	1.00	0-3	Geocell
3	51	2.55	15-16	Embankment
3	76	3.80	63-71	Surcharge
4	6	1.50	0-3	LWA
4	24	2.40	4-5	Embankment
4	36	2.99	52-60	Surcharge
5	10	0.50	0-2	Preload
5	16	1.95	17-30	EPS
5	34	2.85	37-42	Embankment
5	44	3.35	42-50	Surcharge

3.6 Test section 4 (Fig. 8 and 12)

Section 4 consisted of light weight aggregate (LWA #10/20 mm = “leca”) layer. Before installing the LWA a geotextile reinforcement 400/50 was installed on top of topsoil. At the edges of the embankment a 1 m thick aggregate barrier (Fig 12f) was built, and the LWA layer 1 to 1.5 m was installed between the barriers. At the edges the minimum thickness of the LWA was 1.0 m. The final height of the designed road embankment was ≈2.5 m. On top of the embankment is the surcharge of ≈0.6 m. In total the designed embankment height (including surcharge) over the peat is ≈3.1 m.

3.7 Test section 5 (Fig. 9 and 12)

The section 5 consisted of EPS-block layer. The EPS-blocks were connected to each other with PVC-pipes (≈25 mm) and plastic connectors at the surface of the EPS-layer. The EPS-blocks were protected with 0.5 mm thick linear low-density polyethylene-plastic membrane (LLDPE). The EPS-layer was covered with 0.9 m thick aggregate layer. To obatin better bearing capacity for the final road structure a geogrid (40/40) was installed to the aggregate layer.

Section was constructed in following phases:

1. installation of georeinforcement (400/50) on top of peat layer,
2. preloading of the peat with 0.5 m thick sand embankment for ≈2 weeks,
3. levelling of the preloading embankment and installation of the EPS-blocks,
4. installation of the membrane,
5. installation of the aggregate layers and geogrid (40/40) and
6. paving of the embankment at the level of red line (the thin paving was made for the measuring of the surface of the embankment before and after the overloading).

The total height of the embankment over peat in section 5 is ≈2.5 m.

3.8 Geotechnical dimensioning calculations

Geotechnical calculations for sections 1 to 4 (stability and settlement) were made by Olep (2015) and for Section 5 by Korkiala-Tanttu et al. (2015). Stability calculations have been completed with Novapoint GeoCalc 3.1-geotechnical dimensioning program developed by ViaSys VDC Oy (http://www.viasys.fi/).

Any back calculations have not been conducted but they will be made later during 2016-2017.

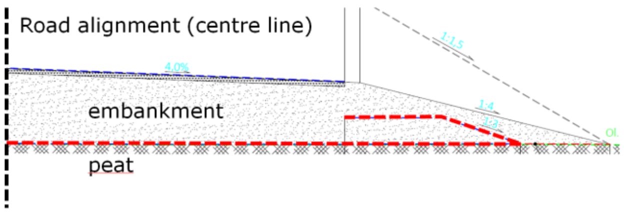


Figure 7. Cross-section of test section 1. 1-layer georeinforcement.

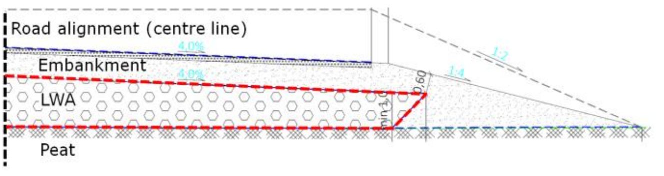


Figure 9. Cross-section of test section 4. Light weight aggregate (LWA) layer.

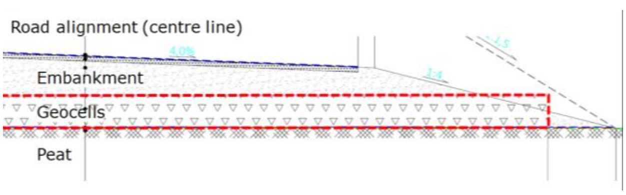


Figure 8. Cross-section of test section 3. Geocell mattress.

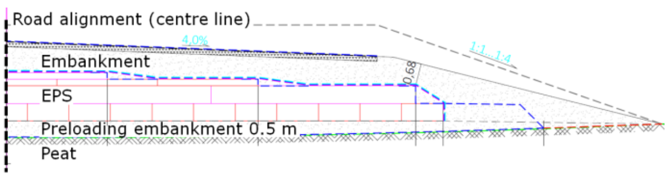


Figure 10. Cross-section of test section 8. EPS-block layer.

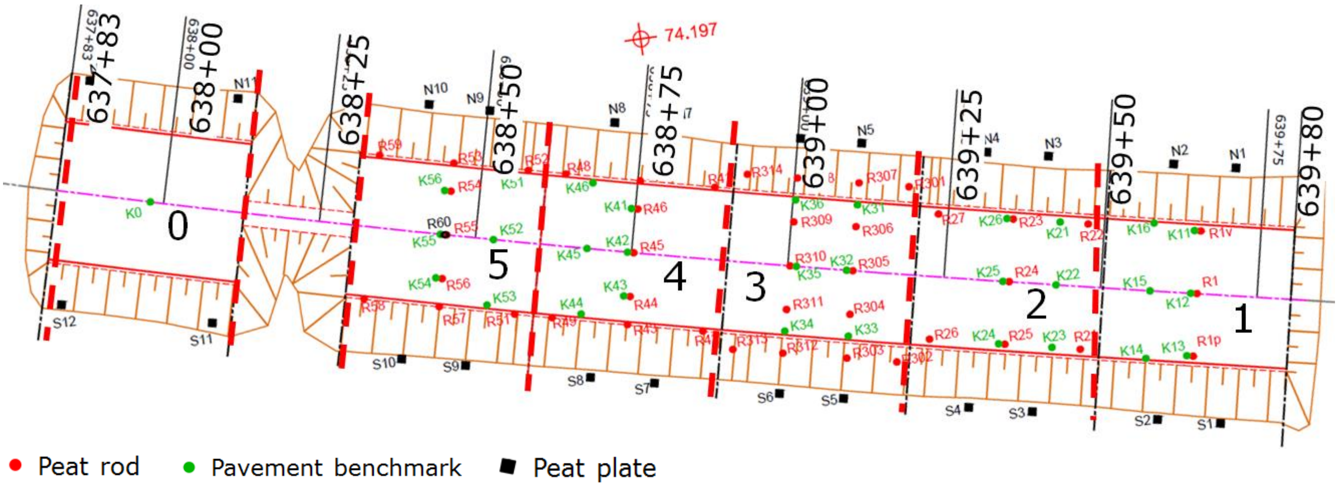


Figure 11. Locations of the leveling benchmarks (red –peat rods, green –pavement benchmarks, black – peat plates, and also the Section 0 slope plates) (Ellmann 2015)

a) Start of construction of sec. 1 (20.7.2015)

b) Construction of embankment sec. 1 (20.7.2015)

c) Installed upper reinforcement, sec. 2 (21.7.2015)

d) Construction of Geocell structure (31.7.2015)

e) Construction of Geocell structure at sec 3. (31.7.2015)

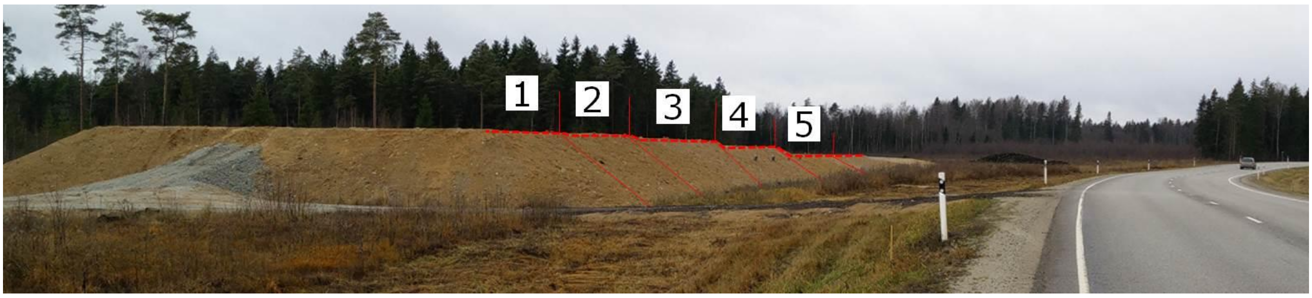
f) Construction of edge barrier at sec. 4. Peat rod in bottom right corner. (12.8.2015)

g) Compaction of the embankement. sec.1 (24.8.2015)

h) Construction of LWA layer at sec 4. (25.8.2015)

i) Installation of EPS-blocks at sec. 5 (16.9.2015)

j) Surface of the EPS-layer at sec. 5. Plastic connectors on between EPS-blocks (24.9.2015)



k) Test sections 1-5 after surcharge loading (11.11.2015)

Figure 12. Photos from the construction of the test embankment.

Figure 13. 3D surface model created from the RPAS photos combined with aerial photos (Julge 2015). Surface after construction of surcharge loading 5.11.2015 (RPAS=Remotely Piloted Aircraft System).

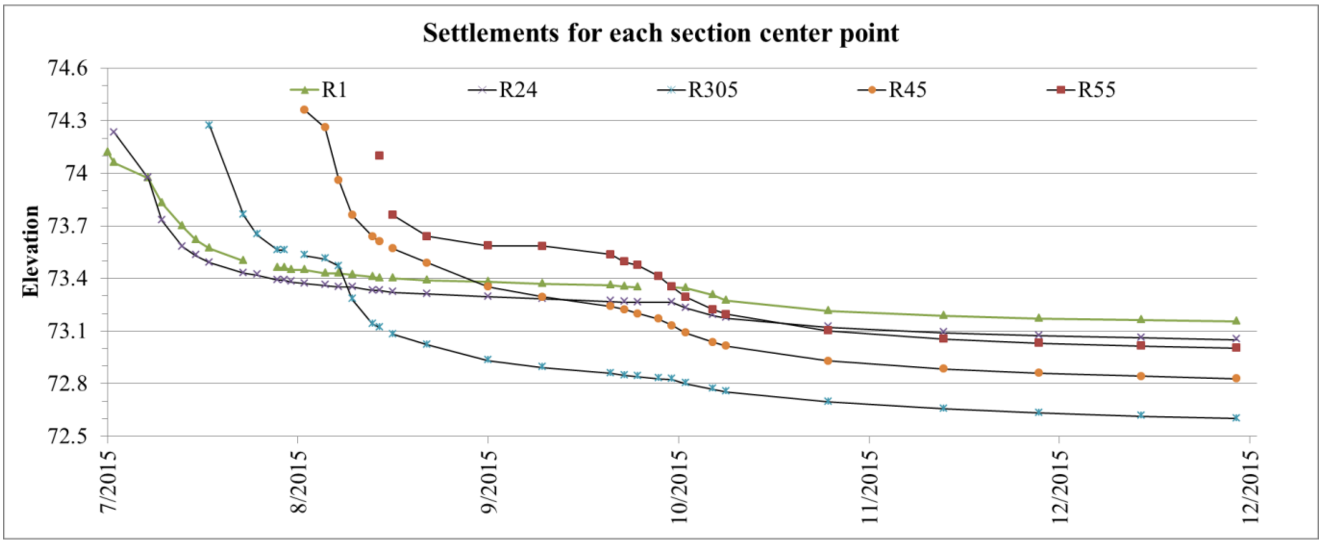


Figure 14. Test sections 1-5 settlement results for the test section center aligment peat rod.

4 INSTRUMENTATION OF THE TEST EMBANKMENTS

4.1 Settlement plates

Altogether 98 measurement points were mounted at the test site. Of this figure:

- 36 settlement plates were placed on top of the geotextile-covered peat layer (Fig. 15)
- 6 settlement plates on top of the upper layer of geotextile in Section 2 (≈1 m above peat layer)
- 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
- 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.

Locations of the instrumentations are presented in Fig. 11. The first installed settlement plates were observed (within the time period of 17.07.2015 until 15.10.2015) 30 times, the minimum amount (for the last installed peat sett. plates, 26.08.2015) of measurements was 14, in average each peat rod was levelled for 20 times. (Ellmann 2015).

4.2 Measured settlements

In test section 1 and 2 the thickness of the peat layer is approximately 2.0-2.15 m and in test sections 3, 4 and 5 from 3.0 to 3.5 m. The test sections 1, 2 and 3 were constructed with natural aggregates and in test section 4 and 5 was used lightening of the embankment.

The settlement results for each test sections centre line are presented in Fig. 14. During first month after construction in test sections 1 and 2 roughly of 90 % of settlements had occurred before installing surcharge loading. Surcharge load to test section 1 and 2 was installed approximately 3 months after starting construction. The settlements 5-6 months after construction were 880-930 mm.

In test section 3 the peat layer is thicker and due to that settlements higher. In test section 3 settlements after 5 months were 1670 mm. However, in test section 1, 2 and 3 the relative compression of the peat layer after 5 to 6 months is between 43-55 %.

Figure 15. Peat roads placed in pre-designed locations on top of the geotextile-covered peat layer. (Ellmann 2015)

The surface of the embankment has been measured by RPAS in several phases. An example of the result of the RPAS measurement is presented in Fig. 13 where is combined 3D surface model created from the RPAS (Remotely Piloted Aircraft System) photos and aerial photos by Julge (2015).

5 CONCLUSIONS

The test sections construction and field-monitoring has provided valuable information of construction at peat areas. 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 methods have some technical benefits and some (geo) technical or economic limitations. Which method is most suitable in different construction cases and places, must be considered case by case.

Below are preliminary geotechnical conclusions on the basis of experiments of test section construction in Võõbu:

- All the methods described can be applied to constructing roads on layers of peat.
- Test sections were constructed with sufficient global stability (no failures).
- The milling of stumps, sticks, etc. and leaving them to remain in place was a success. Excavating and clearing the surface layer would have otherwise disturbed the soft peat layer and the construction site would have almost impossible to operate.
- Installation of one reinforcement layer instead of two is easier to construct. Possible technical advances of two reinforcement layers for the behaviour of the structure have not been identified yet.
- Installation of geocell mattress is very labour intensive and it’s not yet clear if it is technically better than section with one or two reinforcements (more measuring time and analysing is needed).
- With a 2 m thick layer of peat, it seems the best approach is the removal of the peat layer altogether. When the layer is thicker other solutions are recommended.
- The consolidation of the peat increases the strength of peat significantly – even over two or three times the strength – this phenomenon should be studied and utilized in design and construction.
- In addition, construction of mass stabilization is a considered to be a viable option for ground improvement method for Võõbu area (Forsman et al. 2009).

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. Those analysed results are also a valuable basis for the development of national (Estonian Road Administration) guidelines.

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

6 ACKNOWLEDGEMENTS

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