E263 TALLINN–TARTU–LUHAMAA KM 67-68

KOSE-VÕÕBU TEST EMBANKMENT

FINAL REPORT

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Töö on koostatud Maanteeameti teede arengu osakonna tellimusel

Tallinn
2016

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Revision	**1.0**
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	* updated according comments of Maanteeamet 31.10.2016 and 15.11.2016

Ref E263 TALLINN–TARTU–LUHAMAA KM 67-68
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Appendix 2	Cross sectional settlements. 5 p.
Appendix 3	Ellmann, A. 2016 Geodetic monitoring of the Võõbu test site in II-nd and III-d quarter of 2016 (in Estonian). Tallinn University of Technology, Tallinn. 29 pp.
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Appendix 5	Article, Full scale reinforced road embankment test sections over soft peat layer, Võõbu, Estonia. The 17th Nordic Geotechnical Meeting, Reykjavik Iceland 25th - 28th of May 2016. 10 p.
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1. INTRODUCTION

Various road embankment reinforcements over an approx. 1.8 to 3.4 meter thick peat deposit have been constructed in summer-autumn 2015 in the area of Kose-Võõbu in the northern part of Estonia (Fig 1.1, 1.2 and 1.3).

The intent of the research is to validate technical and economic feasibility of different reinforcement methods over designed road alignment (road E263). Test sections consist of six different road embankments. Test sections consisted of: mass replacement, one- and two-layers georeinforcement, geocell structure, light weight aggregate and EPS lightened embankment structures. To accelerate the consolidation of the peat layer, reinforced test sections are loaded with surcharge.

The client of the test construction was Maanteeamet, geotechnical designer AS Geotechnica Inseneribüroo G.I.B and contractor Lemminkäinen Eesti AS. Site supervision was made by Skepast & Puhkim AS, instrumentation and measurements by Tallinna Tehnikaülikool, Teedeinstitut and reporting by Ramboll Finland Oy.

In addition to the Võõbu test sections there is nearby a mass stabilisation test structure constructed in 2009. The mass stabilised test structure is presented in the article *"Mass stabilisation of E263 highway section Kose-Mäo in Estonia"*. (Forsman et al. 2009) and the long period observations of that structure are presented in the report *"Kose-Mäo test stabilization 2009, compression tests 11/2015 (column penetration soundings, report)"* (Forsman et al 2015b).

Figure 1.1. Location of the test area in Võõbu.

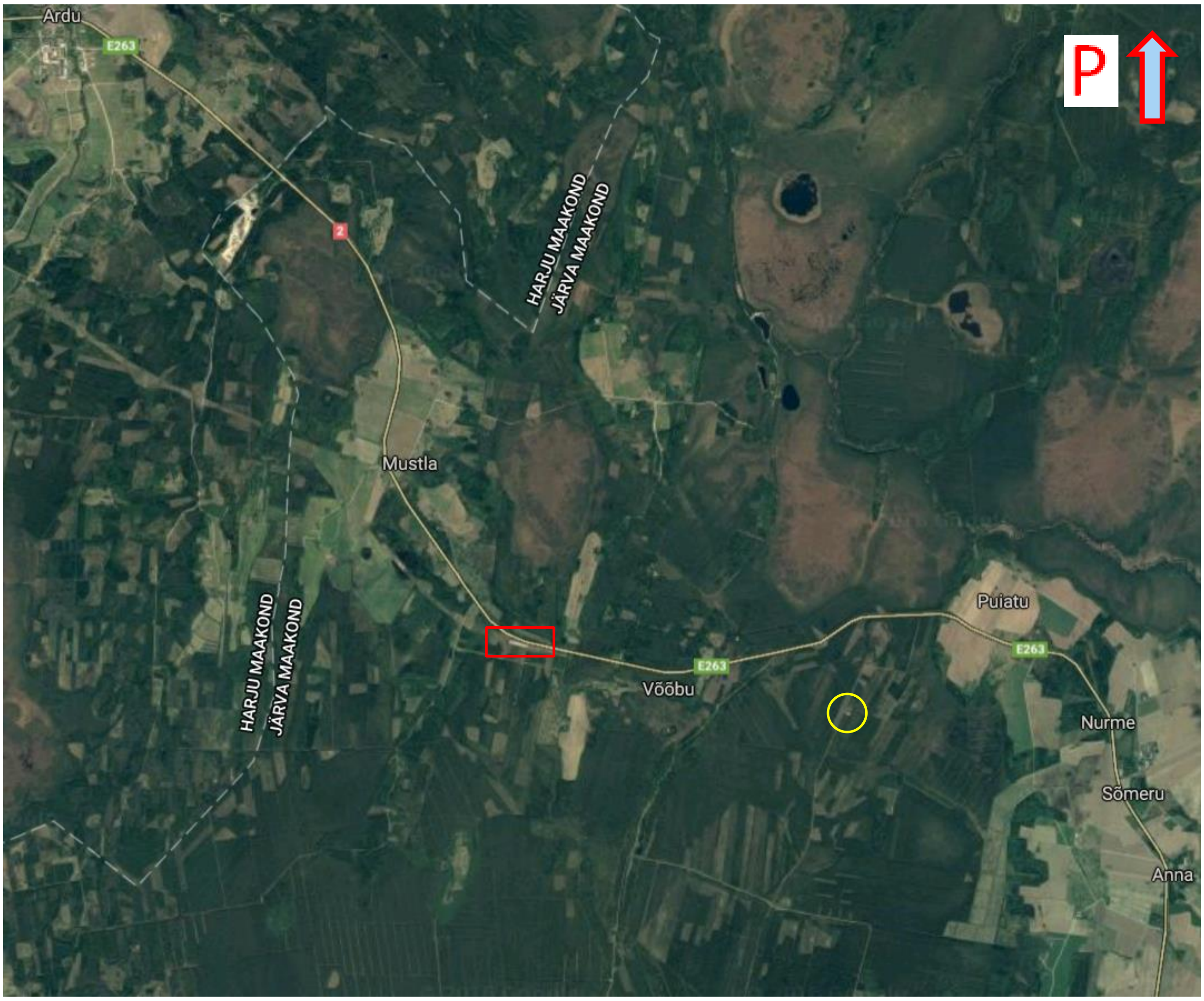

Figure 1.2. Location of the test area of Võõbu between Mustla and Võõbu beside Tallinn-Tartu road. (red box). Location of Kose-Mäo mass stabilization test site is presented with yellow circle.

Figure 1.3. Location of the test structure in Võõbu.

Related reports of Kose-Võõbu test sections

Ellmann, A. 2016 *Geodetic monitoring of the Võõbu test site in II-nd and III-d quarter of 2016* (in Estonian). Tallinn University of Technology, Tallinn. 29 pp.

Ellmann, A. 2016. *Geodetic monitoring of the Võõbu test site in I-th quarter of 2016* (in Estonian). Tallinn University of Technology, Tallinn. 25 pp.

Ellmann, A. 2016. *Geodetic monitoring of the Võõbu test site in IV-th quarter of 2015* (in Estonian). Tallinn University of Technology, Tallinn. 27 pp.

Ellmann, A. 2015. Mounting and monitoring of levelling benchmarks in the Võõbu road construction test site. Tallinn University of Technology, Tallinn

Forsman, J, Dettenborn, T & Skepast, P. 2016. Kose-Võõbu test embankment - Cost comparison report 04/2016. 15 p + 20 app.

Forsman, J, Dettenborn, T & Skepast, P. 2016. Kose-Võõbu test embankment - Preliminary technical analysis, report 04/2016. 41 pp.

Forsman, J, Dettenborn, T & Skepast, P. 2015. Kose-Võõbu test embankment - Construction report 11/2015. 36 p + 276 app.

Forsman, J., Piispanen, P. & Winqvist, F. 2015. Kose-Mäo test stabilization 2009, compression tests 11/2015 (column penetration soundings, report). Espoo 11.12.2015, client Maanteeamet. Ramboll Finland Oy.

Julge, K. 2015. 3D-model from aerial photos. https://sketchfab.com/models/43081376e08f45c89eb5736ec9a4a975

Forsman, J, Dettenborn, T & Skepast, P. 2015. Embankment foundation structures over peat, literature and case study. 37p + 57 app.

Korkiala-Tanttu, L., Gustavsson, H. & Lojander, M. 2015. Mnt2 nr 2 Tallinn-Tartu-Voru-Luhamaa-Kose-Voobu Sektsioon 5 Pk 638+30,50 – 638+60,50, EPS-structure, calculation report. Aalto University, Geoengineering Group. 12 p.

Olep, M. 2015. T2 Võõbu test embankment section, geotechnical calculations (during June and July 2015).

Truu, M. & Tikas, V. 2015. T2 Võõbu katselõigu maaradari mõõdistused. Teede Tehnokeskus. Tallinn, 2015. 6 p.

Maanteeamet 2015. T2 Võõbu katselõigu projekteerimine ja ehitus. Riigihanke „T2 Võõbu katselõigu projekteerimine ja ehitus". HD lisa III Tehniline kirjeldus. 14 p.

Pohjatekniikka OY 2015. Kose-Võõbu tehnilise projekti Mulde ehituse alternatiivide tehnilis-majanduslik võrdluse aruanne ekspertiis.

Kelprojektas 2015. Kose-Võõbu tehnilise projekti Mulde ehituse alternatiivide tehnilis-majanduslik võrdluse aruanne.

Documents 2008-2014	Reaalprojekt 2014. Kose-Võõbu tehnilise projekti geoloogia. Reaalprojekt 2014. Kose-Võõbu tehnilise projekti geodeesia. Ramboll 2009. Kose-Võõbu eelprojekt. Reaalprojekt 2008. Kose-Võõbu eelprojekti geoloogia. Reaalprojekt 2008. Kose-Võõbu eelprojekti geodeesia.

Related articles

Forsman, J, Dettenborn, T, Skepast, P., Mets, M., Olep, M., Ellmann, A., Vallas, I., Tõnts, T. & Kontson, K. 2016. Road Embankment Test Sections over Soft Peat Layer, Võõbu, Estonia. Proceedings of 13th Baltic Sea Geotechnical Conference, Lithuania, 22–24 September 2016, 6 p.

Forsman, J., Marjamäki, T., Jyrävä, H., Lindroos, N., Autiola, M. 2016. Applications of mass stabilization at Baltic Sea region. Proceedings of 13th Baltic Sea Geotechnical Conference, Lithuania, 22–24 September 2016, 6 p.

Forsman, J, Dettenborn, T, Skepast, P., Mets, M., Olep, M., Ellmann, A., Vallas, I., Tõnts, T. & Kontson, K. 2016. Full scale reinforced road embankment test sections over soft peat layer, Võõbu, Estonia. The 17th Nordic Geotechnical Meeting, Reykjavik Iceland 25th - 28th of May 2016, pp. 1279-1288, 10 p.

Forsman, J., Hakari, M., Jyrävä, H., Ritsberg, K. & Skepast, P. 2009. Mass stabilisation of E263 highway section Kose–Mäo in Estonia. XXVII International Baltic Road Conference Riga, Latvia, 24-26.9.2009. 6 p.

2. SITE DESCRIPTION

The test area is a part of Kõrvemaa swamp area (Fig. 1.2 and 1.3). 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 area of sections 1 to 5. 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).

Before construction works the thickness of peat layer in test area was measured (June 2015) with ground penetrating radar (GPR). The average measured dielectric constant was Er=44 which indicates that peat has a high water content.

According to soundings and samples there are three different layers of peat (Figures 2.1 and 2.2). 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 de-composition, w≈400-600 %, τ≈9 kPa
- z=1.5-3.5 m: medium degree of decomposition, w≈700-900 %, τ≈4 kPa

Comprehensive odometer compression tests were conducted on samples from borehole no. 13 (Table 2.1 and Fig. 3.3). Tests were carried out according to standard CEN ISO/TS 17892-5.

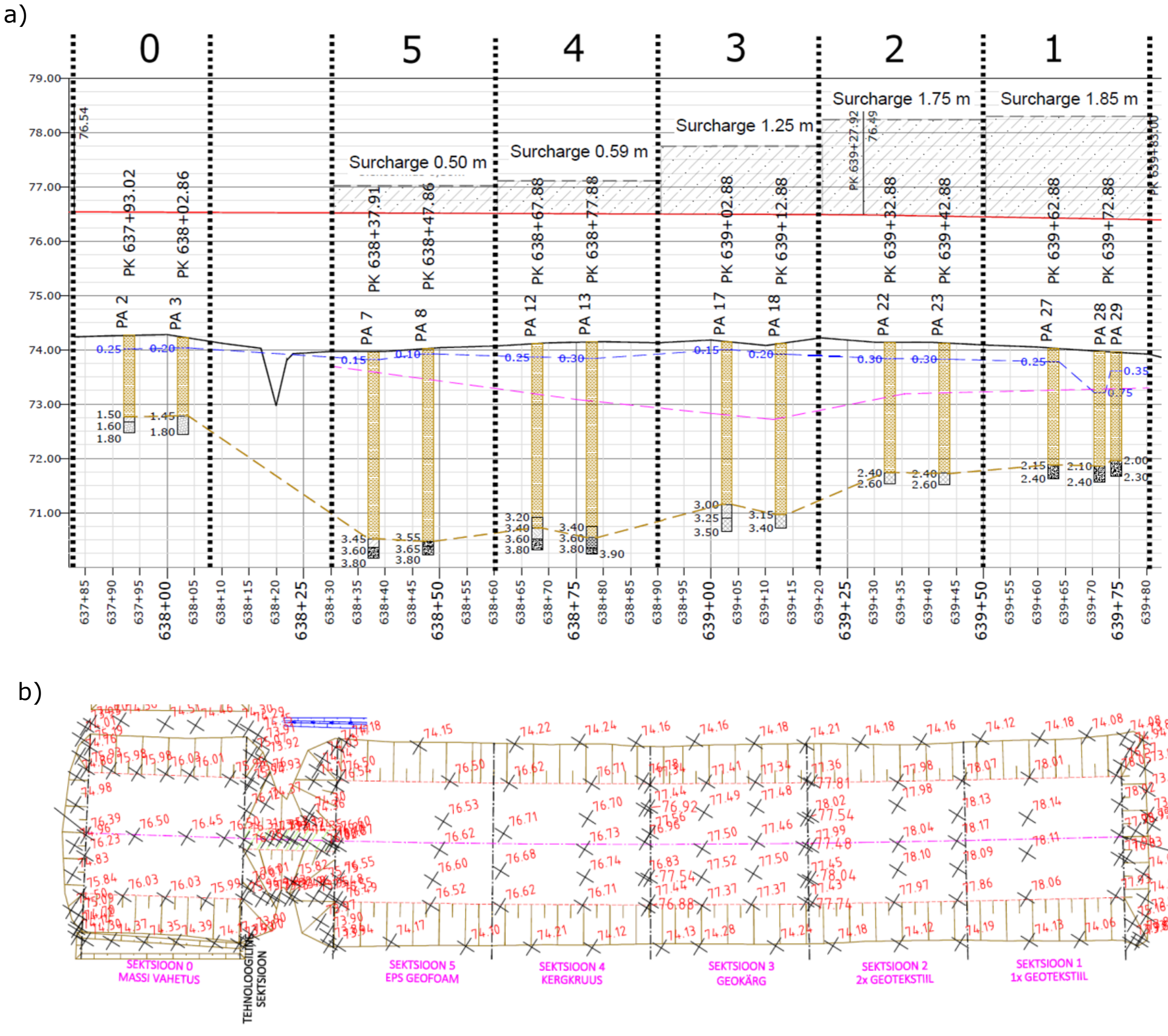

Figure 2.1. a) Longitudinal profile of test area. The red line is the designed level of the road surface. The thickness of the surcharge is as designed before construction of the surcharge. b) Realized level of the surcharge at 30.10.2015 (Ellmann 2016a).

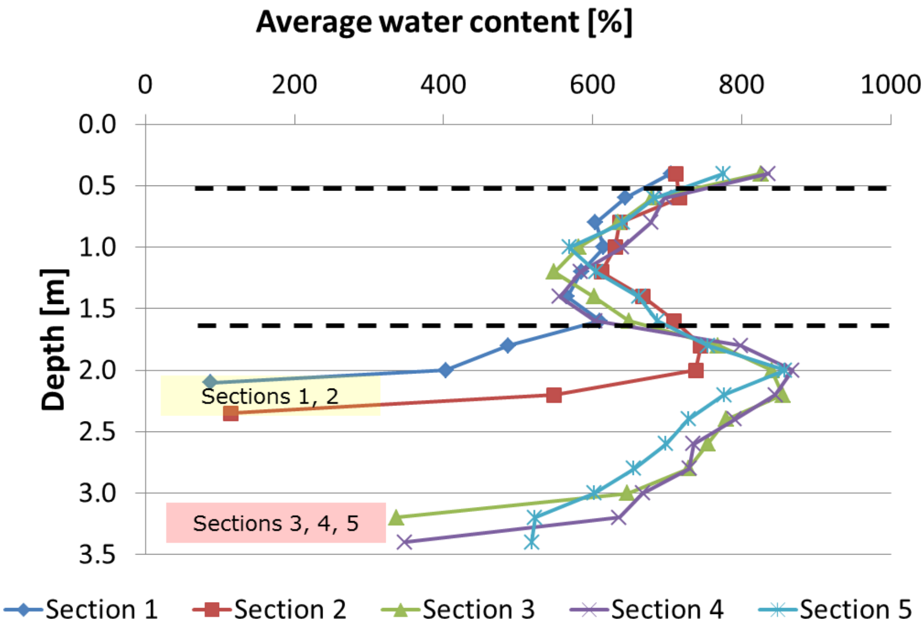

Figure 2.2. Three peat layers and natural water content of peat in the test sections 1 to 5.

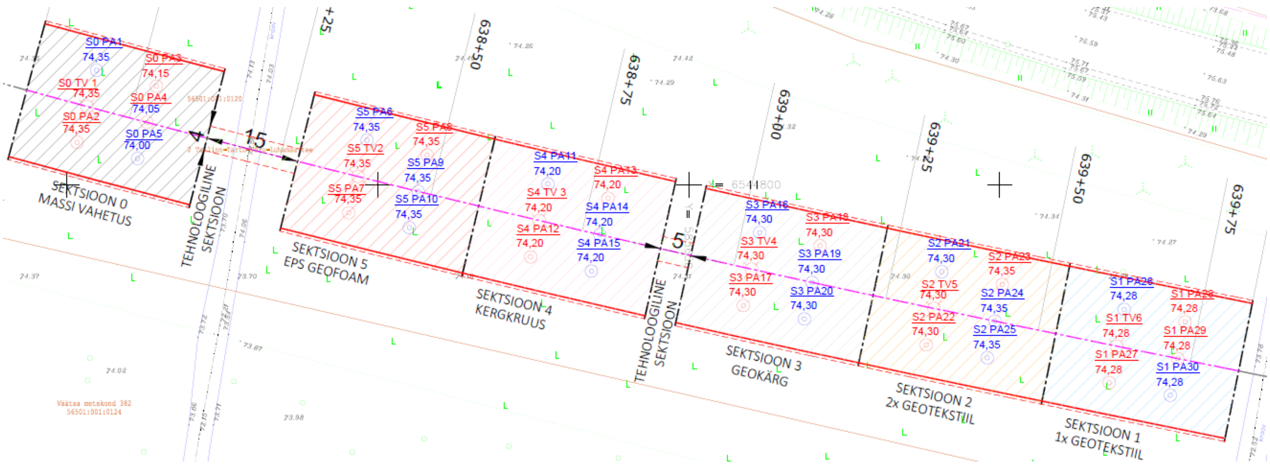

Figure 2.3. Location of soundings and boreholes. The spacing between 3 and 4 does not exist in the final structure layout.

Table 2.1. Odometer 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	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

(1) Loading σ = 0 / 50 / 75 / 100 kPa

* Calculated σ = 25-50 kPa; σ = 50-7:

3. TEST SECTION STRUCTURES AND MATERIALS

3.1 Structures

Description of the structures and construction are presented more detail in cconstruction report 11/2015 (Forsman et. al 2015)

Section 0 consists of mass replacement (Appendix 1, Figure 1). Section 0 is a reference for other structures and it will not be overloaded.

Section 1 consists of one layer of georeinforcement (600/50) on top of peat. In the edges of the embankment georeinforcement was folded at least 5.7 m towards centre line ("wrap around anchoring"). The cross-section 1 is presented in Appendix 1, Figure 2.

Section 2 consists of two layers georeinforcements. On top of the peat was used 400/50 kN/m and upper inside the embankment 200/50 kN/m strength georeinforcement. In the edges of the embankment georeinforcements were folded at least 5.0 m towards centre line. In the middle the vertical distance between the georeinforcements is 0.5-0.8 m. The cross-section of test section 2 is presented in Appendix 1, Figure 3.

Section 3 consists of geocell reinforcement mattress. Before building the geocell mattress geogrid (40/40) was placed on top of the subsoil (peat). The height of the geocell was 1 m and it was filled with 0/64 mm limestone aggregate without compaction inside the geocell. The cross-section of test section 3 is presented in Appendix 1, Figure 4.

Section 4 consists of georeinforcement and light weight aggregate (LWA). Before constructing embankment georeinforcement (400/50) was installed on top of peat layer. At the edges of the embankment was build 1 m thick aggregate barrier and the LWA was installed (1.0-1.5 m) between the barriers. The used LWA was expanded clay aggregate with grain size distribution of 10/20 mm. In the edges the minimum thickness of the LWA was 1 m. The cross-section of test section 4 is presented in Appendix 1, Figure 5.

Section 5 consists of EPS-blocks. EPS-blocks were preliminary designed to be connected to each other with metal rods but this was changed to PVC-pipes (ϕ 25 mm) and plastic connectors at the surface of the EPS-layer.

EPS-blocks were designed to be protected with 0.5 mm thick LLDPE-plastic membrane. EPS-block layer was covered with 0.9 m thick aggregate layer. To get better bearing capacity for the final road structure a geogrid (40/40) was designed to the aggregate layer.

The cross-section of test section 5 is presented in Appendix 1, Figure 6.

3.2 Materials

Descriptions of the materials used in test structures are presented more detail in construction report 11/2015 (Forsman et. al 2015).

3.2.1 Long term water absorption of lightweight aggregate (LWA)

The Finnish Transport Agency guidelines give different design values for LWA depending on the water level conditions. The design values for density are presented in table 3.1.

Table 3.1. Characteristic design values for LWA in different conditions (Leca 2016; Finnish Transport Agency 2011).

Density	Characteristic value
Dry, loose	3.0 kN/m^3
Dry (w = 30 weight-%)	4.0 kN/m^3
Periodically submerged	6.0 kN/m^3
Permanently submerged	10.0 kN/m^3

3.2.2 Long term water absorption of EPS

EPS placed in the ground will absorb water in two ways. One is by water entering possible voids between spheres due to water pressure or capillary rise. Since water vapor may diffuse through the polystyrene when there is a temperature gradient, the water vapor will condense in the spheres if there is a drop in temperature below the dew point. However, in an EPS block of 500 mm thickness or an EPS fill of greater thickness the temperature difference over the block or fill will be very small. Possible water absorption due to water vapor diffusion is therefore expected to be small. (Norwegian public Roads Administration 2002)

Drained conditions:
The tests made to samples that have retrieved from EPS sites where is drained position i.e. blocks are located above the highest groundwater or flood level, all show water contents below 1%. by volume after more than 20 years in the ground. (Norwegian public Roads Administration 2002)

Periodically and permanently submerged conditions:
In blocks, which are periodically submerged, water contents of up to 4 % by volume have been measured. In permanently submerged blocks measured water contents have reached values close to 10 % by volume with some increase over the years. Further increases above 10 % by volume are, however, not to be expected. The water content decreases rapidly above the water table and show values for drained conditions only some 200 mm above the highest water level. (Norwegian public Roads Administration 2002)

4. EXPLORATION METHODOLOGY

4.1 Soundings, sampling and laboratory tests

The soundings and samples at the test area were taken 17.-19.6.2016 with ground investigation machine GM65. The locations for sounding and boreholes are presented in Figure 2.3. Soundings included:

- Total of 13 boring holes
- Approximately 130 samples. The samples were taken with auger drilling method (110 mm).
- One vane shear test from each section (vane 150 mm x 75 mm, 0.5 vertical steps)

Water level have been measured beside test section 3 at both sides (Fig. 4.1) at level +74.1 - +74.3 at period 10/2015 – 03/2016 (Forsman et al. 2016a).

4.2 Geophysical investigations

Before construction the peat layer thickness was measured (10.6.2015) from three survey lines with ground penetrating radar (GPR). The used GPR antennas were 400 MHz and 100 MHz GSSI antennas and also 500 Hz MALA antenna. The 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. The more detailed description of methods and results are presented in GPR-report (Truu & Tikas 2015).

4.3 Settlement measurements

Altogether 98 measurement points for settlement measurements were installed (locations are presented in the Fig. 4.1). The executive summary of mounting and monitoring of levelling benchmarks is presented in report Ellmann 2015.

- 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).

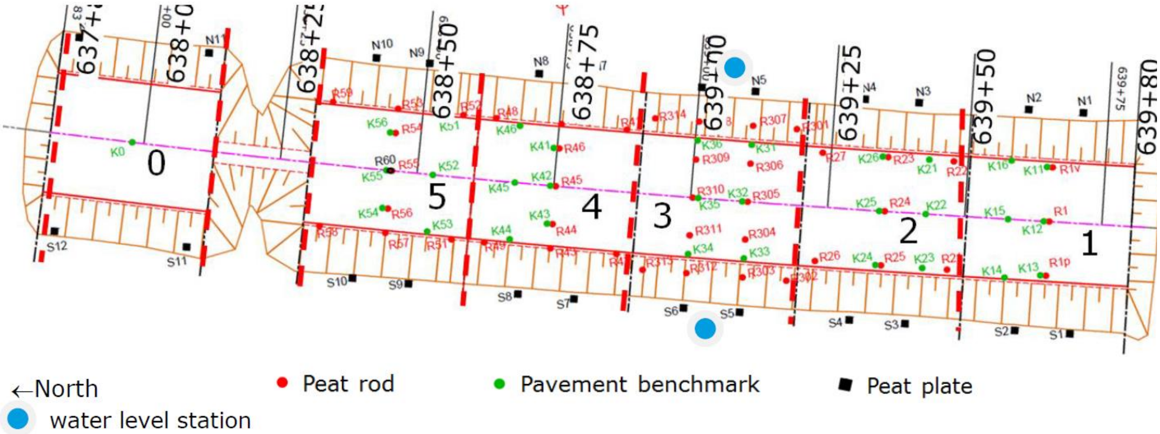

Figure 4.1. Location of the levelling benchmarks. 0. mass replacement, 1. one layer and 2. two layers of georeinforcement, 3. geocell mattress, 4. light weight aggregate and 5. EPS light weight embankment structure. (Forsman et al. 2016a)

5. SETTLEMENT MEASUREMENT RESULTS

In this report is presented settlement measuring results from the construction and installation of the settlement plates at summer and autumn 2015 until the end of September 2016.

5.1 Total settlement

In Figure 5.1 is presented the measured settlements of the peat and pavement benchmarks at the centre line until 27.9.2016. The load presented does not take into account the effect of buoyancy when the bottom of the embankment has settled below ground water.

Until 27.9.2016 the measured settlement is ≈900-1000 mm at sections 1 and 2, ≈1600-1800 mm at sections 3 and 4 and ≈1100-1200 mm at section 5.

5.2 Adjusted settlement

In case the properties of the peat are homogenous and the width of the embankments is the same, the settlement of peat layer is only dependent on the embankment load and the thickness of the peat layer. The latest settlement measuring results are from September 2016 and according those results under the sections 1 / 2 / 3 / 4 / 5 the measured settlements of peat layer are 1004 / 969 / 1750 / 1601 / 1172 mm and relative compressions 51 / 38 / 52 / 46 / 35 % (Tables 5.1 and 5.2 and Figure 5.1).

Table 5.1. Thickness of peat layer, embankment load, measured settlement, relative compression of the peat layer until 27.9.2016 and settlement speed at period 30.8.-27.9.2016. <u>Relative compression</u> = (measured compression of the peat layer) / (original peat layer thickness). In the point code the first number after "R" tells the number of the section (for example in code "R45" means "4" section 4).

Point	Thickness of peat layer [m]	Embankment load [kPa] *	Settlement [mm] until 29.7.2016	Relative compression [%]	Settlement speed 30.8. -27.9.2016 [mm/month]
R1	1.96	97	1004	51	1.3
R24	2.53	76	969	38	1.9
R305	3.29	79	1754	53	3.5
R310	3.39	79	1743	51	2.9
R45	3.47	60	1601	46	3.3
R55	3.37	42	1172	35	2.7

* this load does not take into account the effect of buoyancy

Table 5.2. Measured and adjusted settlement. <u>Peat thickness factor</u> means for example at section 1 = (peat thickness of section 1) / (peat thickness of section 5). <u>Adjusted settlement</u> = (peat thickness factor) × (adjusted settlement).

Point	Thickness of peat layer [m]	Peat thickness factor [-]	Measured settlement [mm] until 29.7.2016	Adjusted settlement [mm] until 29.7.2016
R1	1.96	1.77	1004	1777
R24	2.53	1.37	969	1329
R305	3.29	1.05	1754	1850
R310	3.39	1.02	1743	1785
R45	3.47	1.00	1601	1601
R55	3.37	1.03	1172	1207

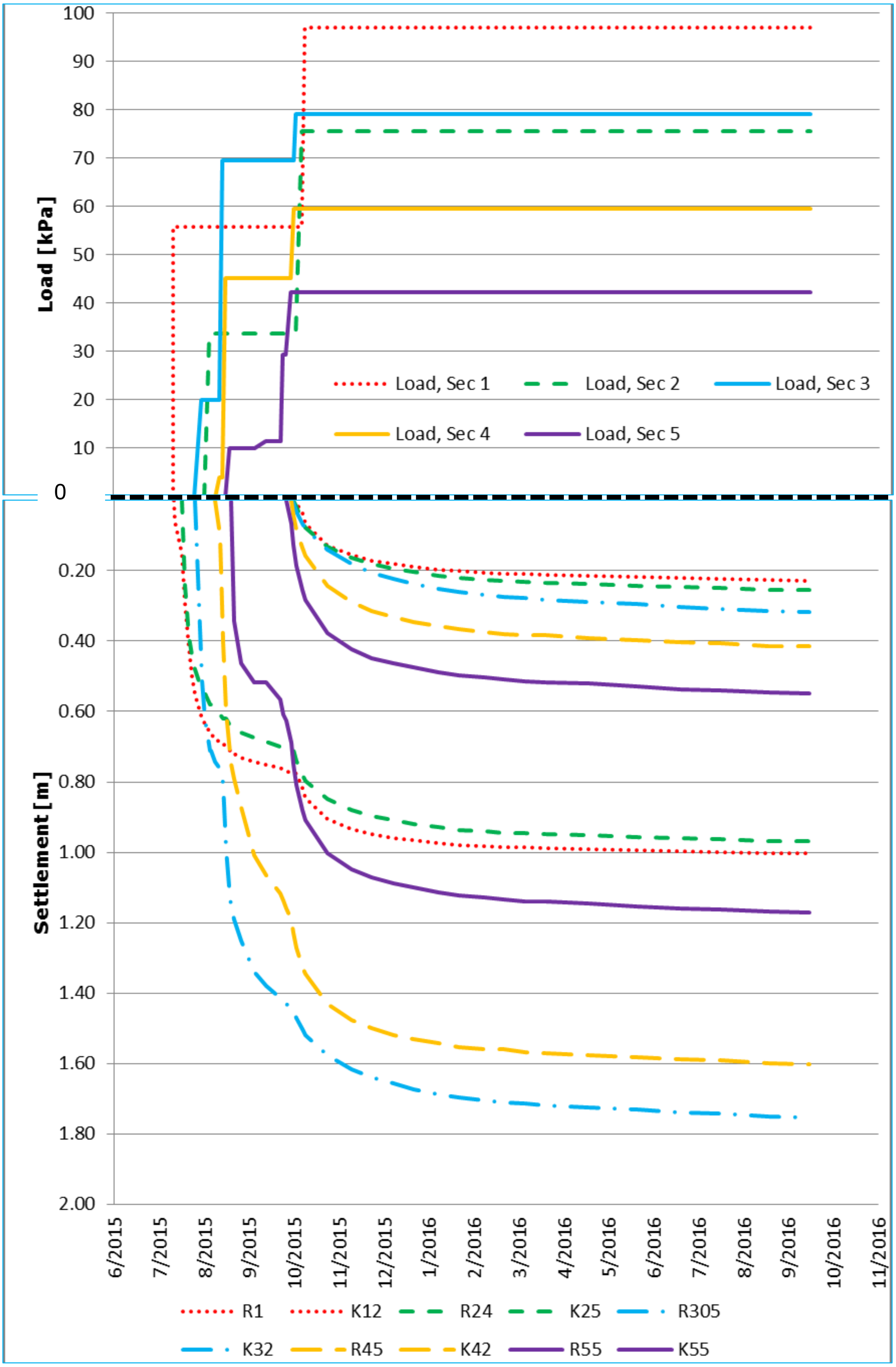

Figure 5.1. Sections 1 to 5. Measured settlements of the settlement plates over peat and surface at the centre line. The load presented does not take into account the effect of buoyancy when the embankment has settled below ground water. In the point code the first number after "R" or "K" tells the number of the section (for example in code "R45" means "4" section 4).

5.3 Settlement speed and estimation

The settlement behaviour of the point R44 (test section 4) is presented in Figure 5.2. The peat under the embankment reacts clearly to loading and the primary and secondary settlement phases of the peat layer are visible.

The fitted settlement curves and settlement observations are presented in Figure 5.3. The fitting has been done on the basis of the observations of the last secondary settlement phase. It seems that the secondary settlement phase has started at 12/2015. The settlement estimations based on the current measurement results are presented in Table 5.3. In the estimations the surcharge embankment is like it is as it's now and the removal of the surcharge has not been taken into account in the estimations. In the Table the final settlements are estimated to be in range 20 to 40 mm for the final road alignment.

The settlement speed after surcharge loading 10/2015 is presented in Figure 5.4.The settlement speed has decreased and at time period 30.8.-27.9.2016 it has been 1.3 to 3.5 mm/month. The slowest settlement speed is in test sections 1 and 2 where the speed is 1.3 to 1.9 mm/month. In sections 3, 4 and 5 where the peat thickness is over 3 m, the settlement speed is 2.9 to 3.5 mm/month. The settlement speed of sections 1 and 2 is small taking into account that both test sections have approximately 1.6 m of surcharge loading that will be removed before construction of the road structures. The removal of the surcharge will decrease the settlement speed of final road.

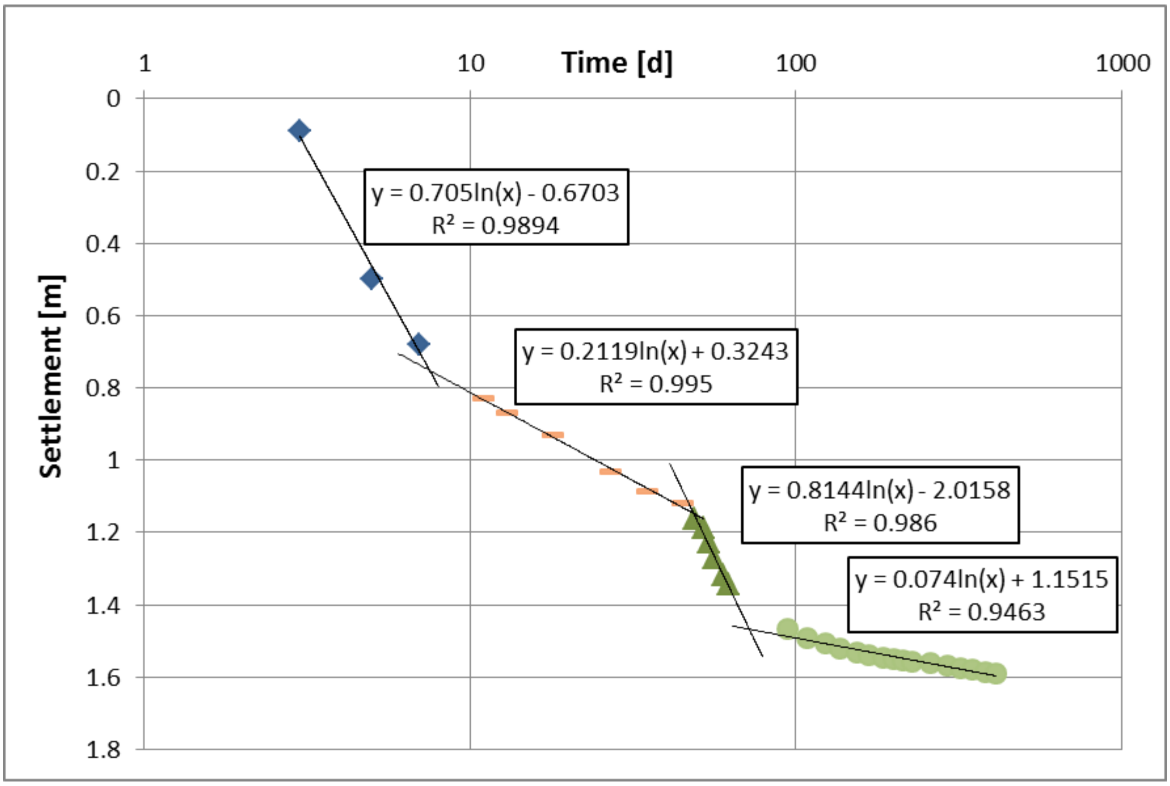

Figure 5.2. Settlement in logarithmic scale and settlement fitting curves. Test section 4, point R44.

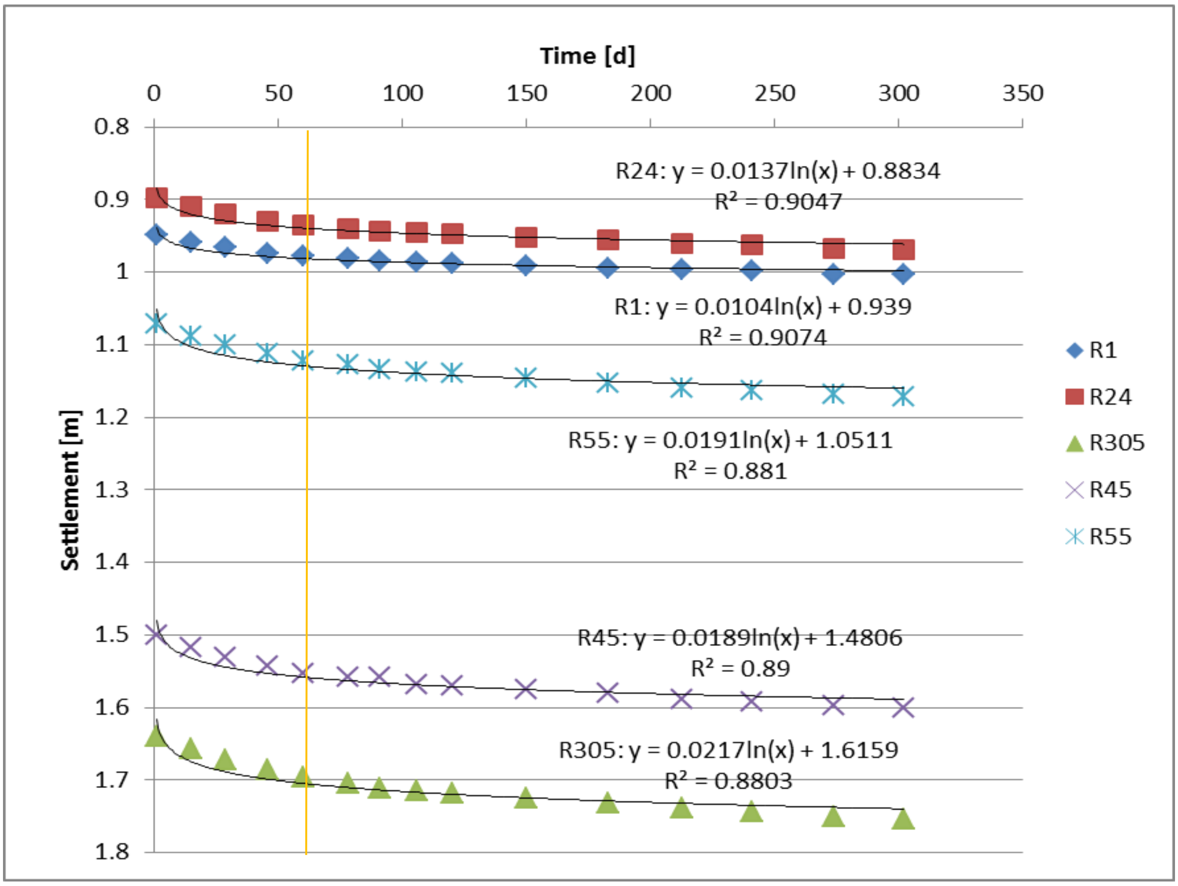

Figure 5.3. Measured secondary settlements of center line settlement plates. The secondary consolidation is estimated to start 12/2015 (≈day 60 in Figure). The curve presented in the Figure has been fitted in logarithmic scale (see Fig. 5.2). In the point code the first number after "R" tells the number of the section (for example in code "R45" means "4" section 4).

Table 5.3. Estimated secondary settlement for the embankment centre line based on the curves and equations presented in Figure 5.3. The estimation does not take into account the removal of surcharge loading.

Settlement plate \ Time	12/2016	12/2017	12/2018	12/2019	12/2020	12/2030	12/2040	12/2070	12/2116
Settlement difference for secondary consolidation from starting date 12/2016									
R1	0	7	11	14	17	19	20	22	23
R24	0	9	15	19	22	25	27	28	30
R305	0	15	24	30	35	39	42	45	48
R45	0	13	21	26	30	34	37	39	42
R55	0	13	21	26	31	34	37	40	42

5.4 Surface layer settlement

In Figure 5.4 and in Table 5.4 is presented the current situation of the test sections pavement surface and comparison to designed road alignment level. In test section 1 and 2 the surface layer has settled 250 to 280 mm below designed road alignment and in test section 3 370 mm. In test sections 4 and 5 the surface has settled 510 to 570 mm below designed road alignment.

Table 5.4. The current test section surface level to designed road alignment (Table data compiled from Ellmann 2016). In the point code the first number after "K" tells the number of the section (for example in code "K45" means "4" section 4).

Location	Surcharge surface level	Designed surface alignment	Measured surface level 27.9.2016	Surface difference * [m]	Designed surcharge thickness [m]	Surcharge over red line ** [m]
K12	+78.28	+76.43	+76.20	-0.23	1.85	1.62
K15	+78.28	+76.43	+76.15	-0.27	1.85	1.58
K22	+78.24	+76.49	+76.22	-0.27	1.76	1.49
K25	+78.24	+76.49	+76.19	-0.29	1.76	1.46
K32	+77.77	+76.52	+76.15	-0.36	1.25	0.89
K35	+77.77	+76.52	+76.14	-0.37	1.25	0.88
K42	+77.12	+76.53	+76.04	-0.49	0.59	0.11
K45	+77.12	+76.53	+75.99	-0.54	0.59	0.06
K52	+77.04	+76.54	+75.98	-0.56	0.51	-0.05
K55	+77.04	+76.54	+75.95	-0.58	0.51	-0.08

* measured level – designed level

** surcharge over designed road alignment surface ("red line"), situation in 27.9.2016

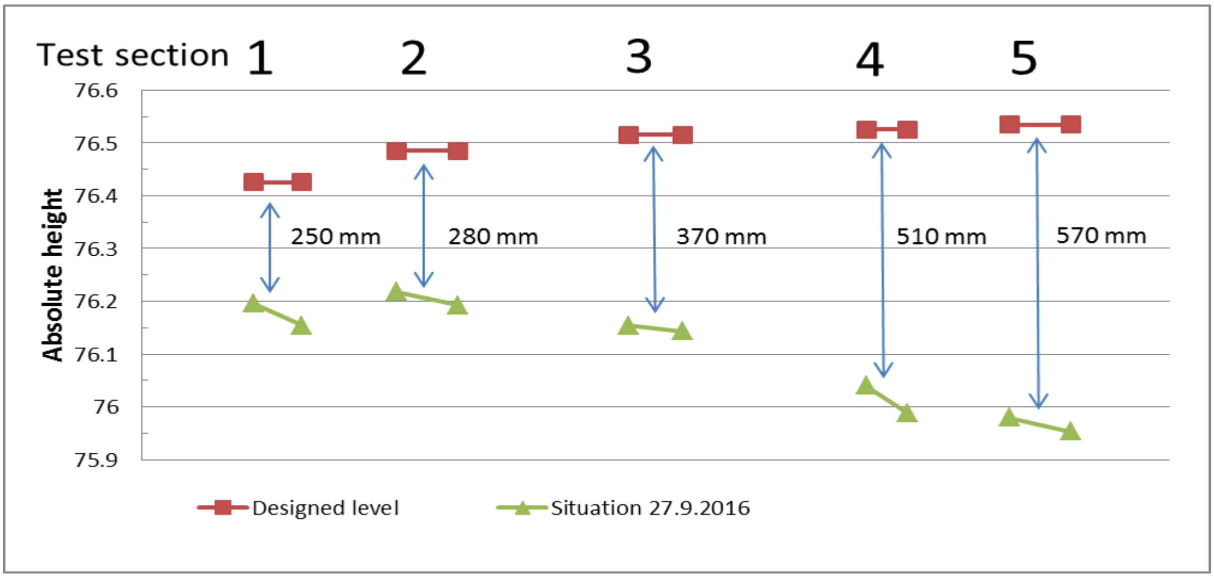

Figure 5.4. The current situation of the surface level compared to designed level of the road alignment (red line).

5.5 Cross-sectional settlements

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. In Appendix 1 is presented the settlement difference graphs for each test section.

Based on these measurement results on September 2016 it seems that the final road cross-section profile is not settling unevenly. 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.

5.6 Formation of moss on surface of section 4

In the report of Ellman (2016b) is presented photos from formation of moss due to moisture over section 4 (Fig. 5.5a). The reason for that moisture is not known but in the 3D model of Julge (2015) seems to be an anomaly area with exceptional coloured surface at the same area just after the construction of the surcharge embankment. Maybe the properties of that sand are different (grain size distribution, mineral composition, …).

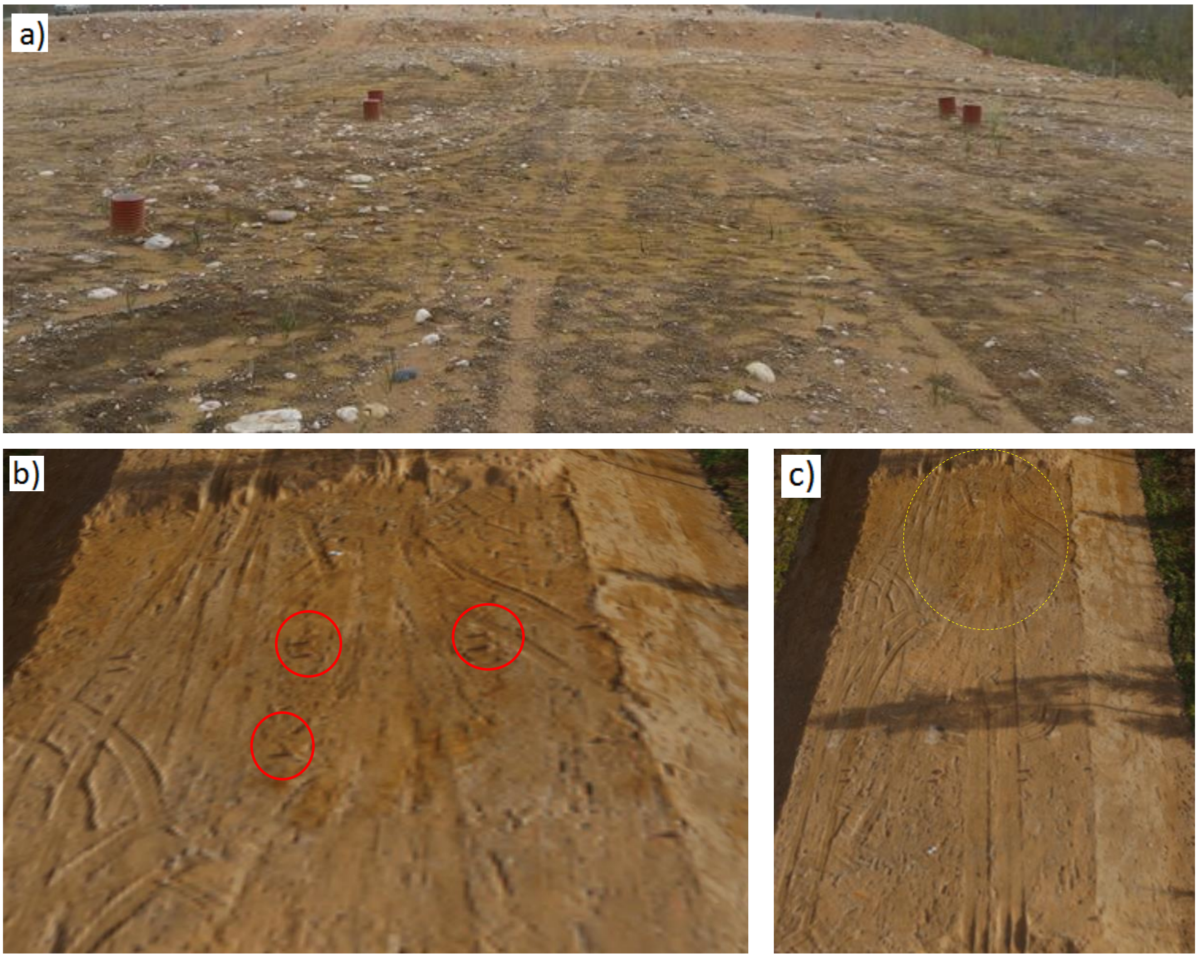

Figure 5.5. Section 4. a) Formation of moss (due to moisture) in the middle of Sections 4, a screenshot from photo 27.9.2016 (Ellman 2016b). b) and c) A screenshot shot from the 3D model of Julge (2015). Red circles are at the location of settlement plates presented in Figure "a" and yellow circle at the area of anomaly coloured sand and formation of moss.

5.7 Compaction of the embankment fill

The total compaction (compression) of the embankment material is presented in Table 5.4. The compaction of the embankment material has occurred shortly after construction of the surcharge loading and will not be significant during road service time. Ellmann (2016) has presented the embankment compaction results in more detail.

Table 5.5. Compaction (compression) of the embankment fill after surcharge loading 10/2015.

Section	1	2	3	4	5
Compaction	3 - 5 mm	2 - 4 mm	4 - 8 mm	0 - 1 mm	6 - 10 mm

5.8 Test sections left under new road alignment

Current test section can be left under construction of the road if need be. Please see further requirements in Appendix 9.

6. FINANCIAL FEASIBILITY STUDY

6.1 Test structures constructed in Kose-Võõbu

The construction material volumes of test sections 0 to 5 are calculated according pay items given by Lemminkäinen AS. The costs of the pay items are estimated according to cost-calculation program Rapal FORE (RAPAL). The unit prices for each pay item and calculation principles are presented in cost-comparison report 4/2016 (Forsman et al. 2016b). In Table 6.1 is presented the cost comparison between the constructed test sections of Võõbu.

Also alternative options (6, 7, 8 and 9) have been costs calculated with assumption that the peat layer thickness is 3 m and the constructed embankment is similar to constructed test section 1. In test section 0 the peat layer thickness has been varied in order to compare it to other test sections. The alternatives costs for mass replacement are calculated for cases where the average thickness of the excavated peat layer is 1.8 m, 3.0 m (0*) and 4.0 m (0**).

A comparison of construction costs with different peat thicknesses is presented in Figure 6.1. The true costs of different construction methods depend several multiple factors such as construction timetable, embankment design (embankment height, allowable settlements, stability), availability of aggregates, locations of peat "dumping" places, geology, geotechnical parameters etc. The most suitable cost efficient design solution should be always designed case by case.

The cost estimations in Figures 6.1 and 6.2 are calculated for embankment height of 2.5 m above initial peat level. The geometry of the standard simplified cross-section used in comparison calculations is presented in Figure 6.2. The embankment dimensions are similar that were constructed in Kose-Võõbu. The calculation does not include road superstructure layers. The material loss due to settlement is estimated with the relative compression of the peat which is measured or calculated based on measurement results. More detailed description of the calculated embankment is given in feasibility report (Forsman et al. 2016b).

The calculations show that the cost for different reinforcement methods depends greatly on the initial costs (=costs of the georeinforcement materials). The increase of the cost is mainly depended of the peat layer thickness and by compression of the peat layer (= embankment material "loss" due to the settlement).

Table 6.1. Cost comparison between different structures (€/m-road). Structures 0, 1, 2, 3, 4 and 5 are tested at Võõbu. Structures 0, 0**, 6, 7, 8 and 9 are theoretical.*

Cost comparison between test sections			Structure											
			0	0*	0**	1	2	3	4	5	6	7	8	9
			1 772 €	2 512 €	3 109 €	1 749 €	1 646 €	2 764 €	2 770 €	3 142 €	3 053 €	8 359 €	3 152 €	2 615 €
Structure	0	1 772 €		-740 €	-1 337 €	23 €	127 €	-991 €	-998 €	-1 370 €	-1 281 €	-6 587 €	-1 380 €	-843 €
	0 *	2 512 €	740 €		-597 €	763 €	866 €	-252 €	-258 €	-630 €	-541 €	-5 847 €	-640 €	-103 €
	0 **	3 109 €	1 337 €	597 €		1 360 €	1 464 €	346 €	339 €	-33 €	56 €	-5 250 €	-43 €	494 €
	1	1 749 €	-23 €	-763 €	-1 360 €		104 €	-1 014 €	-1 021 €	-1 393 €	-1 304 €	-6 610 €	-1 403 €	-866 €
	2	1 646 €	-127 €	-866 €	-1 464 €	-104 €		-1 118 €	-1 124 €	-1 497 €	-1 407 €	-6 713 €	-1 506 €	-969 €
	3	2 764 €	991 €	252 €	-346 €	1 014 €	1 118 €		-6 €	-379 €	-289 €	-5 595 €	-388 €	149 €
	4	2 770 €	998 €	258 €	-339 €	1 021 €	1 124 €	6 €		-372 €	-283 €	-5 589 €	-382 €	155 €
	5	3 142 €	1 370 €	630 €	33 €	1 393 €	1 497 €	379 €	372 €		89 €	-5 217 €	-10 €	527 €
	6	3 053 €	1 281 €	541 €	-56 €	1 304 €	1 407 €	289 €	283 €	-89 €		-5 306 €	-99 €	438 €
	7	8 359 €	6 587 €	5 847 €	5 250 €	6 610 €	6 713 €	5 595 €	5 589 €	5 217 €	5 306 €		5 207 €	5 744 €
	8	3 152 €	1 380 €	640 €	43 €	1 403 €	1 506 €	388 €	382 €	10 €	99 €	-5 207 €		537 €
	9	2 615 €	843 €	103 €	-494 €	866 €	969 €	-149 €	-155 €	-527 €	-438 €	-5 744 €	-537 €	

0 Peat excavation depth = 1.8 m
0 * Peat excavation depth = 3 m
0 ** Peat excavation depth = 4 m
1 one layer of georeinforcement
2 two layer of georeinforcement
3 Geocell
4 LWA
5 EPS
6 Sand Columns
7 Reinforced concrete slab with piling
8 Slag embankment
9 Mass stabilization

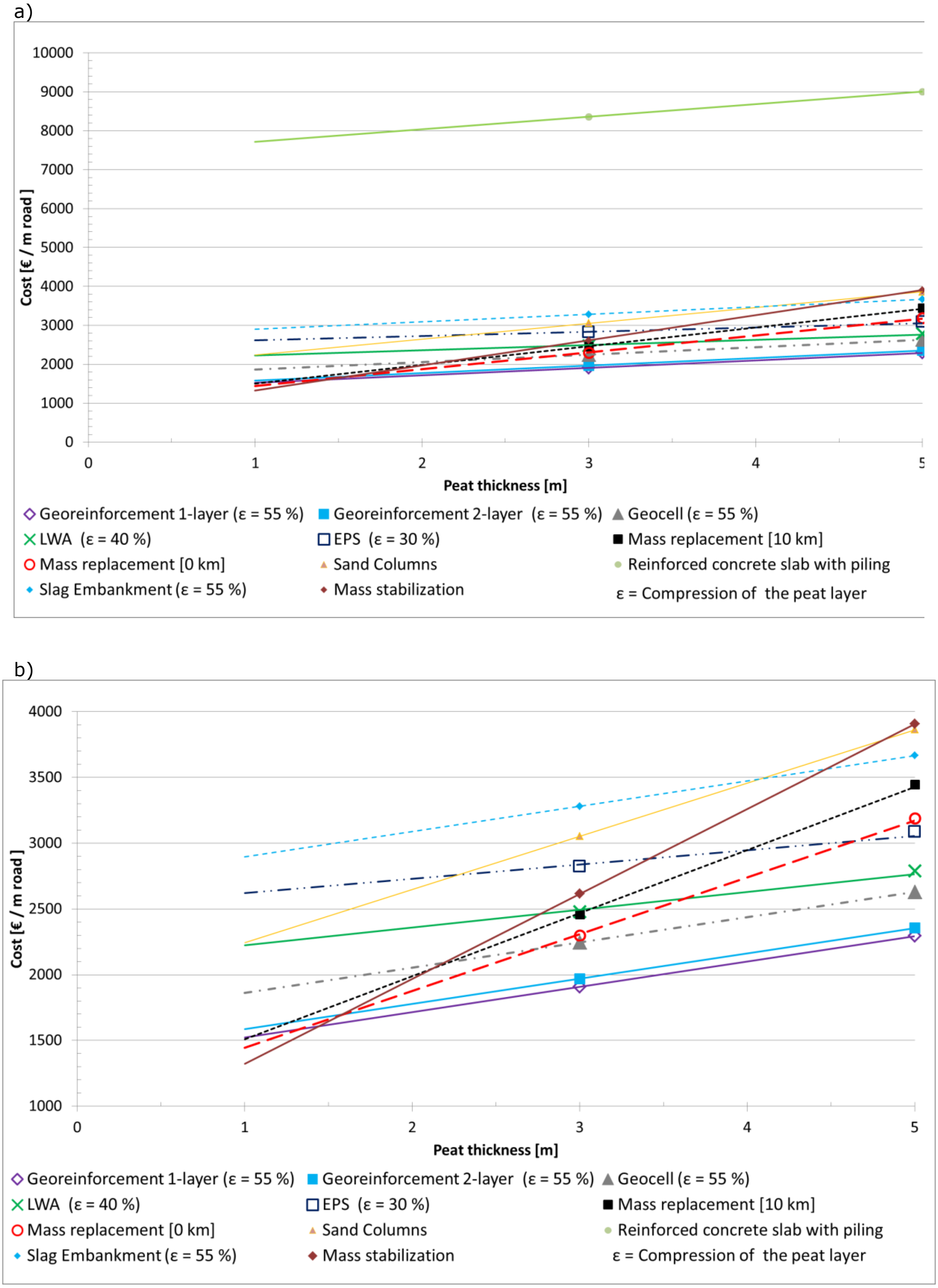

Figure 6.1. Construction costs for different construction methods a) price range limited to 10 000 €/m-road b) price range limited to 4000 €/m-road. The final surface of the embankment ("red line") is 2.5 m over peat level beside the road. The calculation does not include any road superstructure layers.

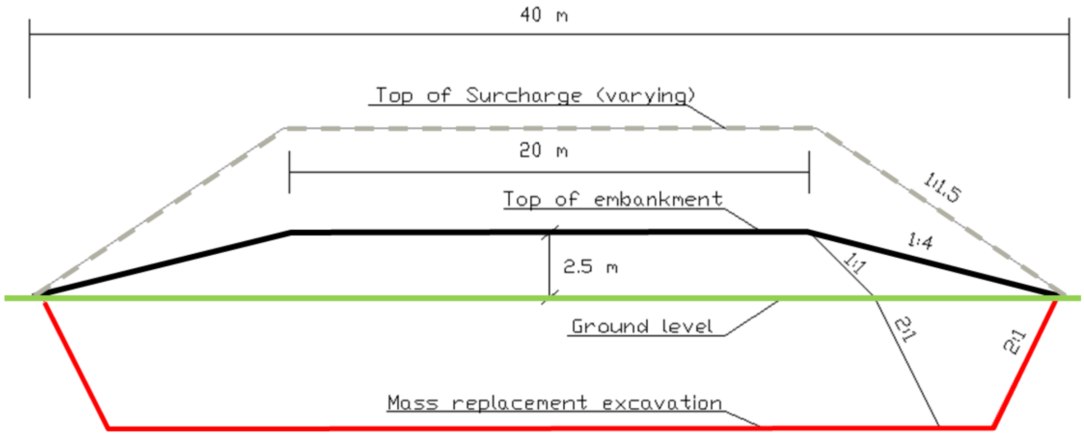

Figure 6.2. Simplified principle cross-section of cost comparison calculations (Figure 6.1) for different peat thicknesses.

<u>1- and 2-layer georeinforcement</u>
The reinforcement costs of the 1- and 2-layer georeinforcement structures will increase as a function of embankment height and peat layer thickness. Higher embankment and deeper peat layer requires stronger georeinforcement in order to secure enough stability of the embankment. The embankment material "loss" due to the settlement is also increasing as a function of embankment height and peat layer thickness.

<u>Geocell</u>
In geocell structure the dominant cost are the initial cost of the geocell materials and the labor costs of building the geocell honeycomb structure from Tensar-geogrids. The costs of geocell will increase as a function of embankment height and peat layer thickness.

<u>LWA and EPS</u>
The high initial material costs increase the costs of the lightened structures. However, the increase of the costs with the increase of the peat layer thickness can be smaller than in georeinforcement structures, because the relative compression of the peat layer is smaller and because of that the material loss is smaller.

<u>Mass replacement</u>
The cost of mass replacement is very sensitive for the unit price of the aggregate of the mass replacement, peat layer thickness and the transportation distance and the disposing cost of the peat.

<u>Mass stabilization</u>
The price of mass stabilization is very feasible in case of peat depth 2-3 m if it is compared to structures tested in Võõbu. In technical comparison with mass stabilization and Võõbu test structures, it has to consider that the settlement of mass stabilization is minor or does not exist after settlement during construction time but all test sections 1 to 5 are on un-stabilized peat and there will be some settlement after preloading. The cost for 3 m depth mass stabilization is estimated to be 78 465 €.

Even ≈70 % of the unit price of mass stabilization can be dependent of the price of binder. In case the amount (kg/m^3) and unit price (€/kg) of the binder is low, the unit price of the mass stabilization is lower and vice versa the price of mass stabilization is higher when the amount and the price of binder is higher. The price of the binder can be lower for example in the case of fly ash based binder and the price can be higher in the case of pure cement.

6.2 Alternative solutions

Reinforced concrete slab with piling
In cost calculations the piles and concrete slab are dimensioned according to Finnish Transport Agency guidelines and Eurocode (Appendix 6). The piles middle to middle distance is 2.1 m × 2.3 m and the thickness of the reinforced slab is 400 mm. In cost calculations the estimated pile length is 6 m (3 m peat layer) and the piles are 300 mm x 300 mm concrete piles. Dimensions of the concrete slab are 34 m x 30 m (1020 m^2). The cost estimation for piles and concrete slab solution is presented in table 6.3 and 6.4. The price estimation for reinforced concrete slab with piling is approximately 250 000 €/section area.

Sand columns
In calculations is used diameter of 0.8 m stone columns and the middle to middle spacing on 2.0 m × 2.0 m. The dimensioning of sand columns is presented in Appendix 6. The total amount of sand columns is 289 (area of 30 m × 34 m). The length of sand column is 3.5 m (3 m peat layer). On top of the sand columns are installed 2-layers of reinforcements to distribute the loads from embankment to piles (2 layers are needed because the reinforcement force is needed in both directions).

The sand columns are constructed by displacement method (Figure 6.3). The metal casing is driven to soil and vibrated out leaving filled sand columns with reinforcement encasement to the soil. The price estimation for reinforced sand columns and basal reinforcement is approximately 86 000 €/section area (Appendix 7).

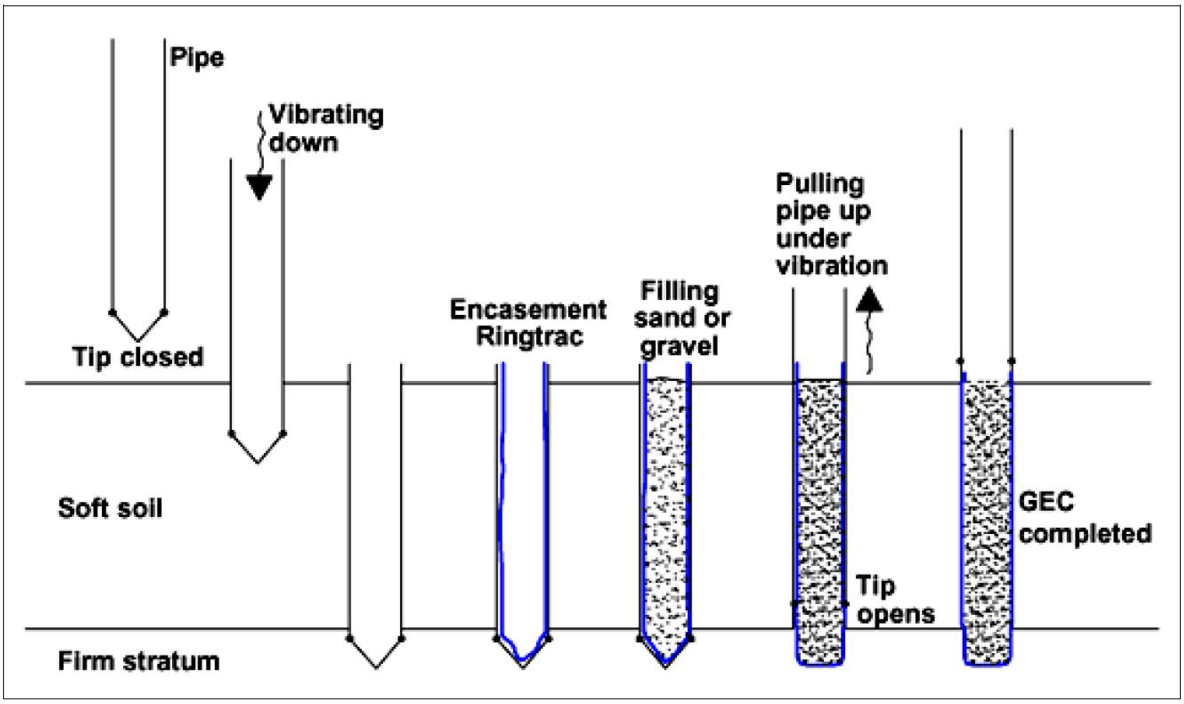

Figure 6.3. Displacement method of construction. (Alexiew et al. 2011)

Granulated blast furnace slag embankment:
The unit weight of granulated blast furnace slag (0/63-0/125) as compacted to structure is approximately 16-19 kN/m^3 which means that slag is not a light weight material. The unit weight depends of the grain size distribution of the granulated slag. The dimensioning of slag embankment is similar to sections 1 or 2 (see Figure 6.2, length of the section 30m). The friction angle and the modulus of the slag is higher than the local sand used in embankments, but those properties don't give any benefits in dimensioning on reinforced embankment.

The better technical properties (E-modulus, friction angle and thermal conductivity) of the slag can be utilized in the dimensioning of the superstructure. The better properties possibly reduce the thicknesses of superstructures and asphalt layers.

In the cost calculations the unit price for granulated blast furnace slag is quotation estimation from SSAB Europe Oy (Table 6.2). The slag is calculated to be imported from Luleå, Sweden to harbor in Tallinn. The price for compacted granulated blast furnace slag (0/63-0/125) is approximately 25 €/m^3. The price for slag is higher for finer grain size distributions. The price estimation for replacing embankment material with granulated blast furnace slag is approximately 95 000 € (Appendix 7).

Table 6.2. Granulated blast furnace slag costs and density (SSAB Europe Oy).

Grain size	Price [€/t]	Bulk Density [t/m^3]	Compacted density [t/m^3]
0/31.5	15.5 - 18.5	1.35	
0/45	14.5 - 17.5	1.35	
0/63	14.2 - 17.2	1.35	1.6 - 1.9
0/90	13.4 - 16.4	1.32	
0/125	13.0 - 16.0	1.30	1.5 - 1.8
0/250	12.6 - 15.6	1.28	
0/350	11.25 - 14.25	1.20	

Table 6.3. Estimated total construction cost for 3 m thick peat (embankment dimensions similar as used in test sections)

Reinforced concrete slab	Sand columns	Slag embankment
250 771 €	91 611 €	94 569 €

Table 6.4. Estimated construction cost for building one meter of highway on top of 3 m thick peat layer (embankment dimensions similar as used in test sections)

Reinforced concrete slab	Sand columns	Slag embankment
8 359 € / m-road	3 054 € / m-road	3152 € / m-road

Cost estimations of alternative solutions in case of different peat thicknesses is presented in Figure 6.1.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

1. Settlement measurement

The timetable for the removing of the surcharge embankment is not known at the moment. The measurements of settlement plates should continue until removing of the surcharge with 6 months intervals. In case the removing is during 2018 or later, the measuring interval can be increased to 12 months.

When the surcharge will be removed, the measuring timetable will be: 1) before removing surcharge loading, 2) after removal of surcharge loading, 3) 1 month after removal of surcharge loading, 4) 3 months, 5) 6 months, 6) 12 months, 7) 18 months, 8) 24 months, 9) 36 months, 10) 48 months, etc.

The measurement points (settlement plates) and program has to be evaluated again at the point when new road alignment is going over the test sections. Then we have to decide what measurement points we will keep and protect.

2. Vane shear tests

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 exactly known with the peat of Võõbu. The proposed vane shear test and sampling program is presented in Figure 7.1.

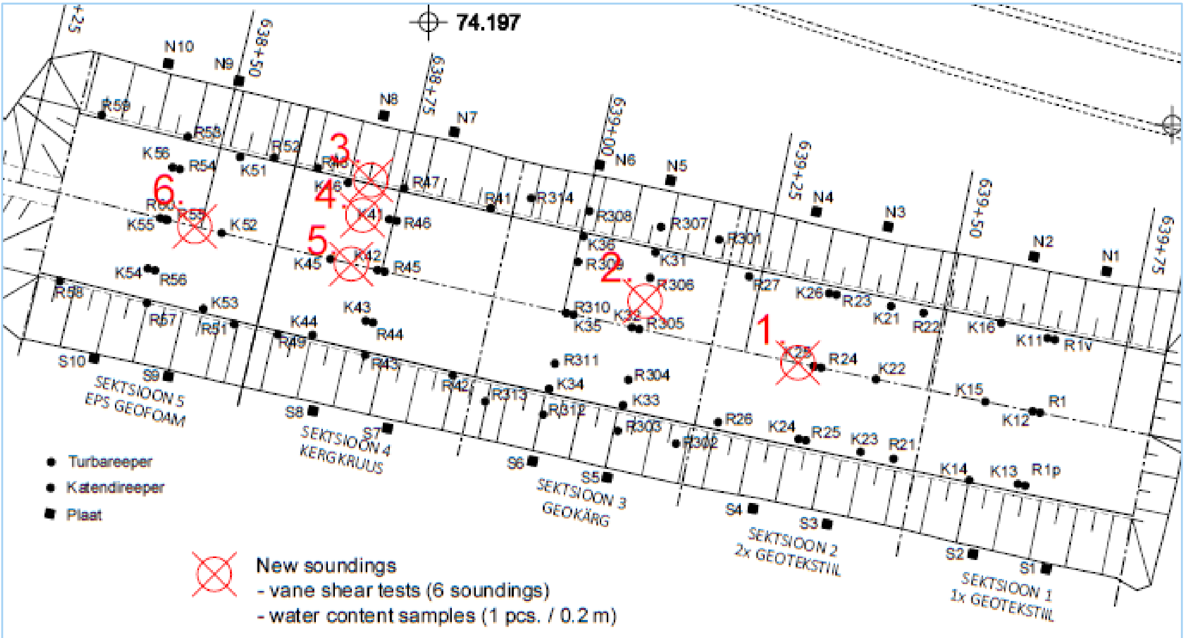

Figure 7.1 Program for new vane tests and sampling (Ramboll 30.5.2016).

3. Mass stabilization test areas

Near Kose-Võõbu test section is located stabilization test field of Kose-Mäo (Fig. 1.2). The soil properties of the stabilization test site were quite similar to Kose-Võõbu (peat thickness of 2.5 to 3 m and water content 760-930 %) As a conclusion from the mass stabilization test site: mass stabilization seems to be reasonably good soil improvement method for Kose-Mäo highway soft soil areas aiming environmental safety, geotechnical advantages and cost savings in the project.

3.1 New mass stabilization test areas: In case mass stabilization will be used at deeper peat areas (z ≈ 3 to 7 m), further test stabilizations are needed and recommended. It seems that the water content is higher at deeper peat layers which means more unfavorable water-cement ratio. With larger mass stabilization volumes it is reasonable to optimize the binder mixture and amount “in situ". Also the settlement of embankment at hardening time can be measured at real test sites and that way get a realistic estimation for the extra embankment volume needed.

<u>3.2 Kose-Mäo mass stabilization embankment heightening</u>: There are settlement plates in Kose-Mäo test site. Those plates have been measured at 2009 and 2015. Some settlement measuring results are confusing because some plates seem to rise instead of settling. To get more reliable settlement measuring results, the heightening of the embankment is reasonable. The strength of the mass stabilized peat of test site is known by the soundings made 11/2015 (Forsman et al. 2015). The modulus of the stabilized peat of that test site is not tested "in situ" but it could be determined by heightening embankment and measuring existing settlement plates. That way the modulus can be calculated on the basis of the embankment load and the settlement.

The area of the Kose-Mäo test embankment is about 45 m × 35 m (A ≈1580 m^2, Figure 7.2). In case the raising of the embankment is 1.0 m, the volume of the embankment material is about 1500 m^3. The volume of surcharge embankment of Võõbu sections 1 and 2 is roughly estimated about 1500 m^3 together. So it seems that the 1-1.5 m heightening of the Kose-Mäo embankment is possible to do with the removed surcharge material of Võõbu test embankment.

a)

b)

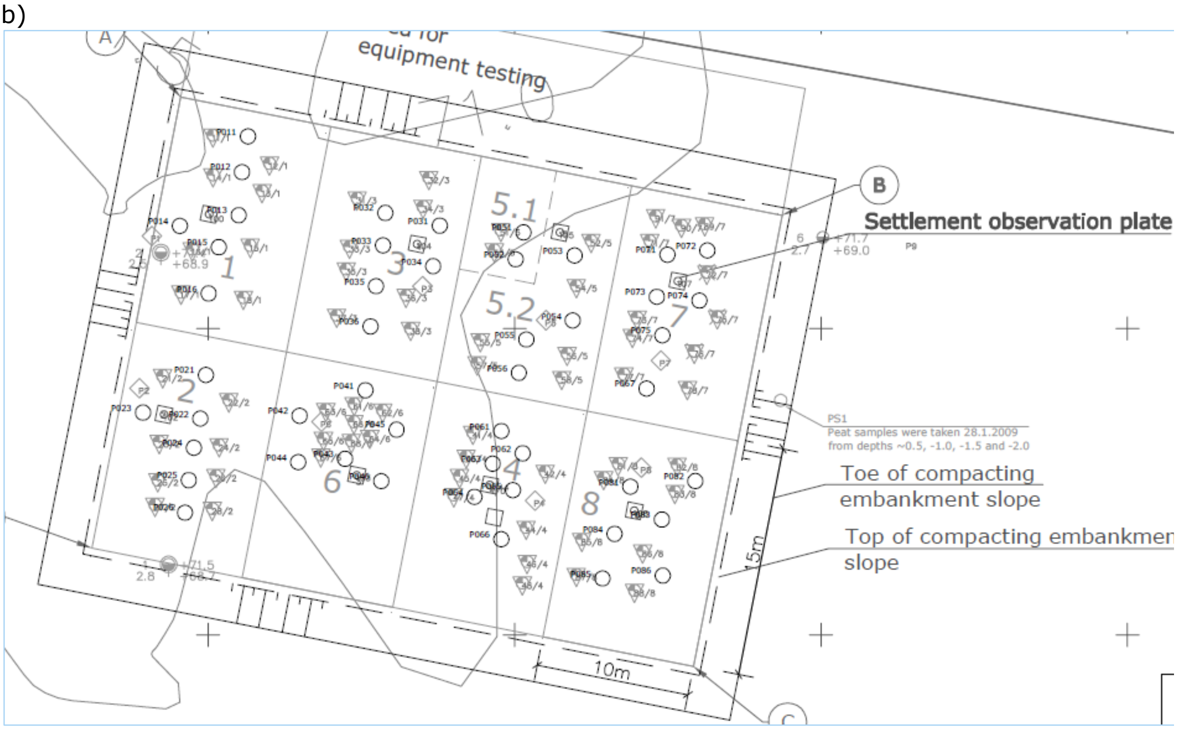

Figure 7.2 Kose-Mäo mass stabilization test site. a) Aerial photo, red circle = Võõbu test area and yellow circle = mass stabilization test site. b) Map of mass stabilization test site.

4. Back-calculations

4.1. Back-calculations of mobilized georeinforcement forces with FEM-analyze: The mobilized tension force in the reinforcements is not measured. The deformations of the embankment are measured and initial soil parameters are determined. With FEM-analyzes the mobilized tension force in georeinforcements can be estimated and with consolidation analysis and FEM-analysis it is possible to estimate the development of the tension forces

4.2. Back-calculations and fitting of the peat consolidation parameters: The peat consolidation parameters have been determined with peat samples from test site and other locations at the peat area. With back calculations and parameter fitting to the settlement observations, there is possible to get more realistic parameters than in laboratory test.

Back calculations is possible to carry out now or later when the observation period is longer. Back calculations are possible to do as a thesis in technical university (e.g. Aalto university) on a basis of a separate order.

8. CONCLUSION

In peat areas the performance estimation of the designed road alignment should be done case by case according to designed geometry, measured geology and realistic timetable. In the design phase the settlement (and stability) calculations need several iterations that will adjust the embankment and surcharge height (loading), embankment material (normal, light weight), need for retaining or soil improving structures (reinforcements, mass stabilization) and construction (and surcharge) timetable.

Methods that leave the peat in place can be split up to 5 groups of techniques where the peat layer has been utilised as a load bearing layer (Figure 8.1). In Figure is marked with red quadrangle methods which have been tested in Võõbu and Kose-Mäo test sections. Additional to those methods have been used mass replacement by excavation method in Võõbu test area.

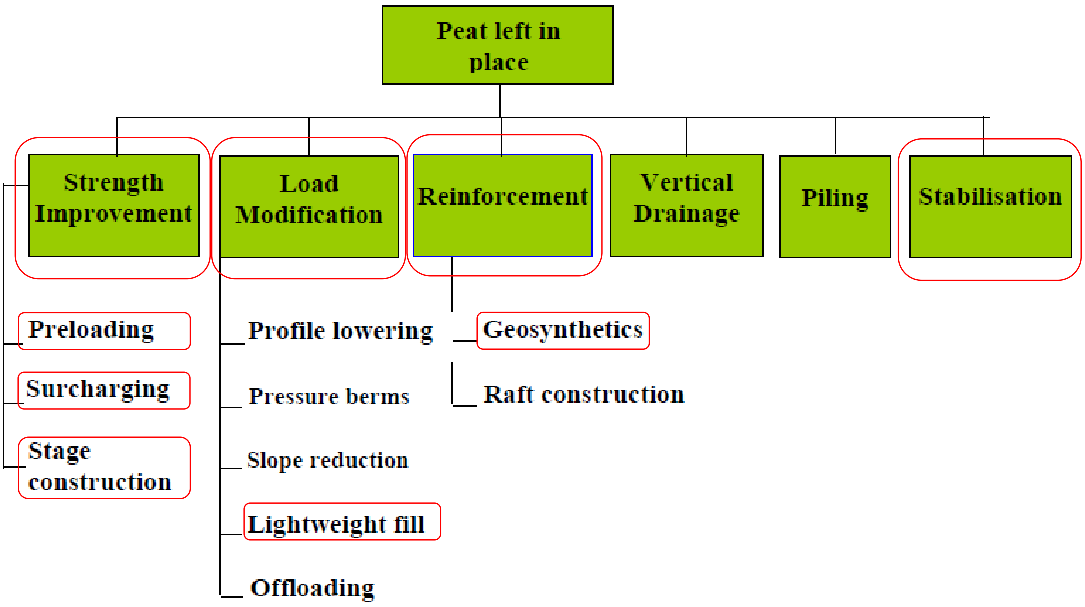

Figure 8.1. Peat left in place techniques (Munro 2004). With red quadrangle marked methods have been tested in Võõbu and Kose-Mäo test embankments.

8.1 "Peat left in place" methods in Võõbu

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. The peat under the embankment reacts clearly to loading and in the settlement results peats primary and secondary settlement phases are visible.

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 September 2016 the final road cross-section profile seems not to 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.

After 1 year surcharge can come to preliminary conclusions:

Test section 1 and 2 (1- and 2- layer georeinforcements)

Georeinforcement structures are feasible options for construction roads in peat areas with moderate peat depth. In Võõbu there was not found a clear benefit of two-layer georeinforcement. The several layer georeinforcement should be considered if more embankment stability is needed in construction or in road service phase.

The design of georeinforcement structure requires careful design for different construction phases. The costs and challenges of georeinforcements structures will increase as a function of embankment height and peat layer thickness. Higher embankment and deeper peat layer requires stronger georeinforcement in order to secure enough stability of the embankment. Deeper peat layer means also longer surcharge time and more risk of uneven settlements.

Test section 3 (geocell)

Geocell structure is labour intensive reinforcement method that requires plenty of georeinforcements. The dominant cost is the initial cost of the geocell materials and the labor costs of building the geocell honeycomb structure from geogrids.

Test section 4 and 5 (LWA and EPS)

The construction method of the light weight section was not the most optimal. The preloading was constructed after construction of LWA and the result is that the LWA-layer is settled into the peat layer under the ground water. In Figure 8.1 is presented estimation where the light weight structures have settled. More optimal is to construct first preloading embankment and after removing of the preloading embankment, construct LWA-layer and superstructure. Recommended principle for the constructing the lightweight structures are presented in Figure 8.2.

The total settlement of a peat layer under road embankment is a function of peat thickness and properties and embankment thickness and width. To the settlement after construction of road superstructure is affecting the same elements than to the total settlement, but the magnitude of the settlement after construction is a function of the surcharge load, loading time and the long period creep and decomposition of the peat. Surcharge loading needs the right load and time. The magnitude of the surcharge is limited by the stability of the embankment. The needed surcharge time is a function of the peat layer thickness and the properties of the peat. In cases where the thickness of the peat layer, the properties of the peat and the load and width of the embankment are quite homogenous, the dimensioning of the surcharge load and time is quite straightforward. When the thickness and the properties of peat layer and the embankment load and width are varying, the dimension and design of the surcharge load and time is very demanding and some uneven settlement can be the final result.

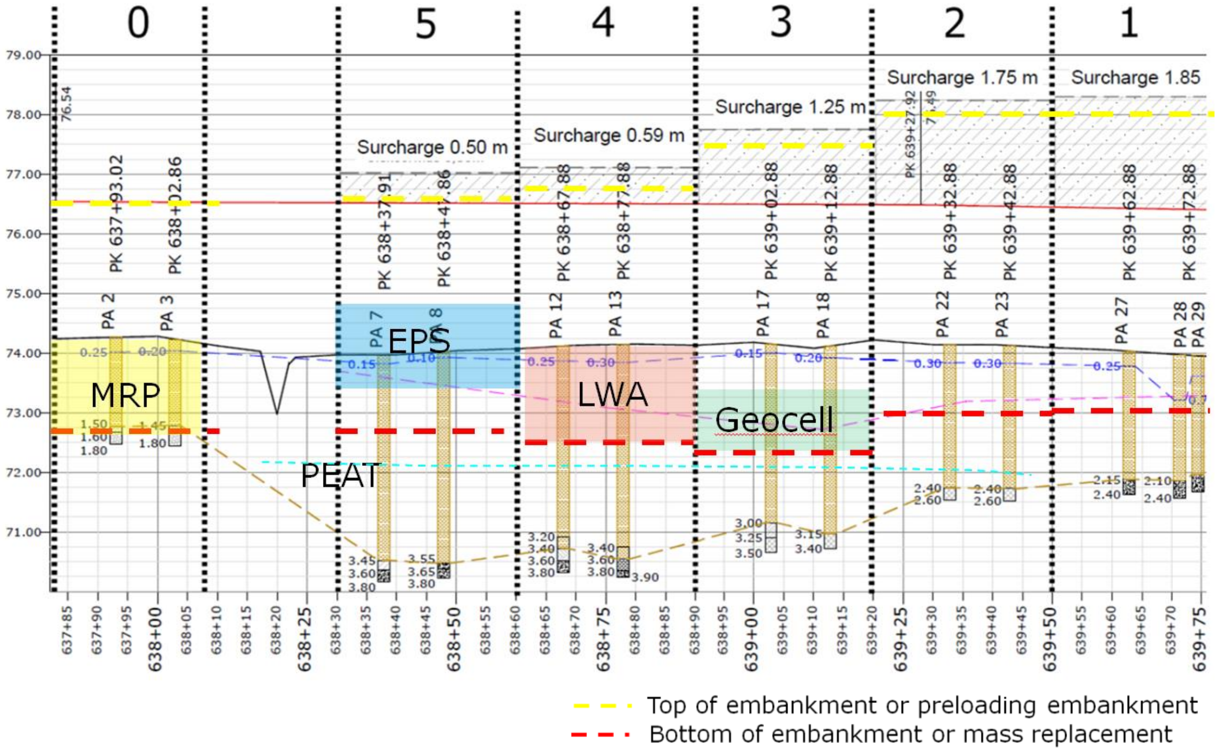

Figure 8.1. Vertical location of the georeinforcements, geocell, LWA and EPS based on settlement measuring results until 03/2016. In sections 1 to 5 the lowest reinforcement is at the bottom of the embankment (red dash line).

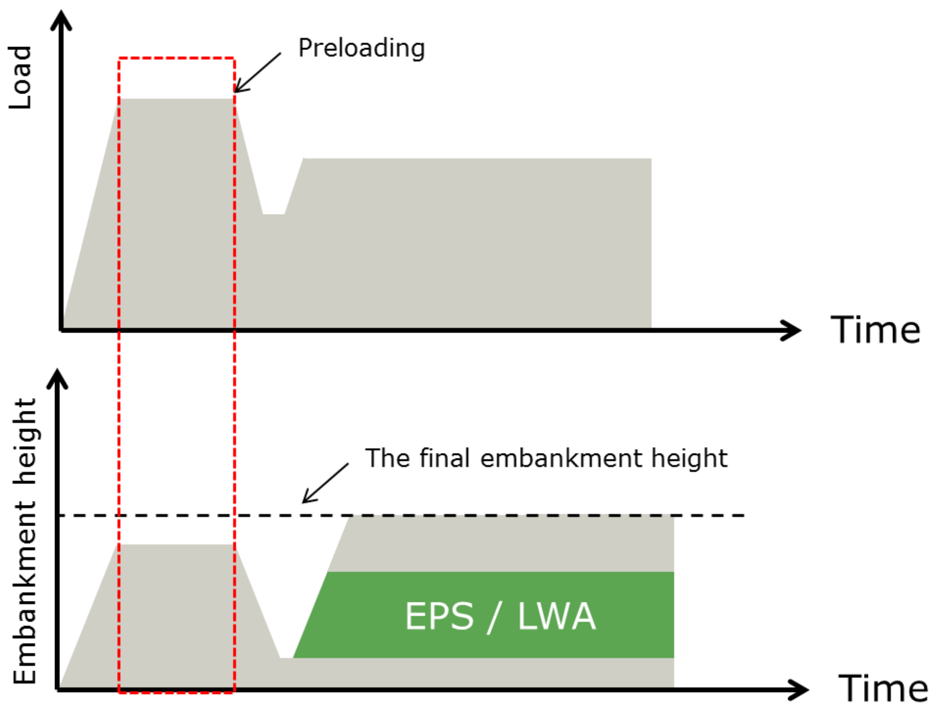

Figure 8.2. The recommend principles of the construction phases of lightened structures at peat area. The load presented is "total load" and it does not take into account the effect of buoyancy when the lower part of the embankment has settled below the ground water level.

8.2 Mass stabilization and mass replacement

<u>Test section 0 (mass replacement)</u>

Mass replacement has been used in section 0 of Võõbu test area. The construction was easy because the peat depth was low and excavated peat was possible to left beside the replacement area. The settlements of the replacement area are minor so the structure was successful. In cases of deeper peat layers, the construction is more challenging, quality controlling difficult and uneven settlements possible.

<u>Kose-Mäo test area (mass stabilization)</u>

Mass stabilisation field test at road section Kose-Võõbu (at km ≈67.1) is made in January and February 2009. The binder was pure cement or mixture of cement + oil shale ash. There have been conducted quality control soundings at 2009 and 2015 to determine the shear strength of the mass stabilized peat. The target shear strength was 50 kPa, which has been achieved in every test area and in some areas the realised strength is 2 to 3 times over the target strength.

According to the quality controlling soundings 2009 and 2015 the average shear strengths of mass stabilised peat layer have mainly increased even up to ≈120 % between 2009 and 2015. The greatest increase has taken place at area 6 where the binder mixture is 70 kg/m^3 cement and 100 kg/m^3 oil shale ash.

According to the settlement measurement results, the stabilisation has not settled even though the extra load was added in the end of 2009. Heave 0-14 cm (average 5 cm) was observed compared to previous 2009 results.

Conclusion: Target strength has achieved and the settlement of the mass stabilised layer is minor so it is showed that mass stabilisation is possible and suitable method at the area of Kose-Mäo.

8.3 Feasibility of the test section (after one year observations)

Feasibility of the Võõbus test section 0 to 5 and Kose-Mäo test mass stabilization is estimated preliminary in the Table 8.1. The preliminary estimation is made on the basis of the technical and economic considerations. The technical estimation of Võõbu test sections is made on the basis of only one year observations and before the removing of the preloading embankment and vane shear test through the embankment.

Table 8.1 Feasibility of the Võõbu test sections 0 to 5 (preliminary estimation on the basis of one year observations) and Kose-Mäo mass stabilization test embankment.

Section	Stability	Settlement after removing of preload (period 1 to 30 years)	Differential settlement in cross section	Costs €/m-road (when 3 m peat layer, see Table 6.1)
Võõbu 0	ok!	≈no **	no	3100
Võõbu 1	ok? *	< 100 mm	possibly? ***	1700
Võõbu 2	ok? *	< 100 mm	possibly? ***	1700
Võõbu 3	ok? *	< 100 mm	possibly? ***	2800
Võõbu 4	ok? *	< 100 mm	possibly? ***	2800
Võõbu 5	ok? *	< 100 mm	possibly? ***	3100
Kose-Mäo	ok!	≈no **	no	2600

* The shear strength of the peat under the embankment is not determined with vane tests => the real factor of the safety is not known

** No preloading

*** The edges of the road are settling more than central line during 1 year loading => good for drainage

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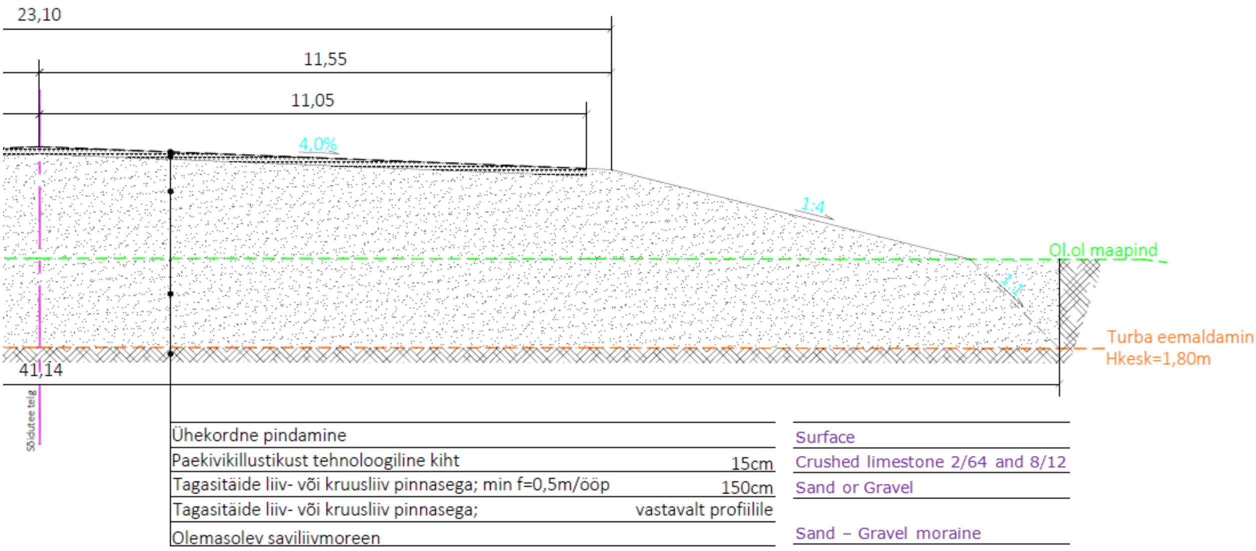


Figure 1. Cross-section of section 0 (mass replacement)

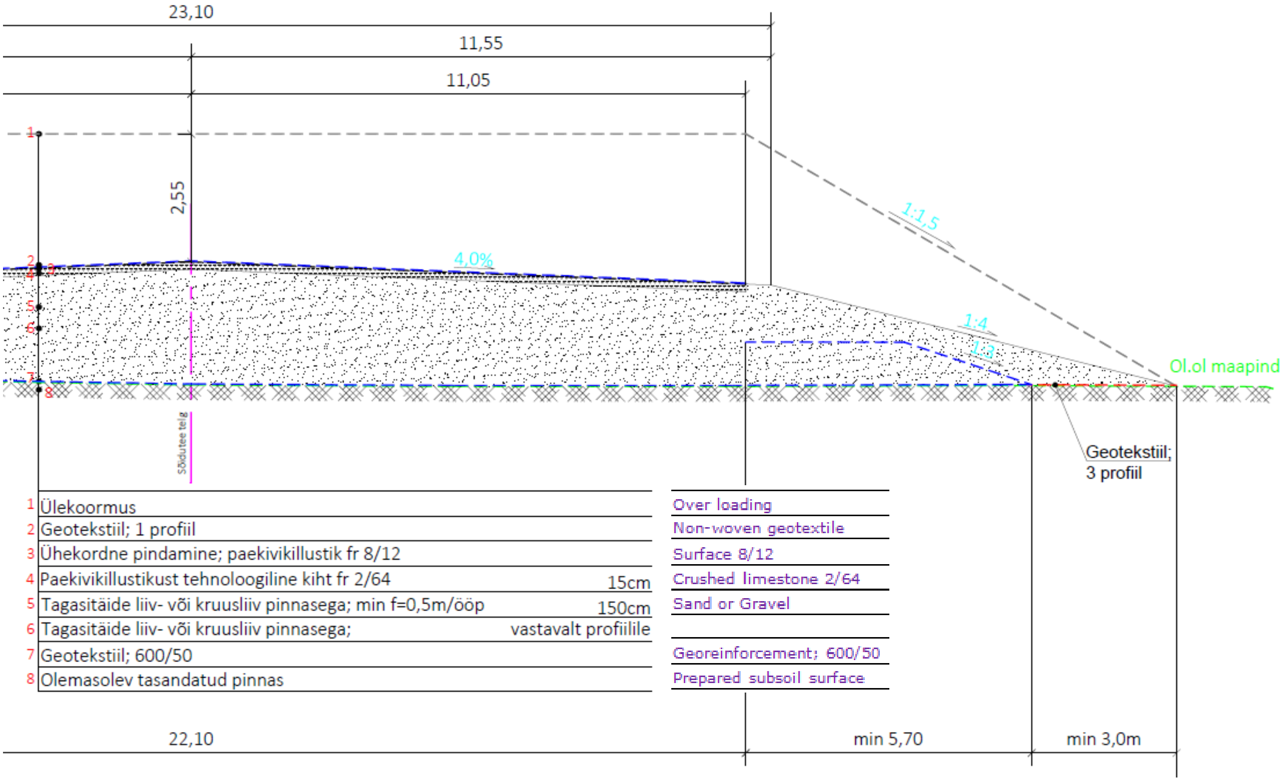


Figure 2. Cross-section of section 1 (one layer of georeinforcement)

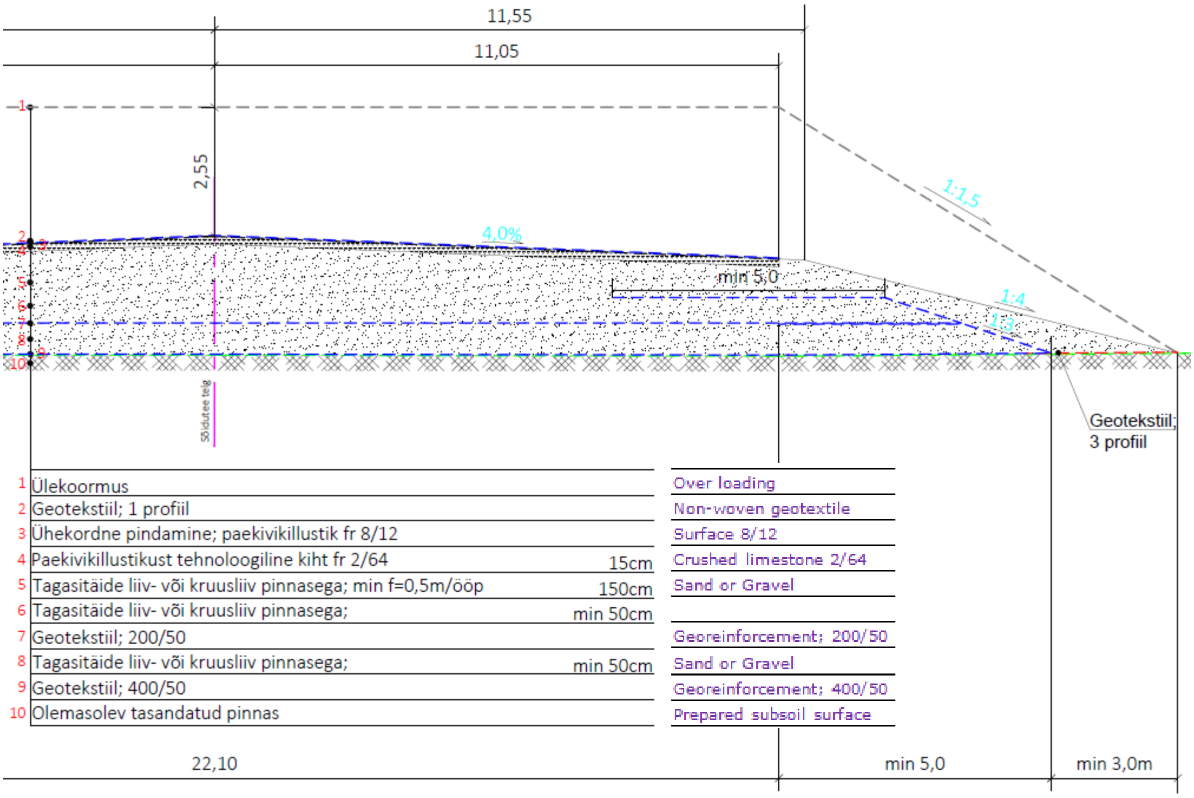


Figure 3. Cross-section of section 2 (two layers of georeinforcements)

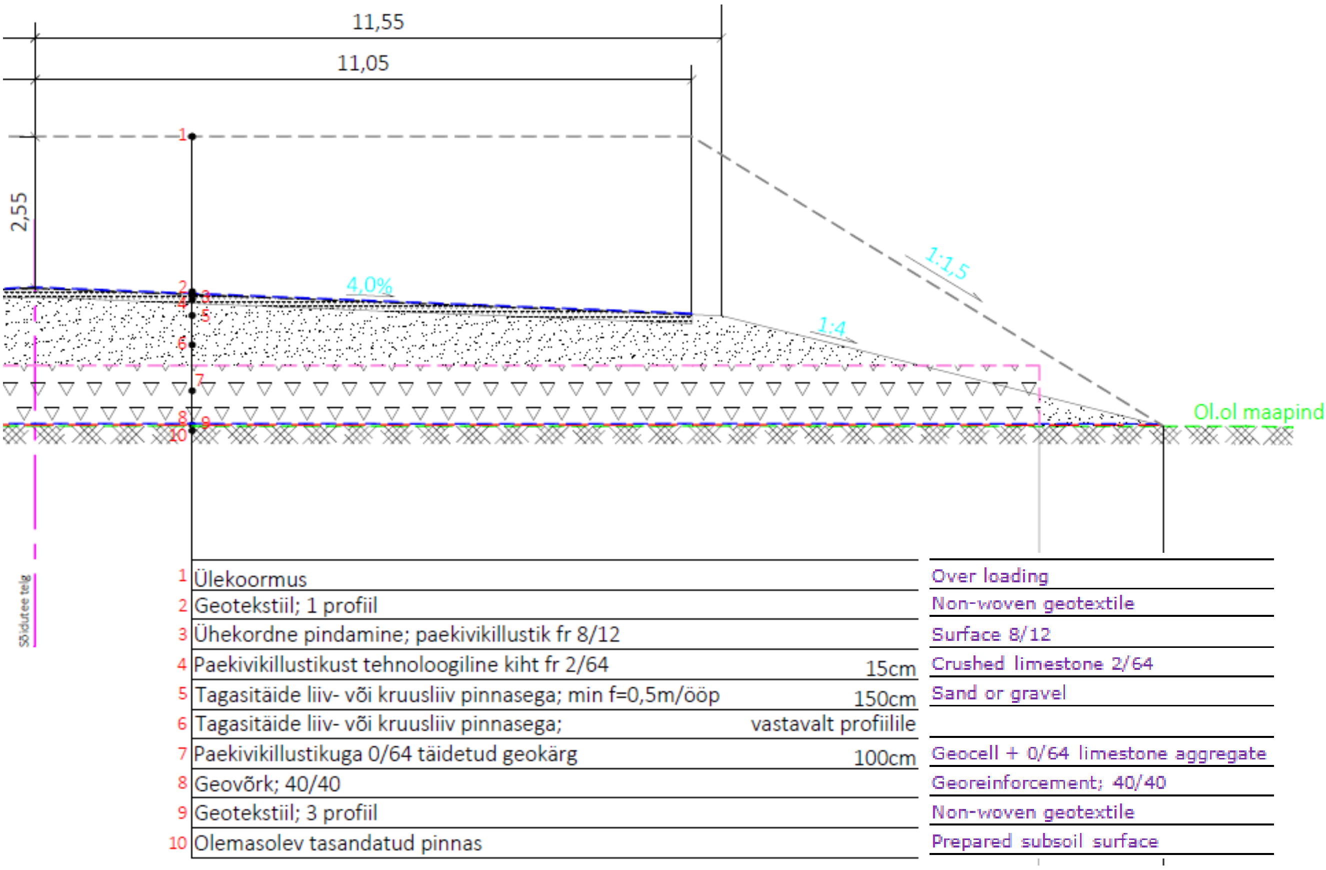


Figure 4. Cross-section of test section 3. Geocell-structure (1m) on top of georeinforcement.

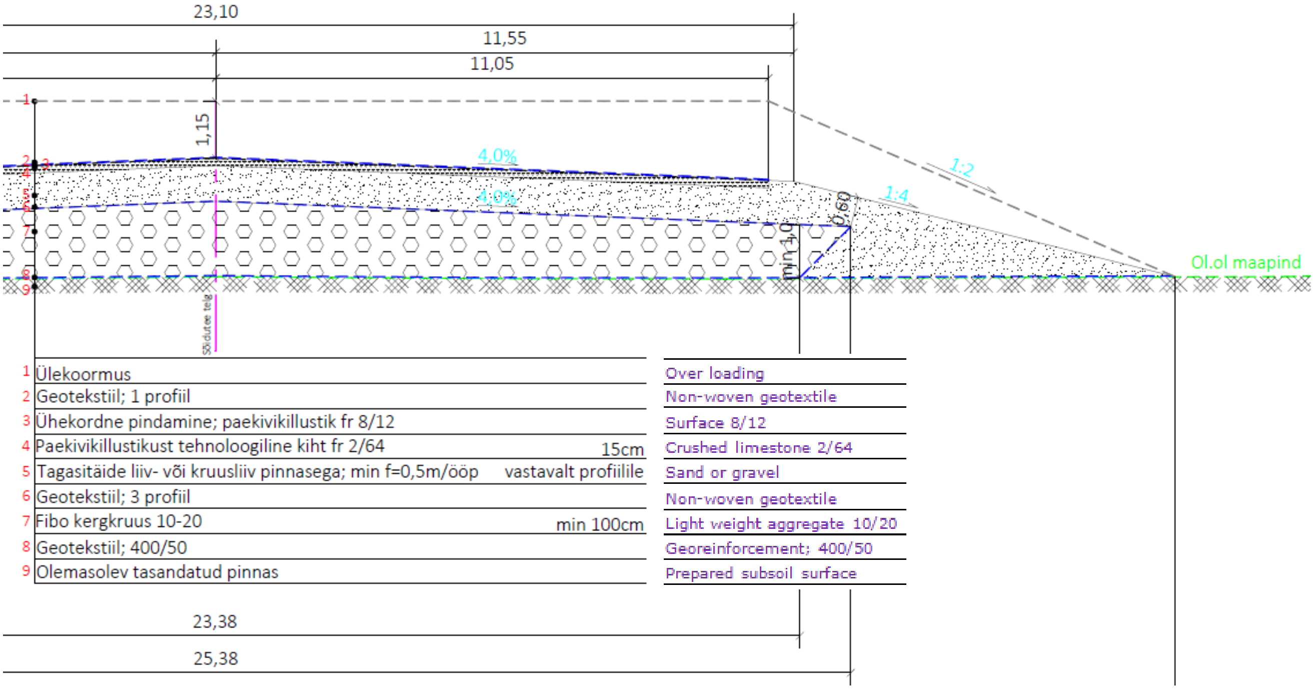
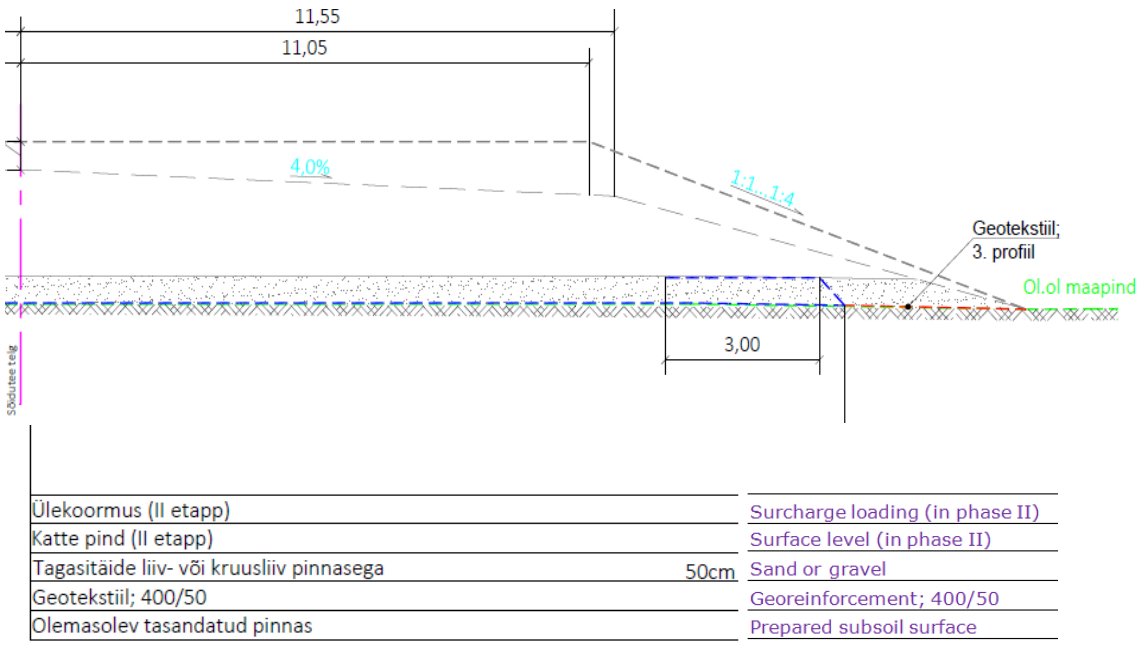


Figure 5. Cross-section of test section 4. Light weight aggregate reinforcement.

a)



b)

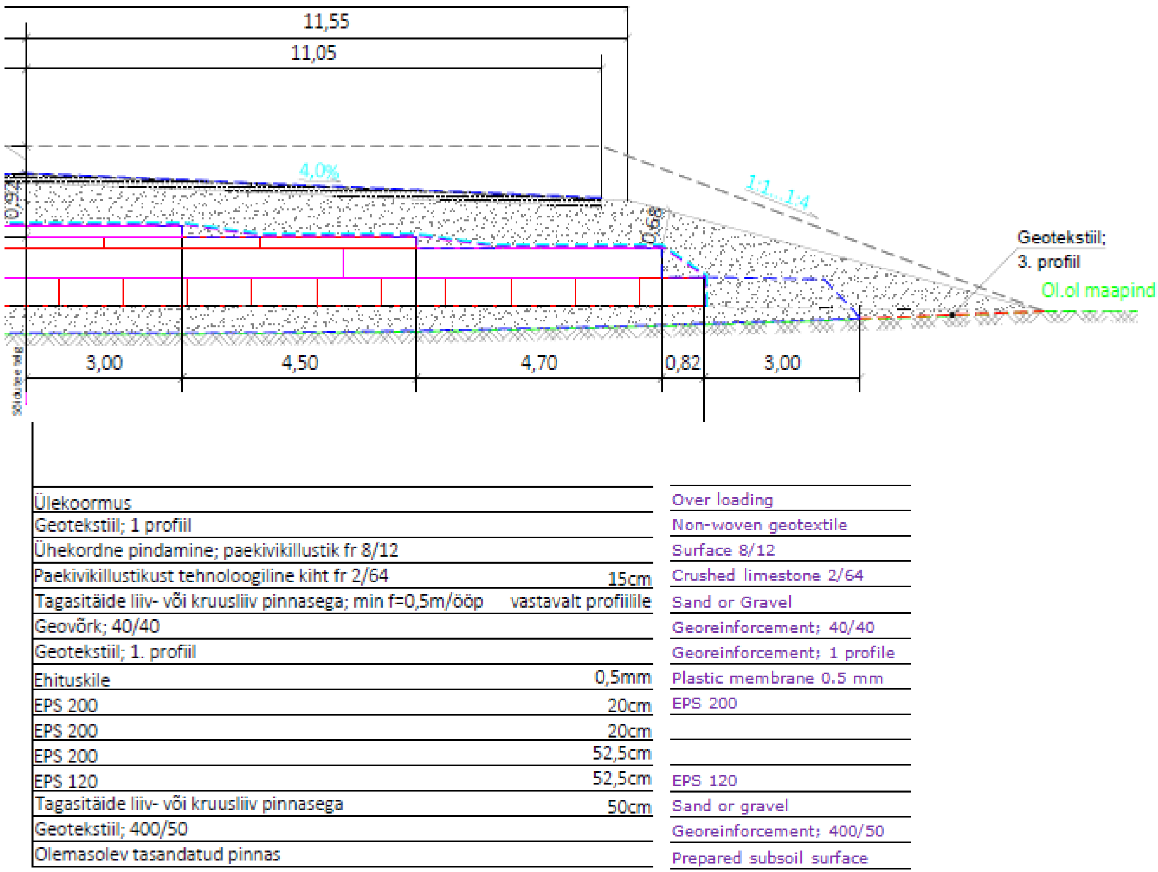
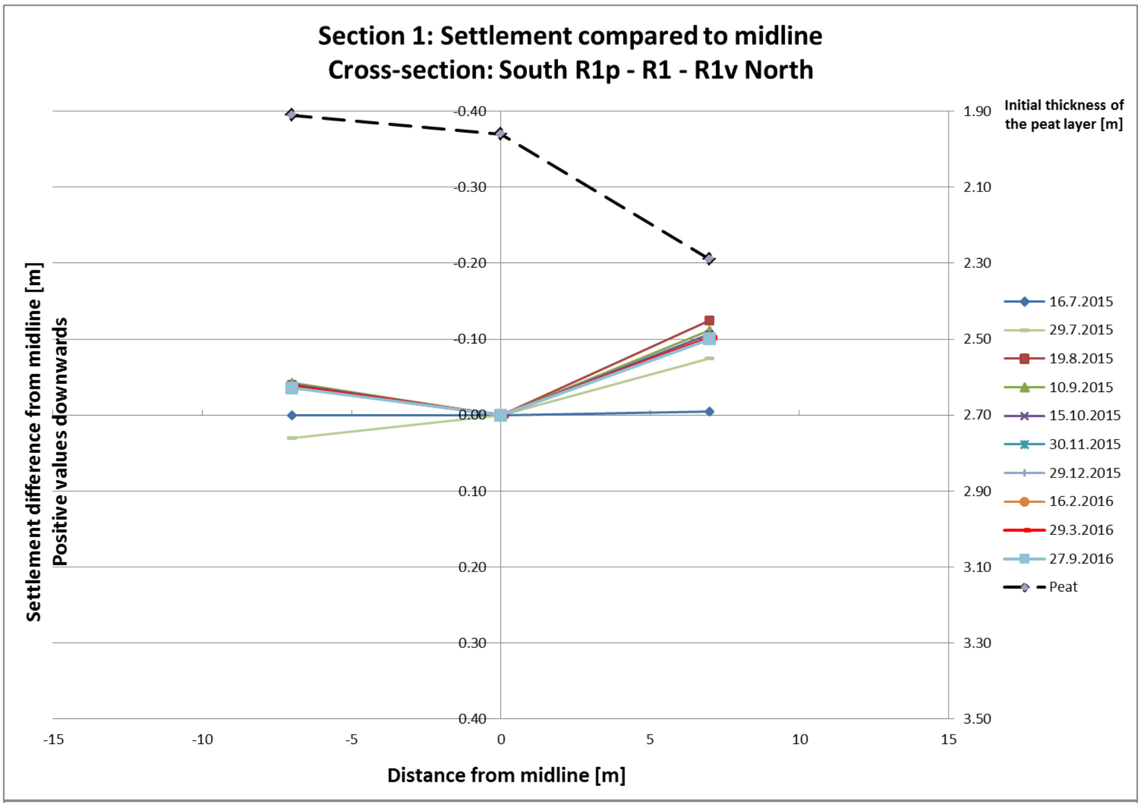
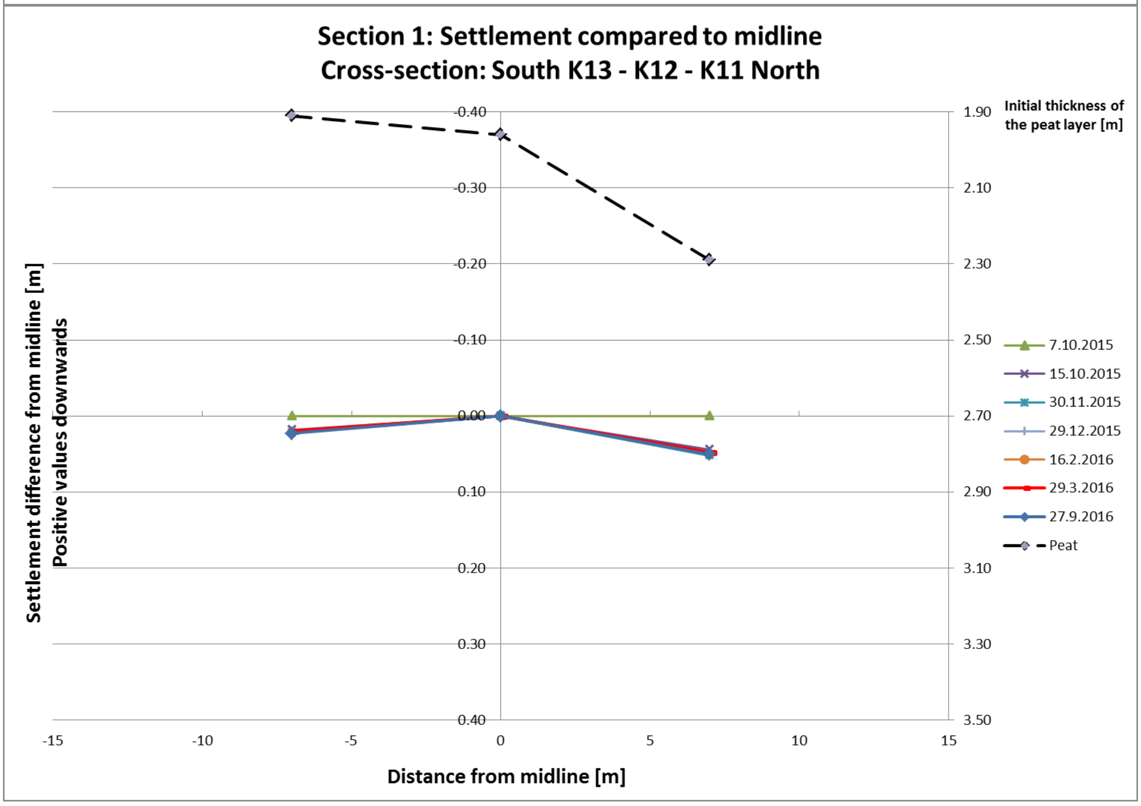
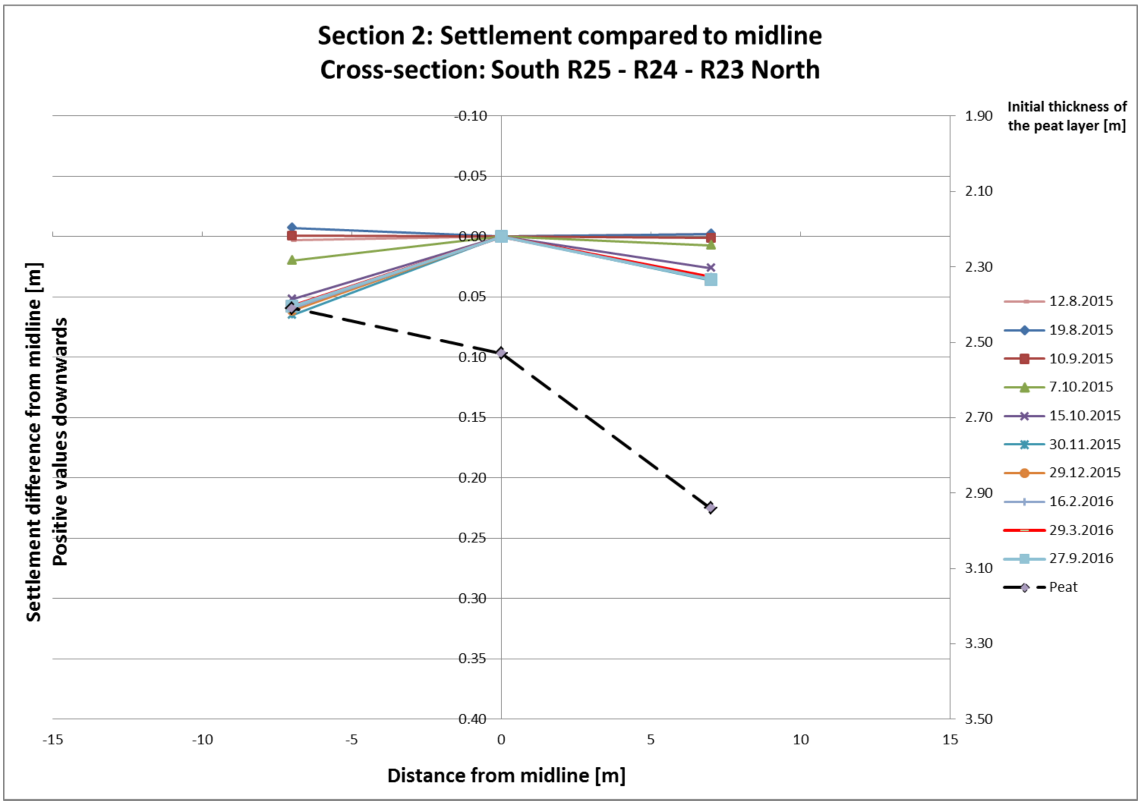
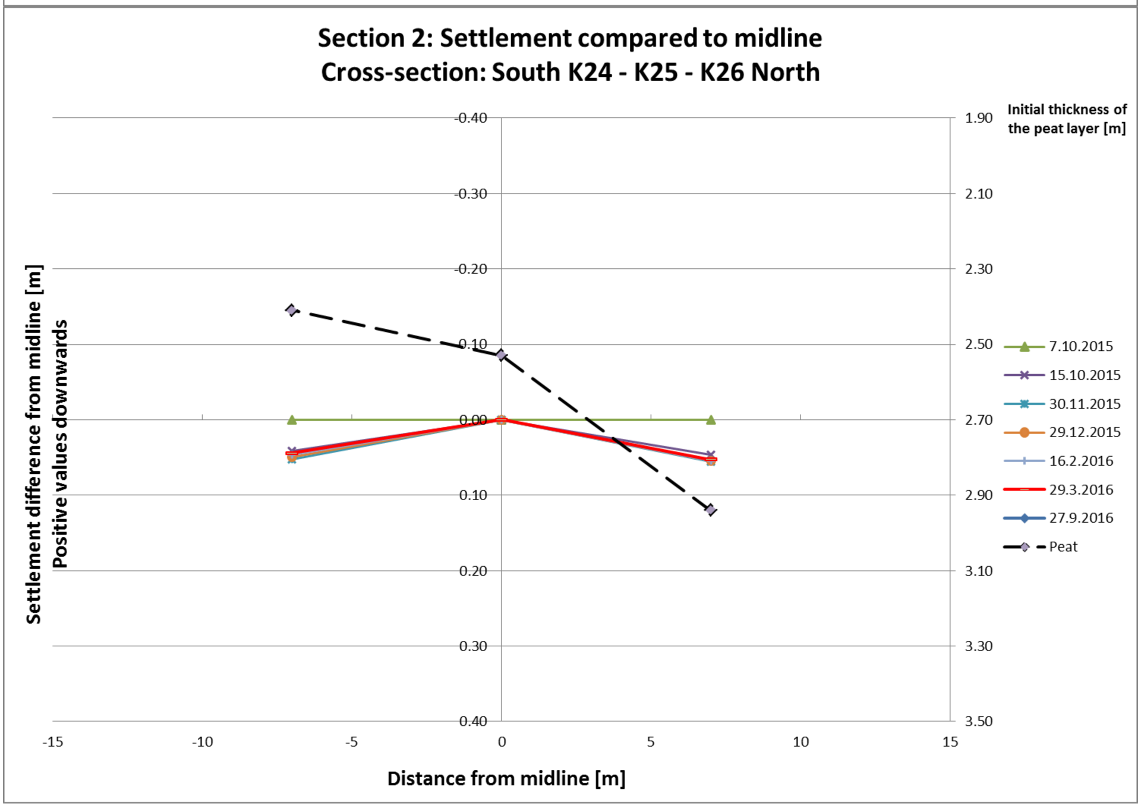


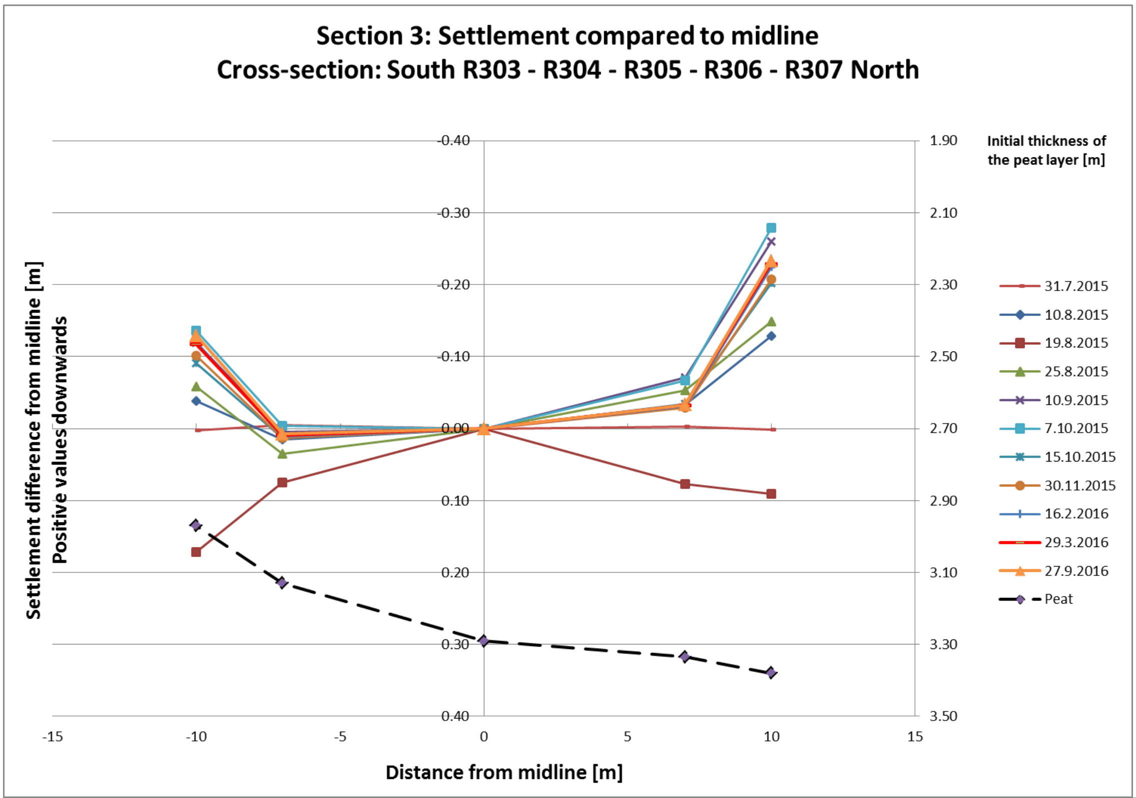
Figure 6. Cross-section of test section 5. EPS-block embankment. a) First phase and b) Second phase.

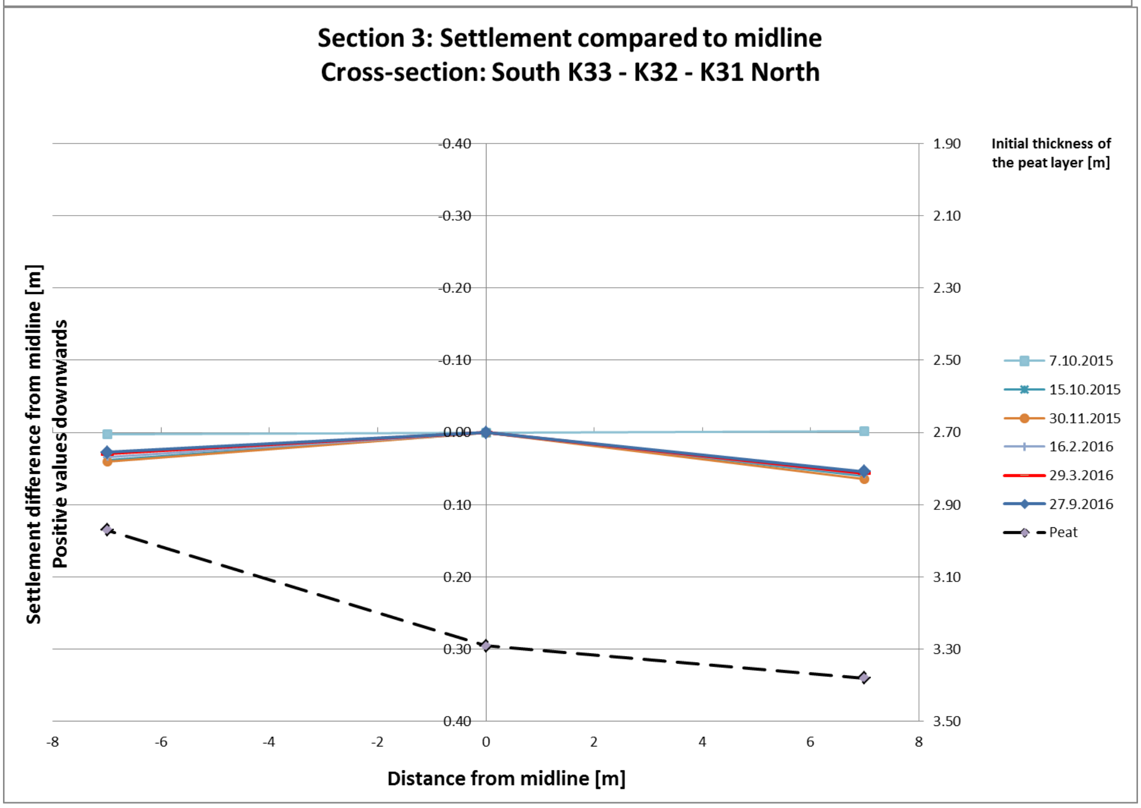

Section 1: Settlement compared to midline
Cross-section: South R1p - R1 - R1v North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-15
-10
-5
0
5
10
15
16.7.2015
29.7.2015
19.8.2015
10.9.2015
15.10.2015
30.11.2015
29.12.2015
16.2.2016
29.3.2016
27.9.2016
Peat

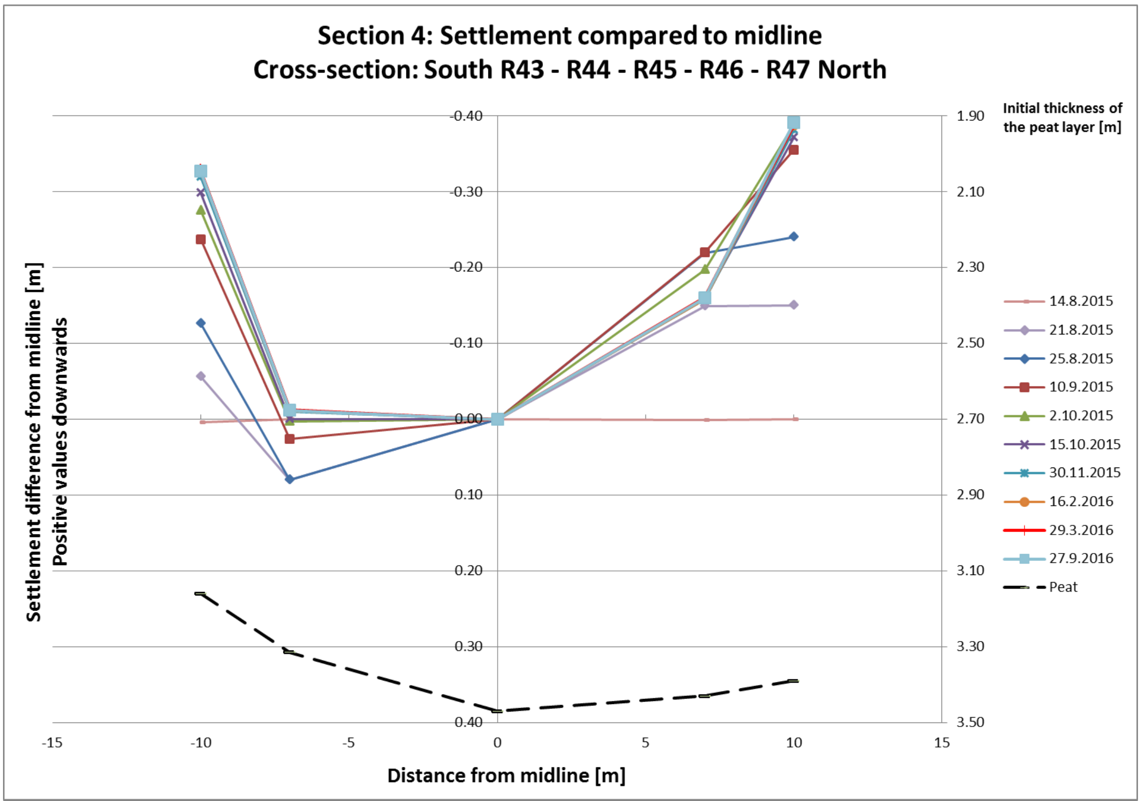

Section 1: Settlement compared to midline
Cross-section: South K13 - K12 - K11 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-15
-10
-5
0
5
10
15
7.10.2015
15.10.2015
30.11.2015
29.12.2015
16.2.2016
29.3.2016
27.9.2016
Peat


Section 2: Settlement compared to midline
Cross-section: South R25 - R24 - R23 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-15
-10
-5
0
5
10
15
12.8.2015
19.8.2015
10.9.2015
7.10.2015
15.10.2015
30.11.2015
29.12.2015
16.2.2016
29.3.2016
27.9.2016
Peat

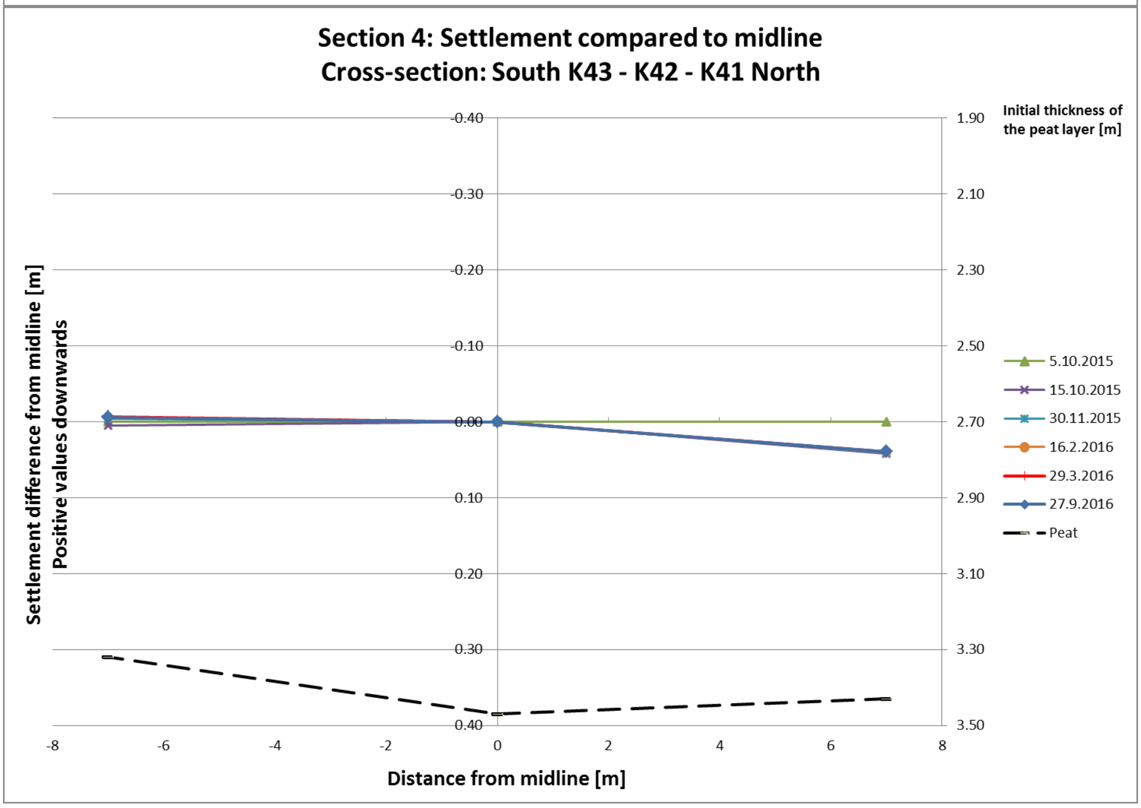

Section 2: Settlement compared to midline
Cross-section: South K24 - K25 - K26 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-15
-10
-5
0
5
10
15
7.10.2015
15.10.2015
30.11.2015
29.12.2015
16.2.2016
29.3.2016
27.9.2016
Peat


Section 3: Settlement compared to midline
Cross-section: South R303 - R304 - R305 - R306 - R307 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
31.7.2015
10.8.2015
19.8.2015
25.8.2015
10.9.2015
7.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat

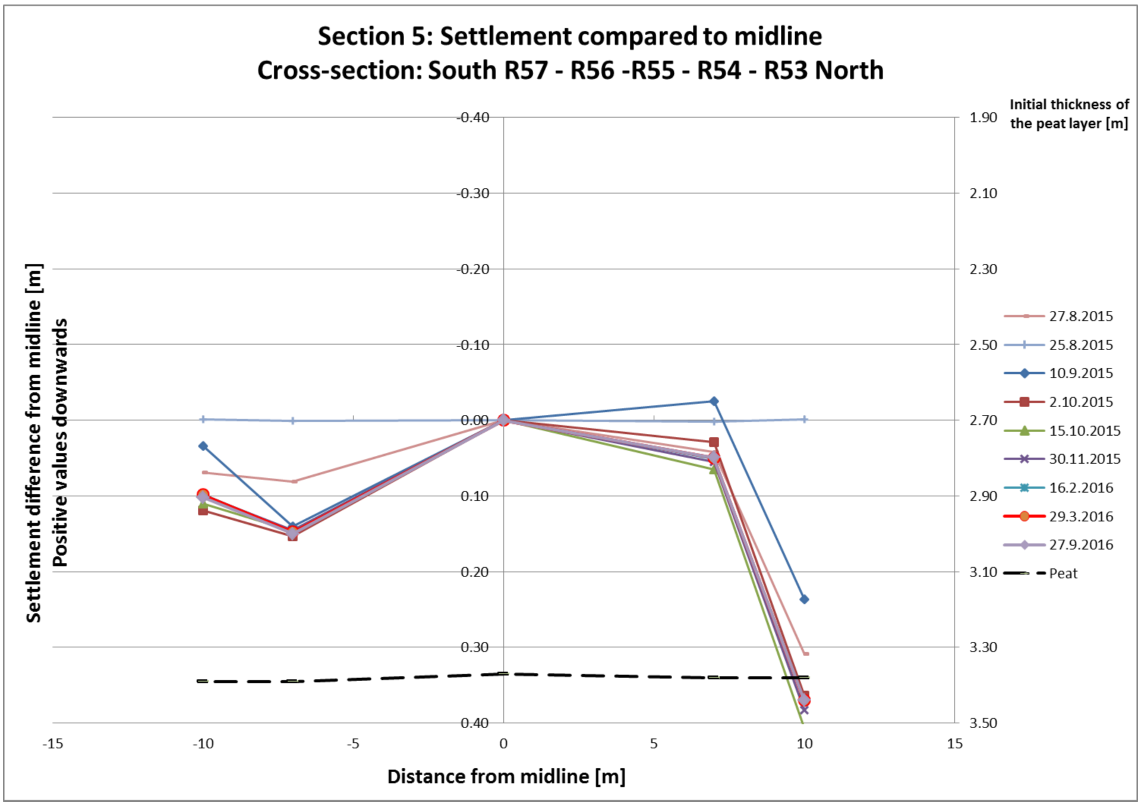

Section 3: Settlement compared to midline
Cross-section: South K33 - K32 - K31 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
7.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat



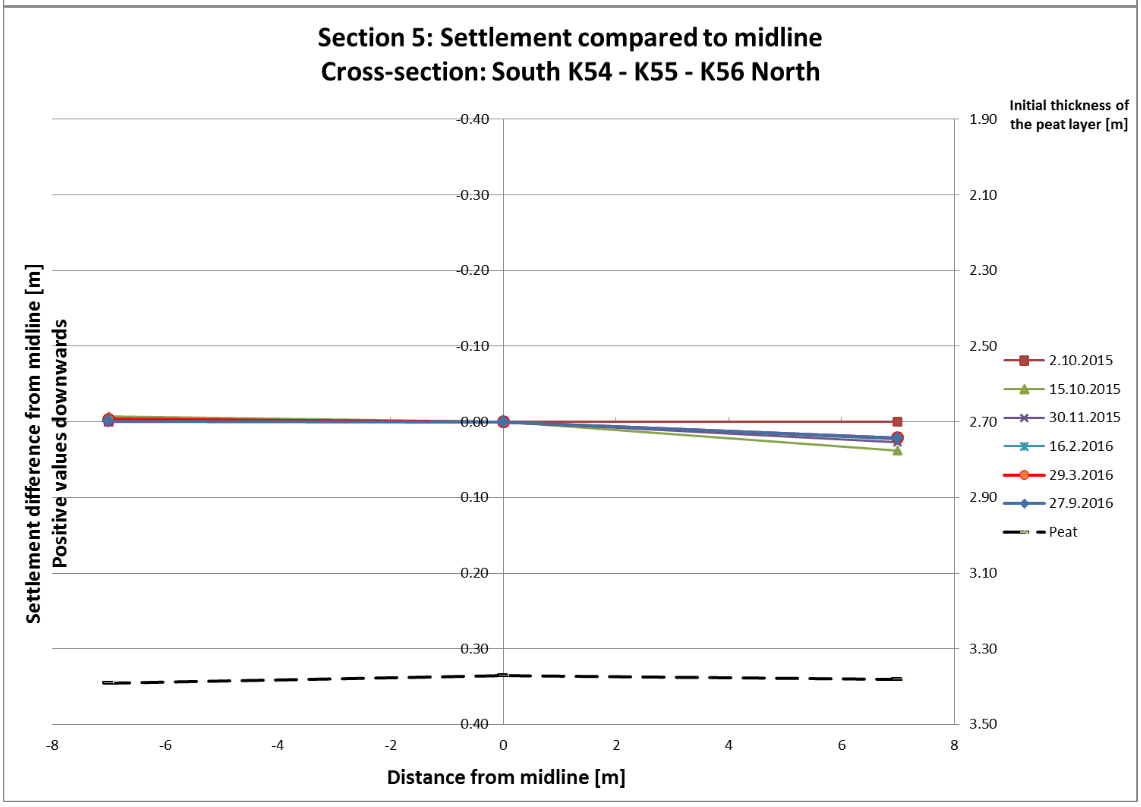
Section 4: Settlement compared to midline
Cross-section: South R43 - R44 - R45 - R46 - R47 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
14.8.2015
21.8.2015
25.8.2015
10.9.2015
2.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat



Section 4: Settlement compared to midline
Cross-section: South K43 - K42 - K41 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
5.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat



Section 5: Settlement compared to midline
Cross-section: South R57 - R56 -R55 - R54 - R53 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-15
-10
-5
0
5
10
15
27.8.2015
25.8.2015
10.9.2015
2.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat



Section 5: Settlement compared to midline
Cross-section: South K54 - K55 - K56 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-8
-6
-4
-2
0
2
4
6
8
2.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat

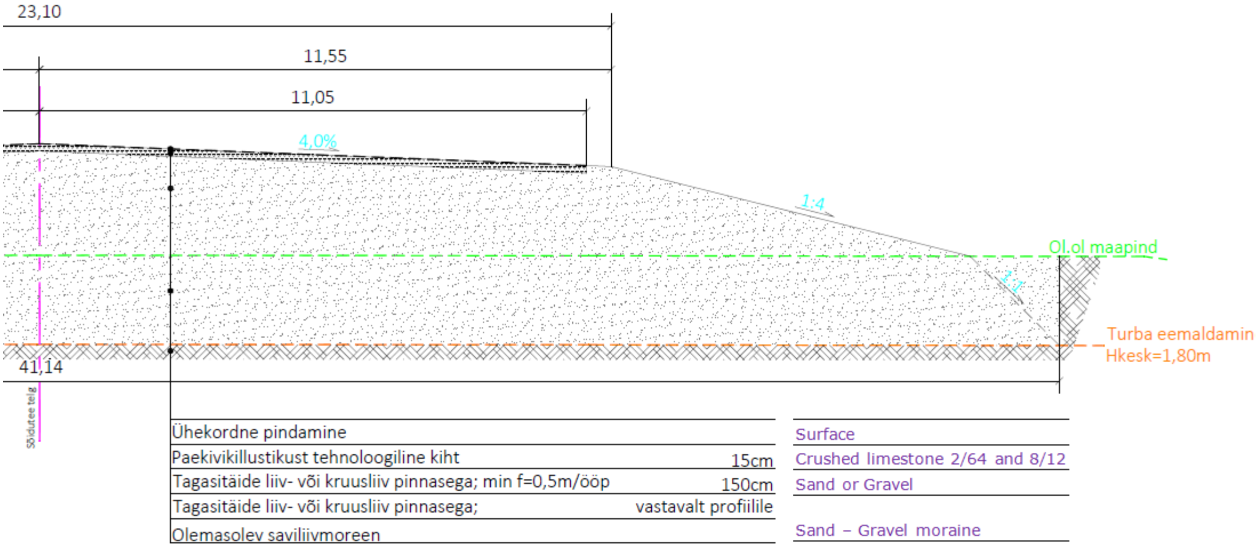


Figure 1. Cross-section of section 0 (mass replacement)

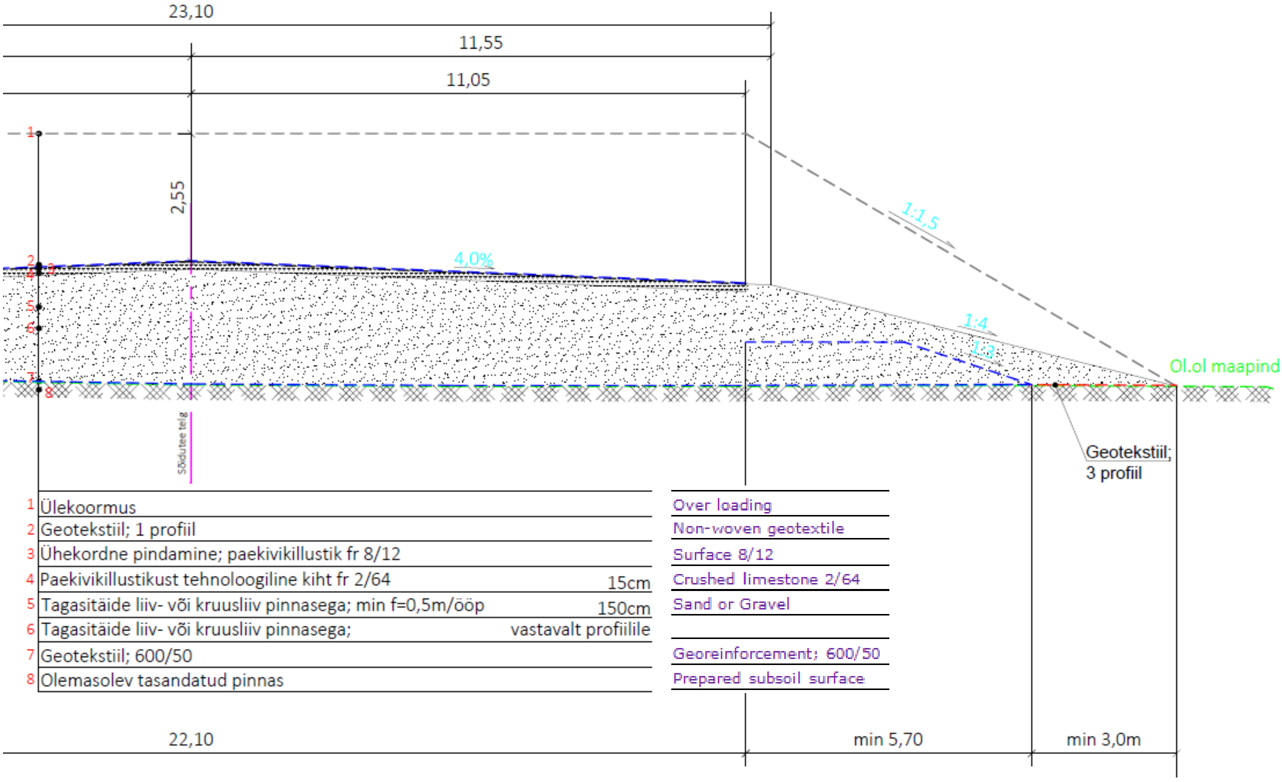


Figure 2. Cross-section of section 1 (one layer of georeinforcement)

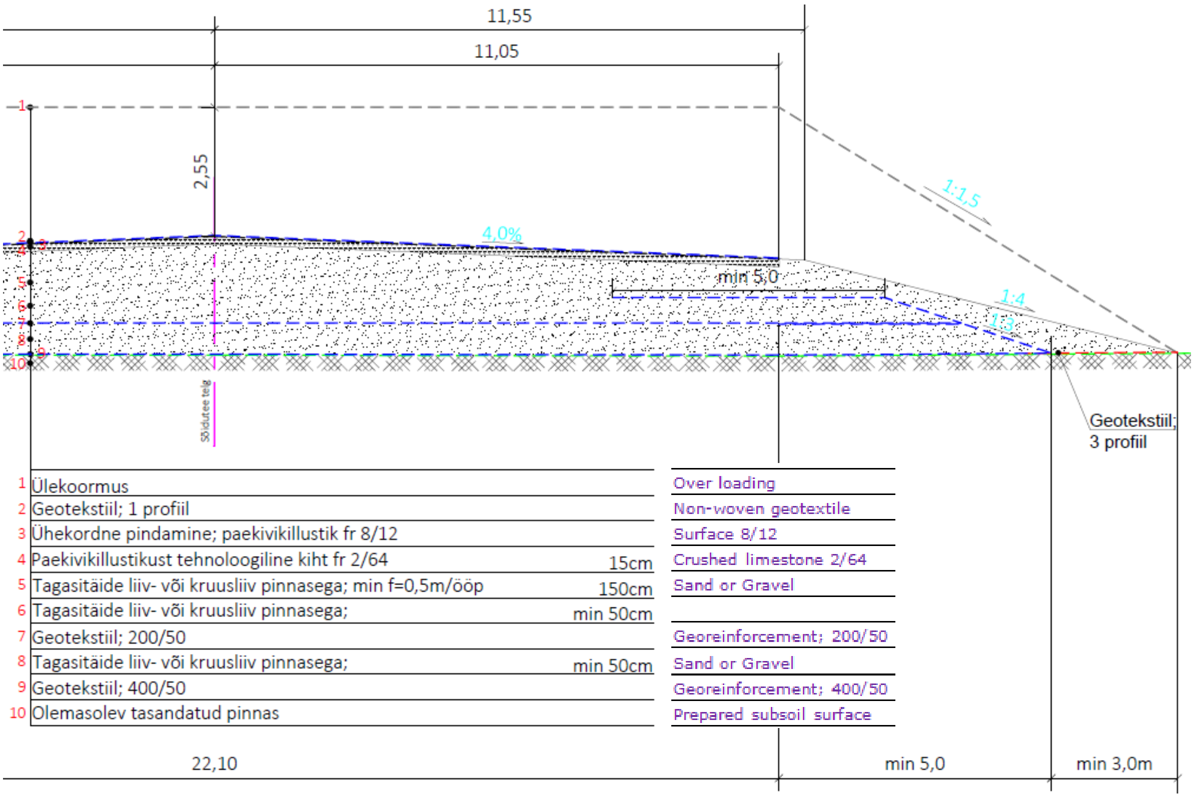


Figure 3. Cross-section of section 2 (two layers of georeinforcements)

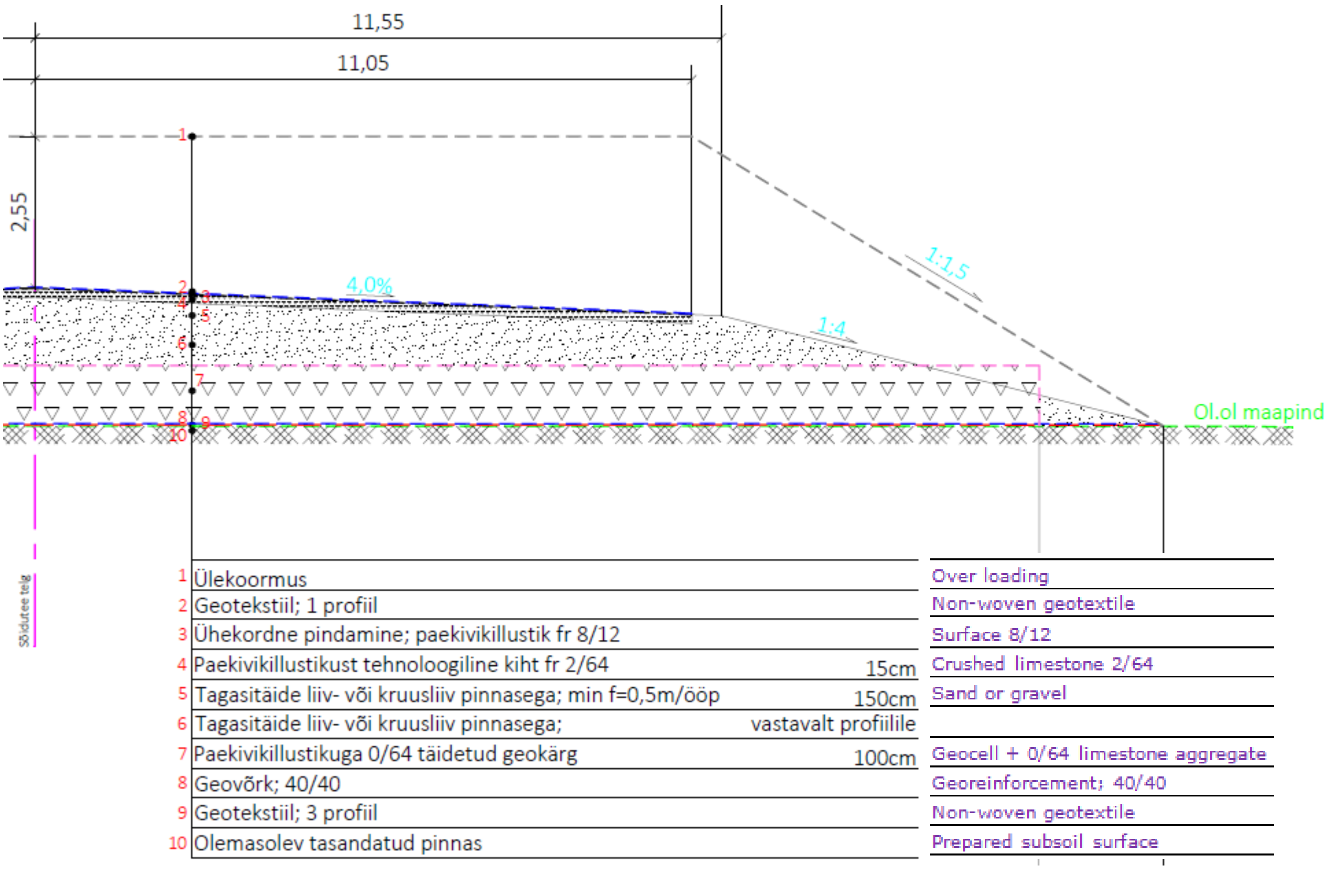


Figure 4. Cross-section of test section 3. Geocell-structure (1m) on top of georeinforcement.

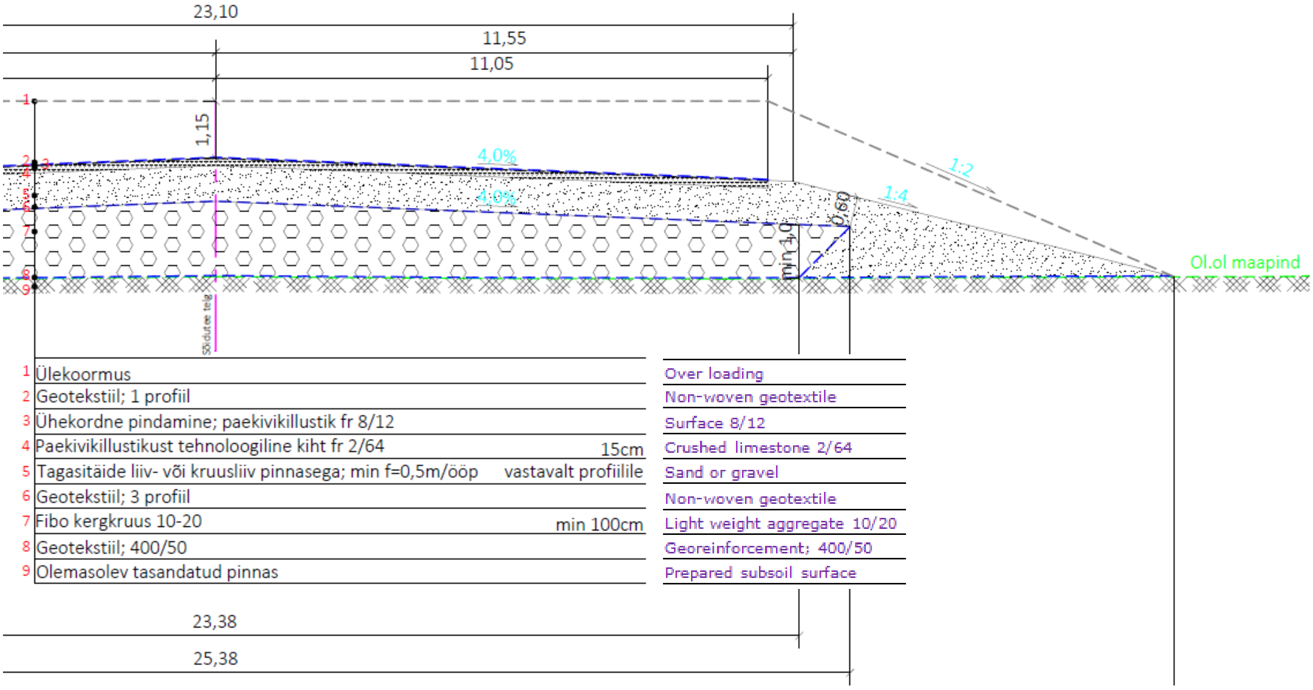
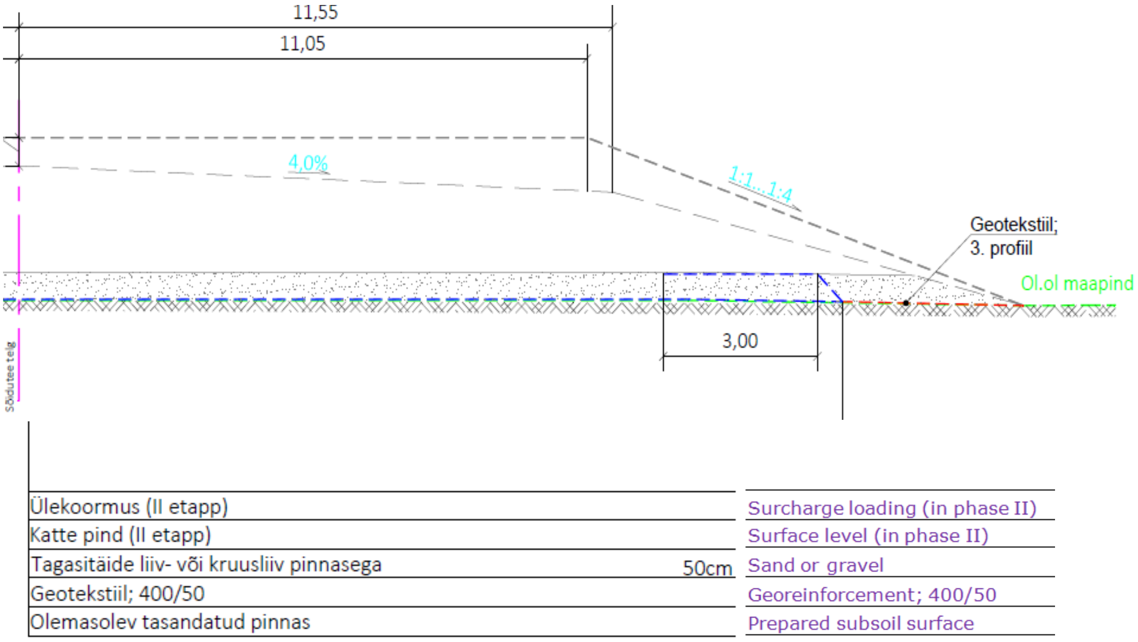


Figure 5. Cross-section of test section 4. Light weight aggregate reinforcement.

a)



b)

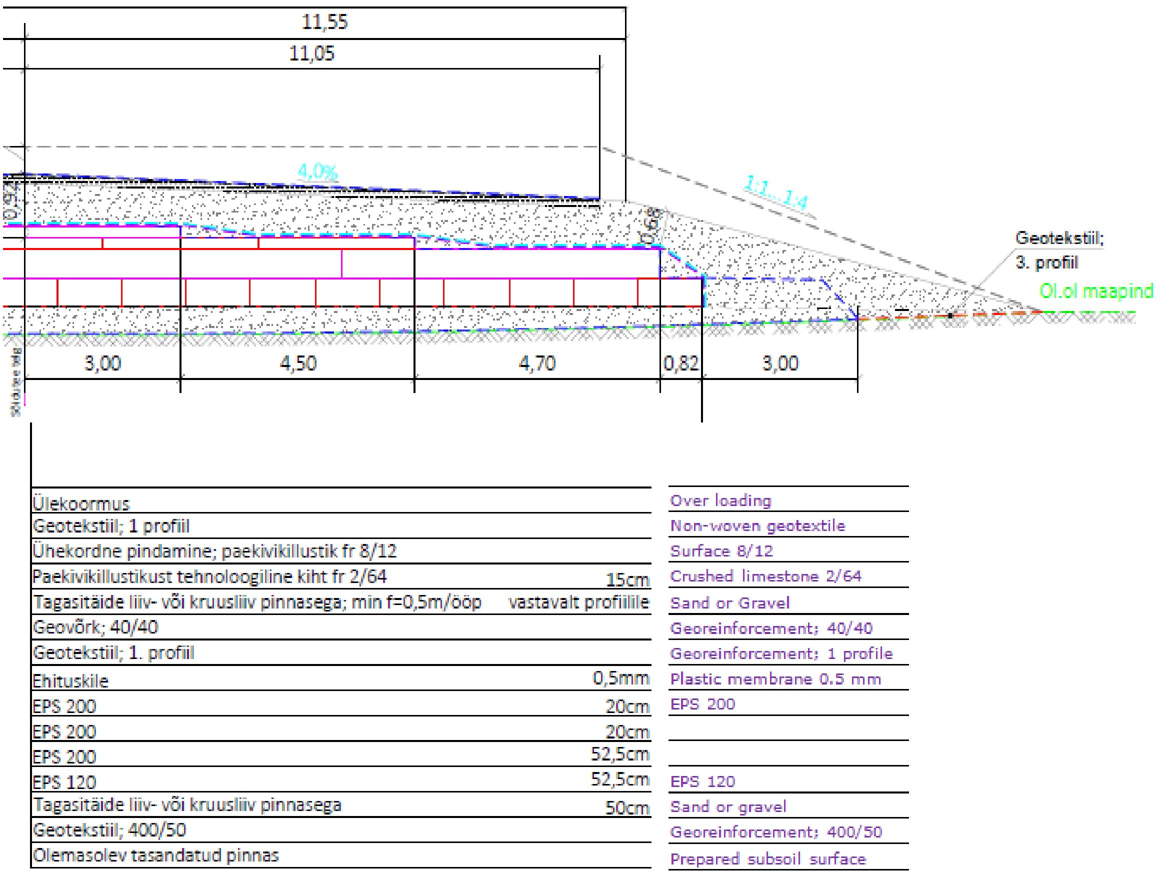
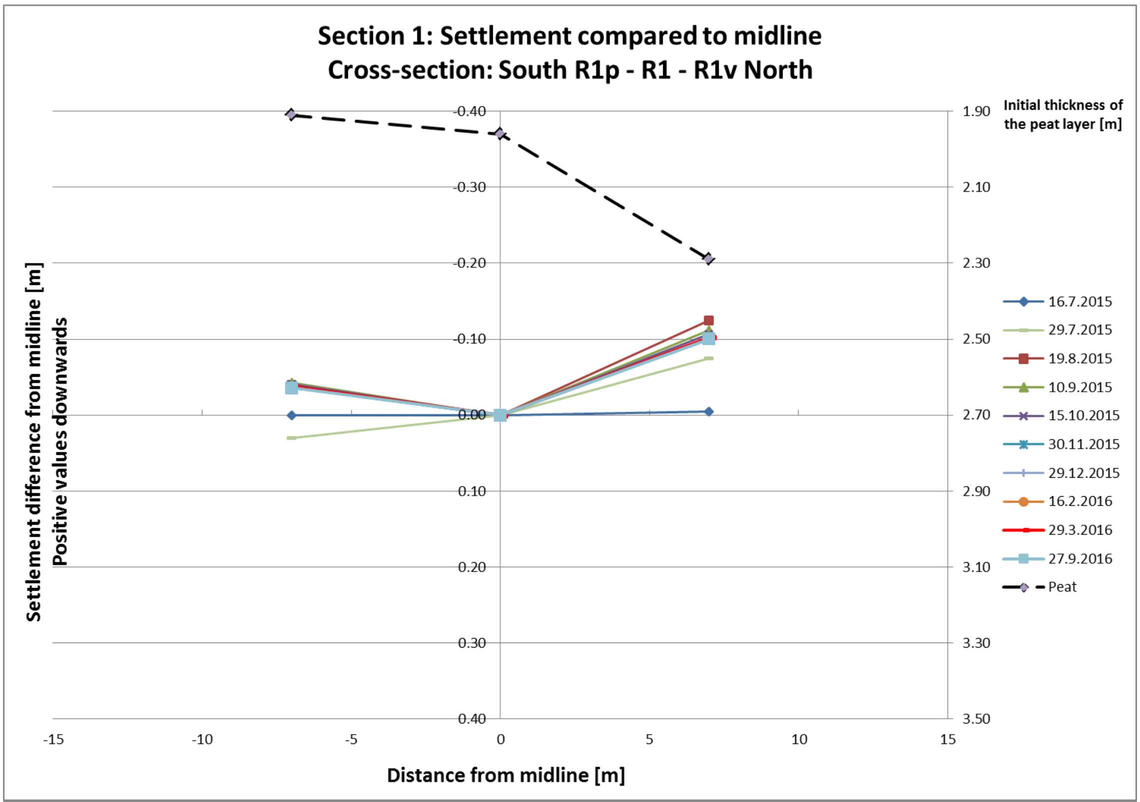
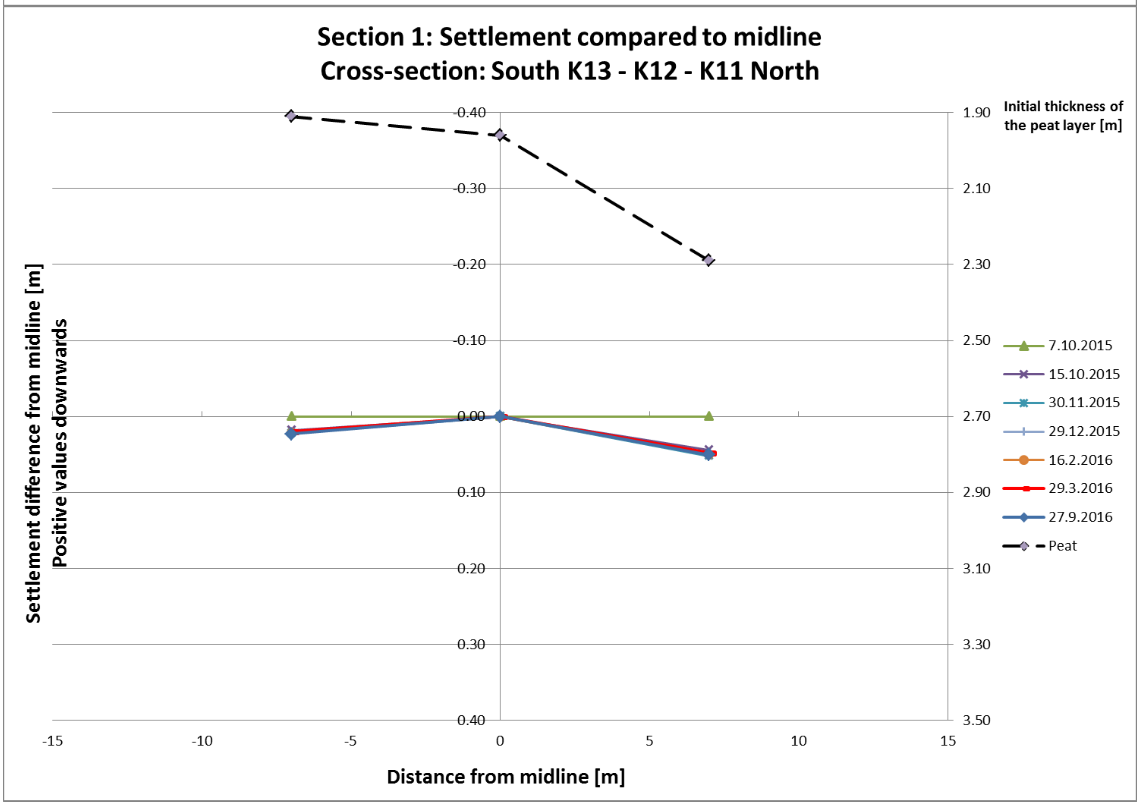
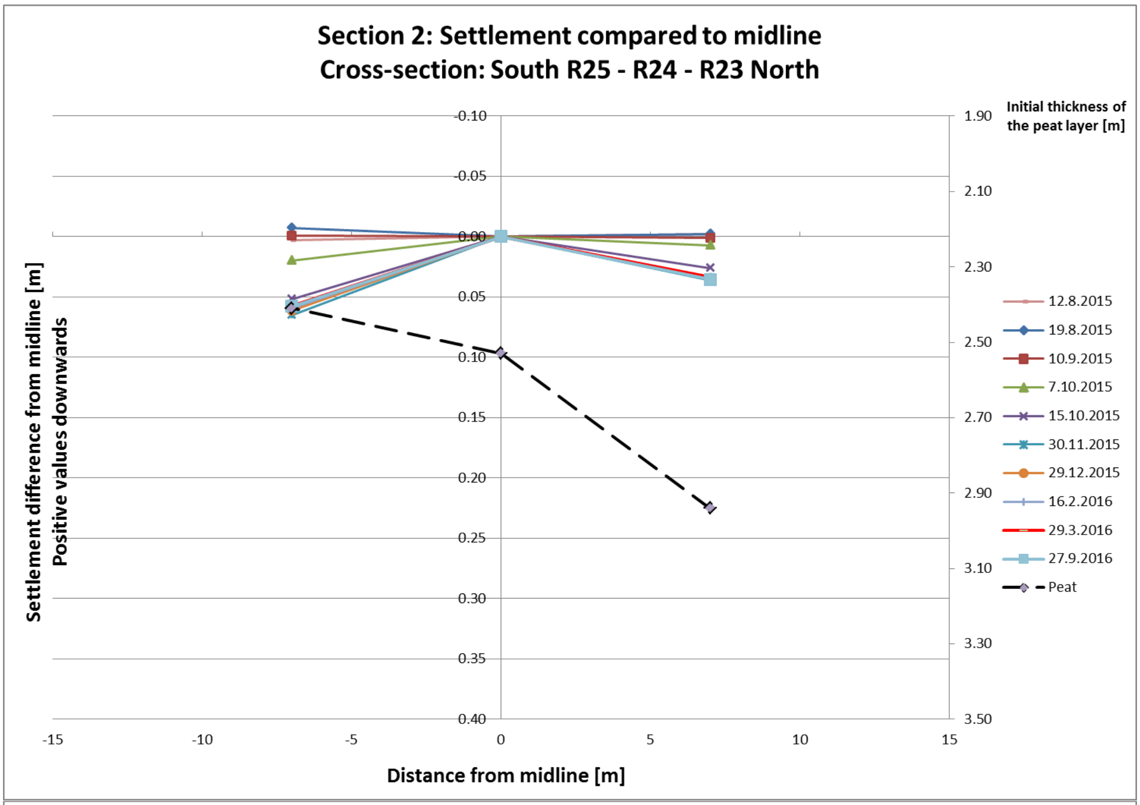


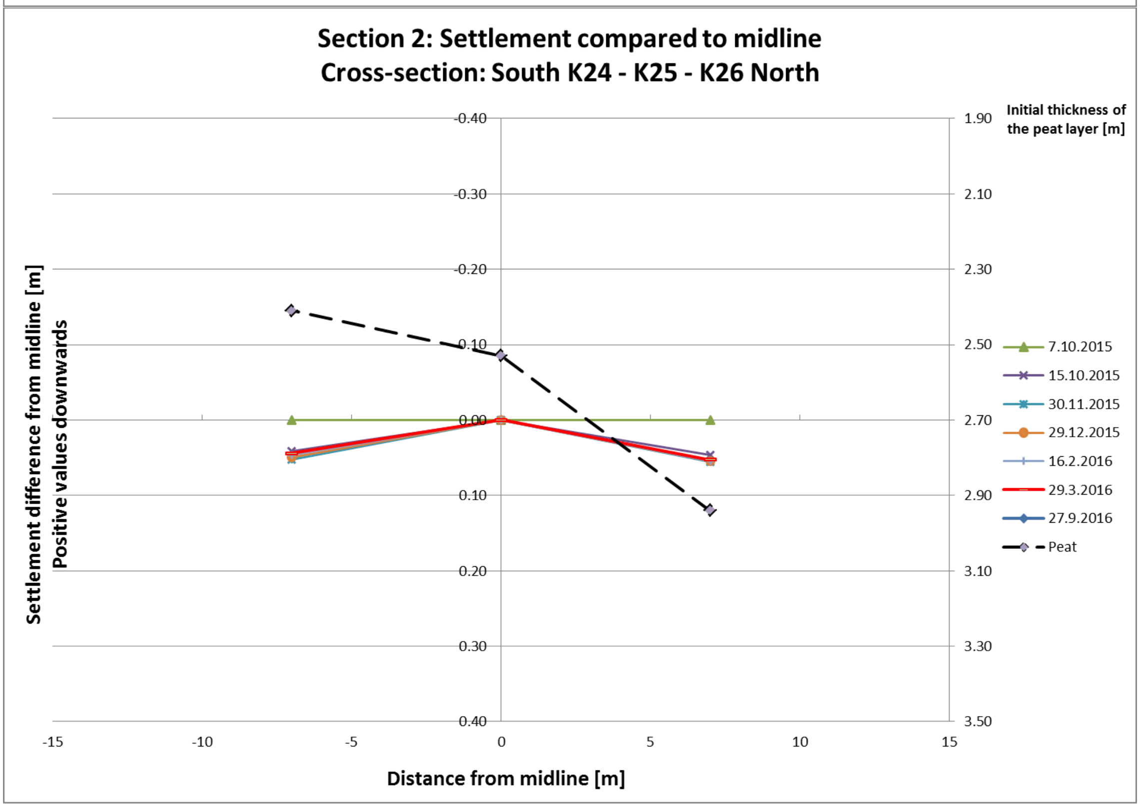
Figure 6. Cross-section of test section 5. EPS-block embankment. a) First phase and b) Second phase.


Section 1: Settlement compared to midline
Cross-section: South R1p - R1 - R1v North
Settlement difference from midline [m]
Positive values downwards
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
-15
-10
-5
0
5
10
15
Distance from midline [m]
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
Initial thickness of the peat layer [m]
16.7.2015
29.7.2015
19.8.2015
10.9.2015
15.10.2015
30.11.2015
29.12.2015
16.2.2016
29.3.2016
27.9.2016
Peat

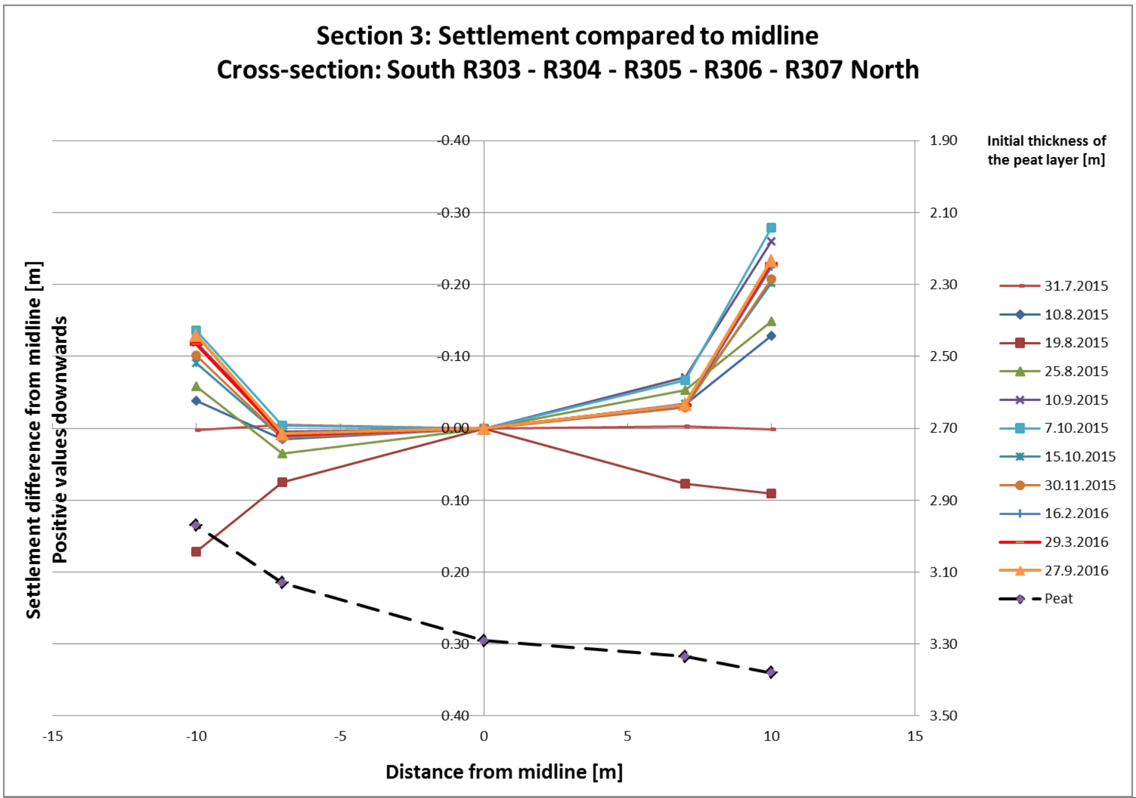

Section 1: Settlement compared to midline
Cross-section: South K13 - K12 - K11 North
Settlement difference from midline [m]
Positive values downwards
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
-15
-10
-5
0
5
10
15
Distance from midline [m]
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
Initial thickness of the peat layer [m]
7.10.2015
15.10.2015
30.11.2015
29.12.2015
16.2.2016
29.3.2016
27.9.2016
Peat

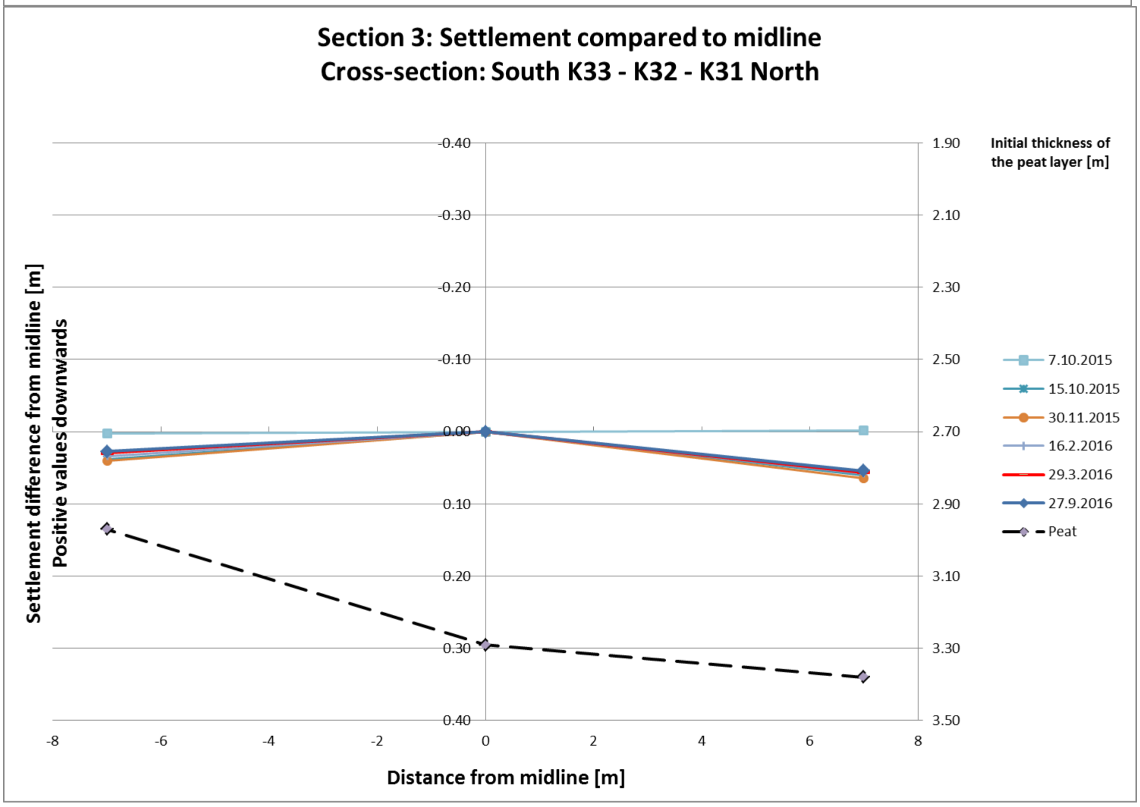


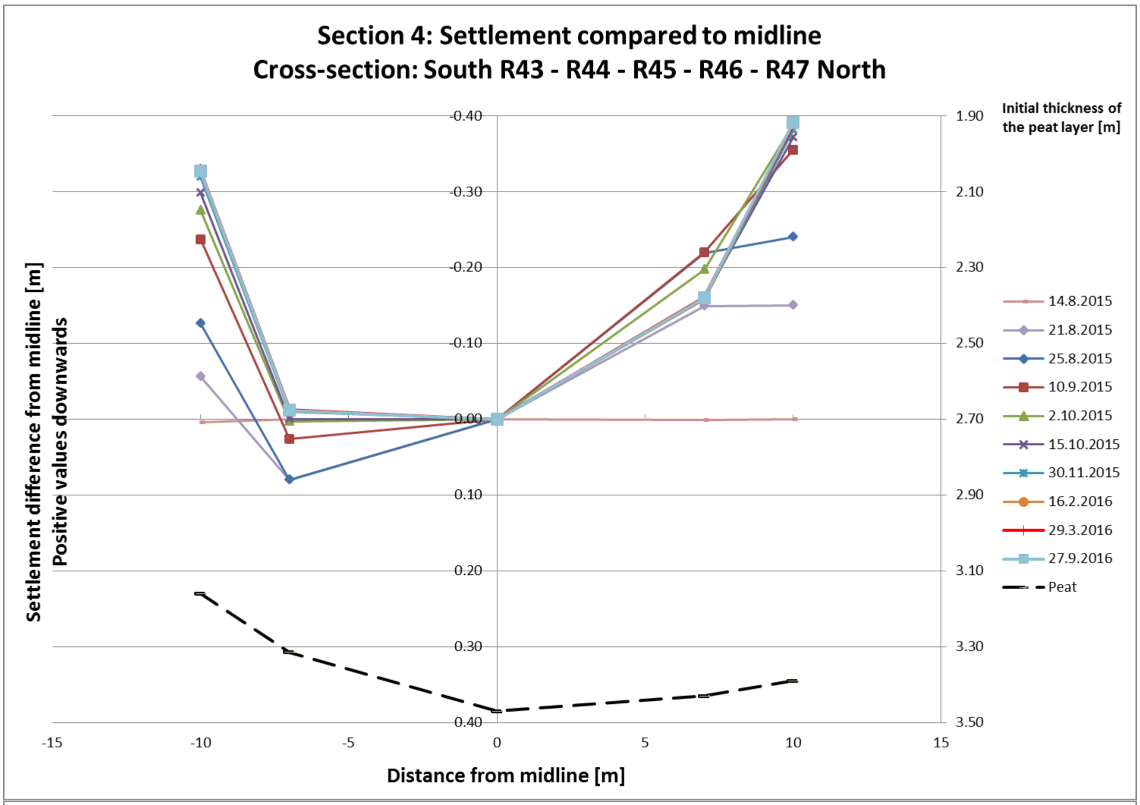
Section 2: Settlement compared to midline
Cross-section: South R25 - R24 - R23 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
-15
-10
-5
0
5
10
15
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
12.8.2015
19.8.2015
10.9.2015
7.10.2015
15.10.2015
30.11.2015
29.12.2015
16.2.2016
29.3.2016
27.9.2016
Peat

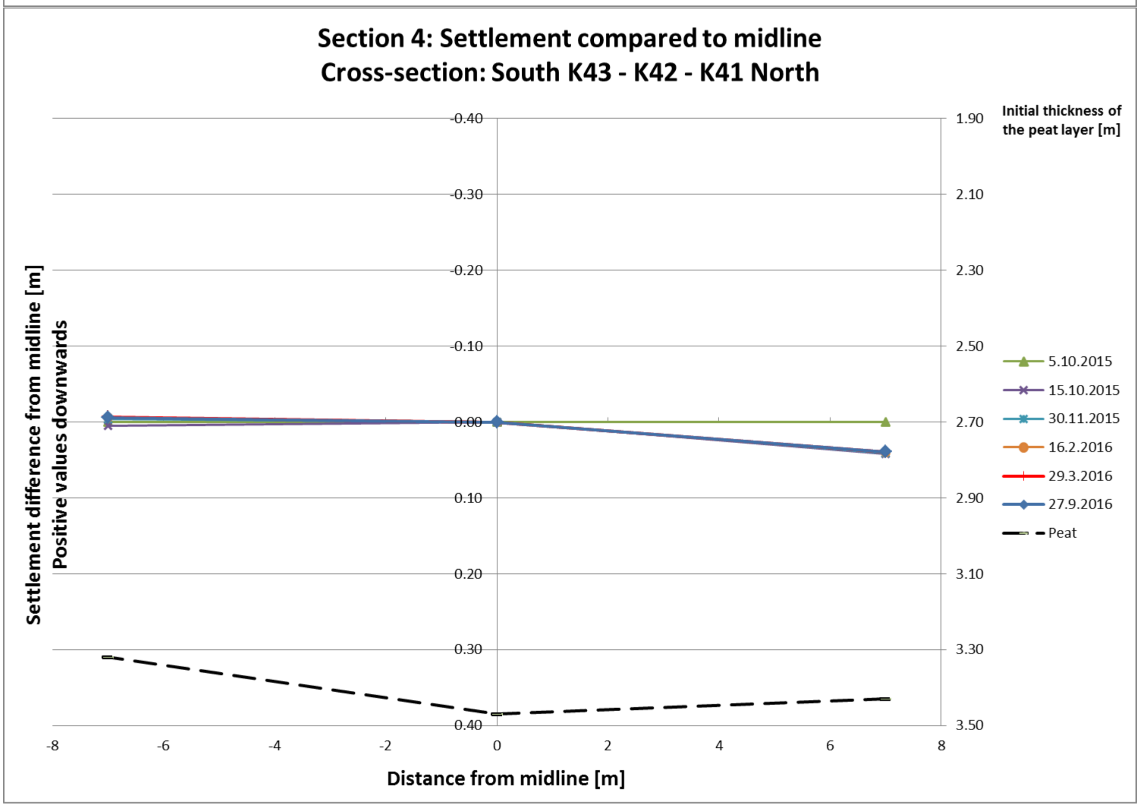


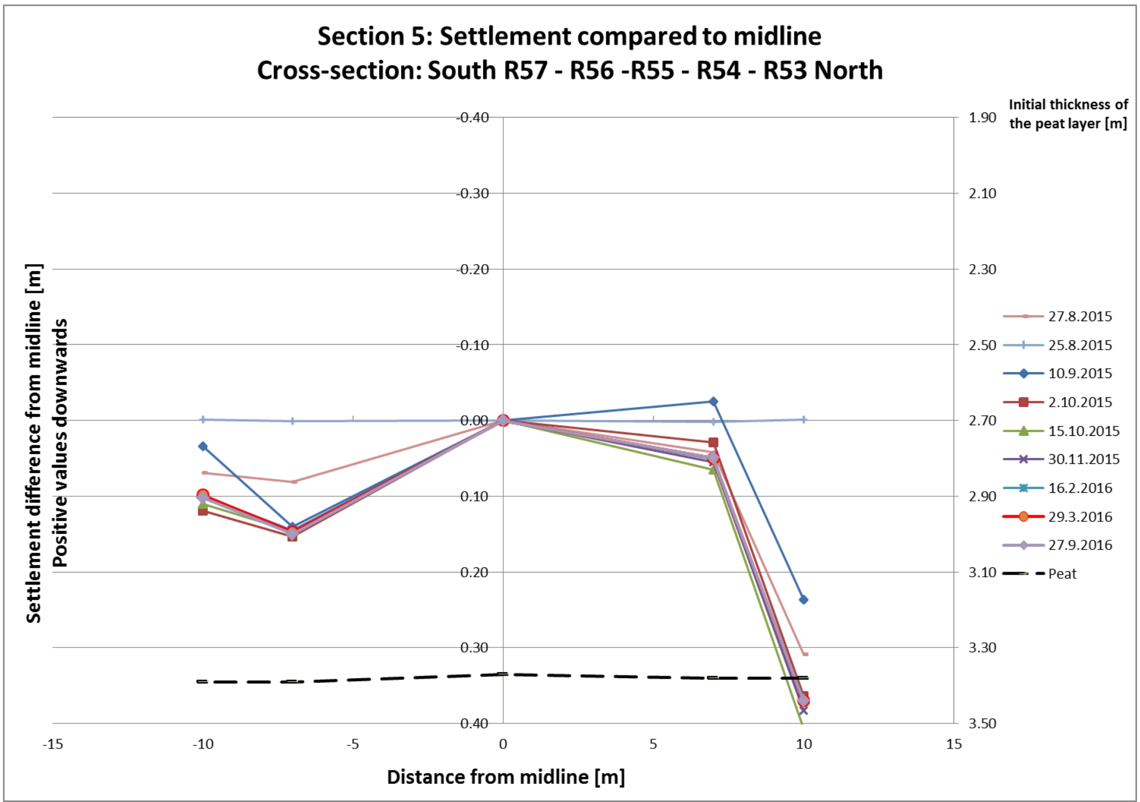
Section 2: Settlement compared to midline
Cross-section: South K24 - K25 - K26 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
-15
-10
-5
0
5
10
15
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
7.10.2015
15.10.2015
30.11.2015
29.12.2015
16.2.2016
29.3.2016
27.9.2016
Peat

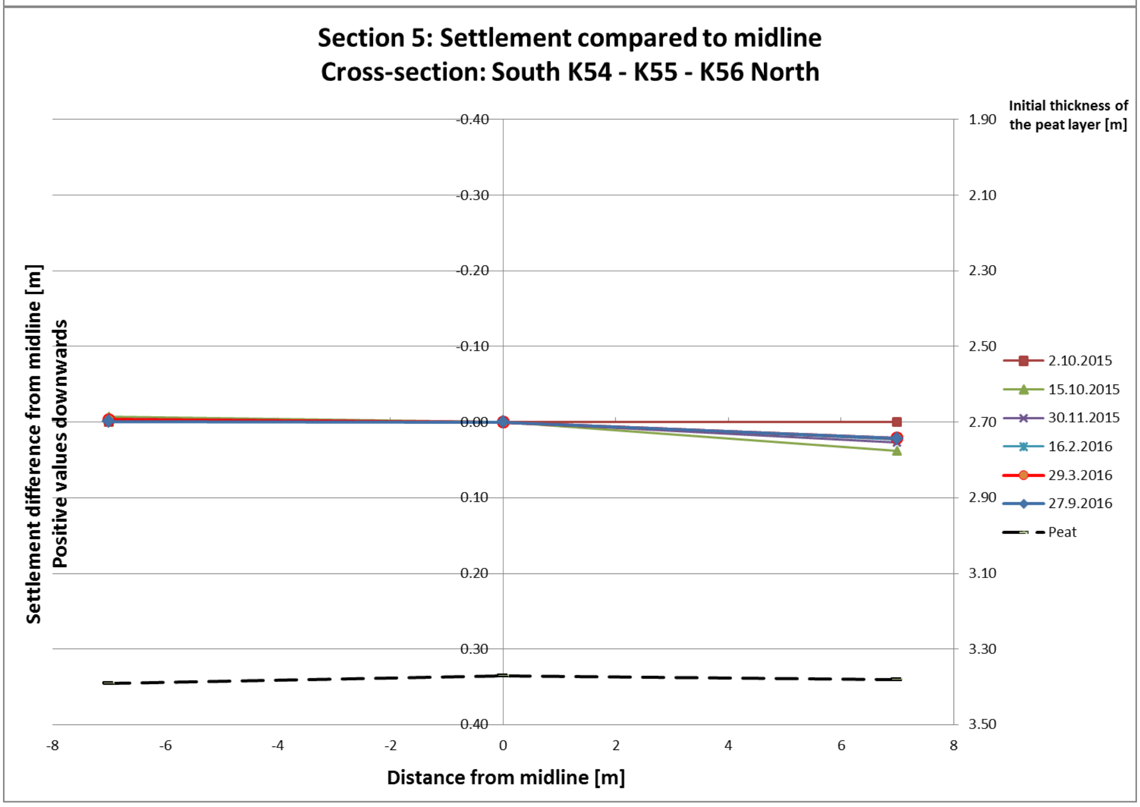

Section 3: Settlement compared to midline
Cross-section: South R303 - R304 - R305 - R306 - R307 North
Settlement difference from midline [m]
Positive values downwards
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-15
-10
-5
0
5
10
15
Distance from midline [m]
31.7.2015
10.8.2015
19.8.2015
25.8.2015
10.9.2015
7.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat


Section 3: Settlement compared to midline
Cross-section: South K33 - K32 - K31 North
Settlement difference from midline [m]
Positive values downwards
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-8
-6
-4
-2
0
2
4
6
8
Distance from midline [m]
7.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat


Section 4: Settlement compared to midline
Cross-section: South R43 - R44 - R45 - R46 - R47 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
14.8.2015
21.8.2015
25.8.2015
10.9.2015
2.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat


Section 4: Settlement compared to midline
Cross-section: South K43 - K42 - K41 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
5.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat


Section 5: Settlement compared to midline
Cross-section: South R57 - R56 -R55 - R54 - R53 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-15
-10
-5
0
5
10
15
27.8.2015
25.8.2015
10.9.2015
2.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat


Section 5: Settlement compared to midline
Cross-section: South K54 - K55 - K56 North
Settlement difference from midline [m]
Positive values downwards
Distance from midline [m]
Initial thickness of the peat layer [m]
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
-8
-6
-4
-2
0
2
4
6
8
2.10.2015
15.10.2015
30.11.2015
16.2.2016
29.3.2016
27.9.2016
Peat

Appendix 3

1918
TALLINNA TEHNIKAÜLIKOOL
TEEDEINSTITUUT

VÕÕBU KATSELÕIGU VAATLUSREEPERITE 2016.a. II ja III KVARTALI GEODEETILISE MONITOORINGU

ARUANNE

Geodetic monitoring of the Võõbu test site in II-nd and III-d quarter of 2016

Geodeesia õppetooli juhataja: Artu Ellmann

Tallinn 10/2016

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1. Sissejuhatus

Käesolev aruanne käsitleb Maanteeameti (edaspidi Tellija) ning Ramboll Eesti AS (praeguse nimetusega Škepast ja Puhkim OÜ) vahel 15.06.2015 sõlmitud teadus- ja arendustööde töövõtulepingu nr 15-00248/008 „Mnt nr 2 Tallinn-Tartu-Võru-Luhamaa km 67-68 Võõbu katsesektsioonide jälgimine ja teaduslik analüüs“ ja hilisema lisalepingu raames 2016 aasta II ja III kvartalis läbi viidud geodeetilise monitooringu tulemusi.

Ajavahemikus 01.04.2016 kuni 27.09.2016 toimus (kord kalenderkuus) kokku kuus (6) mõõtetsüklit. Igas mõõtetsüklis viidi läbi vaatlusreeperite ja -plaatide kõrgtäpne nivelleerimine. Tööde läbiviimisel lähtuti spetsiaalselt selleks tööks väljatöötatud metoodikast, mõõtmiste ja andmetöötluse põhimõtetest, mis on üksikasjalikult kirjeldatud tööaruandes Ellmann (2015) „Võõbu katselõigu vaatlusreeperite paigaldamise ning kõrgusmäärangu aruanne.“ TTÜ Teedeinstituut, 11/2015. Lisaks kirjeldavad 2015 a. IV kvartali ja 2016 a I kvartali geodeetilise monitooringu tulemusi vastavalt aruanded Ellmann (2016) „Võõbu katselõigu vaatlusreeperite 2015-a IV kvartali monitooringu aruanne“ ja Ellmann (2016) „Võõbu katselõigu vaatlusreeperite 2016-a I kvartali monitooringu aruanne“.
Et käesoleva aruande põhirõhk on 2016. a II ja III kvartali mõõtmistulemuste kirjeldamisele, siis on siinkohal püütud hoiduda eelnimetud aruannetes juba sisalduva informatsiooni asjatust dubleerimisest. Siiski parema ülevaatlikkuse huvides kaasatakse käesoleva aruande vajumiepüüridele ka mõõtmistulemusi, mis järgnesid katselõigu ülekoormuse paigaldamisele 2015.a. IV kvartalis. Nii keskendubki käesolev aruanne ülekoormusjärgsete mõõdistustulemuste omavahelisele võrdlusele ja saadud erinevustele.
Geodeetilised tööd korraldas TTÜ teedeinstituudi geodeesia õppetooli juhataja professor Artu Ellmann, kes koostas ka käesoleva aruande. Aruandega kaasneb ka elektrooniline liides *Koormusjargsed vajumid 27092016.xlsx (lisatakse puhtandiversioonile)*. Käesoleva aruande tabelite pealkirjad ning jooniste selgitused on dubleeritud inglise keelde, hõlbustamaks antud teelõigu kohta geotehniliste hinnangute koostamist.

2. Nivelleerimise tulemused

Kokku kordusnivelleeriti kõik 98 nivelleerimismärki ning veetasemed veemõõdujaamades, sellest:

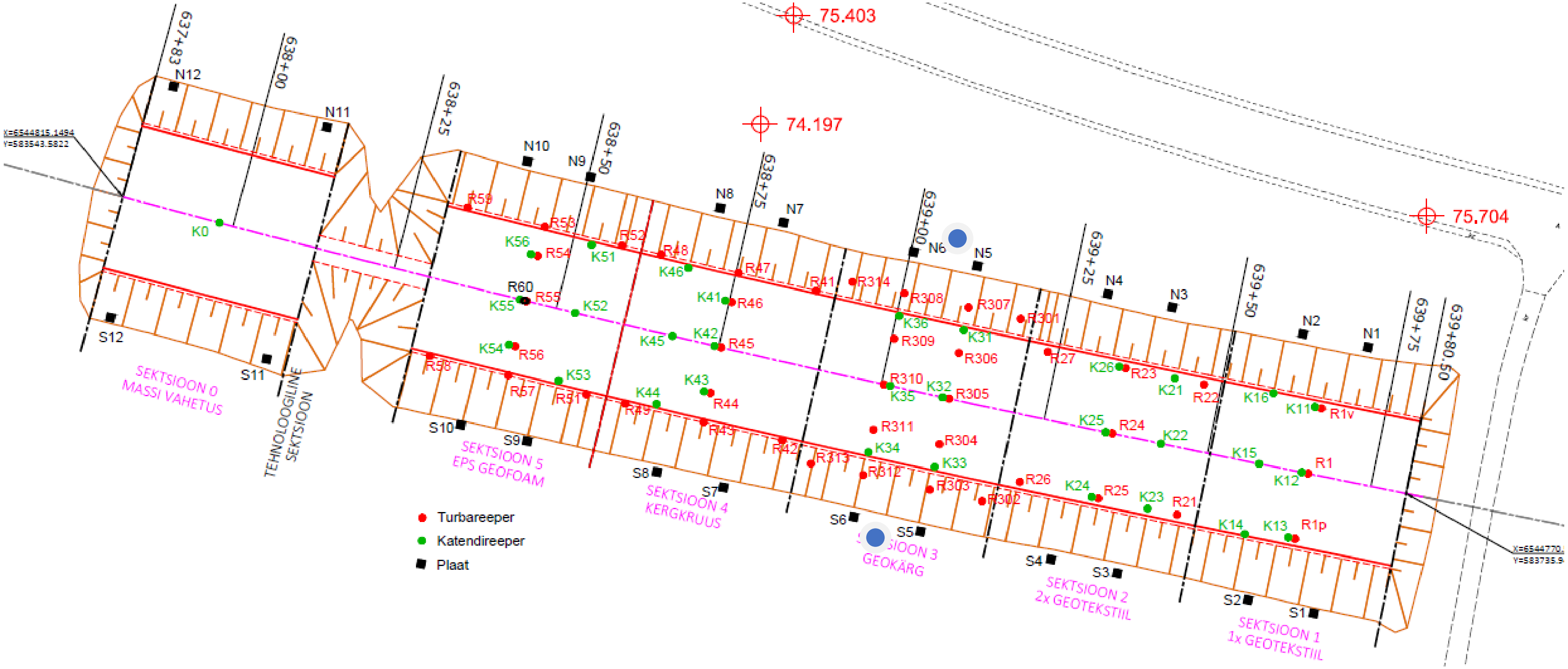
- 36 pikavardalist reeperit turbakihile laotatud geotekstiilile (edaspidi „turbareeper“)
- 6 pikavardalist reeperit 2. sektsiooni ülemisele tekstiilikihile
- 1 reeper EPS pealispinnale (5. sektsiooni keskpaik),
- 5x6 pikavardalist katendireeperit (1. kuni 5. sektsioon) ning 1 sepanaela tüüpi reeper (0-sektsioonis)
- 20 turbaplaati teemuldest 1 m kaugusel
- 4 vaatlusplaati 0-sektsiooni nõlvade nihke tuvastamiseks.
- Veetasemed teemulde põhja- ja lõunaküljel

Reeperitippude ning turba- ja nõlvaplaatide kõrgused määrati digitaalnivelliiri Trimble DiNi03 ja ribakoodlattidega (vt. Ellmann (2015) tööaruannet) geodeetilise nivelleerimisega vahevaadete meetodil. Ka nüüd tugineti kahele lähtepunktile - pinnasereeper (absoluutkõrgusega 74.197 m) ning Tallinn-Tartu mnt paremasse teeserva paigaldatud asfaldinael (absoluutkõrgusega 75.704 m), vt Ellmann (2015) tööaruande jaotis 5.1. Reeperite stabiilsuse kontrolliks mõõdeti aruandlusalusel vaatlusperioodil paaril korral nende omavahelised kõrguskasvud. Ilmnesid vaid 2.8 millimeetriline (pinnasereeperi kõrgusväärtus 74.19985 m asfaldinaela 7570 „kataloogikõrguse“ suhtes) erinevus esialgsest (2015 a. suvel) kõrguskasvust, mistõttu lähtereeperite võimaliku ebastabiilsuse mõju lõpptulemustele on üsna mõõtmistäpsuse piires. Seetõttu erinevuste võimalike põhjuste väljaselgitamisega põhjalikumalt ei tegeldud (st. et ei selgitatud välja kumb reeperitest on stabiilsem). Pealegi järgiti kõikidel mõõtmiskordadel sama mõõteskeemi - nii kasutati asfaldinaela vaatlusreeperite kõrgusmääranguks, samas kui maareeper oli lähteks turba- ja nõlvaplaatide ning veetaseme kõrgusmäärangul.

Nivelleerimisele kuulusid turba- ja katendireeperite tipud, ning turba- ning nõlvaplaatide pealispinnad, vt asendiskeemi joonisel 1. Nivelleerimistulemuste salvestamisel ning välimaterjalides juhinduti vaatlusreeperitele eelnevalt määratud numbritest, vt asendiskeemi (joonis 1) ja Ellmann (2015) tööaruande Tabeleid 1 kuni 3.

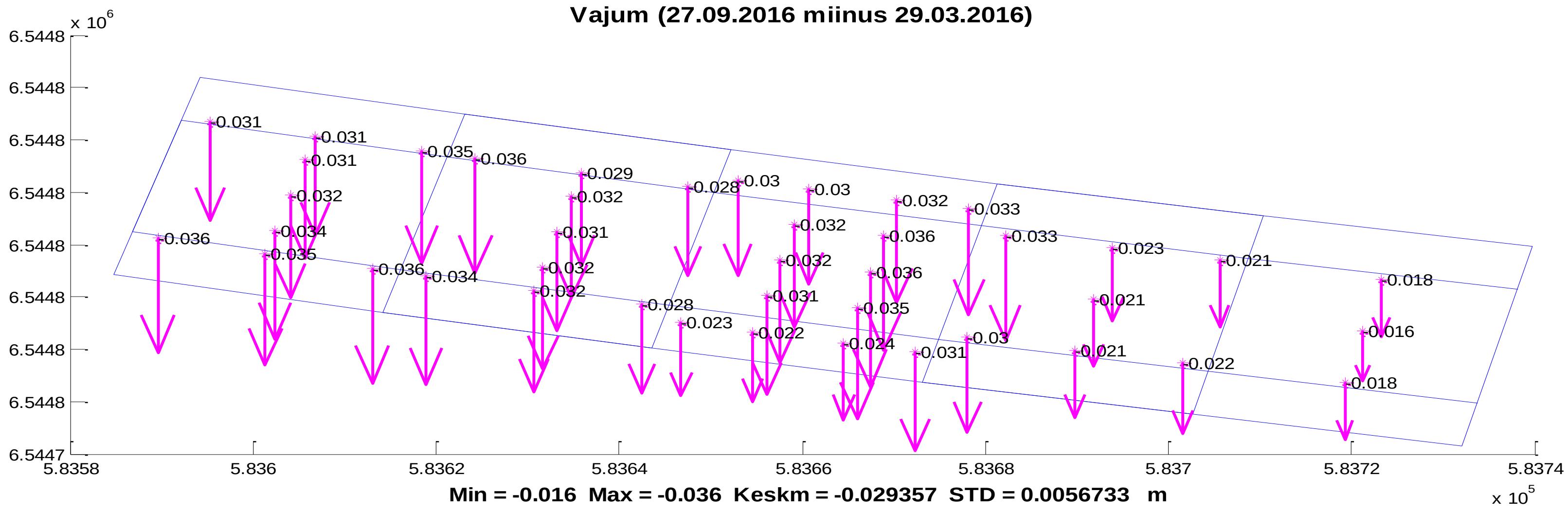
Välimõõtmiste andmed vormistati andmetöötlusprogrammiga Excel lõplikeks tulemusteks (turbakihi ja katendi kõrgused ning tuvastatud vajumid). Et aga antud uuringu seisukohast on huvipakkuvamad hoopis turbapinnase ning teekatendi kõrgused, siis reeperitippude nivelleeritud kõrgused teisendati reeperivarraste kogupikkuste väärtuste abil, vt. tabel 1 teine veerg (allikaks Ellmann (2015) tööaruande Tabelid 1 ja 3). Lõplikud tulemused on esitatud tabelites 1 ja 2.

Kõrgtäpsest nivelleerimisest ilmnes, et 2016.a II ja III kvartalis on nii turba- kui katendireeperid vajunud vahemikus 2 cm (1. ja 2. sektsioon) kuni 3,5 cm (3., 4. ja 5. sektsioon), vt joonised 2 kuni 4, aga ka tabelite 1 ja 2 eelviimane veerg. Alates ülekoormuse paigaldamisest (15.10.2015) varieeruvad koguvajumid alates 16 cm (1. ja 2. sektsioon) kuni 27 cm (4. ja 5. sektsioon), vt. tabelite 1 ja 2 viimane veerg. Vajumid on toimunud sektsiooniti küllaltki ühtlaselt, seda hoolimata ülekoormuse paksuste paarikordsest erinevusest (näit. 5 sektsiooni ülekoormus on „vaid“ 0.6…1 m, kui 1. sektsioonis küünib see 2.2 m). Reeperite vajumid pole veel stabiliseerunud, kuna vajumite kiirus vaatlusperioodi lõpul (september 2016) on vahemikus 2 kuni 3 mm/kalenderkuus.



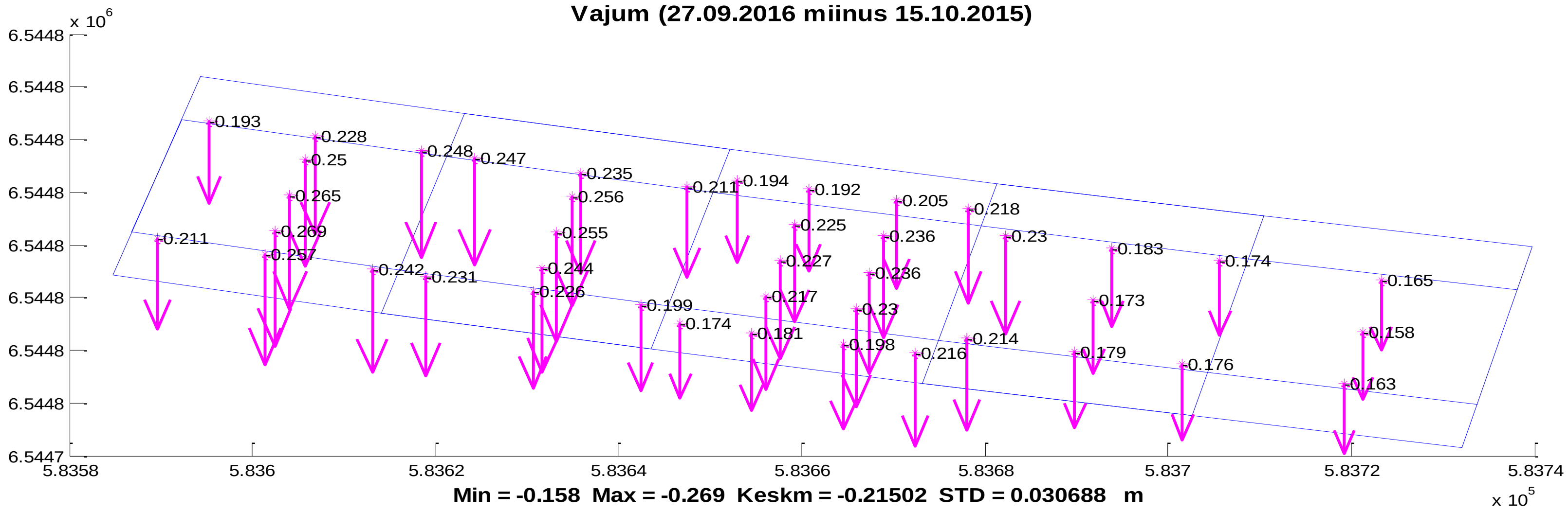
Joonis 1. Võõbu teelõigu vaatlusreeperite nummerdamine ja paigutus. Siniste sõõridega on tähistatud veemõõdutorude asukohad teemulde põhja- ja lõunaservas.

Figure 1. Locations and numbering of the leveling benchmarks (red –peat rods, green –pavement benchmarks, black –peat plates, and also the 0-Section slope plates). The blue circles denote locations of the water level stations.



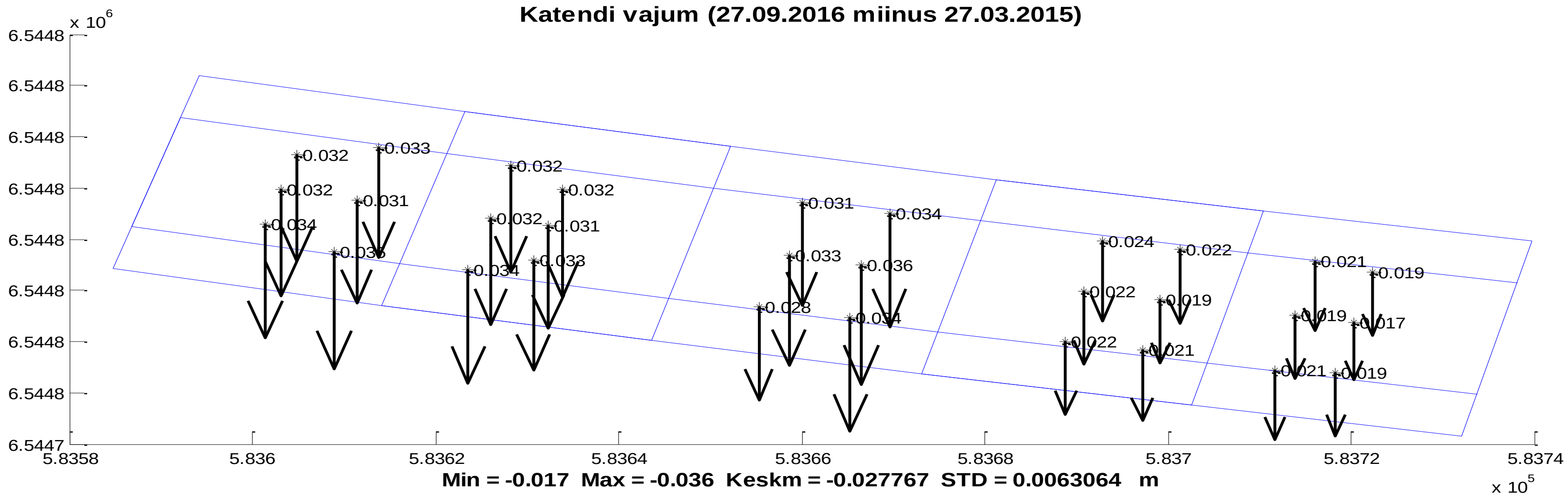
Joonis 2. Turbareeperite vajumid 2016.a. II ja III kvartalis (alates 29.03.2016 kuni 27.09.2016).

Figure 2. Subsidence values (dates from 29.03.2016 until 27.09.2016) at the peat rod locations.



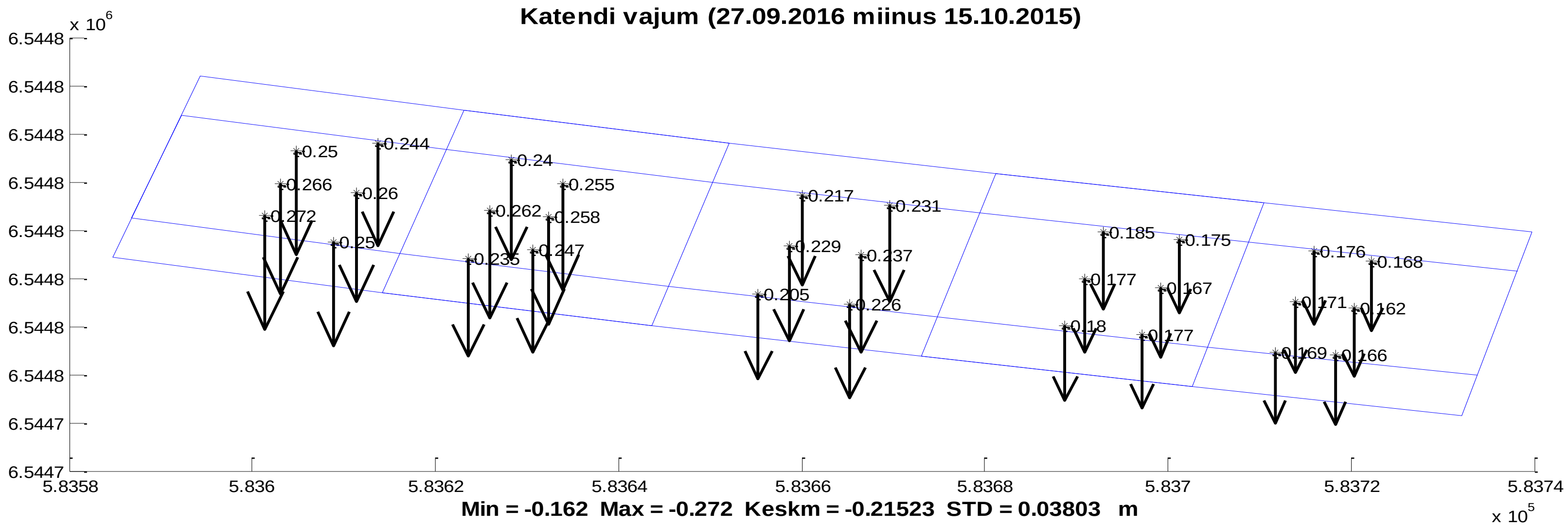
Joonis 2A. Turbareeperite koguvajumid alates ülekoormuse paigaldamisest (alates 15.10.2015 kuni 27.09.2016).

Figure 2A. Total subsidence values (dates from 15.10.2015 until 27.09.2016) at the peat rod locations.



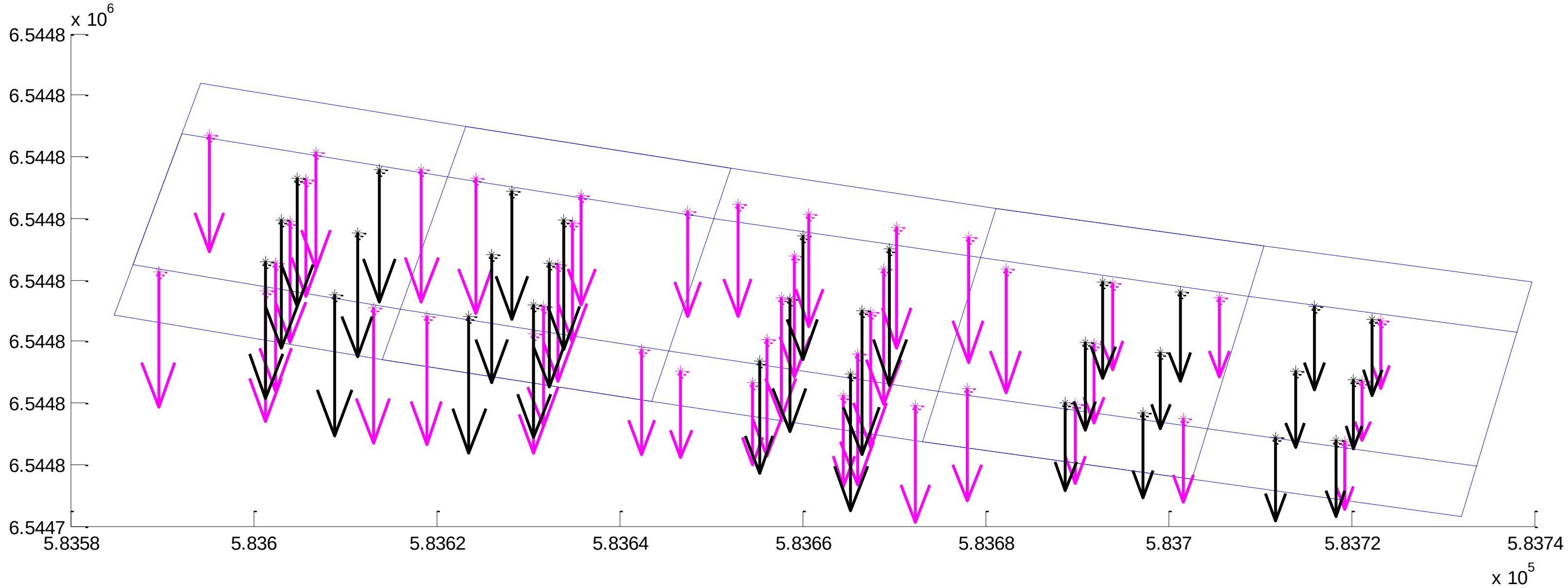
Joonis 3. Katendireeperite vajumid 2016.a. II ja III kvartalis (alates 29.03.2015 kuni 27.09.2016).

Figure 3. Subsidence values (dates from 29.03 until 27.09.2016) at the locations of pavement benchmarks.



Joonis 3A. Katendireeperite koguvajumid alates ülekoormuse paigaldamisest (alates 15.10.2015 kuni 27.09.2016).

Figure 3A. Total subsidence values (dates from 15.10.2015 until 27.09.2016) at the locations of pavement benchmarks.



Joonis 4. Turba- ja katendireeperite vajumid 2016.a. II ja III kvartalis (alates 29.03.2016 kuni 27.09.2016).

Figure 4. Subsidence (dates from 29.03.2016 until 27.09.2016) at the locations of peat rods and pavement benchmarks

Tabel 1. Turba- ja katendireeperite monitooringu tulemused (vt. ka elektroonilist liidest *Koormusjargsed vajumid 27092016.xlsx*) 2016 a. II ja III kvartalis. Iga sektsiooni suurim koguvajum on esile toodud rasvase fondiga. Reeperivarraste kogupikkuste allikaks on Ellmann (2015) tööaruande tabelid 1 ja 3.

Table 1. Peat rods and pavement benchmarks' monitoring results (see the attached file *Koormusjargsed vajumid 27092016.xlsx)* in the II and III quarters of 2016. The largest subsidence values within each section are indicated in bold font.

Benchmark number	Lenght of rod		Absolute heights of the peat layer and the pavement						Sub-sidence	Total sub-sidence
Reeperi number	Reeprivarda pikkus		Turba /katendi kõrgusväärtused						Vajum	Koguvajum
		29.03.2016	28.04.2016	31.05.2016	30.06.2016	28.07.2016	30.08.2016	27.09.2016	29.03-27.09	15.10-27.09
Sektsioon 1										
R1v	4,933	73,221	73,217	73,215	73,212	73,208	73,205	73,203	0,018	0,165
R1	5,032	73,133	73,129	73,127	73,124	73,122	73,118	73,117	0,016	0,158
R1p	5,018	73,111	73,108	73,105	73,103	73,099	73,095	73,093	0,018	0,163
K11	2,335	75,747	75,742	75,739	75,736	75,733	75,729	75,727	0,019	0,168
K12	1,935	76,212	76,209	76,206	76,203	76,201	76,197	76,196	0,017	0,162
K13	2,335	75,817	75,813	75,810	75,807	75,804	75,799	75,797	0,019	0,166
K14	2,335	75,764	75,760	75,756	75,753	75,750	75,745	75,742	0,021	0,169
K15	1,935	76,173	76,169	76,165	76,162	76,160	76,156	76,154	0,019	0,171
K16	2,335	75,694	75,690	75,686	75,683	75,680	75,675	75,673	**0,021**	**0,176**
Sektsioon 2										
R21	3,943	74,114	74,110	74,106	74,102	74,099	74,094	74,092	0,022	0,176
R22	3,950	74,142	74,137	74,135	74,131	74,128	74,123	74,121	0,021	0,174
R23	4,050	74,017	74,013	74,009	74,004	74,001	73,996	73,994	0,023	0,183
R24	5,073	73,022	73,018	73,014	73,010	73,007	73,003	73,001	0,021	0,173
R25	3,909	74,178	74,174	74,171	74,167	74,164	74,159	74,156	0,021	0,179
R26	4,266	73,737	73,732	73,727	73,721	73,717	73,710	73,707	0,030	0,214
R27	4,244	73,751	73,745	73,739	73,733	73,728	73,722	73,718	**0,033**	**0,230**
K21	2,235	75,774	75,771	75,767	75,763	75,760	75,755	75,753	0,022	0,175
K22	1,835	76,237	76,233	76,230	76,226	76,224	76,220	76,218	0,019	0,167
K23	2,235	75,783	75,780	75,776	75,773	75,769	75,764	75,762	0,021	0,177
K24	2,235	75,801	75,798	75,795	75,790	75,787	75,782	75,780	0,022	0,180
K25	1,835	76,214	76,209	76,205	76,201	76,199	76,194	76,192	0,022	0,177
K26	2,235	75,794	75,790	75,786	75,781	75,778	75,773	75,770	0,024	0,185
Sektsioon 3										
R301	3,985	72,865	72,861	72,853	72,848	72,844	72,832	72,832	0,033	0,218
R302	3,981	72,752	72,748	72,745	72,737	72,734	72,726	72,721	0,031	0,216
R303	4,001	72,673	72,666	72,671	72,662	72,659	72,649	72,649	0,024	0,198
R304	5,077	72,510	72,504	72,498	72,490	72,487	72,479	72,476	0,035	0,230
R305	5,027	72,554	72,547	72,540	72,533	72,529	72,521	72,518	**0,036**	0,236
R306	5,013	72,524	72,517	72,511	72,503	72,499	72,492	72,488	**0,036**	0,236
R307	3,971	72,714	72,711	72,703	72,696	72,693	72,686	72,682	0,032	0,205
R308	3,974	72,389	72,385	72,379	72,373	72,369	72,363	72,358	0,030	0,192
R309	5,068	72,473	72,467	72,462	72,455	72,452	72,444	72,442	0,032	0,225
R310	4,943	72,599	72,593	72,587	72,580	72,577	72,570	72,568	0,032	0,227
R311	5,097	72,500	72,491	72,489	72,482	72,479	72,472	72,469	0,031	0,217
R312	3,985	72,563	72,566	72,561	72,553	72,551	72,543	72,540	0,022	0,181
R313	3,964	72,535	72,534	72,530	72,522	72,521	72,514	72,512	0,023	0,174
R314	3,976	72,615	72,611	72,606	72,599	72,596	72,588	72,585	0,030	0,194
K31	1,735	75,754	75,749	75,743	75,735	75,731	75,723	75,719	0,034	0,231
K32	1,335	76,191	76,183	76,177	76,169	76,165	76,158	76,155	**0,036**	**0,237**
K33	1,735	75,718	75,712	75,706	75,699	75,695	75,687	75,683	0,034	0,226
K34	1,735	75,704	75,701	75,697	75,690	75,687	75,680	75,677	0,028	0,205
K35	1,335	76,175	76,169	76,163	76,156	76,152	76,145	76,143	0,033	0,229
K36	1,735	75,762	75,757	75,752	75,745	75,741	75,734	75,731	0,031	0,217
Sektsioon 4										
R41	3,765	73,322	73,318	73,314	73,308	73,304	73,298	73,294	0,028	0,211
R42	3,778	73,192	73,189	73,183	73,177	73,174	73,167	73,164	0,028	0,199
R43	3,972	72,963	72,957	72,952	72,946	72,942	72,935	72,931	0,032	0,226
R44	4,085	72,733	72,728	72,721	72,714	72,711	72,704	72,701	0,032	0,244
R45	3,989	72,790	72,784	72,779	72,772	72,769	72,762	72,759	0,031	0,255
R46	3,779	72,952	72,946	72,941	72,933	72,930	72,923	72,920	0,032	0,256
R47	3,764	73,160	73,157	73,152	73,145	73,141	73,134	73,131	0,029	0,235
R48	3,782	73,056	73,051	73,045	73,038	73,034	73,026	73,020	**0,036**	0,247
R49	3,767	73,032	73,028	73,020	73,014	73,009	73,002	72,998	0,034	0,231
K41	0,985	75,771	75,766	75,760	75,753	75,749	75,743	75,740	0,032	0,255
K42	0,685	76,071	76,065	76,059	76,052	76,049	76,043	76,040	0,031	0,258
K43	0,985	75,788	75,782	75,776	75,769	75,766	75,759	75,755	0,033	0,247
K44	1,135	75,579	75,572	75,568	75,560	75,556	75,549	75,545	0,034	0,235
K45	0,685	76,021	76,015	76,009	76,001	75,998	75,992	75,989	0,032	**0,262**
K46	1,135	75,619	75,614	75,608	75,601	75,597	75,590	75,587	0,032	0,240
Sektsioon 5										
R51	3,732	72,975	72,970	72,963	72,955	72,950	72,943	72,939	**0,036**	0,242
R52	3,893	72,799	72,795	72,788	72,780	72,775	72,769	72,764	0,035	0,248
R53	4,013	72,741	72,738	72,732	72,725	72,720	72,714	72,710	0,031	0,228
R54	3,633	73,005	73,000	72,994	72,986	72,983	72,977	72,974	0,031	0,250
R55	3,640	72,963	72,957	72,950	72,943	72,940	72,934	72,931	0,032	0,265
R60	1,250	75,221	75,217	75,210	75,202	75,199	75,193	75,190	0,031	0,268
R56	3,841	72,856	72,851	72,844	72,835	72,832	72,825	72,822	0,034	0,269
R57	3,885	72,873	72,870	72,863	72,855	72,850	72,842	72,838	0,035	0,257
R58	3,983	72,761	72,756	72,750	72,743	72,739	72,730	72,725	**0,036**	0,211
R59	3,743	72,994	72,991	72,985	72,978	72,974	72,967	72,963	0,031	0,193
K51	0,985	75,533	75,528	75,523	75,515	75,510	75,504	75,501	0,033	0,244
K52	0,585	76,011	76,005	75,999	75,991	75,988	75,982	75,980	0,031	0,260
K53	0,985	75,534	75,529	75,523	75,515	75,510	75,503	75,499	0,035	0,250
K54	0,835	75,686	75,680	75,674	75,666	75,662	75,655	75,652	0,034	**0,272**
K55	0,585	75,985	75,980	75,973	75,965	75,962	75,956	75,953	0,032	0,266
K56	0,835	75,703	75,697	75,691	75,683	75,679	75,673	75,670	0,032	0,250

Tabel 2. Turba- ja nõlvaplaatide monitooringu tulemused (vt. ka elektroonilist liidest *Koormusjargsed vajumid 27092016.xlsx*) 2016. a II ja III kvartalis.

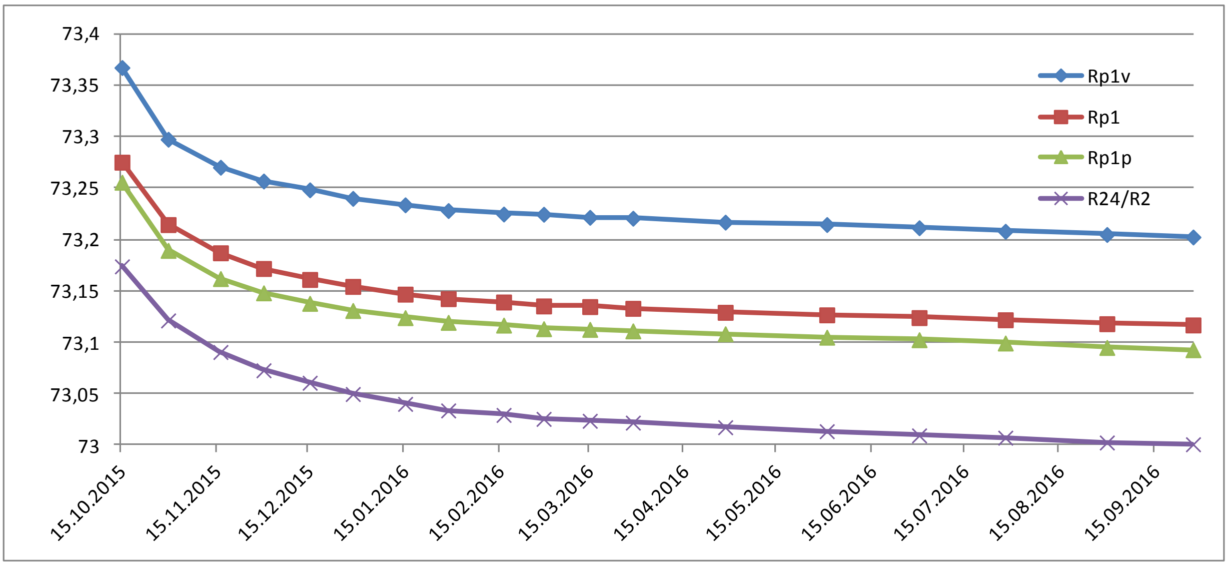
Table 2. Peat and slope plates' related monitoring results (see the attached file *Koormusjargsed vajumid 27092016.xlsx*) in the II and III quarters of 2016.

Turbaplaadid **Peate plates**		**Turba ja nõlvaplaatide kõrgusväärtused** Absolute heights of peat and slope plates							**Sub-sidence** **Vajum**	**Total sub-sidence** **Koguvajum**
	15.10.2015	**29.03.2016**	**28.04.2016**	**31.05.2016**	**30.06.2016**	**28.07.2016**	**30.08.2016**	**27.09.2016**	**29.03-27.09**	**15.10-27.09**
S1	74,115	74,15013	74,1028	74,08372	74,089	74,083	74,0943	74,09361	-0,057	-0,021
S2	74,186	74,19438	74,15318	74,133	74,133	74,124	74,138	74,133	-0,061	-0,053
S3	74,261	74,26822	74,23929	74,219	74,22025	74,21437	74,230	74,224	-0,045	-0,038
S4	74,338	74,32323	74,30743	74,294	74,296	74,28857	74,300	74,295	-0,029	-0,043
S5	74,240	74,21904	74,20109	74,186	74,185	74,181	74,187	74,181	-0,038	-0,059
S6	74,286	74,26498	74,24714	74,23104	74,23302	74,226	74,23832	74,232	-0,033	-0,055
S7	74,260	74,23947	74,22117	74,205	74,206	74,200	74,209	74,203	-0,036	-0,057
S8	74,236	74,23415	74,19152	74,169	74,175	74,164	74,175	74,167	-0,068	-0,069
S9	74,209	74,19117	74,18198	74,160	74,162	74,152	74,165	74,156	-0,035	-0,053
S10	74,181	74,18442	74,15603	74,133	74,138	74,127	74,147	74,142	-0,042	-0,039
N1	74,128		74,13791	74,120	74,122	74,121	74,128	74,12683	NA	-0,001
N2	74,227	74,23978	74,2245	74,211	74,209	74,208	74,227	74,22398	-0,016	-0,003
N3	74,430	74,42465	74,41612	74,404	74,405	74,395	74,415	74,407	-0,018	-0,023
N4	74,270	74,2762	74,26537	74,246	74,243	74,230	74,259	74,251	-0,025	-0,019
N5	74,205		74,18509	74,167	74,164	74,157	74,172	74,167	NA	-0,038
N6	74,300	74,28006	74,27753	74,261	74,25345	74,25	74,26375	74,2588	-0,021	-0,041
N7	74,261	74,26575	74,25405	74,234	74,231	74,219	74,237	74,230	-0,035	-0,031
N8	74,230		74,20719	74,190	74,187	74,175	74,193	74,189	NA	-0,041
N9	74,247	74,26001	74,23176	74,198	74,208	74,178	74,213	74,202	-0,058	-0,045
N10	74,415	74,44368	74,38528	74,367	74,366	74,346	74,381	74,362	-0,082	-0,053
Sektsioon 0 nõlvaplaadid /slope plates										
N11	75,009	75,00167	75,00187	75,00309	75,00289	75,003	75,00057	75,00163	0,000	-0,008
N12	75,046	75,03759	75,03676	75,03807	75,03748	75,038	75,03472	75,03612	-0,001	-0,010
S11	74,573	74,56936	74,56875	74,56977	74,56954	74,570	74,56709	74,56863	-0,001	-0,004
S12	74,879	74,86951	74,86859	74,87045	74,87043	74,870	74,86689	74,8686	-0,001	-0,011

Märka, et 29.03.2016 jääkatte all olnud turbaplaatidele (sellised on tabelis tähistatud märkega „jääs") kõrguseid ei määratud.

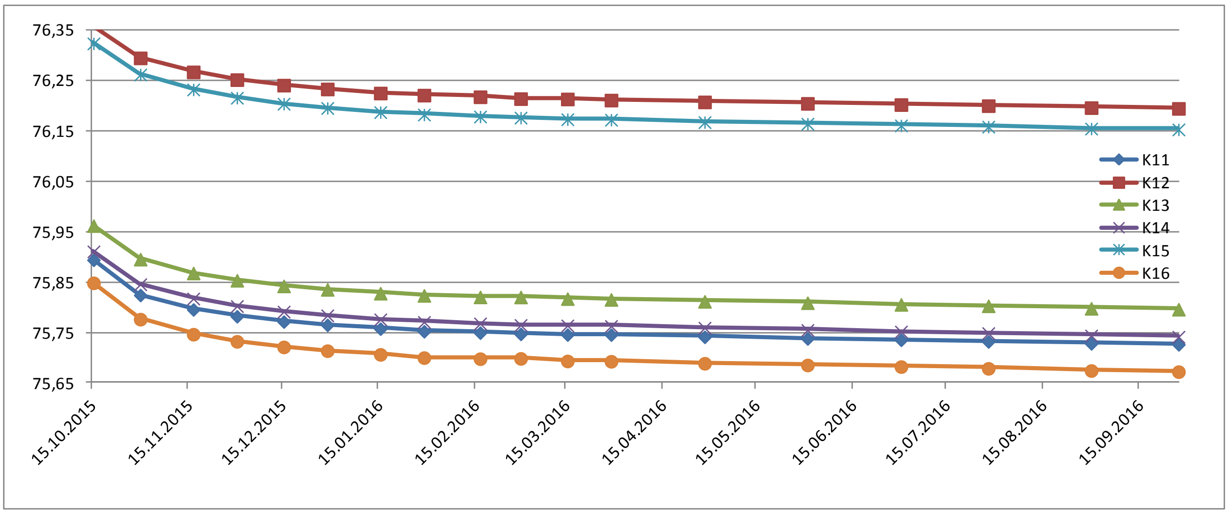
3. Vajumite graafikud sektsiooniti ja profiilidena

Alljärgnevad joonised 5 kuni 14 kajastavad turba- või katendikihi vajumeid epüüridena ja sektsiooniti. Parema ülevaatlikusse huvides ning ajalise ülekattuvuse saavutamiseks esitatakse ka ülekoormuse paigaldamise järgsed vaatlustulemused (alates 15.10.2015). Jooniste koostamise aluseks on käesoleva aruande elektrooniline liides *Koormusjargsed vajumid 27092016.xlsx*.



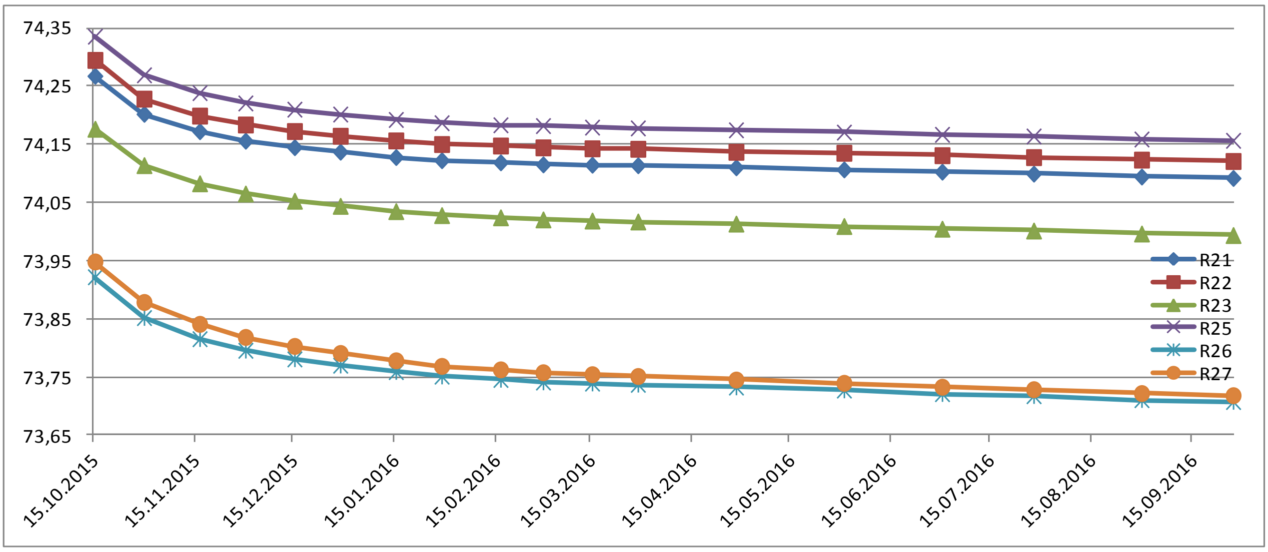
Joonis 5. Turbakihi vajumite graafik 1. sektsiooni reeperite ja 2. sektsiooni tsentraalreeperi asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad, vertikaalteljel absoluutkõrgused.

Figure 5. Subsidence rates for the Section 1 benchmarks and the central peat rod in Section 2 since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



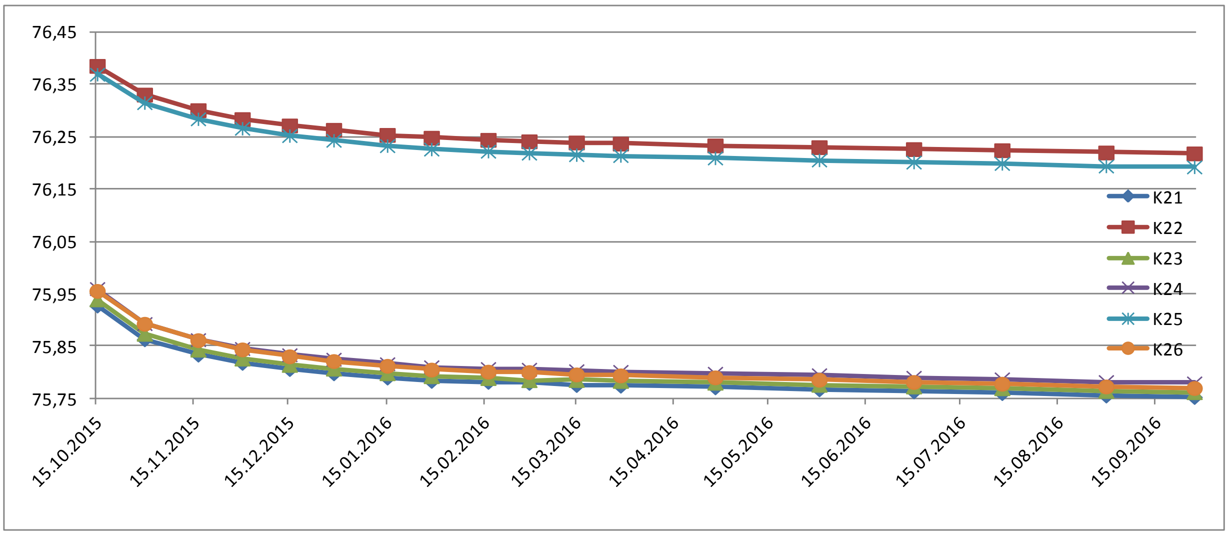
Joonis 6. Teekatendi vajumite graafik 1. sektsiooni katendireeperite asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad (alates ülekoormuse paigaldamise lõpust), vertikaalteljel absoluutkõrgused.

Figure 6. Subsidence rates for the Section 1 pavement benchmarks since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



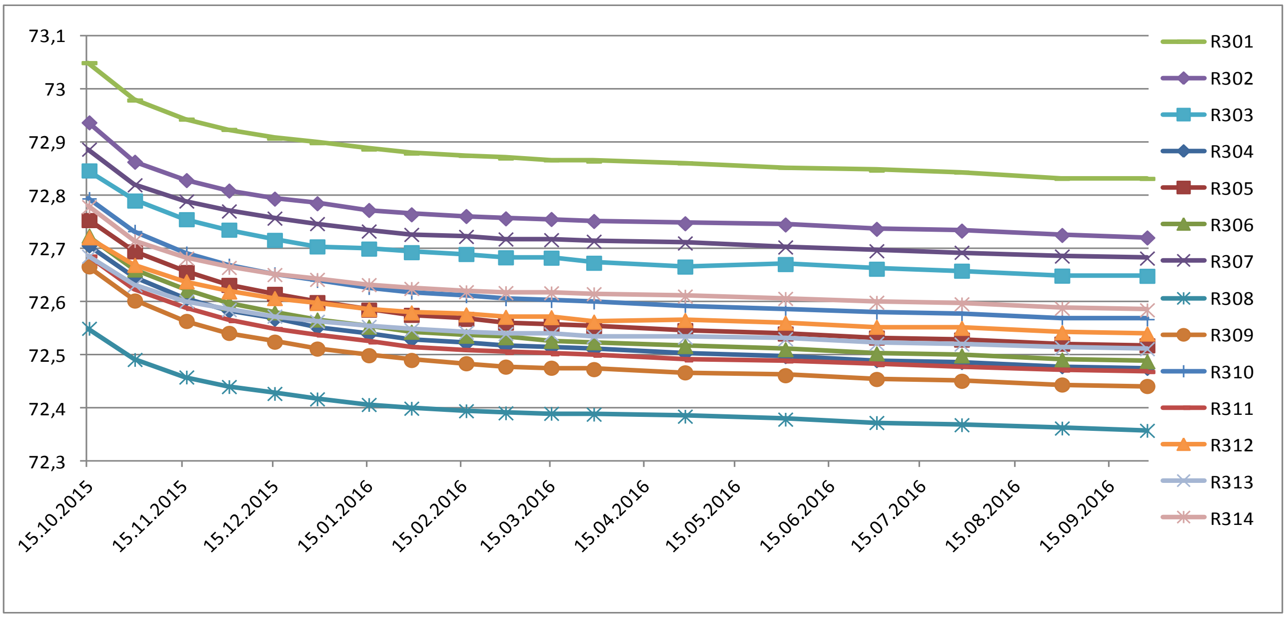
Joonis 7. Vajumite graafik 2. sektsiooni äärereeperite asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad (alates ülekoormuse paigaldamise lõpust), vertikaalteljel absoluutkõrgused.

Figure 7. Subsidence rates for the Section 2 side benchmarks since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



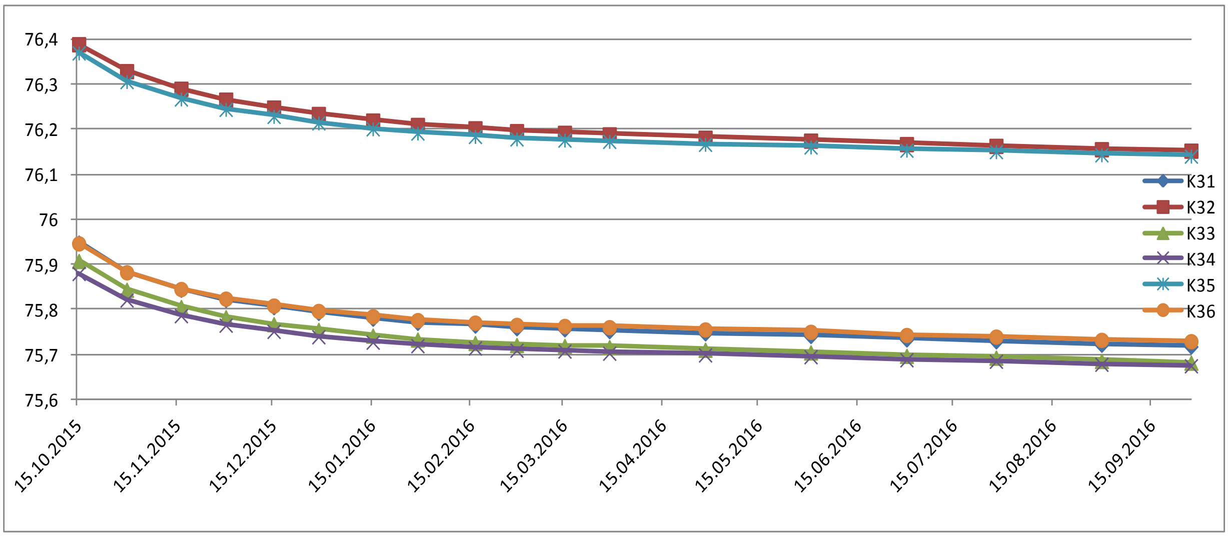
Joonis 8. Teekatendi vajumite graafik 2. sektsiooni katendireeperi asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad, vertikaalteljel absoluutkõrgused.

Figure 8. Subsidence rates for the Section 2 pavement benchmarks since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



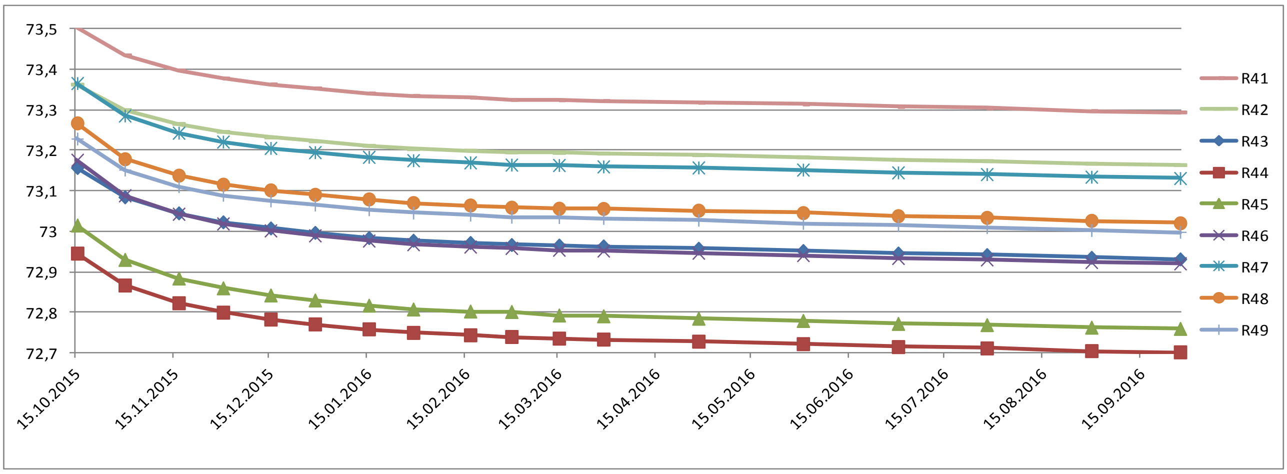
Joonis 9. Turbakihi vajumite graafik 3. sektsiooni turbareeperite asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad, vertikaalteljel absoluutkõrgused.

Figure 9. Subsidence rates for the Section 3 peat rods since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



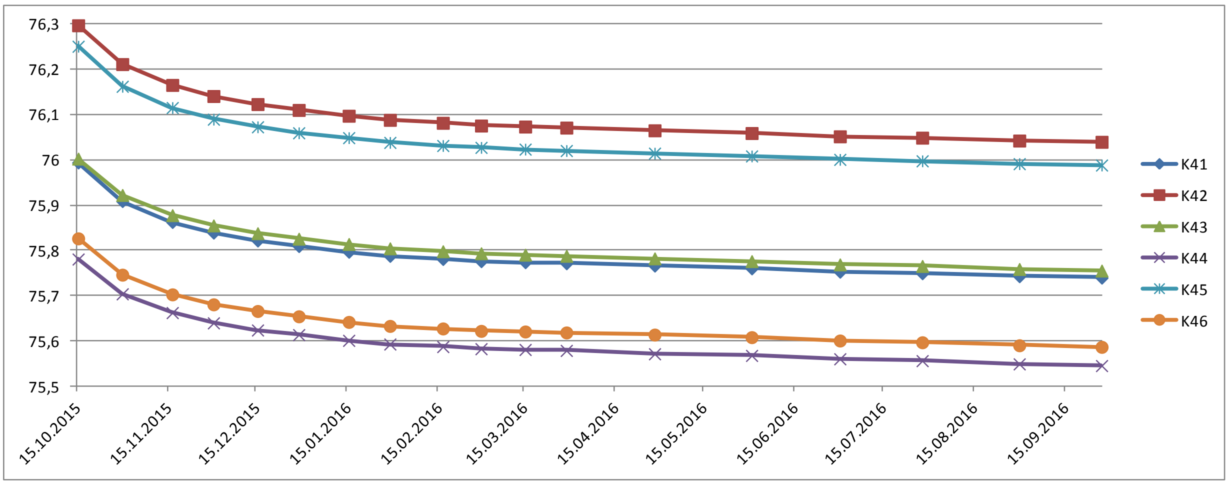
Joonis 10. Teekatendi vajumite graafik 3. sektsiooni katendireeperi asukohtades alates 15.10.2015 kuni 29.03.2016. Horisontaalteljel on kuupäevad, vertikaalteljel absoluutkõrgused.

Figure 10. Subsidence rates for the Section 3 pavement benchmarks since 15.10.2015 up to 29.03.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



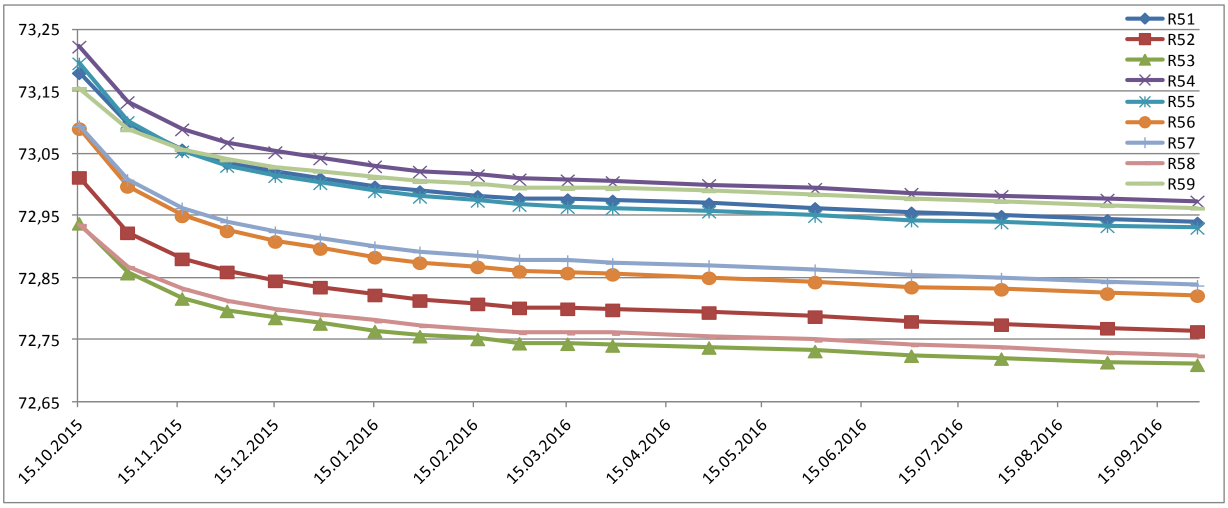
Joonis 11. Turbakihi vajumite graafik 4. sektsiooni turbareeperi asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad, vertikaalteljel absoluutkõrgused.

Figure 11. Subsidence rates for the Section 4 peat rods since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



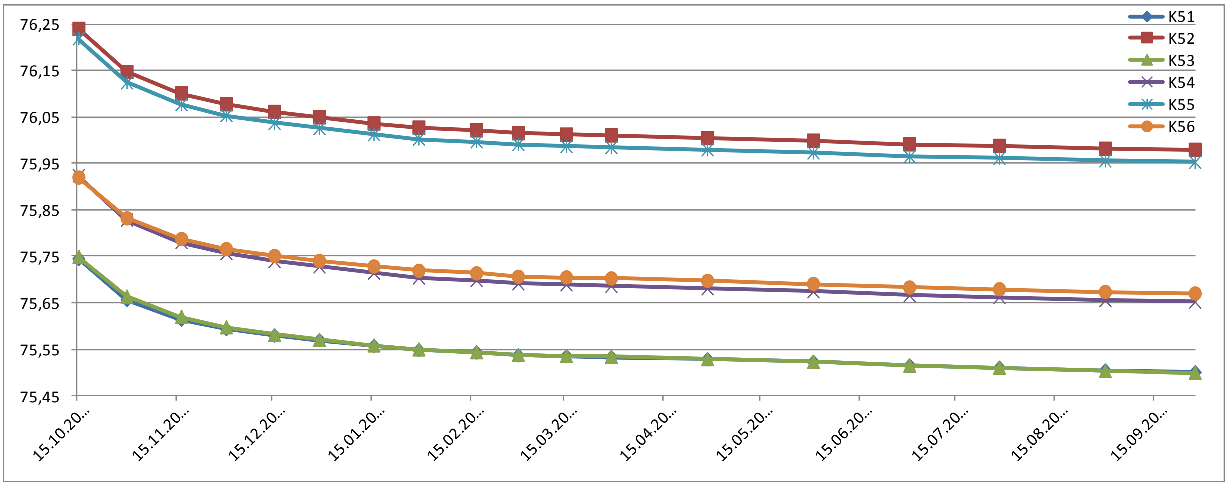
Joonis 12. Teekatendi vajumite graafik 4. sektsiooni katendireeperi asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad, vertikaalteljel absoluutkõrgused.

Figure 12. Subsidence rates for the Section 4 pavement benchmarks since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



Joonis 13. Teekatendi vajumite graafik 5. sektsiooni turbareeperite asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad, vertikaalteljel absoluutkõrgused.

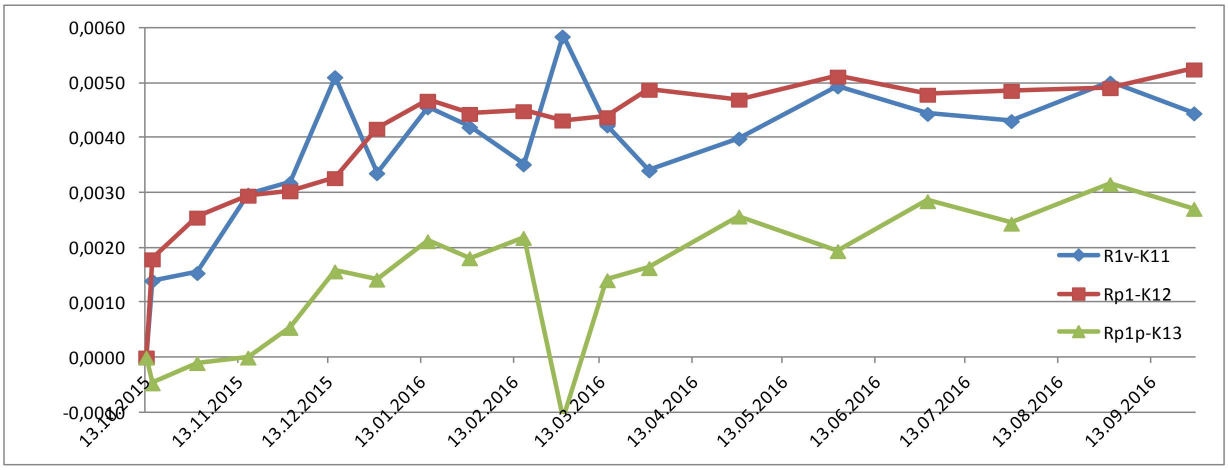
Figure 13. Subsidence rates for the Section 5 peat rods since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.



Joonis 14. Teekatendi vajumite graafik 5. sektsiooni katendireeperite asukohtades alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad, vertikaalteljel absoluutkõrgused. (K51 graafik on sarnaste kõrgusväärtuste tõttu „peitunud“ K53 graafiku taha)

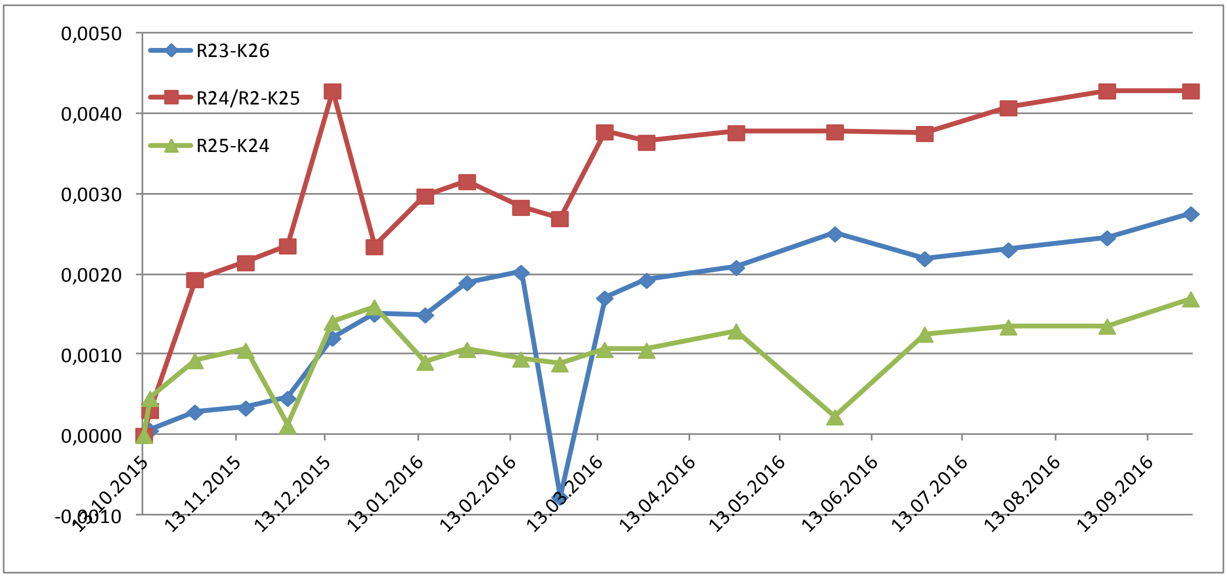
Figure 14. Subsidence rates for the Section 5 pavement benchmarks since 15.10.2015 up to 27.09.2016. Vertical axis denotes the absolute heights, the horizontal axis refers to the calendar dates.

Kuna osa katendireepritest oli asetatud turbareeperi tipu vahetusse lähedusse (kaugusele 1 m, vt ka joonised 1 kuni 4), siis võimaldab see uurida antud reeperipaari asukohas teemulde tihenemist ülekoormuse mõjul. Tihenemine toimub juhul, kui reeperipaari katendireeper vajub rohkem kui turbareeperist paariline. Joonistel 15 kuni 19 on toodud reeperipaaride vajumite erinevused sektsiooniti, vt. ka käesoleva aruande elektroonilises liideses toodud arvväärtuseid. Joonistel toodud positiivsed väärtused väljendavad teemulde tihenemist, mis ülekoormuse mõjul (alates kevadest on olnud stabiilsed) ning ei ületa 1 cm. Esineb teatud varieerumist, tulenevalt sektsioonides mulde rajamise tehnoloogiast, vt arutelu allpool.



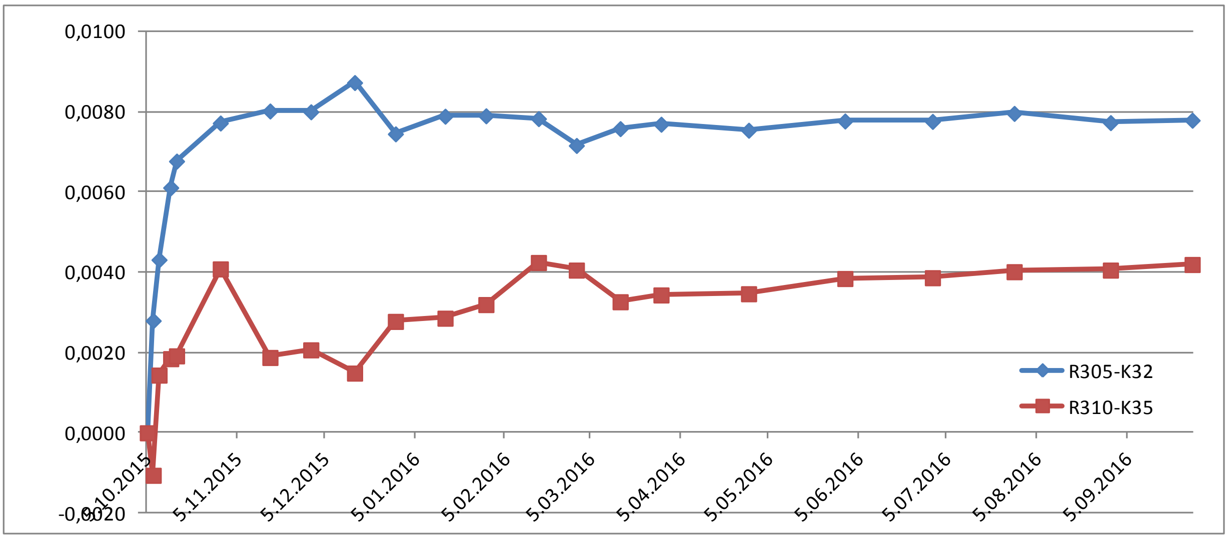
Joonis 15. Teemulde tihenemise graafik 1. sektsiooni reeperipaaride asukohtades alates 13.10.2015 kuni 27.09.2016. Graafikute teravad sakid on tõenäoliselt põhjustatud juhuslikest mõõtmisvigadest. Horisontaalteljel on kuupäevad (alates sektsiooni katendireeperite paigaldamisest), vertikaalteljel tihenemisväärtused meetrites.

Figure 15. Estimates of the road embankment compaction at the location of paired benchmarks in section 1 from 13.10.2015 up to 27.09.2016. Occurrence of sharp peaks may denote random errors. Vertical axis denotes the compaction estimates, the horizontal axis refers to the calendar dates. Unit is meter.



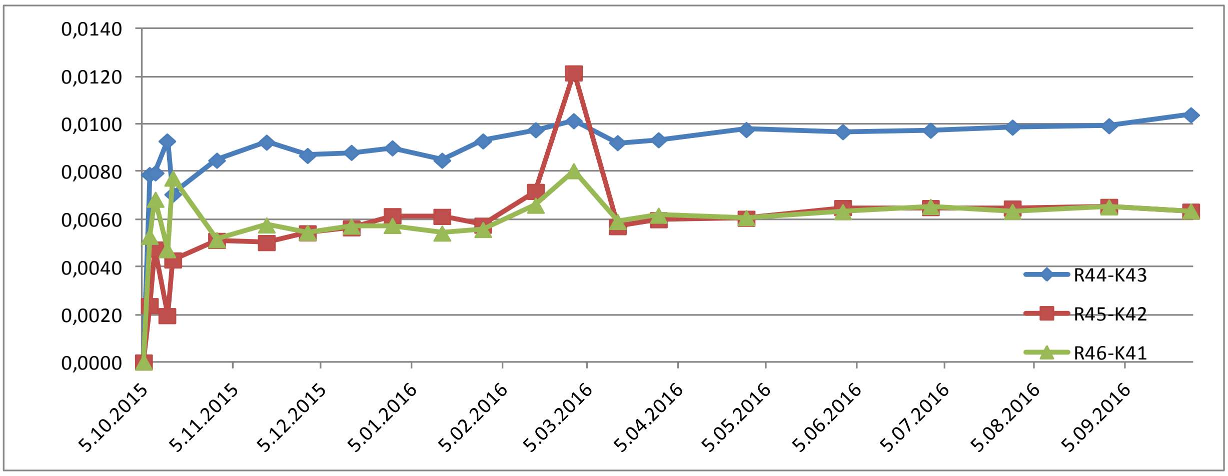
Joonis 16. Teemulde tihenemise graafik 2. sektsiooni reeperipaari asukohtades alates 13.10.2015 kuni 27.09.2016. Graafikute teravad sakid on tõenäoliselt põhjustatud juhuslikest mõõtmisvigadest. Horisontaalteljel on kuupäevad (alates sektsiooni katendireeperite paigaldamisest), vertikaalteljel tihenemisväärtused meetrites.

Figure 16. Estimates of the road embankment compaction at the location of paired benchmarks in section 2 from 13.10.2015 up to 27.09.2016. Occurrence of sharp peaks may denote random errors. Vertical axis denotes the compaction estimates, the horizontal axis refers to the calendar dates. Unit is meter.



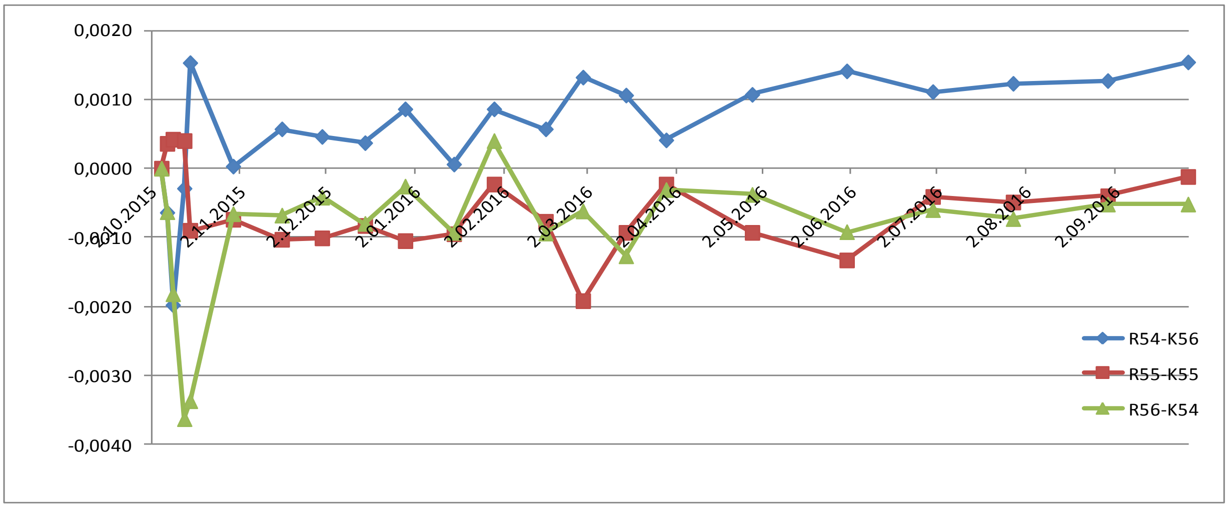
Joonis 19. Teemulde tihenemise graafik 3. sektsiooni reeperipaaride asukohtades alates 05.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad (alates sektsiooni katendireeperite paigaldamisest), vertikaalteljel tihenemisväärtused meetrites.

Figure 19. Estimates of the road embankment compaction at the location of paired benchmarks in section 3 from 05.10.2015 up to 27.09.2016. Vertical axis denotes the compaction estimates, the horizontal axis refers to the calendar dates. Unit is meter.



Joonis 20. Teemulde tihenemise graafik 4. sektsiooni reeperipaaride asukohtades 2015.a. alates 05.10.2015 kuni 27.09.2016. Graafikute teravad sakid on tõenäoliselt põhjustatud juhuslikest mõõtmisvigadest. Horisontaalteljel on kuupäevad (alates sektsiooni katendireeperite paigaldamisest), vertikaalteljel tihenemisväärtused meetrites.

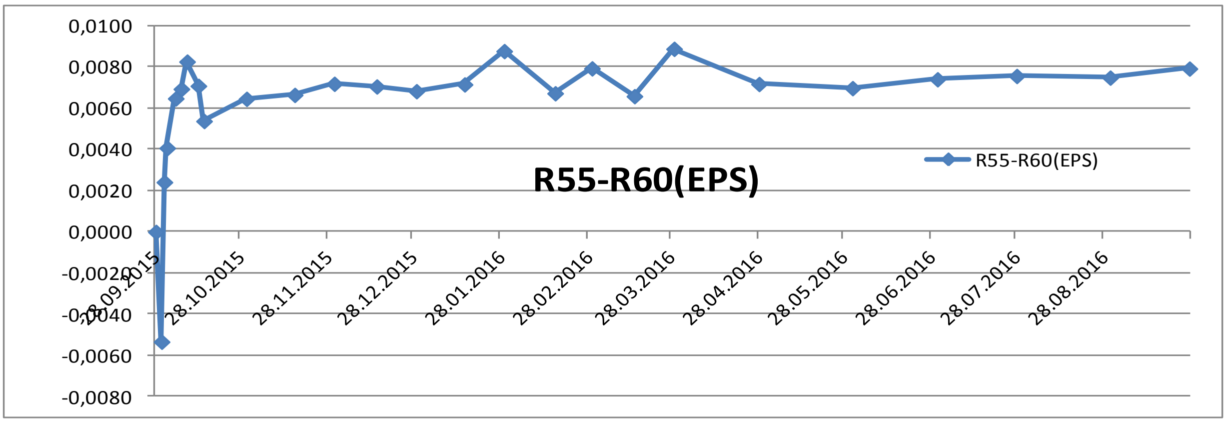
Figure 20. Estimates of the road embankment compaction at the location of paired benchmarks in section 4 from 05.10.2015 up to 27.09.2016. Occurrence of sharp peaks may denote random errors. Vertical axis denotes the compaction estimates, the horizontal axis refers to the calendar dates. Unit is meter.



Joonis 21. Teemulde tihenemise graafik 5. sektsiooni reeperipaaride asukohtades alates 02.10.2015 kuni 27.09.2016. Graafikute teravad sakid on tõenäoliselt põhjustatud juhuslikest mõõtmisvigadest. Horisontaalteljel on kuupäevad (alates sektsiooni katendireeperite paigaldamisest), vertikaalteljel tihenemisväärtused meetrites.

Figure 21. Estimates of the road embankment compaction at the location of paired benchmarks in section 5 from 02.10.2015 up to 27.09.2016. Occurrence of sharp peaks may denote random errors. Vertical axis denotes the compaction estimates, the horizontal axis refers to the calendar dates. Unit is meter.

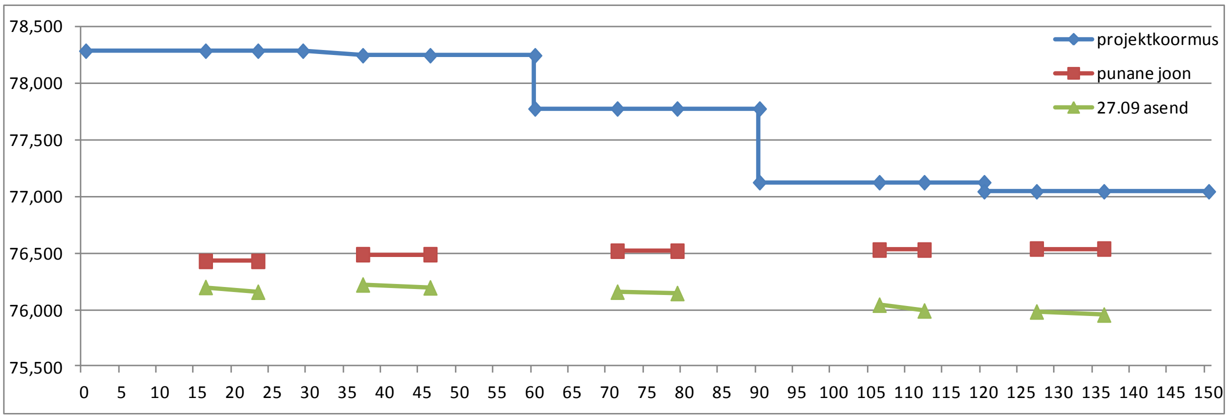
Märka, et eelnevate jooniste piigid ja negatiivsed arvväärtused võivad olla tingitud nivelleerimise juhuslikest vigadest. Mõõtmiste tihedus ja aegridade pikkus on siiski piisavad teemulde tihenemisväärtuste määranguks. Tuleb märkida, et aruandlusperioodil mulde olulist tihenemist ei täheldatud. Seni on tihenemine sektsioonides 1 kuni 10 mm piires ja stabiliseerumas. Suurim on see 4. sektsioonis, mida ilmselt saab selgitada muldematerjaliks oleva kergkruusa tihenemisega ülekoormuse esimestel kuudel, vt joonis 20. Samas 5. sektsiooni (EPS) reeperipaaride mõõtmistulemused teekatte edasist tihendamist ei näita. Arvatavalt on see tingitud asjaolust, et 5. sektsiooni muldest moodustab põhiosa EPS materjal. Seda kinnitab 5. sektsiooni tsentraalse turbareeperi R55 lähikonda (ca 30 cm kaugusele) paigaldatud lisareeper R60, mille alus toetub EPS pealispinnale. Selle reeperipaari kõrguste omavaheline võrdlemine võimaldab tuvastada EPS materjali kokkusurumist, vt joonis 20. Nähtub, et teemulde pealmise kihi ja ülekoormuse lisamine on senini põhjustanud EPS materjali kokkusurumise ca 7…8 mm võrra, seda vaid mulde ehitusperioodil. Ülekoormuse lisamine aga EPS edasist olulist kokkupressimist ei näita.



Joonis 20. EPS materjali tihenemise graafik 5. sektsiooni keskkohas alates 28.09.2015 kuni 27.09.2016. Miinusväärtusega „võnge“ võib olla põhjustatud ehitustehnika riivest katendieelse ehituse lõppfaasis. Horisontaalteljel on kuupäevad (EPS-pealse reeperi paigaldamisest), vertikaalteljel tihenemisväärtused meetrites.

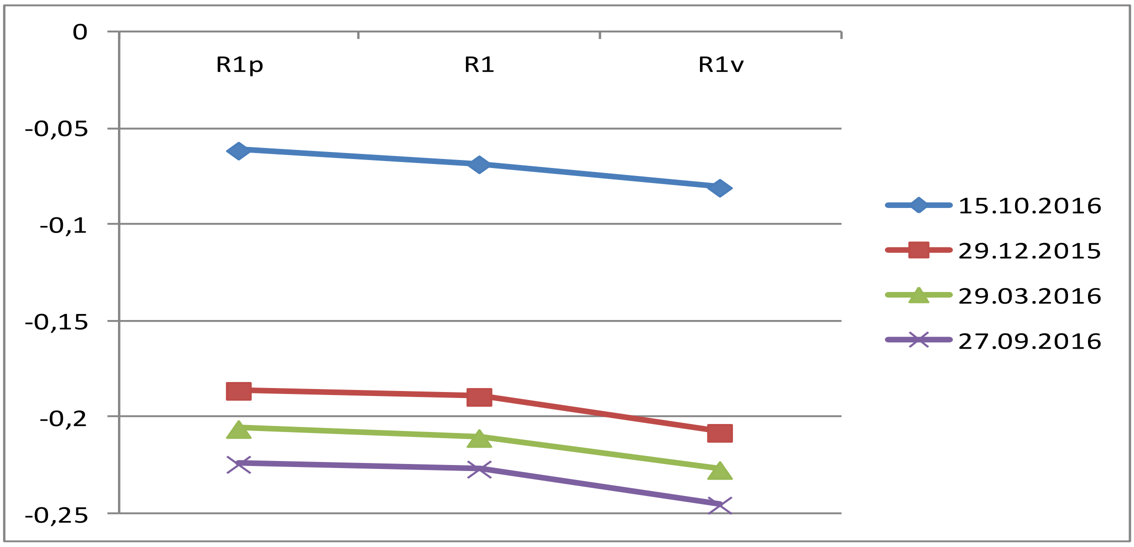
Fig. 20. Estimates of the EPS-material compaction at the location of the centrally paired benchmarks in section 5 from 28.09.2015 up to 27.09.2016. Vertical axis denotes the compaction estimates, the horizontal axis refers to the calendar dates. Units in meters.

Joonis 21 kujutab läbi absoluutkõrguste vajumeid katselõigu pikiteljel katendireeperite asukohtades. Ilmneb, et suurimate vajumitega sektsioonide 4 ja 5 keskosas on ülekoormuse pealispind praeguseks (27.09.2016) pea samal nivoopinnal projektse "punase joonega" (välja ehitatud 02.10.2015).



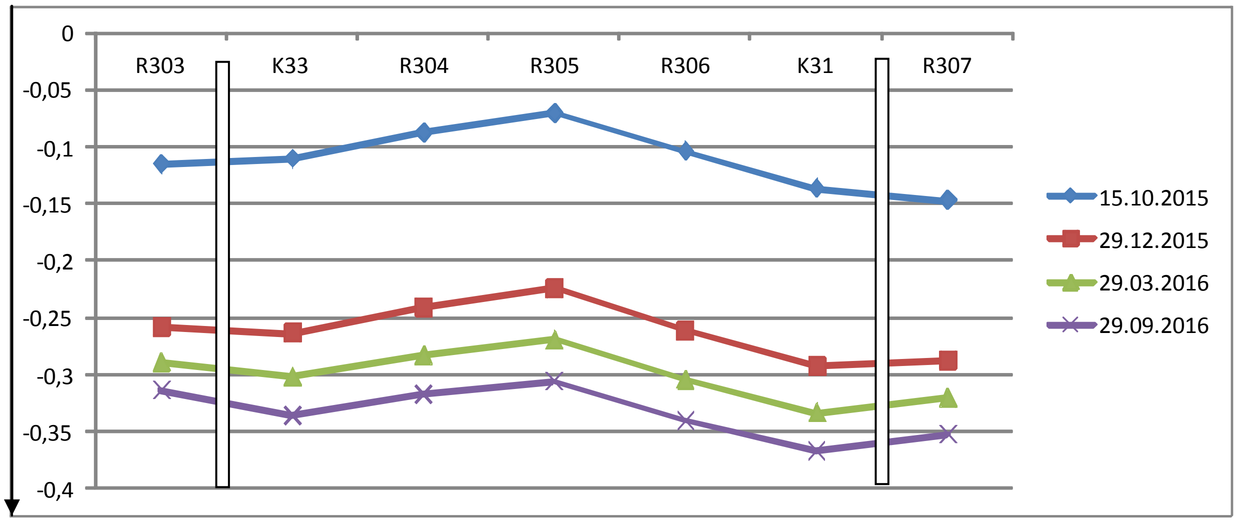
Joonis 21. Absoluutkõrgused katselõigu pikiteljel katendireeperite asukohtades 27.09.2016 seisuga. Horisontaalteljel on kaugused 1. sektsiooni Tartu poolsest otsast (piketaaživäärtus 639+80.4, joonise parempoolsele servale vastab piketaazivväärtus 638+30.4)

Alljärgnevatel joonistel 22 kuni 25 on kujutatud vajumeid sektsioonide keskel ristprofiilidena turba- ja katendireeperite asukohtades. Jooniste parem pool kujutab olemasoleva Tallinn- Tartu maantee poolsete reeperite (vt. ka reeperite plaanilisi asukohti joonisel 1). Nähtub, et reeglina on teemulde põhjapoolsem serv rohkem vajunud kui soopoolne serv. Selle võib tingida asjaolu, et ehitusperioodil liikus kogu ehitustehnika teisele (soopoolsele) poolele rajatud ajutisel teel, seega tihendades toona rohkem antud teepoole alust pinnast. Samas võib see olla tingitud turbakihi paksuse varieerumisest, mille väärtuste kohta aruande koostajal andmed paraku puuduvad.

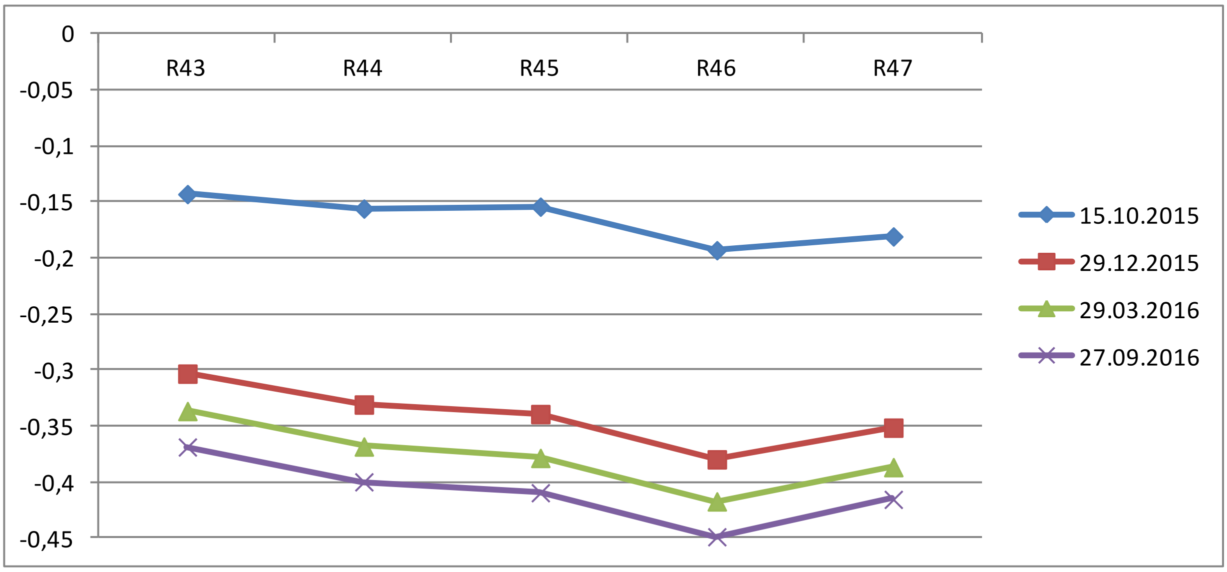


Joonis 22. 1. sektsiooni keskpaiga (piketaaziväärtus 639+65.4) vajumid ristprofiilina turbareeperite asukohtades 09.10.2015 (ülekoormuse paigaldamise algus antud sektsioonis) mõõtmiste suhtes. Joonise paremal poolel on olemasoleva Tallinn-Tartu maantee poolne reeper R1v. Ühik on m.

Sektsioonis 3. on paigaldatud ka nõlvareeperid (vt. joonis 1), st et seal on ülekoormuse kiht väiksem kui teekatendi kohal. Jooniselt 23 nähtub, et tulemusena on nõlvareeperite asukohtades kohati vajumid väiksemad. Tee keskosa esialgselt väiksem vajumväärtus võib olla tingitud asjaolust, et ülekoormuse kiht on seal õhem (ca 1/3 võrra) kui teeservades (teekatendi põikkalde, ca 4 cm 1 m kohta, tõttu), lisaks kulges vahetult selle kõrval ehitusaegne ajutine tee.

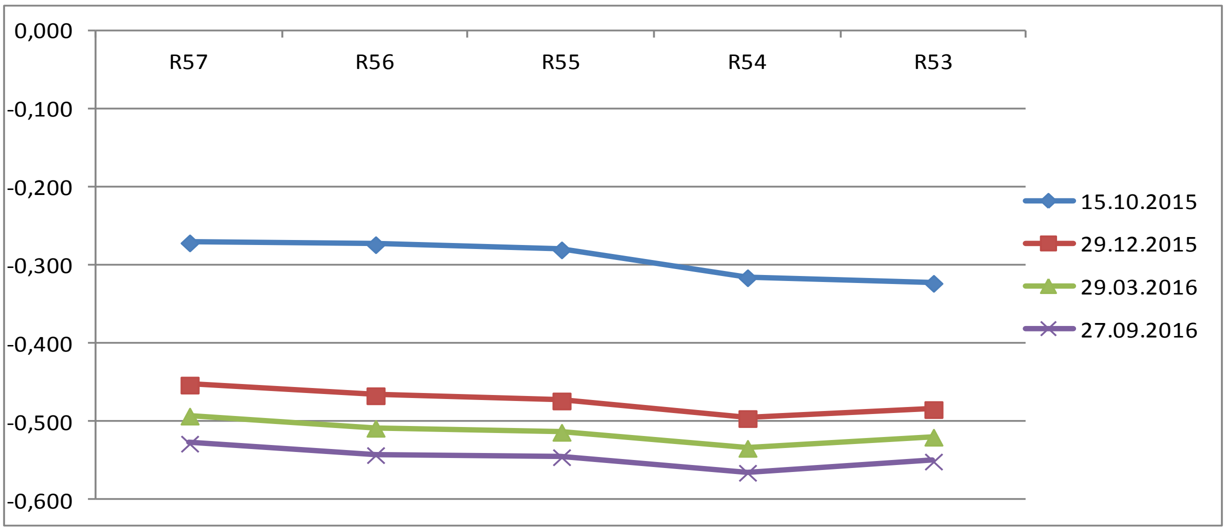


Joonis 23. 3. sektsiooni keskpaiga (piketaaziväärtus 639+05.4) vajumid ristprofiilina turbareeperite asukohtades 07.10.2015 (ülekoormuse paigaldamise algus antud sektsioonis) mõõtmiste suhtes. Joonise paremal poolel on olemasoleva maantee poolne nõlvareeper R307. Vertikaaljooned tähistavad nõlva ülemiste servade asukohti. Ühik on m.



Joonis 24. 4. sektsiooni keskpaiga (piketaaziväärtus 638+75.4) vajumid ristprofiilina turbareeperite asukohtades 05.10.2015 (ülekoormuse paigaldamise algus antud sektsioonis) mõõtmiste suhtes. Joonise paremal poolel on olemasoleva maantee poolne reeper R47. Ühik on meeter.

Et 5. sektsioon ehitati viimasena, siis katend vajus tuntavalt ka veel enne ülekoormuse paigaldamist. Realistliku pildi vajumite dünaamikast annab joonis 25, mis kujutab 5.sektsiooni vajumeid 02.10.2015 kuupäeva (katendi paigaldamine) suhtes.



Joonis 25. 5. sektsiooni keskpaiga (piketaaziväärtus 638+45.4) vajumid ristprofiilina turbareeperite asukohtades 02.10.2015 (katendi paigaldamine, 3 päeva enne ülekoormuse paigaldamise algust antud sektsioonis) mõõtmiste suhtes. Joonise paremal poolel on olemasoleva maantee poolne reeper R53. Ühik on meeter.

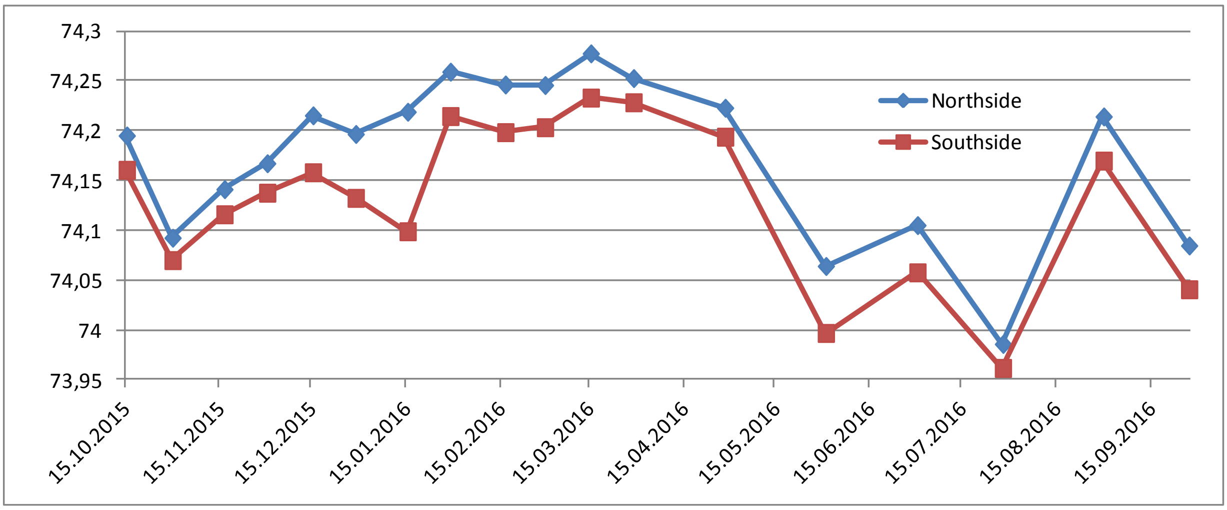
Reeperite punktandmed annavad siiski vaid osalise pildi vajumistest. Nimelt visuaalsel vaatlusel tuvastati 27.09.2016 nii 4. ja 5 sektsiooni keskel ülekoormuse pealispinnas suur lohk, kuhu sadevesi koguneb (sammalgi kohati kasvama hakanud), vt Lisa 1. Kuna sektsiooni ääred näikse olevat kõrgemad, siis vesi jääb sinna lohku lõksu. Mäletamist mööda siluti ülekatte pealispind 2015 a sügisel üsna tasaseks, aga ilmselt vahepealsed ebaühtlased vajumised on oma töö teinud.

Seega oleks teedeformatsioonide ulatuse ning jaotise täpsustamiseks järgnevalt tarvis ikkagi üritada puhastatud teekatendit 3D laserskaneerida.

4. Veetaseme vaatlused ja tulemuste seos turbaplaatide vertikaalliikumistega

Veetaseme mõõtmiseks oli 15.10.2015-ks paigaldatud teine-teisele poole teemullet (nõlva alumisest servast ca 1,5 m kaugusele) 3. sektsiooni keskpaika veetaseme vaatlustorud. Veevaatlustoru servale määrati nivelleerimisega igakordselt kõrgusväärtus. Veetaseme kõrgusväärtuse teadasaamiseks lahutati toruservast mõõdulatiga või -lindiga mõõdetud vertikaalne vahemaa veetasemeni.

Veetaseme väärtused on esitatud joonisel 26, mille koostamise aluseks on käesoleva aruande elektrooniline liides.

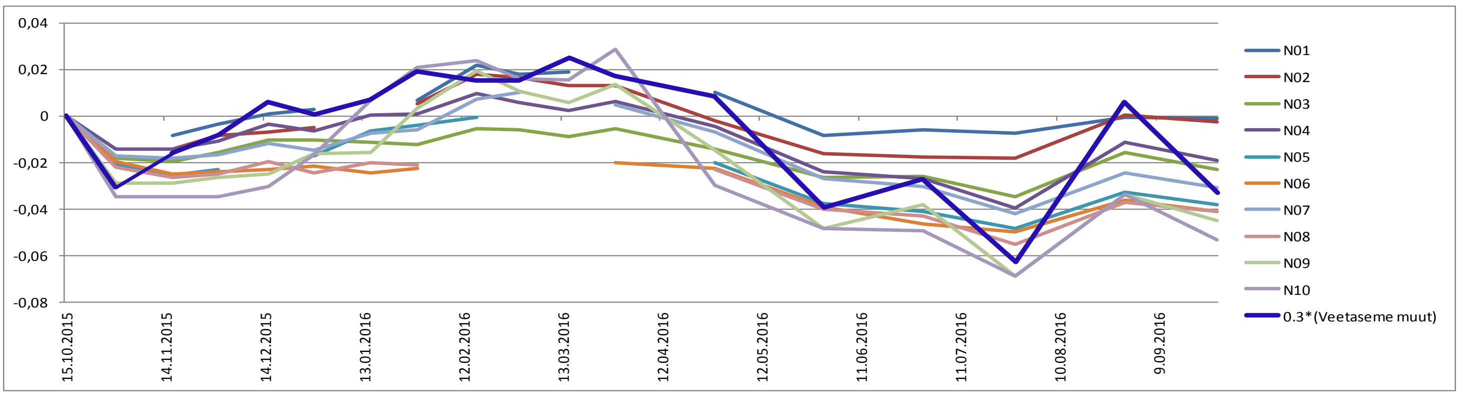


Joonis 26. Veetasemed (absoluutkõrgustena) teemulde põhja- ja lõunaküljel alates 15.10.2015 kuni 27.09.2016.

Figure 26. Off-embankment water levels (absolute heights with respect to the sea level) from 15.10.2015 up to 27.09.2016.

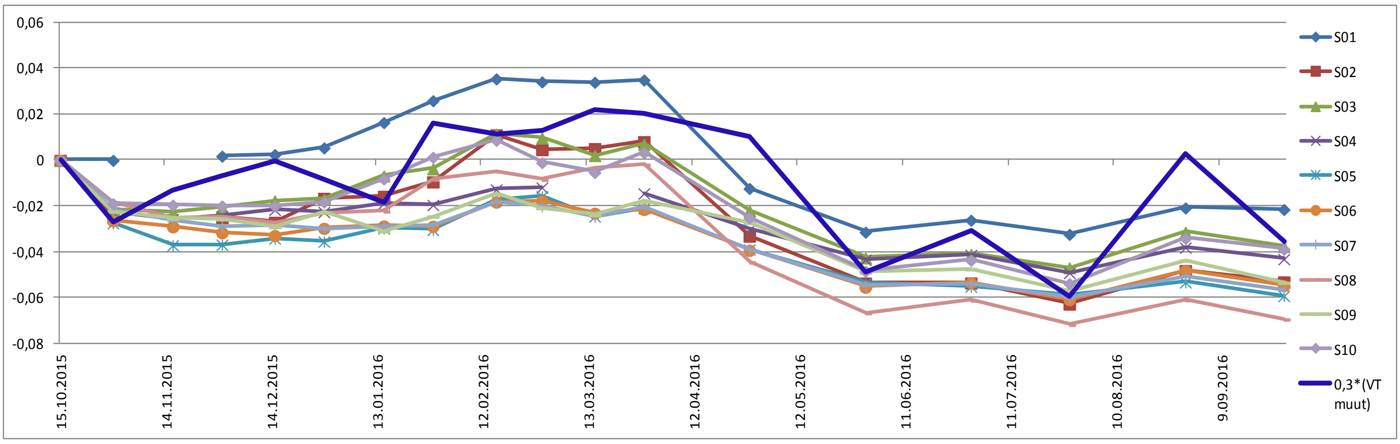
Ilmneb, et teemulde põhjaküljel (Tallinn-Tartu mnt. poolses servas) on veetase endiselt igas mõõtetsüklis ca 2…4 cm kõrgem kui teemulde (soopoolsel) lõunaküljel. Ühtlasi on ilmnenud veetaseme muutuste seos teemulde kõrvale paigaldatud turbaplaatide vertikaalliikumistega.

Nimelt 2015/2016 talveperioodil läbiviidud mõõtmiste põhjal tuvastati turbaplaatide vertikaalliikumised (domineeriva üles-suunaga). Toona jäi ebaselgeks, kas tõusuväärtused on tingitud maapinna külmumisest või teemulde vajumissurve tõttu kõrvalpinnase ülestõukumisest. Käesoleval aruandlusperioodil nivelleerimistulemustest tuletatud turbaplaatide vertikaalliikumiste võrdlus võimaldas tuvastada seost veetaseme muuduga. Joonistel 27 ja 28 on toodud põhja- ja lõunapoolsete turbaplaatide (vastavalt N01…N10 kuni S01…S10) kõrgusväärtuste muudud algse ajapunkti (15.10.2015) suhtes. Lisaks on jämeda sinise joonega joonisele kantud koefitsiendiga 0.3 läbi korrutatud veetaseme muut sama (15.10.2015) kuupäeva suhtes. Koefitsient 0.3 on leitud visuaal-empiiriliselt. Alternatiivseks võimaluseks oleks olnud leida korrelatsioon iga individuaalse turbaplaadi vertikaalliikumise ja veetaseme muudu osas ning hiljem saadud tulemused keskmistada.



Joonis 27. Teemulde põhjakülje turbaplaatide kõrguste muutuste graafik ajavahemikus 15.10.2015 kuni 27.09.2016. Jämeda sinise joonega on tähistatud koefitsiendiga 0.3 läbi korrutatud veetaseme muut samal ajaperioodil. Ühikud meetrites.

Figure 27. Height changes of the peat plates in the northern side of the road embankment from 15.10.2015 to 27.09.2016. The bold blue line visualizes the waterlevel changes (multiplied by an empirical coefficient 0.3) during the same time- period. Units in meters.



Joonis 28. Teemulde lõunakülje turbaplaatide kõrguste muutuste graafik vahemikus 15.10.2015 kuni 27.09.2016. Jämeda sinise joonega on tähistatud koefitsiendiga 0.3 läbi korrutatud veetaseme muut samal ajaperioodil. Ühikud meetrites.

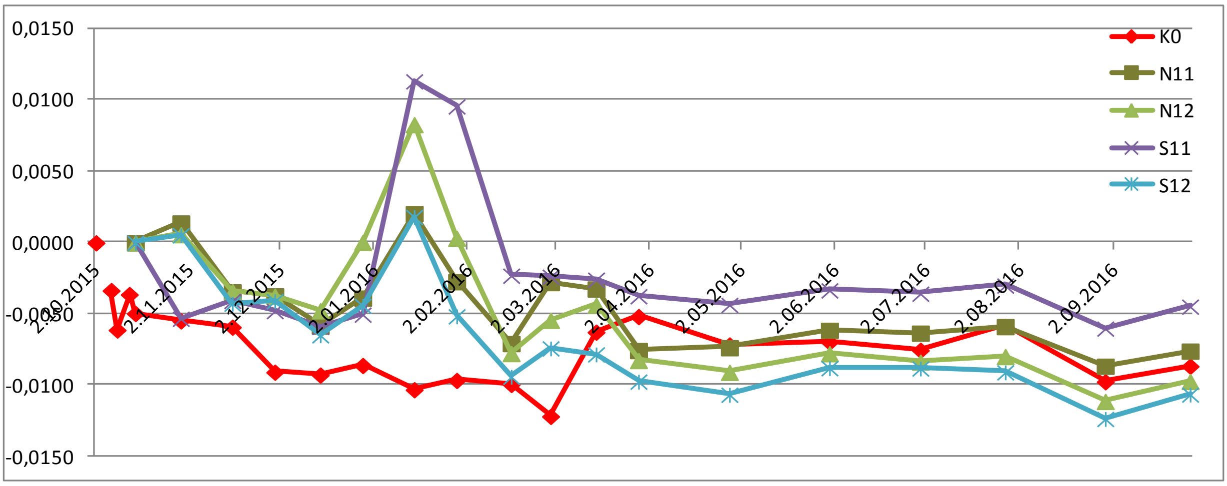
Figure 28. Height changes of the peat plates in the southern side of the road embankment from 15.10.2015 to 27.09.2016. The bold blue line visualizes the waterlevel changes (multiplied by an empirical coefficient 0.3) during the same time- period. Units in meters.

Seega võiks arvata, et teemulde nõlva alumisest servast ca 1 m kaugusel olev turbapinnas ei ole oluliselt mõjustatud teemulde aluse maapinna „vajumislehtrist“. Samas veetaseme hooajalistest muutustest hoolimata on visuaalselt tuvastav üldine (praegusesk mõne sentimeetrini ulatuv) ajaline langustrend.

Tuleb nimetada, et mõned turbaplaadid olid jääkattest ning külmakerkest tingituna mõnevõrra kaldu vajunud (S08 ja S09), mõned plaadid olid ka purunenud (N02, N05, N06). Seetõttu selliste turbaplaatide kõrgusmäärangu täpsus on ca 5...7 mm.

5. 0-sektsiooni (massivahetus) deformatsioonid

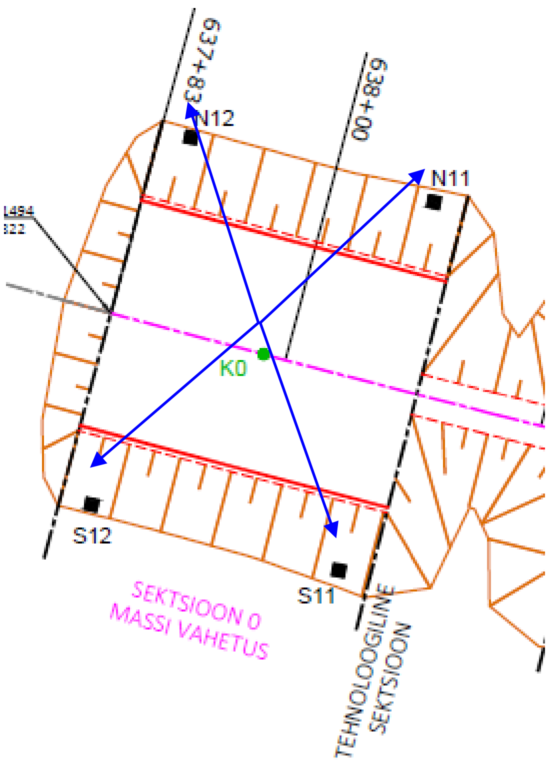
Massivahetusega (ning ilma ülekoormuseta) 0-sektsioonis nivelleeriti ka ainukese katendireeperi ning nelja nõlvaplaadi kõrgused. Ilmneb, et külmade perioodil olid nõlvareeperid mõjustatud külmakerkest, kuid vaatlusperioodi lõpuks on nõlvareeperid (sarnaselt 0-sektsiooni tsentraalreeperile K0) vaid pisut 2015 aasta sügisega võrreldes vajunud. Tulemused on toodud joonisel 29.



Joonis 29. 0-sektsiooni reeperite vajumid alates 15.10.2015 kuni 27.09.2016. Horisontaalteljel on kuupäevad, vertikaalteljel vajumiväärtused.
Figure 29. Subsidence of the 0-th section benchmarks since 15.10.2015 up to 27.09.2016. Unit is meter.

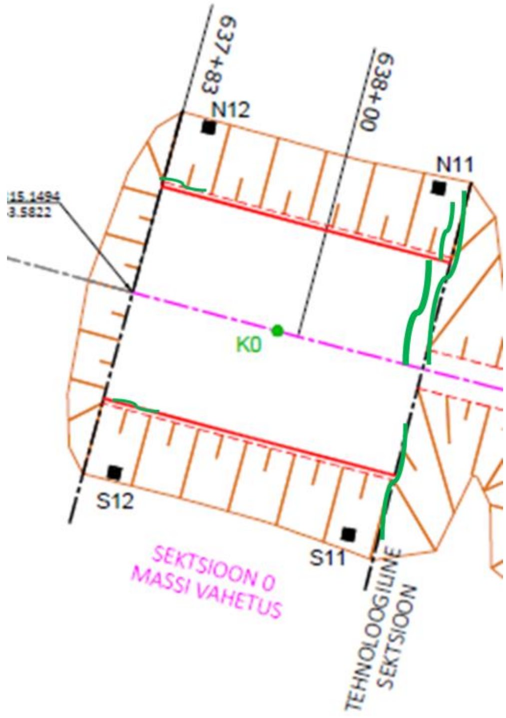
Et vaatlusalused reeperid on vertikaalsuunaliselt liikunud vähe ja enam-vähem ühtlaselt, siis nõlvade „libisemist" käesoleval vaatlusperioodil ei täheldatud.

Aruandlusperioodil tehtud vahemaade mõõtmiste (vt. joonis 30) tulemusena on nõlvaplaatide kaugused tsentraalreeperi (K0) suhtes jäänud praktiliselt samaks (mõõtmistäpsuse piirides) algkaugustega (15.10.2015).



Joonis 30. 0-sektsiooni nõlvareeperite kaldkauguste (tähistatud siniste nooltega) mõõtmine katendireeperi suhtes.
Figure 30. Distance measurements in between the central bechmark and the slope plates in the 0-section

Lisaks varasemalt tuvastatud pragudele mitmeruutmeetrise ala vertikaalsuunalist (ca 3-4 cm) vajumisele 0-sektsioonis, vt joonis 31 ning Ellmann (2016) aruannet, aruandlusperioodil uusi pragusi teekatendis ei tuvastatud.



Joonis 31. 0-sektsiooni pragude (tähistatud rohelisega) asukohad 29.12.2015 ja 27.09.2016 seisuga.

Figure 31. Location of cracks (denoted in green) in the 0- section by 29.12.2015 and 27.09.2016.

6. Üleantavad materjalid

Tellijale edastatakse:

- Tööde teostamise aruanne, mis sisaldab tööde teostamise kirjeldust ja saavutatud tulemusi
- elektrooniline liides *Koormusjargsed vajumid 27092016.xlsx*

Mõõdistuste toorandmed (nivelleerimise andmefailid) säilitatakse süstematiseerituna TTÜ teedeinstituudi geodeesia õppetooli arvutites, osapooltel võimaldatakse nendele ligipääs.

Lisa 1. Fotod 4. ja 5. sektsiooni pealispinnast

Visuaalsel vaatlusel tuvastati 27.09.2016 nii 4. ja 5 sektsiooni keskel suur lohk, kuhu sadevesi koguneb (sammalgi kohati kasvama hakanud).

Foto. 1. 5. sektsiooni keskosa, vaade Tartu suunale. Taken in the middle of Section 5 (view towards Tartu)

Foto. 2. 4. sektsiooni keskosa, vaade Tartu suunale. Taken in the middle of Section 5 (view towards Tartu)

Foto 3. Eelnimetatud kohtade niiskuse tõttu sambla tekkimine. Formation of moss (due to moisture) in the middle of Sections 4 and 5

Käesolevas aruandes on kakskümmend üheksa (29) järjestikku nummerdatud lehekülge.

06.10.2016

"Historical Experience and Challenges of
Geotechnical Problems in Baltic Sea Region"
Lithuanian Geotechnical Society
Lithuania, 22–24 September 2016

Proceedings of 13th Baltic Sea Geotechnical Conference
ISSN 2424-5968 / ISBN 978-609-457-957-8
eISSN 2424-5976 / eISBN 978-609-457-956-1
DOI: http://doi.org/10.3846/13bsgc.2016.046

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.

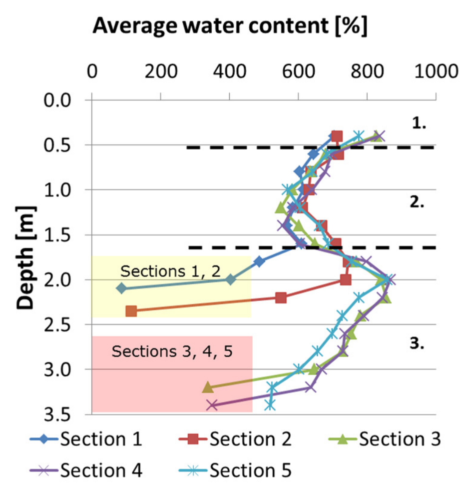


Fig. 1. Three peat layers and natural water content of peat in the test sections 1 to 5

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 = 0–0.5 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 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=30E9DBABB750EB6F!183&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 buoyance 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 homogenous, 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 "ficticious" 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 "ficticious" 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.

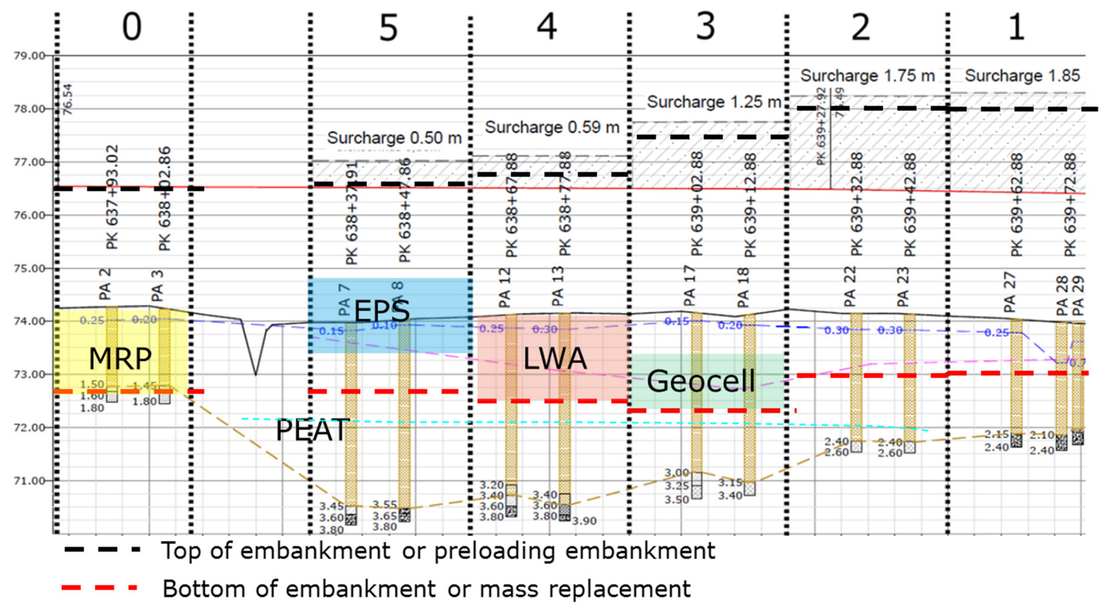


Fig. 2. Longitudinal profile of test sections 0–5 (March 2016 situation). The thin "red line" is the designed level of the road surface. The top and bottom level of embankment is presented with thick dashed red and black lines. The location of the mass replacement (MPR), EPS, LWA and Geocell are hatched 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

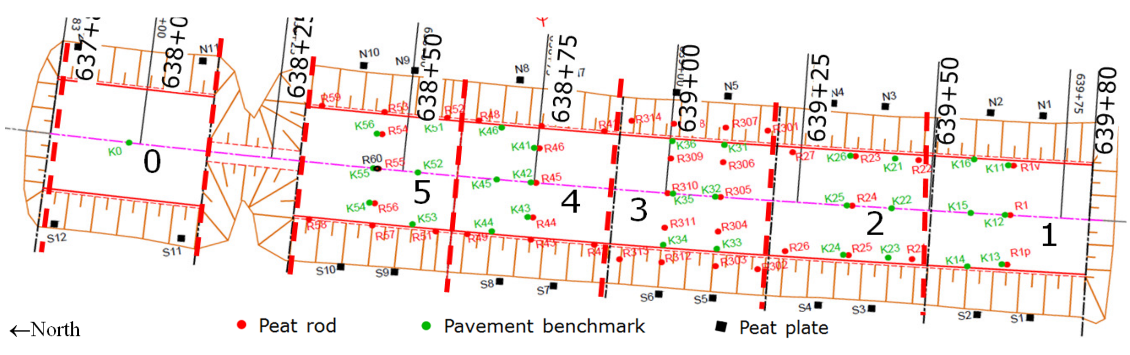


Fig. 3. Location of the levelling benchmarks: 0. mass replacement: 1 – one layer and 2 – two layers of georeinforcement, 3 – geocell mattress, 4 – light weight aggregate and 5 – EPS light weight embankment structure (Ellmann 2015)

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 surcharce level	Load and measured settlemet 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/m² / 0.77 m	~90 kN/m² / 0.89–0.99 m	~50%	20–50 mm
2	17/76 days	~50 kN/m² / 0.71 m	~86 kN/m² / 0.95 m	~40%	~40 mm
3	16/63 days	~50 kN/m² / 1.44 m	~75 kN/m² / 1.72 m	~58%	~30–60 mm
4	5/52 days	~45 kN/m² / 1.06–1.23 m	~62 kN/m² / 1.41–1.57 m	~49%	~10–40 mm
5	37/42 days	~35 kN/m² / 0.75–0.90 m	~45 kN/m² / 1.14–1.29 m	~37%	~0–40 mm

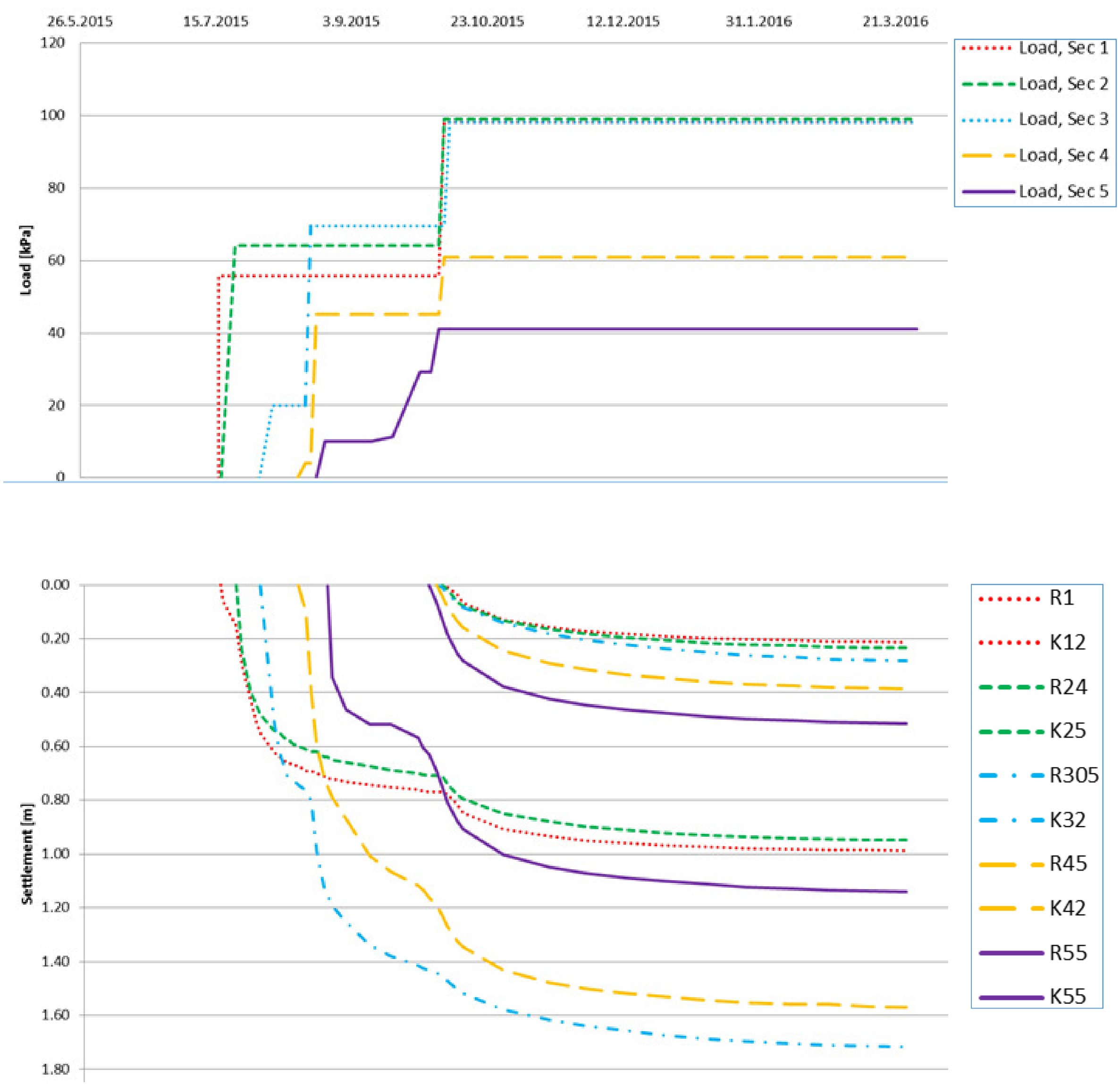


Fig. 4. Sections 1 to 5. Measured settlements of the peat and pavement benchmarks at the centre line (after Ellmann 2016). Measurements are until March 2016. The load presented in the upper Figure does not take into account the effect of buoyancy when the embankment has settled below ground water. Settlement 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

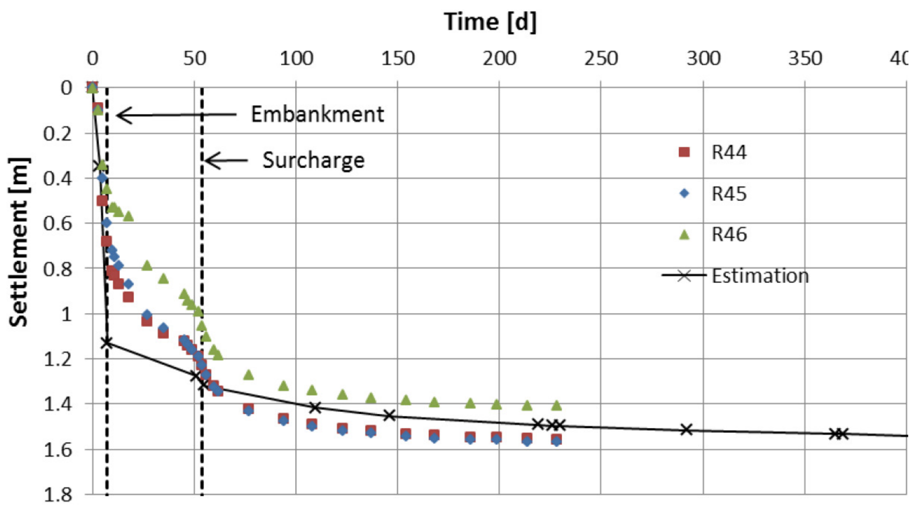
Settlement estimations

Preliminary settlement calculations were made using Novapoint GeoCalc 3.1-program (2013) with "Variable permeability" method and "Compressibility index (Cc). 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.



Peat	1	2	3
k_0 [m/a]	252	73	136
σ_p	POP 20 kPa	NC	NC
Cc	6.6	7	4.5
e_0	15	15	11
Cr	0.7		
γ [kN/m^3]	10.3		

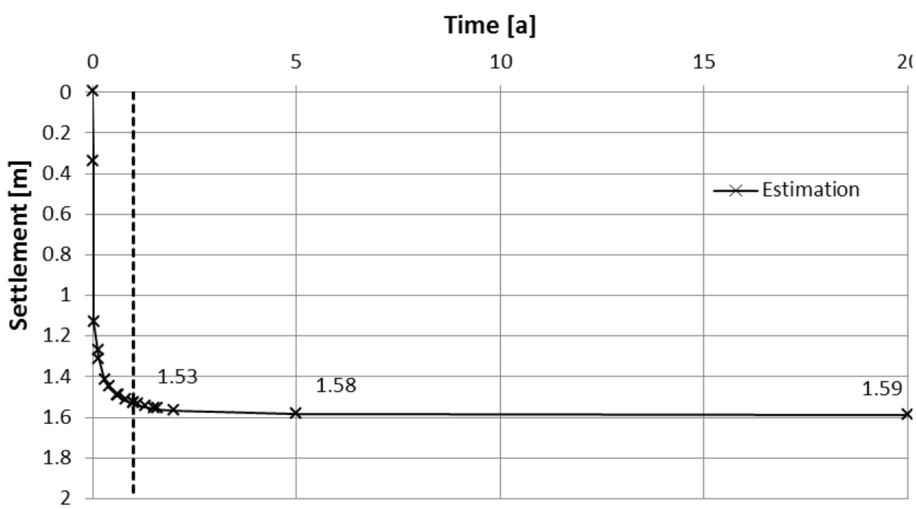


Fig. 5. Section 4. Measured (R44, R45, R46) and calculated settlements at period 0–1 year (upper Figure) and calculated (estimated) settlement after removal of surcharge loading (time 20 years). Settlement calculation parameters for Geocalc-program (Novapoint GeoCalc 2013) are presented on the right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

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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

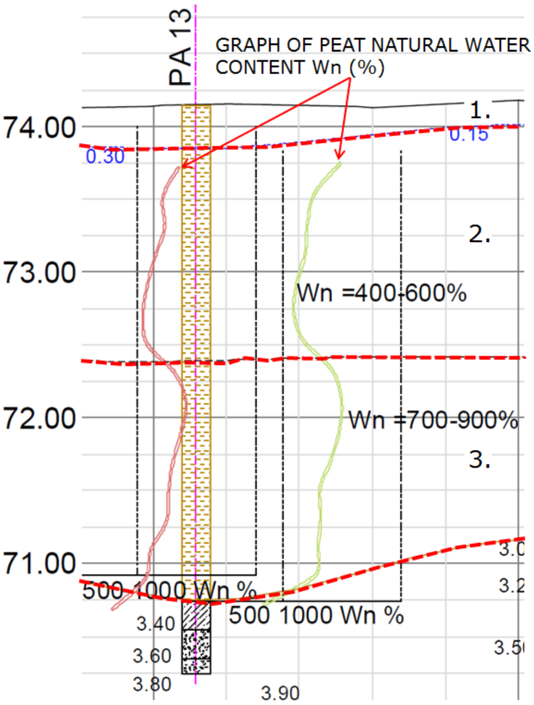


Figure 2. Bore hole 13. Three peat layers and natural water content of peat in two points.

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.

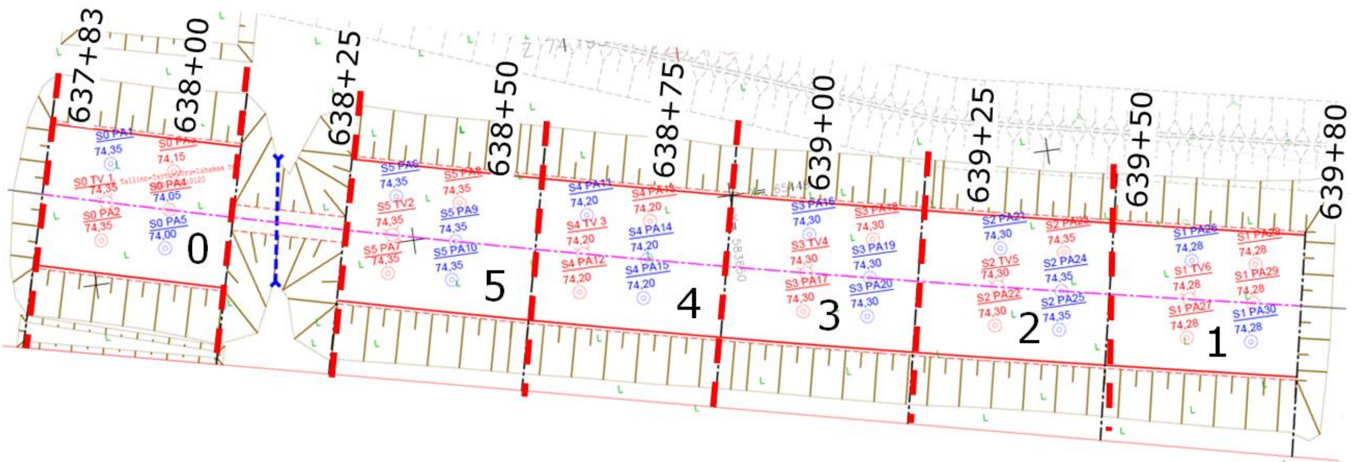
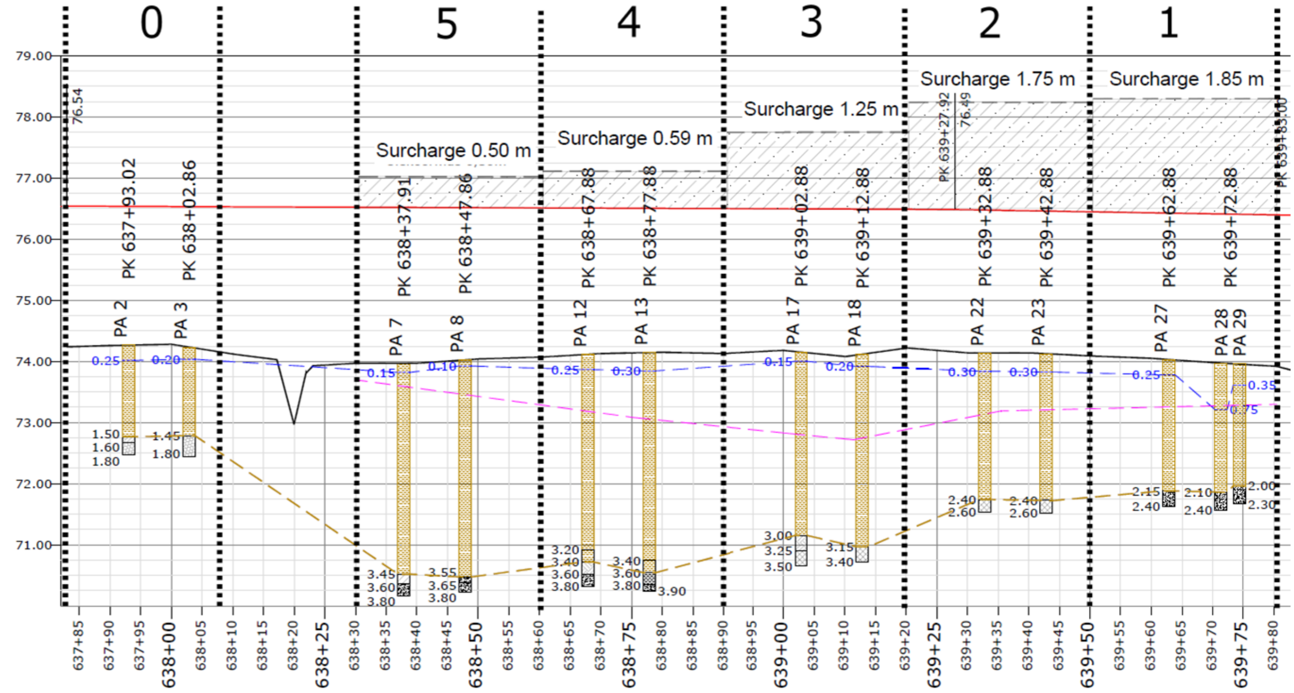


Figure 4. Location of ground investigations points. Distance between posts 639+80 -637+83 is ≈200 m.

a)



b)

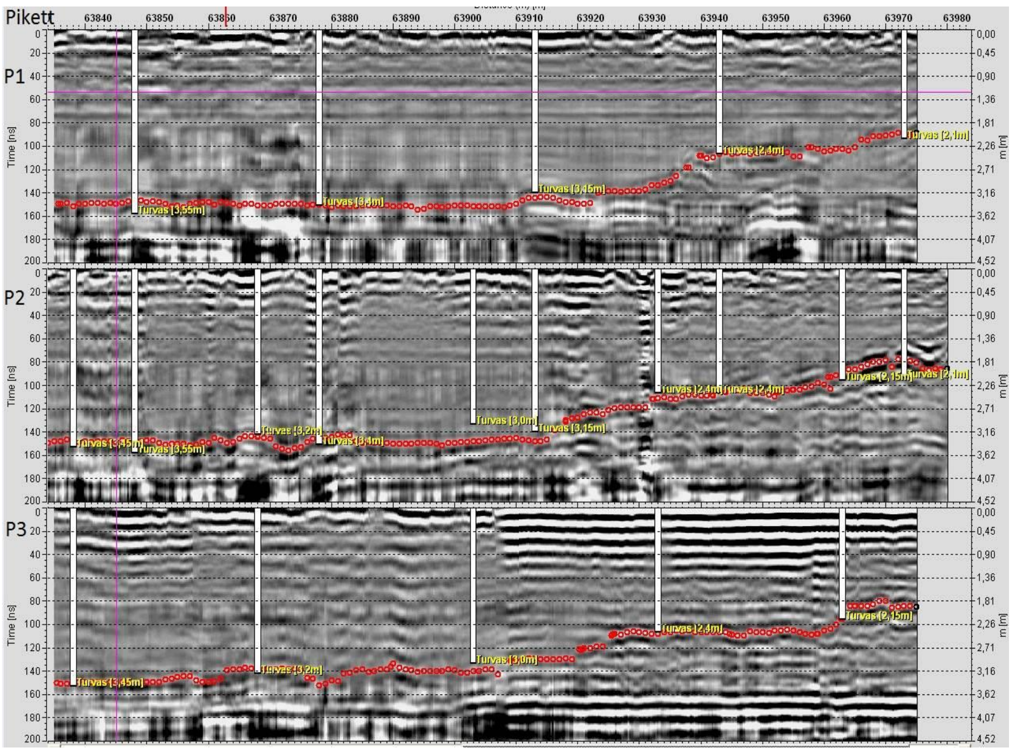


Figure 5. a) Longitudinal profile of test area. The red line is the designed level of the road surface. b) soundings and georadar results from 3 lines (red dotted line is the interpreted bottom of the peat layer).

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.

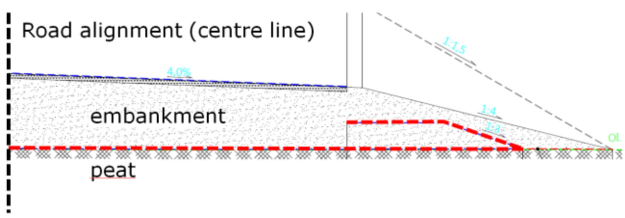


Figure 7. Cross-section of test section 1. 1-layer georeinforcement.

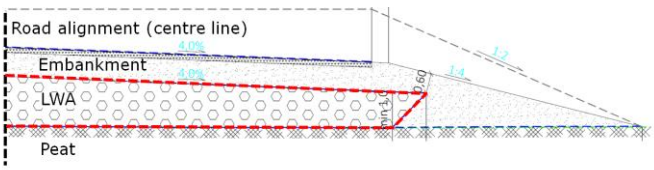


Figure 9. Cross-section of test section 4. Light weight aggregate (LWA) layer.

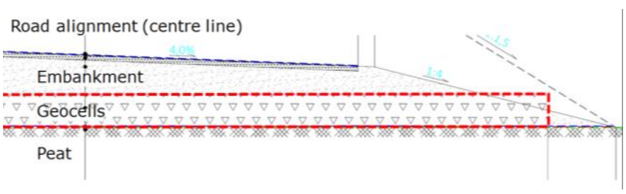


Figure 8. Cross-section of test section 3. Geocell mattress.

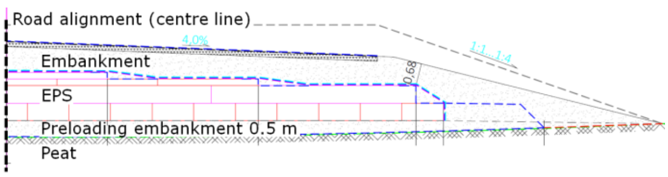


Figure 10. Cross-section of test section 8. EPS-block layer.

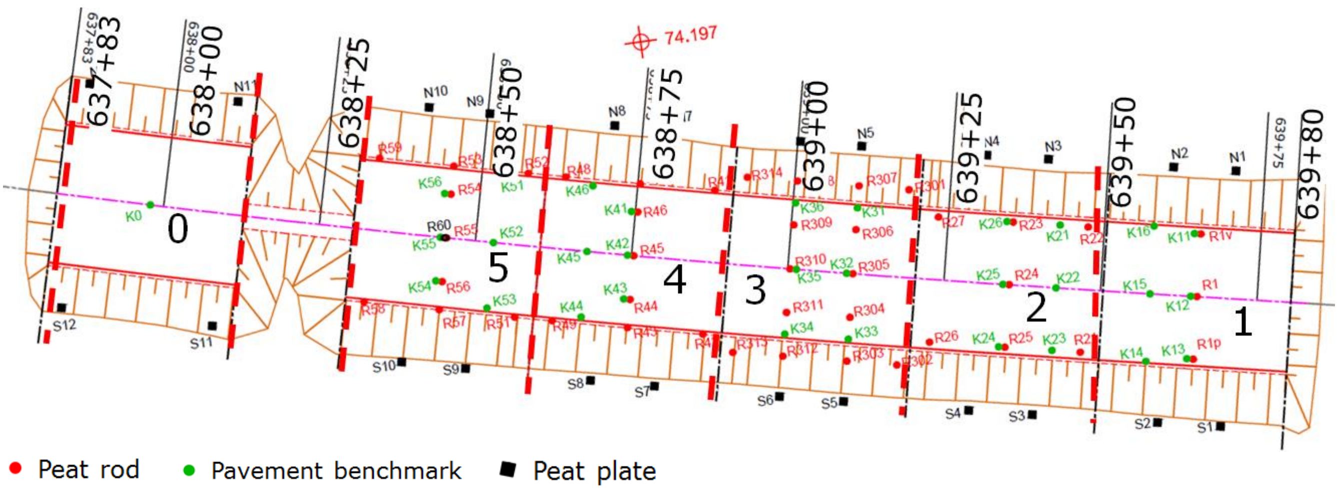


Figure 11. Locations of the leveling benchmarks (red –peat rods, green –pavement benchmarks, black – peat plates, and also the Section 0 slope plates) (Ellmann 2015)

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)

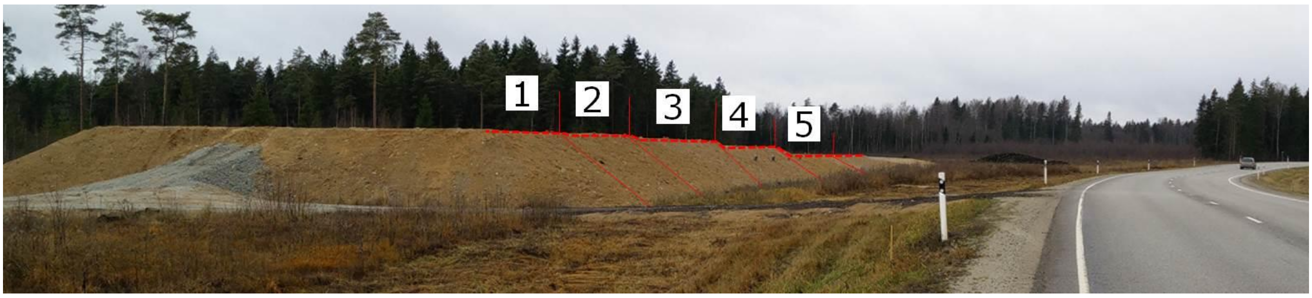
f) Construction of edge barrier at sec. 4. Peat rod in bottom right corner. (12.8.2015)

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).

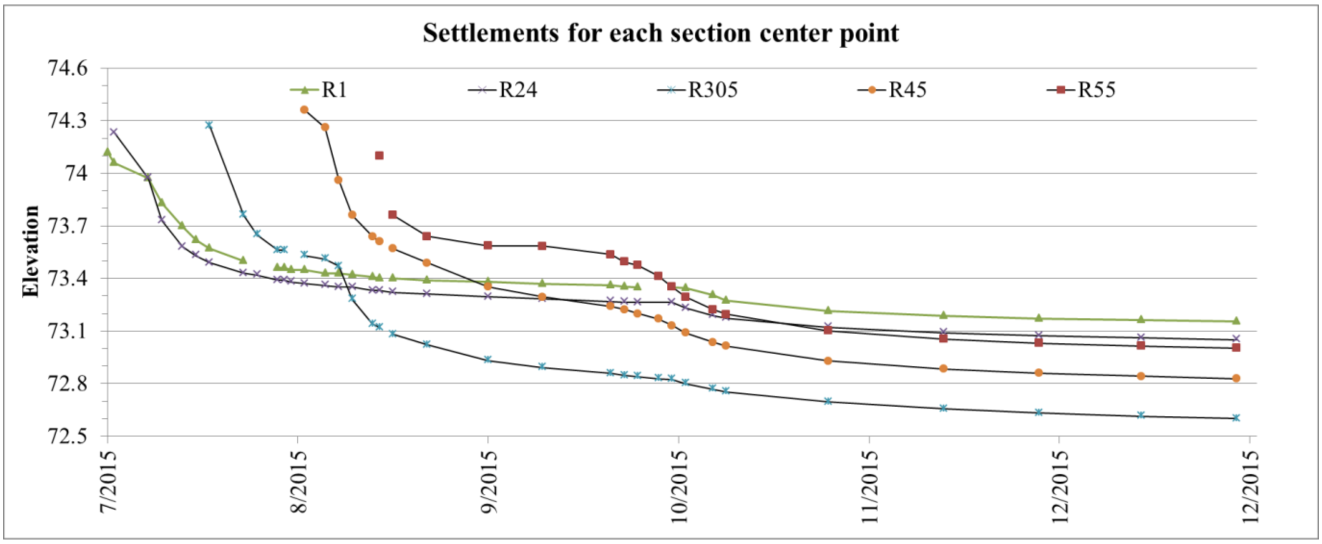


Figure 14. Test sections 1-5 settlement results for the test section center aligment peat rod.

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

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

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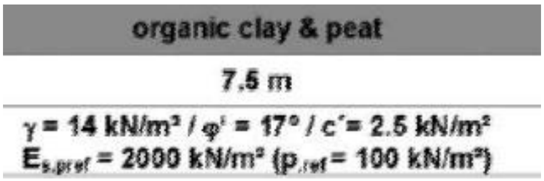
Dimensioning of sand column structure:

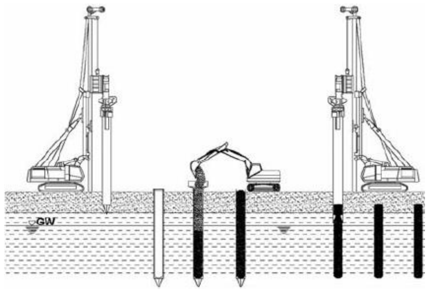
Dimensioning of the sand columns is made in two phases: 1.dimensioning of the sand column and 2. dimensioning of the basal reinforcement over columns at the bottom of the embankment

Dimensioning of the sand columns for cost calculation has been made based on case study of Bastion Wijfwall Houten, Netherland. This case study is presented in the Appendix 7.1 of report "*Embankment foundation structures over peat, literature and case study*" (Forsman, J, Dettenborn, T & Skepast, P. 2015).

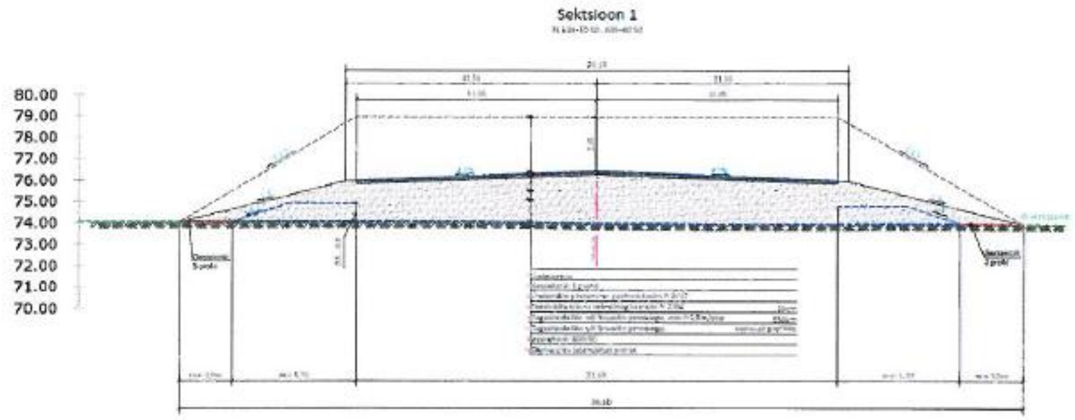
On the basis on the experiences of the Bastion W.H. structure sand columns (ϕ 0.8 m, cc ≈1.85 m and ≈90 kPa embankment load) seems reasonable to select ϕ 0.8 m and cc 2.0 m to cost calculation. The strength of the peat is low (<<15 kPa) which means that sand column are not possible without geosynthetic encased columns (georeinforcement sleeve around column, UTS 200 kN/m^2 in case of Bastion W.H.). Estimated settlement of that test structure was <0.4 m.

The strength of the basal reinforcement was 500 kN/m in case of Bastion W.H. The dimensioning of the basal reinforcement for Võõbu case have been made according "Georeinforcement handbook" (Geolujitetut maarakenteet 2012/2) of Finnish Transport Agency. On the basis of that dimensioning (pages 1/11-11/11) the dimensioning strength of the basal reinforcement is 143 kN/m, which means UTS-strength ≈430 kN/m. A polyester reinforcement with UTS 500 kN/m fulfills that requirement. Two layers of basal reinforcement is needed in two directions. Also a wrap-around anchoring structure is needed in edge of the embankment.





Geolujitettu paalutettu penger (DA2*)



1. Rakenteen lähtötiedot

1.1 Geometria

Penkereen korkeus:	$H_m = 2.4\ m$	Penkereen leveys:	$L_{penger} = 22m$
Penkereen luiska-kaltevuus 1:n	$n = 4$		
Luiskan leveys:	$L_s = n \cdot H_m = 9.6\,m$	Paalujen k/k väli (sis. toleranssin):	$s_{kk} = 2\ m$
Luiskan keskimääräinen korkeus:	$h_s = \dfrac{H_m}{2} = 1.2\,m$	Paaluhatun leveys:	$a = 0.8m$
Pientareen leveys:	$L_{piennar} = 0.5m$	Paaluhattujen väli:	$s_{kk} - a = 1.2\,m$

1.2 Penkereen ja geovahvisteen parametrit

Pengermateriaalin tilavuuspaino:	$\gamma_{penger} = 20\ kN\ m^{-3}$
Pengermateriaalin kriittisen tilan leikkauskestävyyskulma:	$\phi_{cv.k} = 32°$
Pengermateriaalin ja lujitteen välisen liukuvastuksen / ja ulosvetovastuksen korjauskerroin:	$\alpha_1 = 0.9$
Geovahvisteen alkumuodonmuutos:	$\varepsilon_v = 0.04$

1.3 Liikennekuormat :

Muuttuva kuorma (ajokaistalla): $q_I = 25\ kN\ m^{-2}$

Muuttuva kuorma (pientareella): $q_p = 9\ kN\ m^{-2}$

1.4 Taulukon A.3a(FI) Kuormien γ(F) tai kuorman vaikutusten γ(E) osavarmuusluvut (STR/GEO, mitoitustapa DA2*):

	Yhtälö 6.10a:	Yhtälö 6.10b:
Pysyvä kuorma:	$\gamma_{G\_a} = 1.35$	$\gamma_{G\_b} = 1.15$
Määräävä muuttuva kuorma (tieliikennekuorma):	$\gamma_{Q\_a} = 0$	$\gamma_{Q\_b} = 1.35$

1.5 Geolujitteen osavarmuusluvut, NCCI7:

Lujitteen materiaali- kerroin: $\gamma_{re} = 1$

Liukuminen lujitteen pintaa pitkin: $\gamma_s = 1.1$

Lujitteen ulosvetovastus (ankkuroituminen): $\gamma_p = 1.1$

1.6 Aktiivimaanpainekerroin:

Coulombin kaava:

Aktiivi seinäkitkakulma: $\delta_a = \frac{2}{3} \cdot \phi_{cv.k} = 0.37$ $\delta_a = 21.33 \cdot °$

$$K_{ad} = \frac{cos(\phi_{cv.k})^2}{cos(\delta_a) \cdot \left(1 + \sqrt{\frac{sin(\phi_{cv.k} + \delta_a) \cdot sin(\phi_{cv.k})}{cos(\delta_a)}}\right)^2}$$

$$= \frac{cos(32 \cdot °)^2}{cos(0.37) \cdot \left(1 + \sqrt{\frac{sin(32 \cdot ° + 0.37) \cdot sin(32 \cdot °)}{cos(0.37)}}\right)^2}$$

$K_{ad} = 0.28$

2. Laskentamallin soveltuvuus tarkastelutapaukseen

2.1 Paalutetun penkereen paikallismurtumaehto:

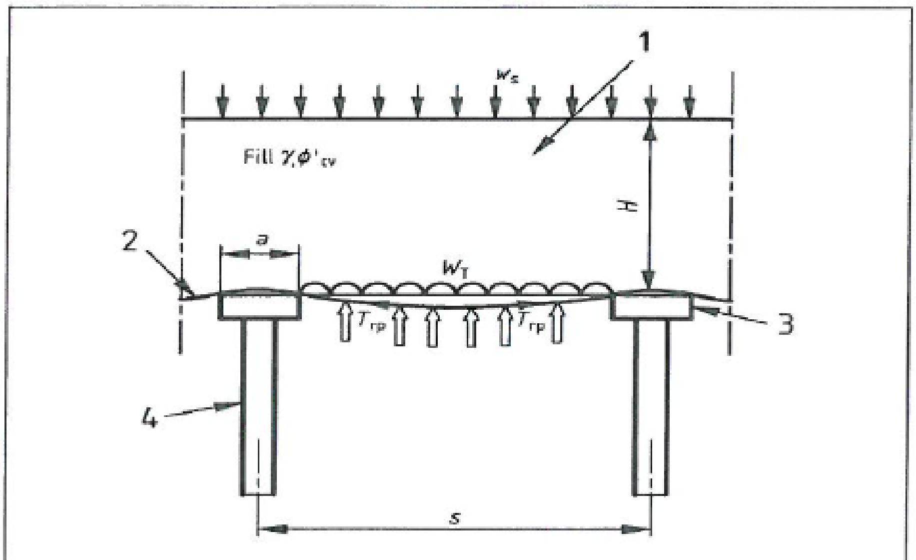
$$H_m = 2.4\,m \quad \geq \quad 0.7\cdot\left(s_{kk} - a\right) = 0.7\cdot(2\cdot m - 0.8\cdot m) = 0.84\,m \qquad \text{=> OK}$$

2.2 Paalujen pinta-alan peittävyysehto:

$$\frac{a^2}{s_{kk}^{\;2}} = \frac{(0.8\cdot m)^2}{(2\cdot m)^2} = 0.16 \qquad \geq 0.10 \qquad \text{=> OK}$$

3. Pystysuoran kuorman vastaan ottamiseen vaadittava lujitevoima (T_{rp})

Figure 79 Variables used in determination of T_{rp}



Key
1 Embankment
2 Reinforcement
3 Pile cap
4 Pile

$$\frac{p'_c}{\sigma'_v} = \left(\frac{C_c\cdot a}{H_m}\right)^2$$

p'_c on paaluhatulla vaikuttava pystysuora jännitys, kN/m^2
σ'_v pengertäytteen pohjalla vaikuttava pystysuora jännitys, kN/m^2
C_c holvaantumiskerroin
a paaluhatun leveys
e, f paalumateriaalista riippuvia kertoimia

Hiekkapaalut:

$e_p = 1.5 \qquad f = 0.07$

3.2 Holvaantumiskerroin:

$$C_c = \frac{e_p \cdot H_m}{a} - f = \frac{1.5 \cdot 2.4 \cdot m}{0.8 \cdot m} - 0.07 = 4.43$$

3.3 Jännitysten suhde:

$$\frac{p'_c}{\sigma'_v} = \left(\frac{C_c \cdot a}{H_m}\right)^2 = \left(\frac{4.43 \cdot 0.8 \cdot m}{2.4 \cdot m}\right)^2 = 2.18$$

3.4 Paaluhattujen välinen tasainen kuorma (korkea penger):

$H_m = 2.4\,m \quad > \quad 1.4 \cdot (s_{kk} - a) = 1.4 \cdot (2 \cdot m - 0.8 \cdot m) = 1.68\,m$

=> Liikennekuormalla ei ole vaikutusta paaluhattujen väliseen tasaiseen kuormaan

$$w_t = \frac{1.4 \cdot \gamma_{penger} \cdot s_{kk} \cdot (s_{kk} - a)}{s_{kk}^2 - a^2} \cdot \left(s_{kk}^2 - a^2 \cdot \frac{p'_c}{\sigma'_v}\right)$$

=> $$w_t = \frac{1.4 \cdot \gamma_{penger} \cdot s_{kk} \cdot (s_{kk} - a)}{s_{kk}^2 - a^2} \cdot \left[s_{kk}^2 - a^2 \cdot \left(\frac{C_c \cdot a}{H_m}\right)^2\right]$$

$$= \frac{1.4 \cdot 20 \cdot kN \cdot m^{-3} \cdot 2 \cdot m \cdot (2 \cdot m - 0.8 \cdot m)}{(2 \cdot m)^2 - (0.8 \cdot m)^2} \cdot \left[(2 \cdot m)^2 - (0.8 \cdot m)^2 \cdot \left(\frac{4.43 \cdot 0.8 \cdot m}{2.4 \cdot m}\right)^2\right]$$

$$w_t = 52.09 \cdot \frac{kN}{m}$$

Yhtälö 6.10a:

$$w_{t\_a} = \gamma_{G\_a} \cdot w_t = 1.35 \cdot \frac{52.09 \cdot kN}{m} = 70.32 \cdot \frac{kN}{m}$$

Yhtälö 6.10b:

$$w_{t\_b} = \gamma_{G\_b} \cdot w_t = 1.15 \cdot \frac{52.09 \cdot kN}{m} = 59.9 \cdot \frac{kN}{m}$$

3.5 Kuormasta muodostuva lujitevoima:

$$T_{rp} = \frac{w_t \cdot (s_{kk} - a)}{2 \cdot a} \cdot \sqrt{1 + \frac{1}{6 \cdot \varepsilon}}$$

Yhtälö 6.10a:

$$T_{rp\_a} = \frac{w_{t\_a} \cdot (s_{kk} - a)}{2 \cdot a} \cdot \sqrt{1 + \frac{1}{6 \cdot \varepsilon_v}}$$

$$= \frac{\frac{70.32 \cdot kN}{m} \cdot (2 \cdot m - 0.8 \cdot m)}{2 \cdot 0.8 \cdot m} \cdot \sqrt{1 + \frac{1}{6 \cdot 0.04}}$$

$$T_{rp\_a} = 119.88 \cdot \frac{kN}{m}$$

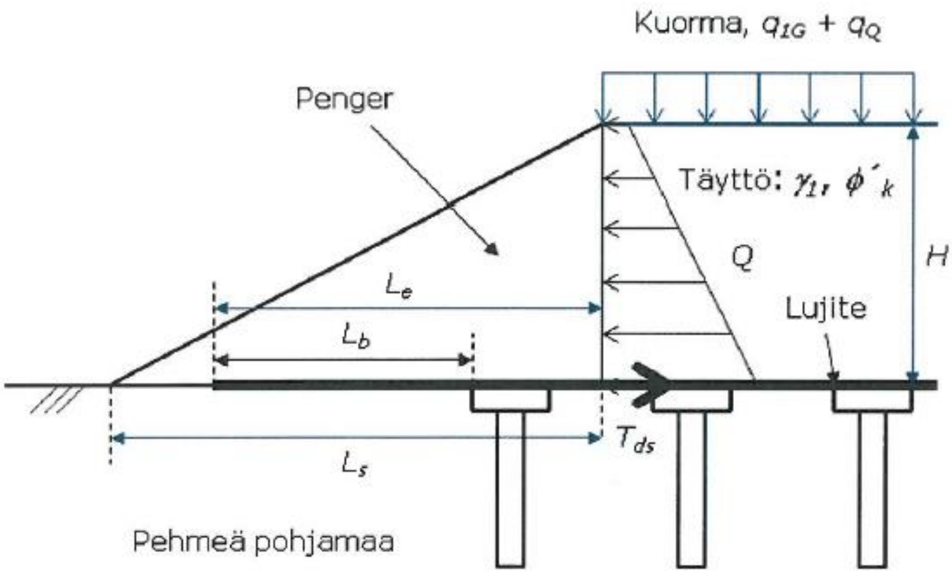
Yhtälö 6.10b:

$$T_{rp\_b} = \frac{w_{t\_b} \cdot (s_{kk} - a)}{2 \cdot a} \cdot \sqrt{1 + \frac{1}{6 \cdot \varepsilon_v}}$$

$$= \frac{\frac{59.9 \cdot kN}{m} \cdot (2 \cdot m - 0.8 \cdot m)}{2 \cdot 0.8 \cdot m} \cdot \sqrt{1 + \frac{1}{6 \cdot 0.04}}$$

$$T_{rp\_b} = 102.12 \cdot \frac{kN}{m}$$

4. Vaakasuoran maanpaineen vastaan ottamiseen vaadittava lujitevoima (T_{ds})



Lujitteeseen maanpainekuorman vaikutuksesta mobilisoituva voima (pintakuorma ja maan paino

$$T_{ds}(\gamma_G, \gamma_Q, q) = K_{ad} \cdot H_m \cdot (0.5 \cdot \gamma_G \cdot \gamma_{penger} \cdot H_m + \gamma_Q \cdot q)$$

Lujitteen ja pengermateriaalin välinen leikkauskestävyys luiskan alla

$$R_{ds}(h, L_e) = \gamma_{penger} \cdot h \cdot \alpha_1 \cdot tan(\phi_{cv.k}) \cdot L_e$$

Lujitteen ja pengermateriaalin välisen leikkauskestävyyden tulee täyttää ehto:

$$T_{ds1} \le \frac{R_{ds1}}{\gamma_s}$$

Yhtälöt yhdistämällä saadaan pienin tartuntapituus:

$$L_e(T_{ds}, h) = \frac{T_{ds} \cdot \gamma_s}{\gamma_{penger} \cdot h \cdot \alpha_1 \cdot tan(\phi_{cv.k})}$$

Tartuntapituuden tulee täyttää reunaehto:

$L_s \ge L_e$ missä luiskan leveys $L_s = 9.6 m$

4.1 Kuorma 9 kN/m^2 luiskan reunalla

4.1.1 Lujitteeseen maanpainekuorman vaikutuksesta mobilisoituva voima

Yhtälö 6.10a:

$$T_{ds\_a1} = T_{ds}(\gamma_{G\_a}, \gamma_{Q\_a}, q_p)$$

$$= H_m \cdot K_{ad} (q_p \cdot \gamma_{Q\_a} + 0.5 \cdot H_m \cdot \gamma_{penger} \cdot \gamma_{G\_a})$$

$$= 2.4 \cdot m \cdot 0.3 \cdot (9 \cdot kN \cdot m^{-2} \cdot 0 + 0.5 \cdot 2.4 \cdot m \cdot 20 \cdot kN \cdot m^{-3} \cdot 1.4) = 21.4 \cdot \frac{kN}{m} \qquad T_{ds\_a1} = 21.4 \cdot \frac{kN}{m}$$

Yhtälö 6.10b:

$$T_{ds\_b1} = T_{ds}(\gamma_{G\_b}, \gamma_{Q\_b}, q_p)$$

$$= H_m \cdot K_{ad} (q_p \cdot \gamma_{Q\_b} + 0.5 \cdot H_m \cdot \gamma_{penger} \cdot \gamma_{G\_b})$$

$$= 2.4 \cdot m \cdot 0.28 \cdot (9 \cdot kN \cdot m^{-2} \cdot 1.35 + 0.5 \cdot 2.4 \cdot m \cdot 20 \cdot kN \cdot m^{-3} \cdot 1.15) = 26.24 \cdot \frac{kN}{m} \qquad T_{ds\_b1} = 26.2 \cdot \frac{kN}{m}$$

4.1.2 Lujitteen pienin tartuntapituus ja reunaehdon täyttyminen, kun $L_s = 9.6m$

Yhtälö 6.10a:

$$L_{e\_a1} = L_e(T_{ds\_a1}, h_s)$$

$$= \frac{T_{ds\_a1} \cdot \gamma_s}{h_s \cdot \alpha_1 \cdot \gamma_{penger} \cdot tan(\phi_{cv.k})}$$

$$= \frac{\frac{21.39 \cdot kN}{m} \cdot 1.1}{1.2 \cdot m \cdot 0.9 \cdot 20 \cdot kN \cdot m^{-3} \cdot tan(32 \cdot °)}$$

$$L_{e\_a1} = 1.74\, m$$

$\boxed{Leveys_{1\_a} = \text{"OK"}}$

Yhtälö 6.10b:

$$L_{e\_b1} = L_e(T_{ds\_b1}, h_s)$$

$$= \frac{T_{ds\_b1} \cdot \gamma_s}{h_s \cdot \alpha_1 \cdot \gamma_{penger} \cdot tan(\phi_{cv.k})}$$

$$= \frac{\frac{26.24 \cdot kN}{m} \cdot 1.1}{1.2 \cdot m \cdot 0.9 \cdot 20 \cdot kN \cdot m^{-3} \cdot tan(32 \cdot °)}$$

$$L_{e\_b1} = 2.14\, m$$

$\boxed{Leveys_{1\_b} = \text{"OK"}}$

4.2 Ajoneuvokuorma pientareen leveyden etäisyydellä luiskan reunasta

Kuorma sijaitsee pientareen leveyden etäisyydellä luiskan reunasta.

4.2.1 Lujitteeseen maanpainekuorman vaikutuksesta mobilisoituva voima

Yhtälö 6.10a:

$$T_{ds\_a2} = T_{ds}(\gamma_{G\_a}, \gamma_{Q\_a}, q_1)$$

$$= H_m \cdot K_{ad} \cdot (q_1 \cdot \gamma_{Q\_a} + 0.5 \cdot H_m \cdot \gamma_{penger} \cdot \gamma_{G\_a})$$

$$= 2.4 \cdot m \cdot 0.28 \cdot \left(25 \cdot kN \cdot m^{-2} \cdot 0 + 0.5 \cdot 2.4 \cdot m \cdot 20 \cdot kN \cdot m^{-3} \cdot 1.35\right) = 21.39 \cdot \frac{kN}{m} \qquad T_{ds\_a2} = 21.4 \cdot \frac{kN}{m}$$

Yhtälö 6.10b:

$$T_{ds\_b2} = T_{ds}(\gamma_{G\_b}, \gamma_{Q\_b}, q_1)$$

$$= H_m \cdot K_{ad} \cdot (q_1 \cdot \gamma_{Q\_b} + 0.5 \cdot H_m \cdot \gamma_{penger} \cdot \gamma_{G\_b})$$

$$= 2.4 \cdot m \cdot 0.28 \cdot \left(25 \cdot kN \cdot m^{-2} \cdot 1.35 + 0.5 \cdot 2.4 \cdot m \cdot 20 \cdot kN \cdot m^{-3} \cdot 1.15\right) = 40.49 \cdot \frac{kN}{m} \qquad T_{ds\_b2} = 40.5 \cdot \frac{k}{n}$$

4.2.2 Lujitteen pienin tartuntapituus ja reunaehdon täyttyminen

Lujitteen ja pengermateriaalin välinen kestävyys pientareen osuudella:

$$R_{ds\_piennar} = R_{ds}(H_m, L_{piennar})$$

$$= H_m \cdot L_{piennar} \cdot \alpha_1 \cdot \gamma_{penger} \cdot tan(\phi_{cv.k})$$

$$= 2.4 \cdot m \cdot 0.5 \cdot m \cdot 0.62 \cdot 0.9 \cdot 20 \cdot kN \cdot m^{-3} = 13.5 \cdot \frac{kN}{m} \qquad R_{ds\_piennar} = 13.5 \cdot \frac{kN}{m}$$

Lujitteeseen pientareen osuudella mobilisoituva lujitevoima voi olla enintään:

$$T_{ds\_piennar} = \frac{R_{ds\_piennar}}{\gamma_s} = \frac{2.4 \cdot m \cdot 0.5 \cdot m \cdot 0.62 \cdot 0.9 \cdot 20 \cdot kN \cdot m^{-3}}{1.1} = 12.27 \cdot \frac{kN}{m}$$

Luiskan osuudelle mobilisoituva lujitevoima:

$$T_{ds\_lui}(T_{ds}) = T_{ds} - T_{ds\_piennar}$$

Yhtälö 6.10a:

$$T_{ds\_lui\_a2} = \frac{21.39 \cdot kN}{m} - \frac{12.27 \cdot kN}{m} = 9.12 \cdot \frac{kN}{m}$$

$$L_{e\_a2} = L_e(T_{ds\_lui\_a2}, h_s)$$

$$= \frac{T_{ds\_lui\_a2} \cdot \gamma_s}{h_s \cdot \alpha_1 \cdot \gamma_{penger} \cdot tan(\phi_{cv.k})}$$

$$= \frac{\frac{9.1 \cdot kN}{m} \cdot 1.1}{1.2 \cdot m \cdot 0.9 \cdot 20 \cdot kN \cdot m^{-3} \cdot tan(32 \cdot °)}$$

$$L_{e\_a2} = 0.74\,m$$

$\boxed{Leveys_{2\_a} = \text{"OK"}}$

Yhtälö 6.10b:

$$T_{ds\_lui\_b2} = \frac{40.49 \cdot kN}{m} - \frac{12.27 \cdot kN}{m} = 28.22 \cdot \frac{kN}{m}$$

$$L_{e\_b2} = L_e(T_{ds\_lui\_b2}, h_s)$$

$$= \frac{T_{ds\_lui\_b2} \cdot \gamma_s}{h_s \cdot \alpha_1 \cdot \gamma_{penger} \cdot tan(\phi_{cv.k})}$$

$$= \frac{\frac{28 \cdot kN}{m} \cdot 1.1}{1.2 \cdot m \cdot 0.9 \cdot 20 \cdot kN \cdot m^{-3} \cdot tan(32 \cdot °)}$$

$$L_{e\_b2} = 2.28\,m$$

$\boxed{Leveys_{2\_b} = \text{"OK"}}$

5. Tarvittava tartuntapituus ulosvetovoimalle:

Valitaan mitoittavaksi lujitevoimaksi suurempi kohdissa 4.1 ja 4.2 lasketuista voimista:

$L_p > L_b \quad L_p = 11.2\,m$

Yhtälö 6.10a:

$$T_{ds\_a\_max} = 21.39 \cdot \frac{kN}{m}$$

$$L_{b\_a} = \frac{(T_{rp\_a} + T_{ds\_a\_max}) \cdot \gamma_p}{\gamma_{penger} \cdot h_s \cdot \alpha_1 \cdot tan(\phi_{cv.k})}$$

$$= \frac{\left(\frac{119.88 \cdot kN}{m} + \frac{21.39 \cdot kN}{m}\right) \cdot 1.1}{20 \cdot kN \cdot m^{-3} \cdot 1.2 \cdot m \cdot 0.9 \cdot tan(32 \cdot °)}$$

$$L_{b\_a} = 11.51\,m$$

$\boxed{Leveys_{b\_a} = \text{"EI RIITÄ"}}$

Yhtälö 6.10b:

$$T_{ds\_b\_max} = 40.49 \cdot \frac{kN}{m}$$

$$L_{b\_b} = \frac{(T_{rp\_b} + T_{ds\_b\_max}) \cdot \gamma_p}{\gamma_{penger} \cdot h_s \cdot \alpha_1 \cdot tan(\phi_{cv.k})}$$

$$= \frac{\left(\frac{102.12 \cdot kN}{m} + 4.05 \times 10^4 \cdot kg \cdot s^{-2}\right) \cdot 1.1}{20 \cdot kN \cdot m^{-3} \cdot 1.2 \cdot m \cdot 0.9 \cdot tan(32 \cdot °)}$$

$$L_{b\_b} = 11.62\,m$$

$\boxed{Leveys_{b\_b} = \text{"EI RIITÄ"}}$

=> Lujitteen häntä on ankkuroitava "mutkalle" penkereeseen riittävän tartuntapituuden saavuttam

6. Murtorajatilassa lujitteeseen kohdistuva kokonaislujitevoima penkereen pysty- ja vaakakuormasta:

Yhtälö 6.10a:

Penkereen pituussuunnassa:

$$T_{d\_1a} = T_{rp\_a} = 119.88 \cdot \frac{kN}{m}$$

Penkereen poikkisuunnassa (piennarkuorma):

$$T_{d\_2a} = T_{rp\_a} + T_{ds\_a1}$$

$$= \frac{119.88 \cdot kN}{m} + \frac{21.39 \cdot kN}{m}$$

$$T_{d\_2a} = 141.27 \cdot \frac{kN}{m}$$

Penkereen poikkisuunnassa (ajoneuvokuorma):

$$T_{d\_3a} = T_{rp\_a} + T_{ds\_a2}$$

$$= \frac{119.88 \cdot kN}{m} + \frac{21.39 \cdot kN}{m}$$

$$T_{d\_3a} = 141.27 \cdot \frac{kN}{m}$$

Yhtälö 6.10b:

$$T_{d\_1b} = T_{rp\_b} = 102.12 \cdot \frac{kN}{m}$$

$$T_{d\_2b} = T_{rp\_b} + T_{ds\_b1}$$

$$= \frac{102.12 \cdot kN}{m} + \frac{26.24 \cdot kN}{m}$$

$$T_{d\_2b} = 128.36 \cdot \frac{kN}{m}$$

$$T_{d\_3b} = T_{rp\_b} + T_{ds\_b2}$$

$$= \frac{102.12 \cdot kN}{m} + \frac{40.49 \cdot kN}{m}$$

$$T_{d\_3b} = 142.61 \cdot \frac{kN}{m}$$

7. Laskennan yhteenveto:

1. Lähtötiedot

Korkeus:	$H_m = 2.4\,m$
Penkereen luiskakaltevuus:	$n = 4$
Luiskan leveys (1:n):	$L_s = 9.6\,m$
Pientareen leveys:	$L_{piennar} = 0.5\,m$
Kriittisen tilan leikkauskestävyyskulma:	$\phi_{cv.k} = 32 \cdot {}^\circ$
Pengermateriaalin tilavuuspaino:	$\gamma_{penger} = 20 \cdot \frac{kN}{m^3}$
Muuttuvat kuormat:	$q_p = 9\,kPa$ $q_l = 25\,kPa$

2. Lujitevoimat ja tartuntapituudet:

	Muuttuva kuorma [kN/m]	Lujitevoima T_d [kN/m] Yhtälö 6.10a	Lujitevoima T_d [kN/m] Yhtälö 6.10b	Tartuntapituus L_e [m] Yhtälö 6.10a	Tartuntapituus L_e [m] Yhtälö 6.10b	Lujitepituuden riittävyys
Vaakasuoran maanpaineen vastaanottamiseen vaadittava lujitevoima	9	21,4	26,2	1,74	2,14	OK
	25	21,4	40,5	0,74	2,28	OK
Pystysuoran kuorman vastaanottamiseen vaadittava lujitevoima		119,9	102,1			
Vetovoima lujitteessa murtorajatilassa	pituus-suunta	119,9	102,1			Lujitteen häntä on ankkuroitava "mutkalle" penkereeseen riittävän ankkuripituuden saamiseksi
	9	141,3	128,4			
	25	141,3	142,6	11,51	11,62	

3. Mitoituksen lopputulos:

Lujitteen mitoituslujuus :

- penkereen pituussuunnassa vähintään $f_{d\_pit} = 120 \cdot \frac{kN}{m}$
- penkereen poikkisuunnassa vähintään $f_d = 143 \cdot \frac{kN}{m}$

Lujitteen ankkurointipituus luiskassa on vähintään $L_e = 11.62m$

Pile + concrete slab (1/3):

Summary of the dimension calculations are presented at this page.

Paalulaatan lähtötiedot

- pengerkorkeus + laatan paksuus 2,4 m
- liikennekuorma Livi:n ohjeiden mukaan
- paalujen pituus 7,5 m

Paalulaatan suunnittelun valinnat

- paalutustyöluokka PLT2
- betonin lujuusluokka C30/37-2
- suojabetoni
    - yläpinta 50 mm
    - alapinta 100 mm
- laatan paksuus **0,4** m
- pengertäyttö 2,0 m
- penkereen tiheys 21 kN/m^3
- liikennekuorma 42 kN/m^2
- paalut TB300a (300x300)
- paalujako
    - pituussuunta **2,1** m
    - poikkisuunta **2,3** m

Laskentatulokset

- max. paalukuorma 590 kN
- raudoitus ylä- ja alapinnassa kumpaankin suuntaan d16 k130
    - raudoitusmäärä betonikuutiossa 121 kg/m^3
- lävistysvoima 500 kN
- lävistyskestävyys 580 kN

Pile + concrete slab (2/3):

The punching capacity of concrete slab have been examined in the calculation of this page (only page 1 is presented, the length of the examination is 6 pages).

Alkuarvot

Teräsbetonilaatan lävistys

Neliön muotoinen tuki

Alkuarvot

Laatan korkeus $h := 400mm$

Paalun sivumitta $d_p := 300mm$

Alkuarvot

Materiaali

Materiaalit

Betoni

Betonin lujuusluokka C30/37

$f_{ck} := f_{ck0} \cdot MPa$ $\quad f_{ck} = 30 \cdot MPa$

Toteutusluokka 2

Betonin osavarmuusluvut

$$\gamma_C := \begin{cases} 1.35 & \text{if } tl = 3 \\ 1.5 & \text{if } tl = 2 \end{cases} \qquad \gamma_C = 1.5$$

$\gamma_{C.a} := 1.2$ (onnettomuustilanne)

Puristuslujuuden kerroin $\alpha_{cc} := 0.85$

Betonin puristuslujuuden mitoitusarvo $f_{cd} := \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_C}$ $\quad f_{cd} = 17 \cdot MPa$

Betonin puristuslujuuden mitoitusarvo onnettomuustilanteessa $f_{cd.a} := \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_{C.a}}$ $\quad f_{cd.a} = 21.25 \cdot MPa$

Keskimääräinen puristuslujuus (t=28) $f_{cm} := f_{ck} + 8MPa$ $\quad f_{cm} = 38 \cdot MPa$

Keskimääräinen puristuslujuus

$$f_{ctm} := \begin{cases} 0.30 \cdot \left(\frac{f_{ck}}{MPa}\right)^{\frac{2}{3}} \cdot MPa & \text{if } f_{ck} \le 50MPa \\ 2.12 \cdot \ln\left(1 + \frac{f_{cm}}{10MPa}\right) \cdot MPa & \text{otherwise} \end{cases} \qquad f_{ctm} = 2.896 \cdot MPa$$

Vetolujuuden 5% fraktiili $f_{ctk.0.05} := 0.7 \cdot f_{ctm}$ $\quad f_{ctk.0.05} = 2.028 \cdot MPa$

Vetolujuuden 95% fraktiili $f_{ctk.0.95} := 1.3 \cdot f_{ctm}$ $\quad f_{ctk.0.95} = 3.765 \cdot MPa$

Vetolujuuden mitoitusarvo $f_{ctd} := \frac{f_{ctk.0.05}}{\gamma_C}$ $\quad f_{ctd} = 1.352 \cdot MPa$

Pile + concrete slab (3/4):

The bending moment and shear capacity have examined at pages 3/4 and 4/4.

Betoni		
Lujuusluokka	C30/37	
Toteutusluokka	2	
γc	1,5	
αcc	0,85	
fck	30	MPa
f_{cm}	38	MPa
fcd	17	MPa
fctm	2,9	MPa
fctk,0.05	2	MPa
fctd	1,33	MPa
Ecm	33	GPa
η	1	
λ	0,8	
ε_{cu3}	3,5	%/10
Raudoitus		Sitkeysluokka
Tyyppi	B500B	B
Suunta	poikittais	ulkona
γ_s	1,15	
f_{yk}	500	MPa
f_{yd}	434	MPa
E_s	200	GPa
ε_s	2,5	%/10
$\Delta c_{.dev}$	5	mm

h (paksuus)	400	mm
	c_{nom}	
yläpinta	50	mm
alapinta	100	mm
Halkeilun rajoittaminen		
$w_{tav.raja}$	0,2	mm
$w_{pitkä.raja}$	0,15	mm
k_1	0,8	
k_2	1,0	
k_3	3,4	
k_4	0,425	
$k_{t.tav}$	0,6	
$k_{t.pitkä}$	0,4	
$\alpha_e = E_s/E_{cm}$	6,061	
Viruminen		
Sementti tyyppi	N	
RH	80	%
E_c(1vrk)	34,65	MPa
α	0	
t_0	28,0	vrk
α_1	0,94	
α_2	0,98	
$\beta(f_{cm})$	2,73	
$\beta(t_0)$	0,49	

Alue	Tuen yli		Kenttä		MUUT		MUUT		
	pituus	poikittais	pituus	poikittais	pituus	poikittais	pituus	poikittais	
	yläpinta	yläpinta	alapinta	alapinta	yläpinta	yläpinta	alapinta	alapinta	
	Mx (T)	My (T)	Mx(B)	My (B)	Mx (T)	My (T)	Mx(B)	My (B)	
M_{mrt}	71	76	31	32	0	0	0	0	kN*m/m
M_{tav}	40	43	17	18	1	1	1	1	kN*m/m
$M_{ptikä}$	38	41	16	17	1	1	1	1	kN*m/m
kerros 1	T16k130	T16k130	T16k130	T16k130	T16k130	T16k130	T16k130	T16k130	
φ_{eq}	16	16	16	16	16	16	16	16	mm
k_{eq}	130	130	130	130	130	130	130	130	mm
k_{min}	130	130	130	130	130	130	130	130	mm
φ_{max}	16	16	16	16	16	16	16	16	mm
c_{nom} ($c_{min}+\Delta c_{dev}$)	50	50	100	100	50	50	100	100	mm
$A_{sr.min}/A_{sp}$	31,8 %	20,0 %	26,9 %	20,0 %	31,8 %	20,0 %	26,9 %	20,0 %	
min.tarkista	OK	OK	OK	OK	OK	OK	OK	OK	
$A_{sr.max}$	8000	8000	8000	8000	8000	8000	8000	8000	mm2
max.tarkista	OK	OK	OK	OK	OK	OK	OK	OK	
$d_{.eq}$	326,0	342	276	292	326	342	276,0	292	mm
$k_{min.all}$	56	56	56	56	56	56	56	56	mm
l_{bd}	585	585	410	410	585	585	410	410	mm
l_o	1165	1165	820	820	1165	1165	820	820	mm
r_{min} (min)	40	40	40	40	40	40	40	40	mm
r_{min} (pää)	195	195	195	195	195	195	195	195	mm
$w_{tav.all}$	0,280	0,222	0,244	0,211	0,280	0,222	0,244	0,211	mm
$w_{pitkä.all}$	0,210	0,167	0,183	0,158	0,210	0,167	0,183	0,158	mm

Pile + concrete slab (4/4):
The bending moment and shear capacity have examined at pages 3/4 and 4/4.

MRT									
μ	0,039	0,038	0,024	0,022	0,000	0,000	0,000	0,000	
ω	0,040	0,039	0,024	0,022	0,000	0,000	0,000	0,000	
A_{sr}	512	522	262	255	0	0	0	0	mm2
a	39	39	39	39	39	39	39	39	mm
x	49	49	49	49	49	49	49	49	mm
$M_{pl.Rd}$	206	216	172	183	206	216	172	183	kN*m/m
x_{bal}	190	200	161	170	190	200	161	170	mm
$A_{c.bal}$	152133	159600	128800	136267	152133	159600	128800	136267	mm2
$F_{c.bal}$	2586	2713	2190	2317	2586	2713	2190	2317	kN/m
$M_{pl.Rd.max}$	646	711	463	519	646	711	463	519	kN*m/m
$M_{mrt}/M_{pl.Rd}$	33,1 %	33,8 %	16,9 %	16,5 %	0,0 %	0,0 %	0,0 %	0,0 %	
	OK	OK	OK	OK	NA	NA	NA	NA	
KRT - TAVALLINEN YHD.									
x	69	71	63	65	69	71	63	65	mm
z	303	318	255	270	303	318	255	270	mm
$h_{c.eff}$	110	110	112	112	110	110	112	112	mm
$A_{c.eff}$	110212	109585	112278	111598	110212	109585	112278	111598	mm2
$\rho_{.peff}$	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	
σ_s	85	87	44	44	2	2	3	2	MPa
$s_{r.max}$	602	555	789	733	602	555	789	733	mm
$\Delta\varepsilon_s$	0,000256	0,000262	0,000132	0,000131	0,000006	0,000006	0,000008	0,000007	m/m
w_{tav}	0,154	0,146	0,104	0,096	0,004	0,003	0,006	0,005	mm
$M_{Rd.tav}$	72	65	40	40	72	65	40	40	kN*m/m
$w_{tav}/w_{tav.all}$	55,1 %	65,5 %	42,8 %	45,7 %	1,4 %	1,5 %	2,5 %	2,5 %	
	OK	OK	OK	OK	OK	OK	OK	OK	
KRT - PITKÄAIKAISYHD.									
h_0	400	400	400	400	400	400	400	400	mm
φ_{RH}	1,24	1,24	1,24	1,24	1,24	1,24	1,24	1,24	
φ_0	1,65	1,65	1,65	1,65	1,65	1,65	1,65	1,65	
$1/(1+\varphi_0)$	0,378	0,378	0,378	0,378	0,378	0,378	0,378	0,378	
E_{cc}	13,10	13,10	13,10	13,10	13,10	13,10	13,10	13,10	MPa
$\alpha_{e.pitkä} = E_s/E_{cc}$	15,3	15,3	15,3	15,3	15,3	15,3	15,3	15,3	
x	103	106	93	96	103	106	93	96	mm
z	292	307	245	260	292	307	245	260	mm
$h_{c.eff}$	99	98	102	101	99	98	102	101	mm
$A_{c.eff}$	99103	98117	102343	101277	99103	98117	102343	101277	mm2
$\rho_{.peff}$	0,016	0,016	0,015	0,015	0,016	0,016	0,015	0,015	
σ_s	84	86	43	43	2	2	3	2	MPa
$\Delta\varepsilon_s$	0,000253	0,000259	0,000130	0,000128	0,000007	0,000006	0,000008	0,000007	m/m
$s_{r.max}$	563	515	754	696	563	515	754	696	mm
$w_{pitkä}$	0,142	0,134	0,098	0,089	0,004	0,003	0,006	0,005	mm
$M_{Rd.pitkä}$	56	51	30	30	56	51	30	30	kN*m/m
$w_{pitkä}/w_{pitkä.all}$	67,7 %	80,1 %	53,5 %	56,6 %	1,8 %	2,0 %	3,3 %	3,3 %	
	OK	OK	OK	OK	OK	OK	OK	OK	

TAIVUTUSMOMENTIN TULOKSET									
	pituus yläpinta Mx (T) Tuen yli	poikittais yläpinta My (T) Tuen yli	pituus alapinta Mx(B) Kenttä	poikittais alapinta My (B) Kenttä	pituus yläpinta Mx (T) MUUT	poikittais yläpinta My (T) MUUT	pituus alapinta Mx(B) MUUT	poikittais alapinta My (B) MUUT	
Asp/Asr.min	31,8 %	20,0 %	26,9 %	20,0 %	31,8 %	20,0 %	26,9 %	20,0 %	
min.tarkista	OK	OK	OK	OK	OK	OK	OK	OK	
Asp/Asr	33,1 %	33,8 %	16,9 %	16,5 %	0,0 %	0,0 %	0,0 %	0,0 %	
MRT	OK	OK	OK	OK	NA	NA	NA	NA	
wfrq/wfrq.all	55,1 %	65,5 %	42,8 %	45,7 %	1,4 %	1,5 %	2,5 %	2,5 %	
KRT.freq	OK	OK	OK	OK	OK	OK	OK	OK	
wqp/wqp.all	67,7 %	80,1 %	53,5 %	56,6 %	1,8 %	2,0 %	3,3 %	3,3 %	
KRT.quasi	OK	OK	OK	OK	OK	OK	OK	OK	
Käyttöaste	67,7 %	80,1 %	53,5 %	56,6 %	31,8 %	20,0 %	26,9 %	20,0 %	
Yhteenveto	OK	OK	OK	OK	OK	OK	OK	OK	

LEIKKAUS (vain betoni)					
V_{Ed}	160	kN	ρ_1	0,452 %	
N_{Ed}	0	kN	k	1,76	
b_w	1,000	m	k_1	0,15	
Vetoteräs	poikittais yläpinta Tuen yli		$C_{Rd,c}$	0,1200	
d	342	mm	v_{min}	0,449	MPa
A_{sl}	0,0015	m2	$V_{Rd,c.min}$	154	kN
A_c	0,0004	m2	$V_{Rd,c}$	173	kN
σ_{cp}	0	MPa	V_{Ed}/V_{Rd}	92,6 %	
			$V_{co.tark}$	OK	

		Unit	Amount	Unit Price	Total
Pile and concrete slab foundation over 3 m thick peat				***0.00 €***	***250 771 €***
20201	*Preparing worksite (milling) **	*m2*	*1 332*	*0.57 €*	*759 €*
30106.0	*Excavation from soil extration area **	*m3*	*2 393*	*1.00 €*	*2 393 €*
	Embankment and surcharge (excavation and loading)				
30106.1	*Embankment material **	*m3*	*2 393*	*4.50 €*	*10 769 €*
	Material prices				
30106.2	*Embankment and surcharge material transport **	*m3*	*2 393*	*4.27 €*	*10 218 €*
	30 km				
30402.1	*Working platform for piling 0.5 m*	*m3*	*510*	*1.93 €*	*984 €*
	Material, spreding, compacting (estimated to settle 0.5 m to peat layer)				
30701a	*Geotextile profile 1 **	*m2*	*1 020*	*0.94 €*	*959 €*
30701a	*Reinforced concrete slab*	*m3*	*408*	*380.00 €*	*155 040 €*
30701a	*Concrete piles (300 mm x 300 mm)*	*m*	*1 248*	*35.00 €*	*43 680 €*
30701a	*Piledriving into soil*	*m*	*1 248*	*11.50 €*	*14 352 €*
30701a	*Pile head cutting*	*pcs*	*208*	*20.00 €*	*4 160 €*
30402.1	*Embankment construction **	*m3*	*1 883*	*1.93 €*	*3 634 €*
	Material, spreding, compacting				
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*19.64 €*	*1 964 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Sand columns (3 m thick peat layer)				***0.00 €***	***91 611 €***
20201	*Preparing worksite (milling) **	*m2*	*1 332*	*0.57 €*	*759 €*
30106.0	*Excavation from soil extration area **	*m3*	*2 901*	*1.00 €*	*2 901 €*
	Embankment and surcharge (excavation and loading)				
30106.1	*Embankment material **	*m3*	*2 901*	*4.50 €*	*13 055 €*
	Material prices				
30106.2	*Embankment and surcharge material transport **	*m3*	*2 901*	*4.27 €*	*12 387 €*
	30 km				
30402.1	*Working platform for piling 0.5 m*	*m3*	*510*	*1.93 €*	*984 €*
	Material, spreding, compacting (estimated to settle 0.5 m to peat layer)				
30402.1	*Filling material of the sand columns (d=800, 3.5 m)*	*m3*	*508*	*1.93 €*	*980 €*
	Filling of the columns				
30701a	*Geotextile profile 1 **	*m2*	*1 332*	*0.94 €*	*1 252 €*
30701a	*Geotextiles on top of sand columns (2-layers)*	*m2*	*2 784*	*5.50 €*	*15 313 €*
30701a	*Sand columns geotextile material (d=800 mm)*	*m2*	*2 542*	*7.50 €*	*19 065 €*
30701a	*Metal casing driving into soil and filling of the columns*	*m*	*1 012*	*11.50 €*	*11 638 €*
30701a	*Metal casing vibrating up*	*m*	*1 012*	*5.75 €*	*5 819 €*
30402.1	*Embankment construction **	*m3*	*1 883*	*1.93 €*	*3 634 €*
	Material, spreding, compacting				
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*19.64 €*	*1 964 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Granulated blast furnace slag (design similar to test section 1)				***0.00 €***	***94 569 €***
20201	*Preparing worksite (milling) **	*m2*	*1 332*	*0.57 €*	*759 €*
30106.0	*Excavation from soil extration area **	*m3*	*2 564*	*1.00 €*	*2 564 €*
	surcharge (excavation and loading)				
30106.1	*Embankment (Slag)*	*m3*	*1 883*	*25.00 €*	*47 075 €*
	Material prices				
30106.1	*Surcharge material **	*m3*	*2 564*	*4.50 €*	*11 538 €*
	Material prices				
30106.2	*Embankment (slag) transport*	*m3*	*1 883*	*7.12 €*	*13 407 €*
	50 km				
30106.2	*Surcharge material transport **	*m3*	*2 564*	*4.27 €*	*10 948 €*
	30 km				
30402.1	*Embankment construction **	*m3*	*1 883*	*1.93 €*	*3 634 €*
	Material, spreding, compacting				
30402.21	*Surcharge construction **	*m3*	*2 564*	*1.50 €*	*3 846 €*
	Material, spreding, compact				
30402.22	*Surcharge removal **	*m3*	*2 564*	*1.00 €*	*2 564 €*
	Excavation, loading				
30402.23	*Surcharge transport to next section **	*m3*	*2 564*	*0.55 €*	*1 410 €*
	Transport 2-3 km				
30402.24	*Surcharge material benefit in next section **	*m3*	*2 564*	*-9.77 €*	*-25 050 €*
	Transported to final road embankment where is no ground preparation operations (solid soil areas etc.)				

30402.25	*Material settlement (excavation, material, transport, construction) **	*m3*	*650*	*11.70 €*	*7 605 €*
	settlement = 0.94 m				
30701a	*Geotextile profile 1 **	*m2*	*663*	*0.94 €*	*623 €*
30701b	*Geotextile profile 3 **	*m2*	*180*	*1.41 €*	*254 €*
30702	*Georeinforcement 600/50 **	*m2*	*1 350*	*7.09 €*	*9 568 €*
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*19.64 €*	*1 964 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

1. VÕÕBU KATSELÕIGU TÖÖMAHTUDE LOEND

SEKTSIOON 0

Artikli nr	Tööde kirjeldus	Mõõtühik	Maht
1	2	3	4
30105	Turba kaevandamine; h_{kesk}=1,80m	m^3	2 325
30106	Kaevamine karjäärist (muldkeha ehituseks juurdeveetav materjal + vedu)	m^3	3 778
30402	Muldkeha ehitamine juurdeveetava liiv- või kruusliiv pinnasega	m^3	3 778
40504	Paekivikillustikust tehnoloogiline kiht fr 2/64; h=15cm	m^2	663
44001	1x pindamine paekivikillustikuga fr 8/12	m^2	663

SEKTSIOON 1

Artikli nr	Tööde kirjeldus	Mõõtühik	Maht
1	2	3	4
20201	Raadamine, kändude ja mätaste freesimine	m^2	1 332
30106	Kaevamine karjäärist (muldkeha ehituseks juurdeveetav materjal + ülekoormus + vedu)	m^3	4 447
30402	Muldkeha ehitamine juurdeveetava liiv- või kruusliiv pinnasega	m^3	1 883
30701a	Geotekstiil; 1. profiil	m^2	663
30701b	Geotekstiil; 3. profiil	m^2	180
30702	Geotekstiil; 600/50	m^2	1 350
40504	Paekivikillustikust tehnoloogiline kiht fr 2/64; h=15cm	m^2	663
44001	1x pindamine paekivikillustikuga fr 8/12	m^2	663
xxxxx	Ülekoormuse pinnase paigaldamine	m^3	2 564

SEKTSIOON 2

Artikli nr	Tööde kirjeldus	Mõõtühik	Maht
1	2	3	4
20201	Raadamine, kändude ja mätaste freesimine	m^2	1 129
30106	Kaevamine karjäärist (muldkeha ehituseks juurdeveetav materjal + ülekoormus + vedu)	m^3	4 232
30402	Muldkeha ehitamine juurdeveetava liiv- või kruusliiv pinnasega	m^3	1 752
30701a	Geotekstiil; 1. profiil	m^2	663
30701b	Geotekstiil; 3. profiil	m^2	180
30702a	Geotekstiil; 400/50	m^2	1 295
30702b	Geotekstiil; 200/50	m^2	1 285
40504	Paekivikillustikust tehnoloogiline kiht fr 2/64; h=15cm	m^2	663
44001	1x pindamine paekivikillustikuga fr 8/12	m^2	663
xxxxx	Ülekoormuse pinnase paigaldamine	m^3	2 480

1. VÕÕBU KATSELÕIGU TÖÖMAHTUDE LOEND

SEKTSIOON 3

Artikli nr	Tööde kirjeldus	Mõõtühik	Maht
1	2	3	4
20201	Raadamine, kändude ja mätaste freesimine	m^2	1 142
30106	Kaevamine karjäärist (muldkeha ehituseks juurdeveetav materjal + ülekoormus + vedu)	m^3	3 257
30402	Muldkeha ehitamine juurdeveetava liiv- või kruusliiv pinnasega	m^3	764
30701a	Geotekstiil; 1. profiil	m^2	663
30701b	Geotekstiil; 3. profiil	m^2	1 131
30703	Geovõrk 40/40	m^2	1 131
30706	Paekivikillustikuga täidetud geokärg; h=1,0m	m^2	1 015
40504	Paekivikillustikust tehnoloogiline kiht fr 2/64; h=15cm	m^2	663
44001	1x pindamine paekivikillustikuga fr 8/12	m^2	663
xxxxx	Ülekoormuse pinnase paigaldamine	m^3	2 493

SEKTSIOON 4

Artikli nr	Tööde kirjeldus	Mõõtühik	Maht
1	2	3	4
20201	Raadamine, kändude ja mätaste freesimine	m^2	1 149
30106	Kaevamine karjäärist (muldkeha ehituseks juurdeveetav materjal + ülekoormus + vedu)	m^3	2 267
30402	Muldkeha ehitamine juurdeveetava liiv- või kruusliiv pinnasega	m^3	894
30701a	Geotekstiil; 1. profiil	m^2	663
30701b	Geotekstiil; 3. profiil	m^2	850
30702	Geotekstiil; 400/50	m^2	1 147
40504	Paekivikillustikust tehnoloogiline kiht fr 2/64; h=15cm	m^2	663
44001	1x pindamine paekivikillustikuga fr 8/12	m^2	663
xxxxx	Ülekoormuse pinnase paigaldamine	m^3	1 254
xxxxx	Fibo kergkruus 10-20; h=100cm	m^3	941

1. VÕÕBU KATSELÕIGU TÖÖMAHTUDE LOEND

SEKTSIOON 5

Artikli nr	Tööde kirjeldus	Mõõtühik	Maht
1	2	3	4
20201	Raadamine, kändude ja mätaste freesimine	m^2	1 168
30106	Kaevamine karjäärist (muldkeha ehituseks juurdeveetav materjal + ülekoormus + vedu)	m^3	2 250
30402a	Muldkeha ehitamine juurdeveetava liiv- või kruusliiv pinnasega; (I etapp)	m^3	550
30402b	Muldkeha ehitamine juurdeveetava liiv- või kruusliiv pinnasega; II etapp	m^3	1 010
30701a	Geotekstiil pindamise peale; 1. profiil	m^2	663
30701b	Geotekstiil ehituskile peale; 1. profiil	m^2	826
30701c	Geotekstiil ehituskile peale; 3. profiil	m^2	210
30702	Geotekstiil; 400/50	m^2	1 158
30703	Geovõrk 40/40	m^2	826
40504	Paekivikillustikust tehnoloogiline kiht fr 2/64; h=15cm	m^2	663
44001	1x pindamine paekivikillustikuga fr 8/12	m^2	663
xxxxx	Ülekoormuse pinnase paigaldamine	m^3	690
xxxxx	ESP 120 geofoam; 6100x1240x525; esimene kiht	m^2	795
xxxxx	ESP 200 geofoam; 6100x1240x525; teine kiht	m^2	745
xxxxx	ESP 200 geofoam; 3000x1200x200; kolmas kiht	m^2	450
xxxxx	ESP 200 geofoam; 3000x1200x200; neljas kiht	m^2	180
xxxxx	Ehituskile; h=0,5mm	m^2	826

TEHNOLOOGILINE SEKTSIOON

Artikli nr	Tööde kirjeldus	Mõõtühik	Maht
1	2	3	4
20201	Raadamine, kändude ja mätaste freesimine	m^2	565
30106	Kaevamine karjäärist (muldkeha ehituseks juurdeveetav materjal + vedu)	m^3	460
30107	Kraavide kaevamine	m^3	220
30402	Muldkeha ehitamine juurdeveetava liiv- või kruusliiv pinnasega	m^3	460
30702	Geotekstiil; 3. profiil	m^2	263
51001	Plastiktruup; d=400mm	m	19

Märkused:

1. Esitatud töödemahud on teoreetilised, st need on mõõdetud jooniste alusel ehitustarindi geomeetrilistest mõõtmetest lähtuvalt (materjalid on arvestatud paigaldatuna ja tihendatuna).
2. Geovõrkude ja geotekstiilide mahtude puhul ei ole arvestatud ülekatete ja kadudega.
3. Kõik mahud tuleb tööde käigus täpsustada.
4. Kõikide seadmete ja materjalide puhul on lubatud nende asendamine teiste vähemalt samaväärsete toodetega juhul, kui asendamine kooskõlastatakse Tellijaga.
5. Töömahuloendi koostamisel on kasutatud 02.01.2015 teetööde tehnilise kirjelduse versiooni.

Unit Prices

Pay item		Unit	Price
4000	***Rakennustekniset rakennusosat***		
4900	**Muut rakennusosat**		
44001	Gravel pavement	*m2*	*2.16 €*
	#8/12		
20201	Preparing worksite (milling)	*m2*	*0.57 €*
30105	Excavating peat	*m3*	*1.00 €*
	h = 1.8 m		
30105.1	Peat transportation 30 km	*m3*	*1.42 €*
30106.0	Excavation from soil extration area	*m3*	*1.00 €*
	Embankment and surcharge (excavation and loading)		
30106.1	Embankment and surcharge material	*m3*	*4.50 €*
	Material prices		
30106.2	Embankment and surcharge material transport	*m3*	*4.27 €*
	30 km		
30402.0	Preloading embankment (Phase 1)	*m3*	*1.93 €*
	Material, spreding, compact and leveling after preload		
30402.1	Embankment construction	*m3*	*1.93 €*
	Material, spreding, compacting		
30402.21	Surcharge construction	*m3*	*1.50 €*
	Material, spreding, compact		
30402.22	Surcharge removal	*m3*	*1.00 €*
	Excavation, loading		
30402.23	Surcharge transport to next section	*m3*	*0.55 €*
	Transport 2-3 km		
30402.24	Surcharge material benefit in next section	*m3*	*-9.77 €*
	Transported to final road embankment where is no ground preparation operations (solid soil areas etc.)		
30402.25	Material settlement (excavation, material, transport, construction)	*m3*	*11.70 €*
30701a	Geotextile profile 1	*m2*	*0.94 €*
30701b	Geotextile profile 3	*m2*	*1.41 €*
30702	Georeinforcement 600/50	*m2*	*7.09 €*
30702a	Georeinforcement 400/50	*m2*	*5.37 €*
30702b	Georeinforcement 200/50	*m2*	*3.47 €*
30703	Georeinforcement 40/40	*m2*	*2.72 €*
30706.1	Geocell, Vertical Tensar SR-grid	*m2*	*5.00 €*
30706.2	Geocell, Horizontal TriAx-grid	*m2*	*5.00 €*
30706.3	Geocell, additional cost for assembling	*kpl*	*1 600.00 €*
	5 pax, 4 days, 10e/h		
30706.4	Geocell filling #2/64	*m3*	*19.64 €*
40504	Base layer #2/64 h=15 cm	*m3*	*19.64 €*
	spread, level, compact		
40504.1	Base layer transport	*m3*	*4.27 €*
	30 km		
99999	LWA	*m3*	*45.65 €*
	Fibo LWA 10-20 (include transport 0-150km)		
99999	EPS 120	*m3*	*43.92 €*
	including transport		
99999	Plastic membrane	*m2*	*2.00 €*
99999	EPS 200	*m3*	*57.05 €*
	including transport		

Cost comparison calculations

		Unit	Amount	Unit Price	Total
Test section 0 (Mass replacement)				***0.00 €***	***53 169 €***
30105	*Excavating peat **	*m3*	*2 325*	*1.00 €*	*2 325 €*
	h = 1.8 m				
30105.1	*Peat transportation **	*m3*	*2 325*	*1.42 €*	*3 302 €*
	10 km				
30106.0	*Embankment and surcharge material transport **	*m3*	*3 778*	*4.27 €*	*16 132 €*
	30 km				
30106.0	*Excavation from soil extration area **	*m3*	*3 778*	*1.00 €*	*3 778 €*
	Embankment and surcharge (excavation and loading)				
30106.0	*Embankment and surcharge material **	*m3*	*3 778*	*4.50 €*	*17 001 €*
	Material prices				
30402.1	*Embankment construction **	*m3*	*3 778*	*1.93 €*	*7 292 €*
	Material, spreding, compacting				
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*14.81 €*	*1 481 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Test section 1 (1-layer georeinforcement)				***0.00 €***	***52 484 €***
20201	*Preparing worksite (milling) **	*m2*	*1 332*	*0.57 €*	*759 €*
30106.0	*Excavation from soil extration area **	*m3*	*4 447*	*1.00 €*	*4 447 €*
	Embankment and surcharge (excavation and loading)				
30106.1	*Embankment and surcharge material **	*m3*	*4 447*	*4.50 €*	*20 012 €*
	Material prices				
30106.2	*Embankment and surcharge material transport **	*m3*	*4 447*	*4.27 €*	*18 989 €*
	30 km				
30402.1	*Embankment construction **	*m3*	*1 883*	*1.93 €*	*3 634 €*
	Material, spreding, compacting				
30402.21	*Surcharge construction **	*m3*	*2 564*	*1.50 €*	*3 846 €*
	Material, spreding, compact				
30402.22	*Surcharge removal **	*m3*	*2 564*	*1.00 €*	*2 564 €*
	Excavation, loading				
30402.23	*Surcharge transport to next section **	*m3*	*2 564*	*0.55 €*	*1 410 €*
	Transport 2-3 km				
30402.24	*Surcharge material benefit in next section **	*m3*	*2 564*	*-9.77 €*	*-25 050 €*
	Transported to final road embankment where is no ground preparation operations (solid soil areas etc.)				
30402.25	*Material settlement (excavation, material, transport, construction) **	*m3*	*650*	*11.70 €*	*7 605 €*
	settlement = 0.94 m				
30701a	*Geotextile profile 1 **	*m2*	*663*	*0.94 €*	*623 €*

30701b	*Geotextile profile 3 **	*m2*	*180*	*1.41 €*	*254 €*
30702	*Georeinforcement 600/50 **	*m2*	*1 350*	*7.09 €*	*9 568 €*
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*19.64 €*	*1 964 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Test section 2 (2-layer georeinforcement)				***0.00 €***	***49 366 €***
20201	*Preparing worksite (milling) **	*m2*	*1 129*	*0.57 €*	*644 €*
30106.0	*Excavation from soil extration area **	*m3*	*4 232*	*1.00 €*	*4 232 €*
	Embankment and surcharge (excavation and loading)				
30106.1	*Embankment and surcharge material **	*m3*	*4 232*	*4.50 €*	*19 044 €*
	Material prices				
30106.2	*Embankment and surcharge material transport **	*m3*	*4 232*	*4.27 €*	*18 071 €*
	30 km				
30402.1	*Embankment construction **	*m3*	*1 752*	*1.93 €*	*3 381 €*
	Material, spreding, compacting				
30402.21	*Surcharge construction **	*m3*	*2 480*	*1.50 €*	*3 720 €*
	Material, spreding, compact				
30402.22	*Surcharge removal **	*m3*	*2 480*	*1.00 €*	*2 480 €*
	Excavation, loading				
30402.23	*Surcharge transport to next section **	*m3*	*2 480*	*0.55 €*	*1 364 €*
	Transport 2-3 km				
30402.24	*Surcharge material benefit in next section **	*m3*	*2 480*	*-9.77 €*	*-24 230 €*
	Transported to final road embankment where is no ground preparation operations (solid soil areas etc.)				
30402.25	*Material settlement (excavation, material, transport, construction) **	*m3*	*388*	*11.70 €*	*4 540 €*
	settlement = 0.56 m				
30701a	*Geotextile profile 1 **	*m2*	*663*	*0.94 €*	*623 €*

30701b	*Geotextile profile 3 **	*m2*	*180*	*1.41 €*	*254 €*
30702a	*Georeinforcement 400/50 **	*m2*	*1 295*	*5.37 €*	*6 958 €*
30702b	*Georeinforcement 200/50 **	*m2*	*1 285*	*3.47 €*	*4 463 €*
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*19.64 €*	*1 964 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Test section 3 (Geocell)				***0.00 €***	***82 991 €***
20201	*Preparing worksite (milling) **	*m2*	*1 142*	*0.57 €*	*651 €*
30106.0	*Excavation from soil extration area **	*m3*	*3 257*	*1.00 €*	*3 257 €*
	Embankment and surcharge (excavation and loading)				
30106.1	*Embankment and surcharge material **	*m3*	*3 257*	*4.50 €*	*14 657 €*
	Material prices				
30106.2	*Embankment and surcharge material transport **	*m3*	*3 257*	*4.27 €*	*13 907 €*
	30 km				
30402.1	*Embankment construction **	*m3*	*764*	*1.93 €*	*1 475 €*
	Material, spreding, compacting				
30402.21	*Surcharge construction **	*m3*	*2 493*	*1.50 €*	*3 740 €*
	Material, spreding, compact				
30402.22	*Surcharge removal **	*m3ktr*	*2 493*	*1.00 €*	*2 493 €*
	Excavation, loading				
30402.23	*Surcharge transport to next section **	*m3ktr*	*2 493*	*0.55 €*	*1 371 €*
	Transport 2-3 km				
30402.24	*Surcharge material benefit in next section **	*m3*	*2 493*	*-9.77 €*	*-24 357 €*
	Transported to final road embankment where is no ground preparation operations (solid soil areas etc.)				
30402.25	*Material settlement (excavation, material, transport, construction) **	*m3*	*1 191*	*11.70 €*	*13 935 €*
	settlement = 1.72 m				
30701a	*Geotextile profile 1 **	*m2*	*663*	*0.94 €*	*623 €*

30701b	*Geotextile profile 3 **	*m2*	*1 131*	*1.41 €*	*1 595 €*
30703	*Georeinforcement 40/40 **	*m2*	*1 131*	*2.72 €*	*3 071 €*
30706.1	*Geocell, Vertical Tensar SR-grid **	*m2*	*2 370*	*5.00 €*	*11 850 €*
30706.2	*Geocell, Horizontal TriAx-grid **	*m2*	*1 015*	*5.00 €*	*5 075 €*
30706.3	*Geocell, additional cost for assembling **		*1*	*1 600.00 €*	*1 600 €*
	5 pax, 4 days, 10e/h				
30706.4	*Geocell filling #2/64 **	*m3*	*1 015*	*19.64 €*	*19 935 €*
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*19.64 €*	*1 964 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*1 105*	*4.27 €*	*4 718 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Test section 4 (LWA)				***0.00 €***	***83 101 €***
20201	*Preparing worksite (milling) **	*m2*	*1 149*	*0.57 €*	*655 €*
30106.0	*Excavation from soil extration area **	*m3*	*2 267*	*1.00 €*	*2 267 €*
	Embankment and surcharge (excavation and loading)				
30106.1	*Embankment and surcharge material **	*m3*	*2 267*	*4.50 €*	*10 202 €*
	Material prices				
30106.2	*Embankment and surcharge material transport **	*m3*	*2 267*	*4.27 €*	*9 680 €*
	30 km				
30402.1	*Embankment construction **	*m3*	*894*	*1.93 €*	*1 725 €*
	Material, spreding, compacting				
30402.21	*Surcharge construction **	*m3*	*1 254*	*1.50 €*	*1 881 €*
	Material, spreding, compact				
30402.22	*Surcharge removal **	*m3*	*1 254*	*1.00 €*	*1 254 €*
	Excavation, loading				
30402.23	*Surcharge transport to next section **	*m3*	*1 254*	*0.55 €*	*690 €*
	Transport 2-3 km				
30402.24	*Surcharge material benefit in next section **	*m3*	*1 254*	*-9.77 €*	*-12 252 €*
	Transported to final road embankment where is no ground preparation operations (solid soil areas etc.)				
30402.25	*Material settlement (excavation, material, transport, construction) **	*m3*	*1 046*	*11.70 €*	*12 238 €*
	settlement = 1.51 m				
30701a	*Geotextile profile 1 **	*m2*	*663*	*0.94 €*	*623 €*

30701b	*Geotextile profile 3 **	*m2*	*850*	*1.41 €*	*1 199 €*
30702a	*Georeinforcement 400/50 **	*m2*	*1 147*	*5.37 €*	*6 163 €*
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*19.64 €*	*1 964 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				
99999	*LWA **	*m3*	*941*	*45.65 €*	*42 953 €*
	Fibo LWA 10-20 (include transport 0-150km)				

Test section 5 (EPS)				***0.00 €***	***94 275 €***
20201	*Preparing worksite (milling) **	*m2*	*1 168*	*0.57 €*	*666 €*
30106.0	*Excavation from soil extration area **	*m3*	*2 250*	*1.00 €*	*2 250 €*
	Embankment and surcharge (excavation and loading)				
30106.1	*Embankment and surcharge material **	*m3*	*2 250*	*4.50 €*	*10 125 €*
	Material prices				
30106.2	*Embankment and surcharge material transport **	*m3*	*2 250*	*4.27 €*	*9 608 €*
	30 km				
30402.0	*Preloading embankment (Phase 1) **	*m3*	*550*	*1.93 €*	*1 062 €*
	Material, spreding, compact and leveling after preload				
30402.1	*Embankment construction **	*m3*	*1 010*	*1.93 €*	*1 949 €*
	Material, spreding, compacting				
30402.21	*Surcharge construction **	*m3*	*690*	*1.50 €*	*1 035 €*
	Material, spreding, compact				
30402.22	*Surcharge removal **	*m3*	*690*	*1.00 €*	*690 €*
	Excavation, loading				
30402.23	*Surcharge transport to next section **	*m3*	*690*	*0.55 €*	*380 €*
	Transport 2-3 km				
30402.24	*Surcharge material benefit in next section **	*m3*	*690*	*-9.77 €*	*-6 741 €*
	Transported to final road embankment where is no ground preparation operations (solid soil areas etc.)				
30402.25	*Material settlement (excavation, material, transport, construction) **	*m3*	*838*	*11.70 €*	*9 805 €*

	settlement = 1.21 m				
30701a	*Geotextile profile 1 **	*m2*	*1 489*	*0.94 €*	*1 400 €*
30701b	*Geotextile profile 3 **	*m2*	*210*	*1.41 €*	*296 €*
30702a	*Georeinforcement 400/50 **	*m2*	*1 158*	*5.37 €*	*6 222 €*
30703	*Georeinforcement 40/40 **	*m2*	*826*	*2.72 €*	*2 243 €*
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*19.64 €*	*1 964 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				
99999	*EPS 120 **	*m3*	*417*	*43.92 €*	*18 316 €*
	including transport				
99999	*Plastic membrane **	*m2*	*826*	*2.00 €*	*1 652 €*
99999	*EPS 200 **	*m3*	*517*	*57.05 €*	*29 496 €*
	including transport				

Test section 0 (Mass replacement 3m peat)				***0.00 €***	***75 360 €***
30105	*Excavating peat **	*m3*	*3 875*	*1.00 €*	*3 875 €*
	h = 3 m				
30105.1	*Peat transportation **	*m3*	*3 875*	*1.42 €*	*5 503 €*
	10 km				
30106.0	*Excavation from soil extration area **	*m3*	*5 328*	*1.00 €*	*5 328 €*
	Embankment and surcharge (excavation and loading)				
30106.0	*Embankment and surcharge material **	*m3*	*5 328*	*4.50 €*	*23 976 €*
	Material prices				
30106.0	*Embankment and surcharge material transport **	*m3*	*5 328*	*4.27 €*	*22 751 €*
	30 km				
30402.1	*Embankment construction **	*m3*	*5 328*	*1.93 €*	*10 283 €*
	Material, spreding, compacting				
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*14.81 €*	*1 481 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*7.32 €*	*732 €*
	20-25km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Test section 0 (Mass replacement 4m peat)				***0.00 €***	***93 281 €***
30105	*Excavating peat **	*m3*	*5 160*	*1.00 €*	*5 160 €*
	h = 4 m				
30105.1	*Peat transportation **	*m3*	*5 160*	*1.42 €*	*7 327 €*
	10 km				
30106.0	*Excavation from soil extration area **	*m3*	*6 620*	*1.00 €*	*6 620 €*
	Embankment and surcharge (excavation and loading)				
30106.0	*Embankment and surcharge material transport **	*m3*	*6 620*	*4.27 €*	*28 267 €*
	20-25 km				
30106.0	*Embankment and surcharge material **	*m3*	*6 620*	*4.50 €*	*29 790 €*
	Material prices				
30402.1	*Embankment construction **	*m3*	*6 620*	*1.93 €*	*12 777 €*
	Material, spreding, compacting				
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*14.81 €*	*1 481 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Mass stabilization, case b: z = 1.8 m					***56 256 €***
xxxxx	*Mass stabilization*	*m3*	*2 325*	*15.00 €*	*34 875 €*
	h = 1.8 m				
30106.0	*Embankment (excavation and loading)*	*m3*	*1 453*	*4.27 €*	*6 204 €*
	30 km				
30106.0	*Excavation from soil extration area **	*m3*	*1 453*	*1.00 €*	*1 453 €*
	Embankment and surcharge (excavation and loading)				
30106.0	*Embankment and surcharge material **	*m3*	*1 453*	*4.50 €*	*6 539 €*
	Material prices				
30402.1	*Embankment construction **	*m3*	*1 453*	*1.93 €*	*2 804 €*
	Material, spreding, compacting				
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*14.81 €*	*1 481 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*732 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*2 168 €*
	#8/12				

Mass stabilization, case c: z = 3 m					***78 465 €***
xxxxx	*Mass stabilization*	*m3*	*3 875*	*15.00 €*	*58 125 €*
	h = 3 m				
30106.0	*Excavation from soil extration area **	*m3*	*1 453*	*1.00 €*	*1 453 €*
	Embankment (excavation and loading)				
30106.0	*Embankment and surcharge material **	*m3*	*1 453*	*4.50 €*	*6 539 €*
	Material prices				
30106.0	*Embankment and surcharge material transport **	*m3*	*1 453*	*4.27 €*	*6 204 €*
	20-25 km				
30402.1	*Embankment construction **	*m3*	*1 453*	*1.93 €*	*2 804 €*
	Material, spreding, compacting				
40504	*Base layer #2/64 h=15 cm **	*m3*	*100*	*14.81 €*	*1 481 €*
	spread, level, compact				
40504.1	*Base layer transport **	*m3*	*100*	*4.27 €*	*427 €*
	30 km				
44001	*Gravel pavement **	*m2*	*663*	*2.16 €*	*1 432 €*
	#8/12				

Mass stabilization, case d: z = 4 m					97 740 €
xxxxx	Mass stabilization	m3	5 160	15.00 €	77 400 €
	h = 4 m				
30106.0	Excavation from soil extration area *	m3	1 453	1.00 €	1 453 €
	Embankment (excavation and loading)				
30106.0	Embankment and surcharge material transport *	m3	1 453	4.27 €	6 204 €
	20-25 km				
30106.0	Embankment and surcharge material *	m3	1 453	4.50 €	6 539 €
	Material prices				
30402.1	Embankment construction *	m3	1 453	1.93 €	2 804 €
	Material, spreding, compacting				
40504	Base layer #2/64 h=15 cm *	m3	100	14.81 €	1 481 €
	spread, level, compact				
40504.1	Base layer transport *	m3	100	4.27 €	427 €
	30 km				
44001	Gravel pavement *	m2	663	2.16 €	1 432 €
	#8/12				

Test sections left under new road alignment

The issues with a road embankment at swamp area are: stability, settlement and bearing capacity of the road structure.

Stability:
The true safety factor against slip line failure of the test section 0 is over required. At the moment the safety against the ditch between section 5 and 0 is not ok!

The safety factor of the embankments 1 to 5 seems to be good, but the true safety factor of the sections 1, 2, 3, 4 and 5 is not possible to calculate without new vane shear tests of peat layer under the embankment. The strength of the peat is a "function" of the consolidation (compression) level and that "function" is not exactly known and researched with the peat of Võõbu. There is general information in the guidebooks how the strength of the peat is increasing under loading because of the consolidation and those general "rules" have been used in the preliminary design calculations for the test construction design.

Our recommendation is to carry out vane tests through the test embankments to research the strength increase of the peat during summer 2016 or at least after the cutting of the surcharge embankment. That information about the strength increase of the peat is also needed in the design of the all road alignment at peat area where will be left un-stabilized peat layer under the embankment.

Settlement:
On the basis of the settlement measurements and calculations, it seems that the settlement of every embankment will be clearly lower than 300 mm in ten years. The estimated settlement during ten years is calculated and estimated to be under 100 mm.

The settlement differences between the centre alignment and the edges seems to be minor and it seems that the edges of the embankment are settling more than the centre line – it seems that the road embankment cross section shape is not flattening. Because of that the surface drainage to the edges of the road is possible to work in future.

Bearing capacity:
The bearing capacity is dependent on the superstructure layers which will be constructed over the embankment after the removing of the surcharge and the layer needed for the superstructure. Sections 1, 2, 3 and 5 are normal embankment can be considered as an normal aggregate embankment for the dimensioning of the superstructure (pavement, base course and sub base).

The dimensioning of the superstructure is a little more complicated because of the LWA and EPS. The type and parameters for LWA/EPS and the distance between the upper surface of LWA/EPS and the road surface ("red line") are known so all needed information for the dimensioning of the superstructure exist and that is possible to do as a normal design work of the road designer.

Ditch between sections 5 and 0:
The area of the ditch between section 5 and 0 is not constructed and some earth work is needed there. On chance is to construct a drainage culvert in the middle of the section 0 and move the ditch there later. After the moving of the ditch alignment, the area between sections 5 and 0 is possible to construct according the design of the final road (geotechnical, road and drainage design). Maybe the solution can be a combination of reinforcements, surcharge and light weight material with suitable transition structures to sections 5 and 0. The design of that is not included to the task of Ramboll.