Preloaded Road Embankments: monitoring and analysis of results

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ABSTRACT
The county road, fv. 115 between Vamma and Ringnesdalen, is a 2,5km road, which was constructed in the period 2011 to 2013. The alignment for the road included large embankment fills at three parts of the road.
The construction manager for this project called for geotechnical solutions that were cost effective. In addition, the project had a flexible time frame for the construction of the road. The roads and geotechnics department at the Norwegian Public Roads Administration (NPRA) performed the geotechnical design for this project. Preloading with surcharge the same as planned embankment and with additional 30% weight of embankments were recommended as a solution for solving settlement issues at four sections of the road. The lengths of these four sections are 75, 40, 80 & 100 m and the heights of planned embankments varied from 5 - 13m.
The preloaded embankments were instrumented with a settlement monitoring system. The project has registered settlement results frequently for the first year of construction of the embankments and supplemented with sporadic measurements for two more years.
Settlement calculations were compared to results from field measurements. Calculated settlements are found to be well comparable to measured settlements. Hence it is concluded that estimation of deformation parameters was relatively accurate for the modelled embankments.
The planned preloading was effective in speeding up the settlement at all modelled sections and served its purpose as expected.

Keywords: Preloading, Settlement, Monitoring, Embankment, Oedometer

1 INTRODUCTION

The county road, fv. 115 between Vamma and Ringnesdalen, is a 2.5 km road, which is part of a road network that connects four towns in the eastern region of Norway.
The road alignment was designed with large embankment fills at four different sections of the road. The construction manager for the project needed to minimize the cost of construction in order to realize the project. Hence, the project opted for low cost geotechnical solutions.

One of the project's geotechnical challenges was to limit settlement with in required limits given on NPRA's standard N200.
The project decided to utilize preloading for mitigation of settlement instead of utilization of lightweight materials in embankments.
Four representative sections were selected and used both for calculation of settlement and monitoring during construction of the road. The sections are named after the road chainage, called 940, 1250, 1800 and 2100.

2 SETTELMENT MONITORING

The profiler of the type Consoil is used to measure settlement during construction of embankments. The profiler consists of a probe and a hydrostatic instrument that measures the depth of its probe.
The probe is pushed through a conduit that is installed just under the terrain along a cross section of the road.
The elevation of the conduit is controlled just after the installation as well as during each and every settlement measurement.
Settlement measurements are made at each meter along the length of the conduit.

Figure 1 Installation of conduit for settlement

Figure 2 Settlement measurement by a profiler

3 DESIGN SECTION - 940

The embankment modelled by the section 940 is 75 m long. The section is chosen because of underlying relatively thick compressible soil and hence expectation of considerable settlement.

The figure below shows the cross section with planned embankment as well as estimated depth to rock.

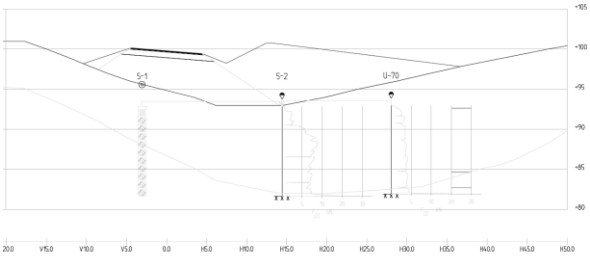

Figure 3 Cross section at chainage 940

3.1 General Soil Properties

The foundation soil consists of thick sea sediments. The soil is classified to be medium sensitive silty clay to clay. The shear strength interpreted to be in the range of 30 – 40 kPa. The shear strength is interpreted from routine laboratory investigation as well as field investigation.

3.2 Deformation Parameters

Oedometer tests of the type CRS (Constant Rate of Strain) were performed on undisturbed samples from Φ 54mm sampler. Two successive sets of specimen were taken at approximately 3.7 and 6.6 m.

A table is given below with our interpretation of deformation parameters from the oedometer test results. The oedometer stiffness (M_{OC}) for both parameter sets is estimated to be 8 Mpa and 5 Mpa for the layers 0-4 m and 4-11 m respectively.

Table 1 Interpreted deformation parameters 940

Parameter set 1					
Depth / Soil layer (m)	σ'_c (kN/m^2)	m (-)	m_{cv} (m2/yrs*kPa)	C_{vOC} (m2/yrs)	C_{vNC} (m2/yrs)
3,7 / (0-4)	140	53	0,08	16	10
6,6 / (4-11)	160	30	0,08	18	12
Parameter set 2					
Depth / Soil layer (m)	σ'_c (kN/m^2)	m (-)	m_{cv} (m2/yrs*kPa)	C_{vOC} (m2/yrs)	C_{vNC} (m2/yrs)
4,0 / (0-4)	140	38	0,05	17	16
6,9 / (4-11)	160	25	0,04	26	25

3.3 Settlement Calculation Results

Settlement was calculated by the software *GeoSuite – Settlement* and by simple Excel based hand calculations.

Calculations were made at section 940 with the deformation parameters presented on Table 1. Results from settlement calculations are presented on figure 4 and 5 below. Calculated settlements are 28cm and 31cm, whereas the time for the preliminary settlement are 4 year and 3.5 year.

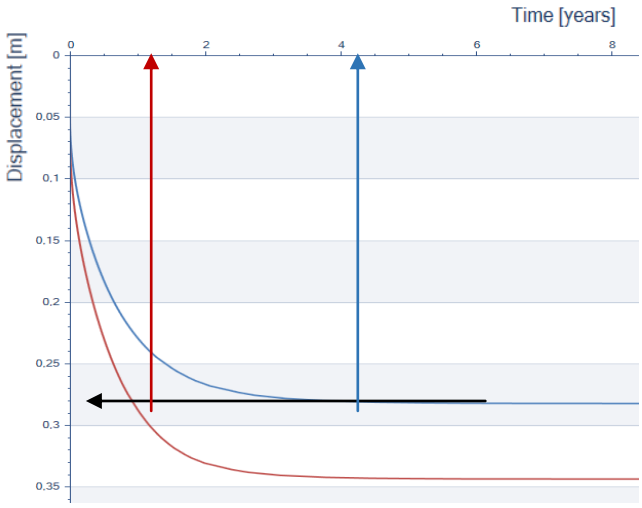

Figure 4 Deformation–time plot_ parameter set 1

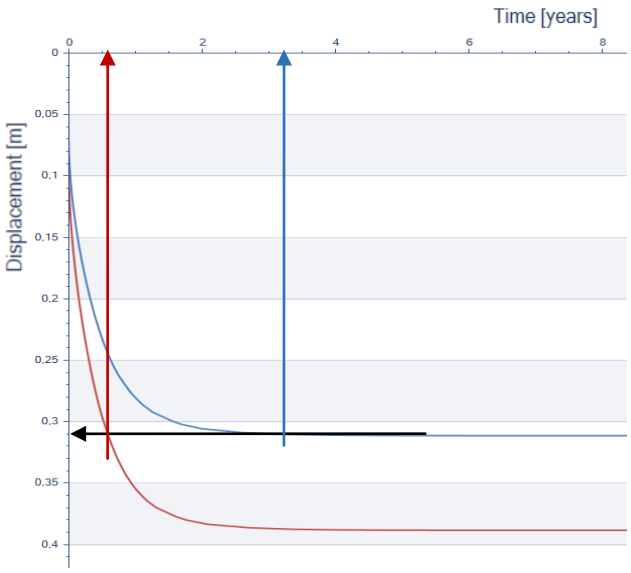

Figure 5 Deformation–time plot_ parameter set 2

The blue curves in *Figure 1* & *Figure 2* indicate settlement for planned embankment. Whereas the red ones show settlement development with a preloading of 30% of the weight of the embankment. As observed on the above two figures the time for settlement is quartered after preloading.

3.4 Field Measurement

The field measurement included monitoring of settlement as well as pore water pressure.

The settlement was measured at section 935 while piezometers were installed at section 920 and 940.
The results from the field measurement are presented in figures 6 - 8.

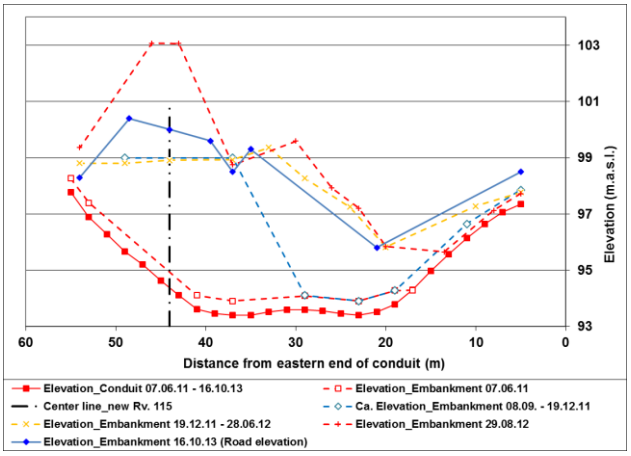

Figure 6 Elevation measurements, section 935

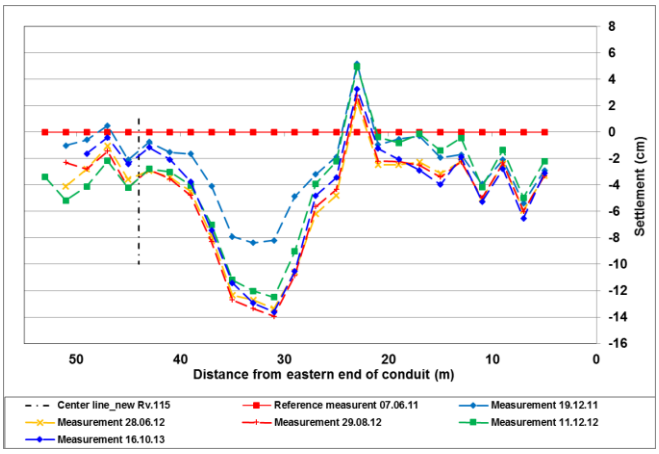

Figure 7 Settlement measurements, section 935

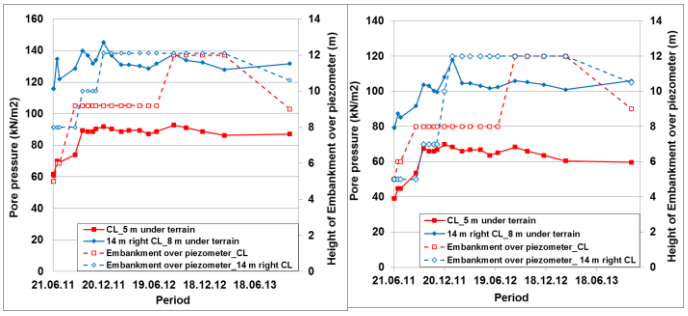

Figure 8 Pore pressure - Section 920 and 940

3.5 Comparison

Calculated settlement values for the two sets of parameters are comparable.
Calculated and measured settlement did not correspond with each other. Therefore, the effect of the preloading was checked by following the pore pressure results.

The reason for lesser settlement values (maximum 14cm) in comparison to the calculated ca. 30 cm settlement could be due to combination of construction of lower embankment as well as the estimation of deformation parameters.
In order to separate these effects further calculation was made with the new geometry for the embankment. The new calculation resulted in a settlement value of 20cm, which is quite comparable to the measured 14 cm value.

4 DESIGN SECTION - 1250

This embankment has a length of 40 m. Design section is chosen at chainage 1250. The figure bellow shows a cross section at 1250.

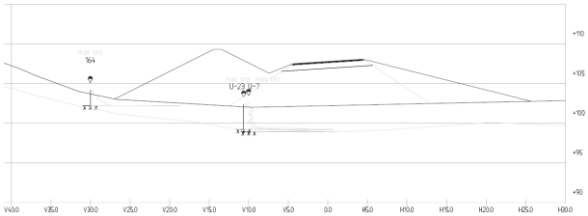

Figure 9 Cross section at chainage 1250

4.1 General soil properties

The soil properties at this cross section are similar to 940.

4.2 Deformation Parameters

CRS oedometer tests were performed on undisturbed sample from Φ 54mm sampler. Two specimen were taken at approximately 1.8 and 2.7 m. The test from 1.8 m was discarded because of poor quality of results. A table is given below with interpreted deformation parameters from the oedometer test result. The oedometer stiffness (M_{OC}) is estimated to be 6 Mpa.

Table 2 Interpreted deformation parameters 1250

Depth / Soil layer (m)	σ'_c (kN/m^2)	m (-)	m_{cv} (m2/yrs*kPa)	C_{vOC} (m2/yrs)	C_{vNC} (m2/yrs)
2.7 / (0-4)	160	20	0,03	20	12

4.3 Settlement Calculation Results

Settlement was calculated by the software *GeoSuite – Settlement* as well as by simple Excel based calculations.

The calculation result is presented on the figure below. Calculated settlement value is ca. 8 cm and the time for preliminary settlement is approximately 7 months.

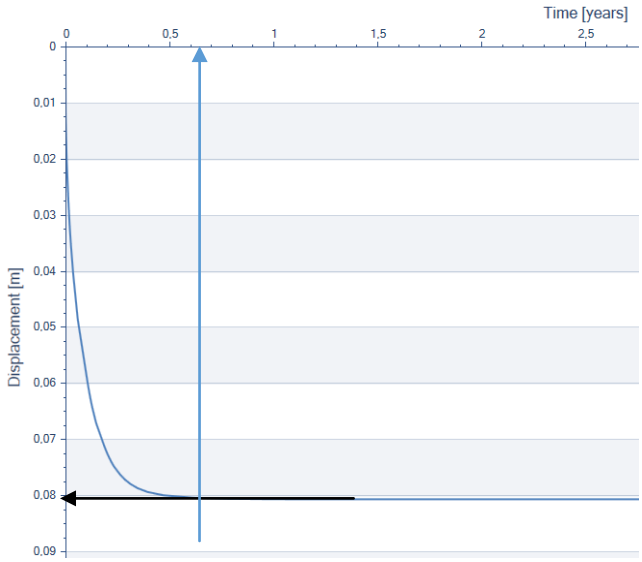

Figure 10 Deformation – time plot, section 1250

4.4 Field Measurement

Settlement and water pressure weremonitored for this section. Both settlement and pore water pressure were measured at 1250. Field measurements are presented below in figure 11 – 13.

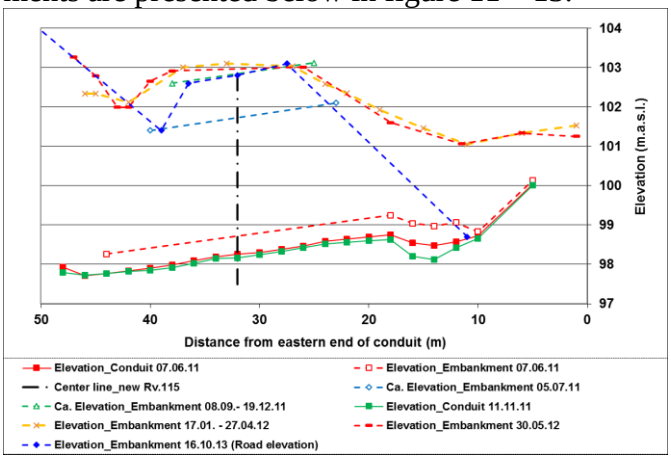

Figure 11 Elevation measurements, section 1250

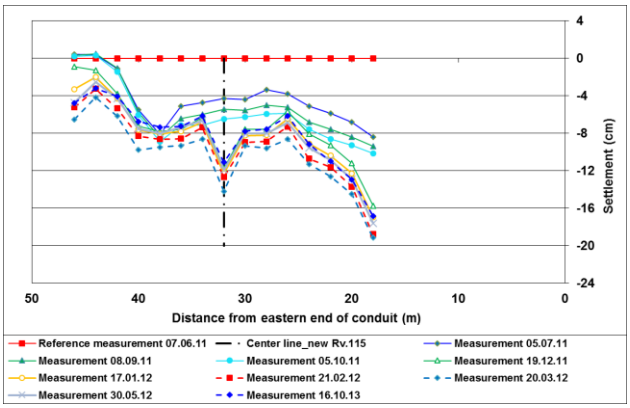

Figure 12 Settlement measurements, section 1250

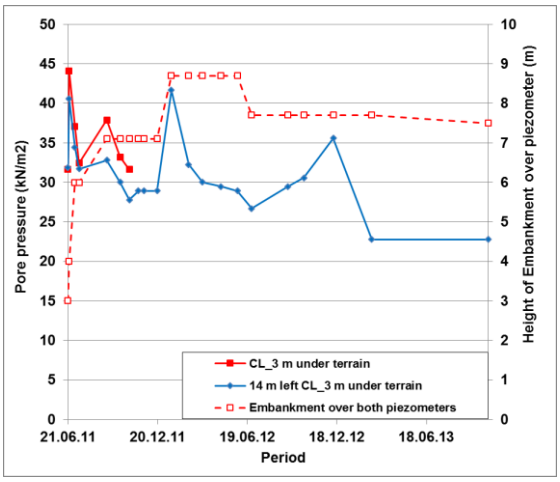

Figure 13 Pore pressure, section 1250

4.5 Comparison

Calculated settlement matched well with the measured settlement. Measured settlement just after the opening of the road is between 8 and 10 cm along the cross section 1250.
Pore water pressure measured at the same time is as expected i.e. a hydrostatic pressure at 3 m depth.

5 DESIGN SECTION - 1810

The embankment modelled by the section 1800 is 80 m in length.

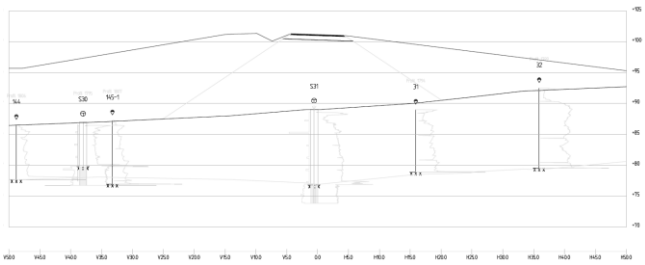

Figure 14 Cross section at chainage 1800

5.1 General Soil Properties

The foundation soil consists of thick sea sediments. The soil is classified as medium sensitive silty clay to clayey silt. The bedrock is 12 m below terrain level.
The undrained shear strength is interpreted to be in the range of 20 – 40 kPa. The shear strength is interpreted from routine laboratory investigation as well as field investigation.

5.2 Deformation Parameters

CRS oedometer tests were performed on undisturbed Φ 54 mm piston samples. Two successive sets of specimen were taken at depth approximately 3.7 and 6.6 m below the terrain level.
A table below is given with interpretation of deformation parameters from the oedometer test results. The oedometer stiffness (M_{OC}) is estimated to be 3 Mpa.

Table 3 Interpreted deformation parameters 1810

Depth / Soil layer (m)	σ'_c (kN/m^2)	m (-)	m_{cv} (m2/yrs*kPa)	C_{vOC} (m2/yrs)	C_{vNC} (m2/yrs)
3,7 / (0-4)	100	31	0,01	2.5	2
6,6 / (4-11)	200	25	0,01	3	2,5

5.3 Settlement Calculation Results

GeoSuite calculations were made at section 1810 with the deformation parameters presented on *Table 3*. The height of the embankment is about 13 m, which corresponds to a surcharge of 260 kPa.
The result from settlement calculation is presented on the figure below. Calculated settlement is about 65 cm, where approximately 13 years is needed for the preliminary settlement.

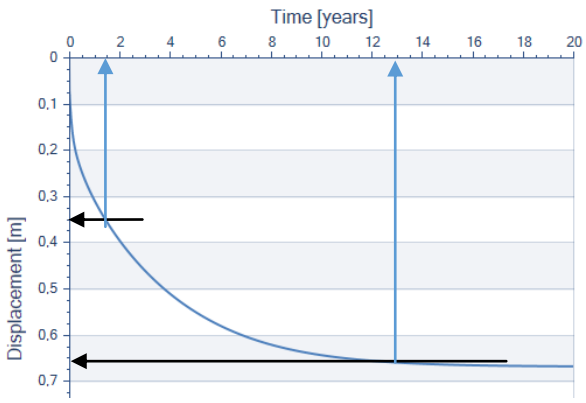

Figure 15 Deformation – time plot, section 1800

Section 1800 was preloaded with the road embankment height. According to NPRA's standard, allowable settlement difference along the road dictates an acceptable maximum settlement of 30cm for the section. Hence as observed on the figure above, it was decided to preload the section for ca. one and a half year.

5.4 Field Measurement

The field measurement included monitoring of settlement as well as pore water pressure.

The settlement was measured at chainage 1810 while piezometers were installed at chainage 1800.
The results from the field measurement are presented in figures 16 - 18.

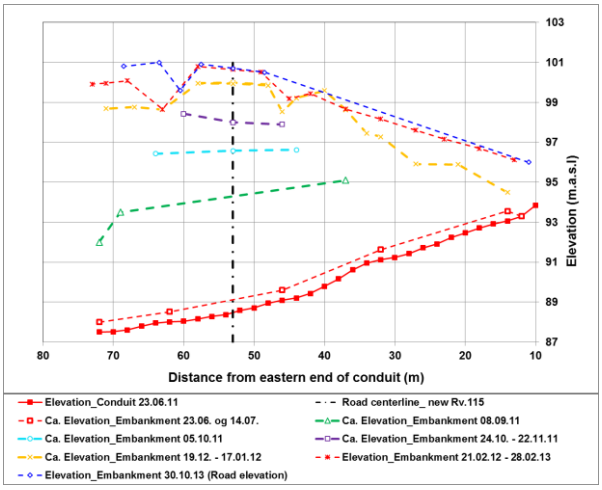

Figure 16 Elevation measurements, section 1800

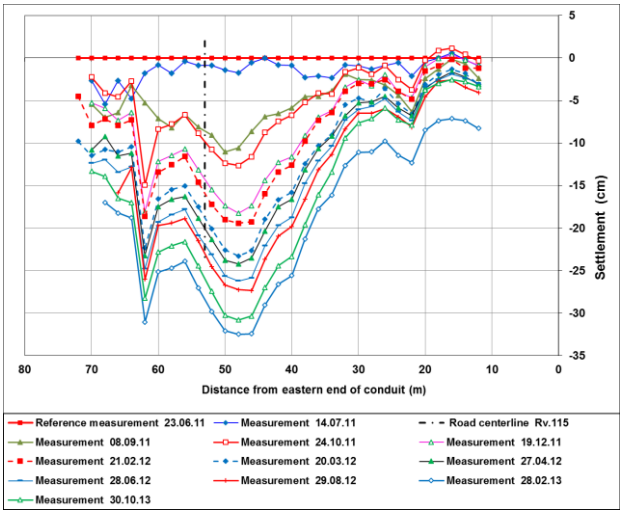

Figure 17 Settlement measurements, section 1810

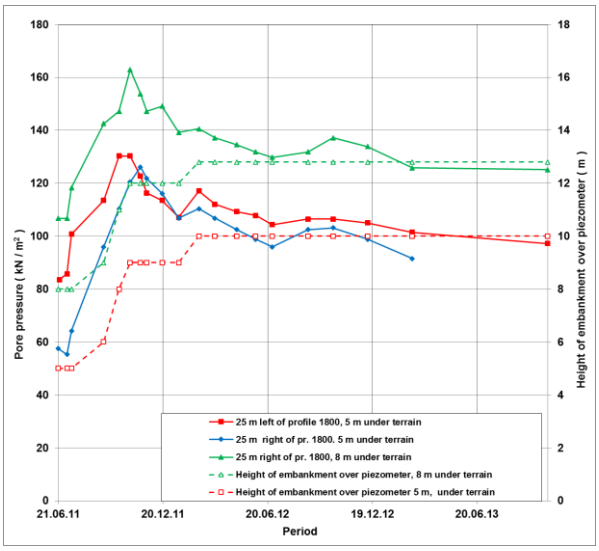

Figure 18 Pore pressure, section 1800

5.5 *Comparison*

Expected settlement was reached with in the predicted period. Calculation results matched well with measured field results.

6 DESIGN SECTION - 2110

The embankment modelled by the section 2110 is 100 m in length. A representative section is presented on the figure below.

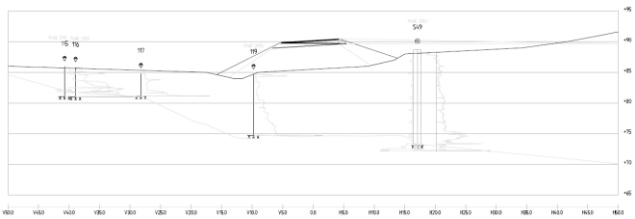

Figure 19 Cross section at chainage 2100

6.1 *General Soil Properties*

The foundation soil consists of medium sensitive, silty clay and clayey silt. The crust is classified as stiff sandy silt.
The undrained shear strength is interpreted to be in the range of 30 – 50 kPa. The bedrock varies 10-15 m below terrain level. The shear strength is interpreted from routine laboratory investigation as well as field investigation.

6.2 *Deformation Parameters*

Deformation parameters used for estimation of settlement are interpreted partly from cone penetration tests (CPTU) and partly from assumptions based on earlier experience. Interpreted deformation parameters are presented on the table given below.

Table 4 Interpreted deformation parameters 2100

Depth / Soil layer (m)	σ'_c (kN/m²)	m (-)	**M** (kN/m²)	C_v (m²/yrs)
1-6	$\sigma_o' + 1/2*\Delta\sigma$	20	4000	4
6-12	$\sigma_o' + 1/2*\Delta\sigma$	20	4000	4

6.3 *Settlement Calculation Results*

Settlement calculation were made with NPRA's Excel based calculation sheet. The height of the embankment is about 4.5m, which corresponds to a surcharge of 90 kPa. Results from settlement calculation is presented on the figure below. Calculated

total settlement is about 37 cm. Time for preliminary settlement is 20 years.

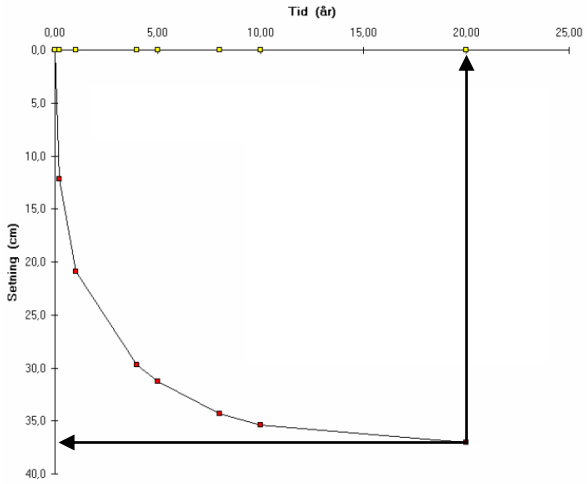

Figure 20 Deformation – time plot, section 2100

NPRA's standard limits acceptable settlement to approximately 8 cm at this road section. The geotechnical design suggested 30% or 50% of embankment height as preloading, which will speed up the time for settlement. In order to fulfil the requirement for acceptable differential settlement the section needed to settle ca. 29 cm. This would take 17 and 11 months respectively for the proposed preloading surcharges.
The magenta and red curves shown on figure 21 represent settlement developments for 30% and 50% preloading. The blue curve is the same as the first part of the settlement curve presented on Figure 20.

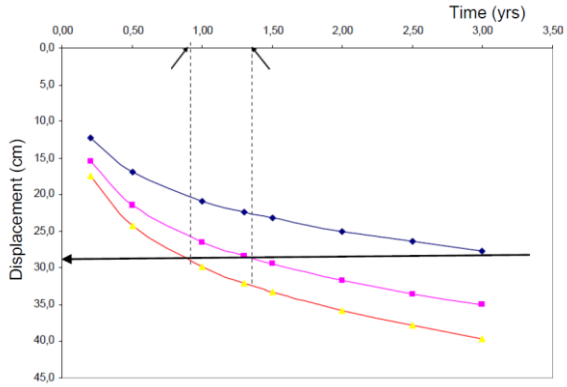

Figure 21 Elevation measurements, section 2110

6.4 Field Measurement

The field measurement monitored both settlement and pore water pressure. Settlement was measured at chainage 2110 while piezometers were installed at chainage 2110 and 2170.

The preloading used along this road section is about 4 m high, which is almost 90 % of the road embankments height. And the duration for the preloading was about 8 months.

The results from the field measurement are presented in Figure 22 – 24.

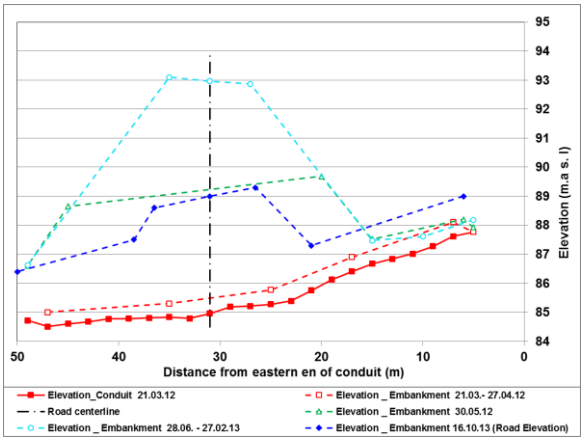

Figure 22 Elevation measurements, section 2110

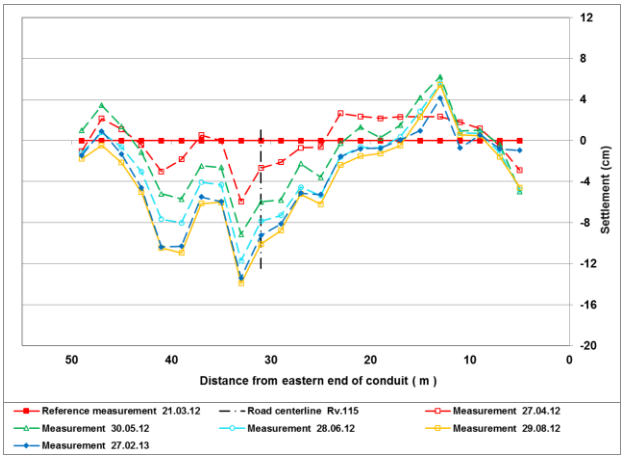

Figure 23 Settlement measurements, section 2110

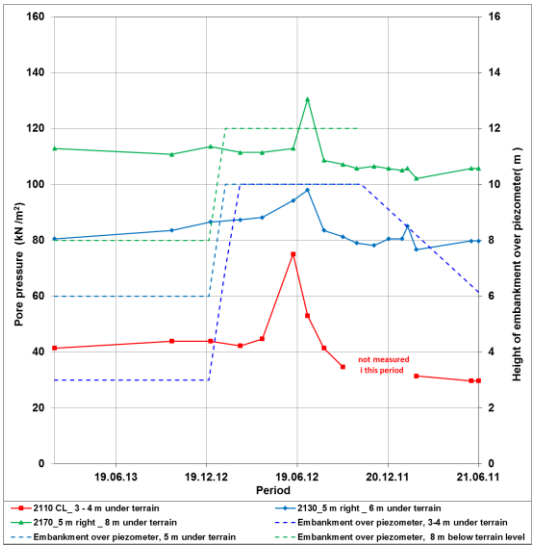

Figure 24 Pore pressure, section 2110 and 2170

6.5 Comparison

Calculated and measured settlement did not correspond with each other. The discrepancy can majorly be accredited to the choice of deformation parameters. In addition the preloading was not constructed as designed. Therefore only pore water pressure measurements were used in deciding when to remove the preloading.

7 CONCLUSION

Measured settlement corresponded well with calculated one for the first three sections where the deformation properties were interpreted from oedometer tests. Deformation parameters interpreted from CPTU and previous experience didn't give comparable results with measured settlement.

Development of pore water pressure was followed and accessed in deciding the removal of preloading in all embankment fills.

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