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E18 Langangen - Rugtvedt

Parcel 2

Draft Geotechnical Report

Owner

AFRY

Parcel

1 2 3 2op

CDE file name: NV-38-E18-LR##-EEE##-FFF###-G##_##-HH##_###-III###-JJJ###-KKK-LLL-####_01	**Pagination :** 522 pages

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Client / Area / Complex	Zone	Entity	Space	Functional system	Constructive system	Component	Temp. / Sub-components	Discipl./ Profess.	Type	Number	Rev	Ste

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Modification follow-up

Rev.	Date	Detail of modifications carried out
01	2021-08-11	Only admnistrative updates: Front page opdated, Document code added, Header (top of page)

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Abbreviation

Abbreviation	**Meaning**
NV	Nye Veier
EGC	Eiffage Génie Civil
AFRY	AFRY Norway AS
PBL	Plan- og bygningsloven (Planning and Building Act)
NVE	Norges vassdrags- og energidirektorat (The Norwegian Water Resources and Energy Directorate)
NGU	Norges geologiske undersøkelse (Geological Survey of Norway)
SVV	Statens Vegvesen (Norwegian Public Roads Administration)

1. OBJECT

Nye Veier has awarded EIFFAGE Génie Civil a design and build contract ("totalentreprise") that includes construction and designing of the new E18 highway between Langangen and Rugtvedt. The construction will include around 17 km of the four-lane road, as well as several bridges and tunnels. AFRY Norway AS assists EIFFAGE in Engineering.

Due to a difference in zoning plan status, the project has been subdivided into 3 parcels:

Parcel	Major geotechnical structures
1: Langangen – Lanner	Blåfjell tunnels, Langangen bridges
2: Lanner – Kjørholt	Bjønnås and Grenland tunnel, Skjelsviksdalen, Herregårdsbekken, Kjørholt
3: Kjørholt – Rugtvedt	Kjørholt and Bamble tunnels, Grenland bridge

Table 1 Parcel subdivision

The present report deals with parcel 2 and therefore is only valid for parcel 2. The present report is dealing with geotechnical engineering in connection with the preparation of a zoning plan for the new E18. Work for that includes mainly following:

- Ground investigation and interpretation of ground investigation

- Input to zoning plan boundaries

- Input to Road disciplines regarding slopes on cuts and fillings, and geotechnical actions in the ground

- Input to Structures disciplines regarding foundation and geotechnical actions on the ground

- Assessment of areas with special geotechnical challenges

- Assessment of area – stability *"områdestabilitet"*

2. BACKGROUND DATA

2.1 GROUND INVESTIGATIONS

Previous ground investigations (GI) have been carried out by Rambøll AS during 2016 – 2019 for the zoning plan. Additional investigations were carried out by Multiconsult AS in 2020 during the tender phase. The data have been summarized in Ground Investigations Reports (GIR). The reports and all digital raw data (field loggings, lab tests, etc.) have been received from Nye Veier for this mission. Interpretation of ground conditions and design parameters are primarily based on this available data.

At the time of writing, there are also ordered new supplement investigations. The results from the survey will most likely be available later in autumn.

Four main parts in parcel 2 deals with geotechnical assessment; Lanner, Herregårdsbekken, Skjelsvikdalen, and Kjørholt. This report will therefore have a focus on mainly those parts and reports carried out in those| parts will be considered relevant. It can be mentioned that the area between Lanner and Herregårdsbekken goes in a tunnel and later in a long tunnel, Grenland tunnel, that stretches from Herregårdsbekken to Kjørholt. The tunnels will not be a part of this report.

Geotechnical investigations performed in Lanner, Herregårdsbekken, Skjelsvikdalen and Kjørholt are listed below:

Ground Investigations	Version A	Version B
Lanner	Report 049	Report 63
Herregårdsbekken	Report 060	Report 039-2
Skjelsvikdalen	Report 040	Report 056
Kjørholt	Report 043	Report 062

Report 063 (10B) Ground Investigations Lanner

Performed 29 total soundings with depth to bedrock; 2,4 – 18,2m. The soundings have finished at bedrock level or drilled 3m in bedrock. No samples have been taken in addition.

Additional GI by Multiconsult in this part is one borehole (ID 3002) that includes samples and lab test, CPTU -, and total sounding.

Report 039-2 Ground investigations Herregårdsbekken

Performed 50 total soundings with depth to bedrock; 1,5 – 25,1m. The soundings have finished with 3m in bedrock or ended in very solid masses where bedrock hasn't been encountered (drilled to as much as 50 – 60m without encountered bedrock). No samples have been taken.

Additional GI by Multiconsult in this part is one borehole (ID 4003) that includes only a total sounding.

Report 056 Ground investigations Skjelsvikdalen

Performed 29 total soundings with depth to bedrock; 3,1 – 31,65m. The soundings have finished with 3m in bedrock. Samples have been taken in addition.

Additional GI by Multiconsult in this part is one borehole (ID 5001) that includes only a total sounding.

Report 062 (6B) Ground investigations Kjørholt

Performed 13 total soundings with depth to bedrock; 1,3 – 8,3m. The soundings have finished at bedrock level or drilled 3m in bedrock. Samples have been taken in addition.

2.2 MODELS AND PROFILES

The geometry used in the geotechnical assessments are derived from:

- Current map basis as at 13.06.2021

- Current road geometry, as well as normal profiles as of 13.06.2021

- Cross-sections generated from the above grounds

- Rock model based on previously performed ground investigations as of 13.06.2021

2.3 COORDINATE AND HEIGHT SYSTEM

The coordinate system is NTM SONE 9 and the height system is N200.

3. PROJECT PREREQUISITES

Geotechnical project prerequisites are described in a separate report, *Design Report.*

3.1 GEOTECHNICAL CATEGORY (GC), CONSEQUENCES/RELIABILITY CLASS (CC/RC), AND SUPERVISION LEVEL (DSL/IL)

For parcel 2 following GC, CC/RC and DSL/IL are valid:

Construction	Geotechnical category (GC)	Consequences/ reliability class (CC/RC)	Design supervision level (DSL)	Inspection level (IL)
Bridges and tunnels	3	3	3	3
High retaining walls (≥5 m)	3	3	3	3
High fills and cuttings (≥10 m) and fills and cuttings in quick clay	3	3	3	3
Constructions in complicated ground and foundation work	3	3	3	3
Quick clay	3	3	3	3
Other constructions	2	2	2	2

Table 2 GC, CC/RC, and DSL/IL for main constructions on parcel 2

3.2 FILL MATERIAL

All road fills are assumed to be carried out with good quality masses (blasted rock or correspondingly).

3.3 CONSTRUCTION PHASE EXECUTING

In this report, little has been made about construction phase execution.

4. TOPOGRAPHY AND GROUND CONDITIONS

4.1 LANNER

The main infrastructures in the area are E18, country road 3260 (which goes between Skjelsvik and Langangen), a traffic control station, and a shooting range. There are few or no settlers in the area. The terrain level for existing roads is relatively flat, in general around +129 - +130 but increases in the areas with visible rock. Terrain map from *Kartverket* ("Norwegian Mapping and Cadastre Authority") for the area can be seen in Figure 1.

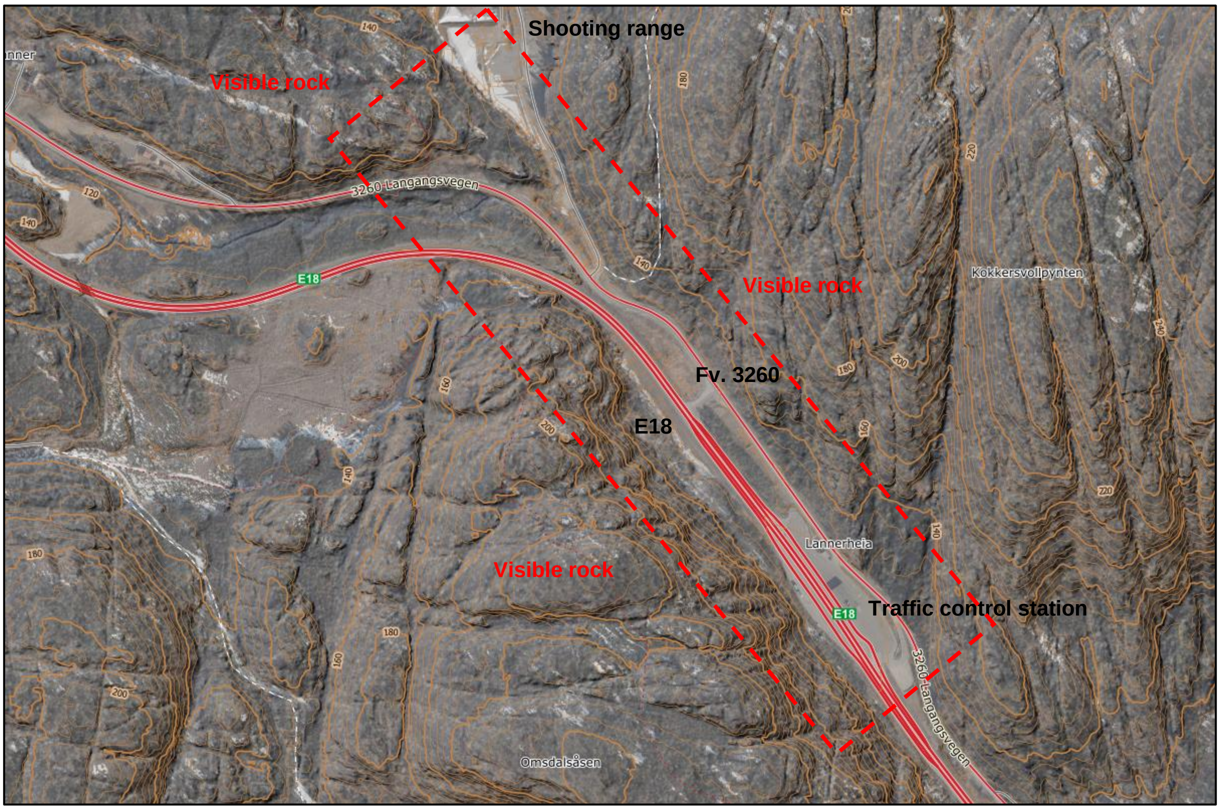

Figure 1 terrain map from hoydedata.no

Soil deposit maps from NGU in Figure 2 implies that the area may consist of several different soil types; visible bedrock, weathering material, bog/organic deposit, till, and marine deposits.

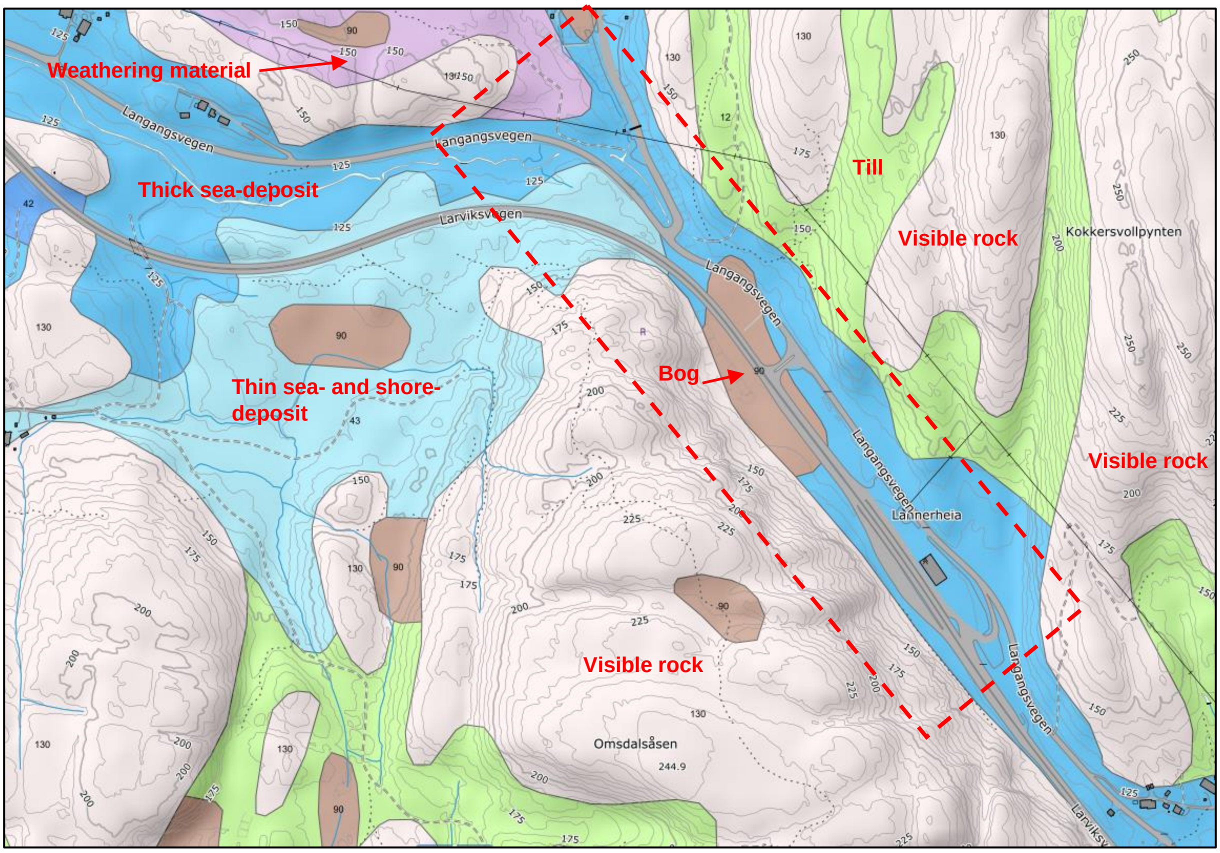

Figure 2 soil deposit map from NGU

4.2 HERREGÅRDSBEKKEN

The main infrastructures are E18, country roads 3260 and 3264, traffic junction "Lillegårdskrysset", railway, local roads, Herregårdsbekken creek, and some minor settler. The terrain level varies, from +10 to +60. There are some visible rock outcrops in the area. for existing roads are relatively flat, in general around +129 - +130 but increases in the areas with visible rock. A terrain map from Kartverket for the area can be seen in Figure 3.

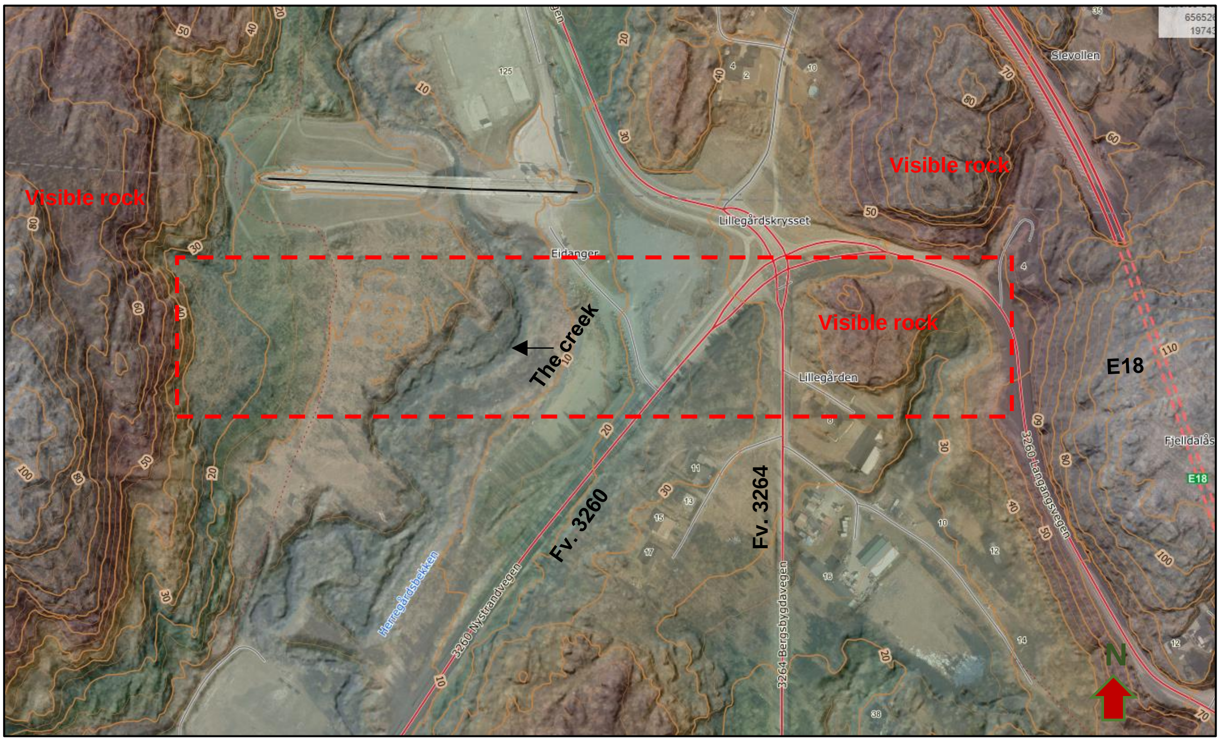

Figure 3 terrain map from hoydedata.no

Soil deposit maps from NGU in Figure 4 implies that the soil types in the area may consist of visible bedrock, marine deposit, creek, and glacier stream deposit.

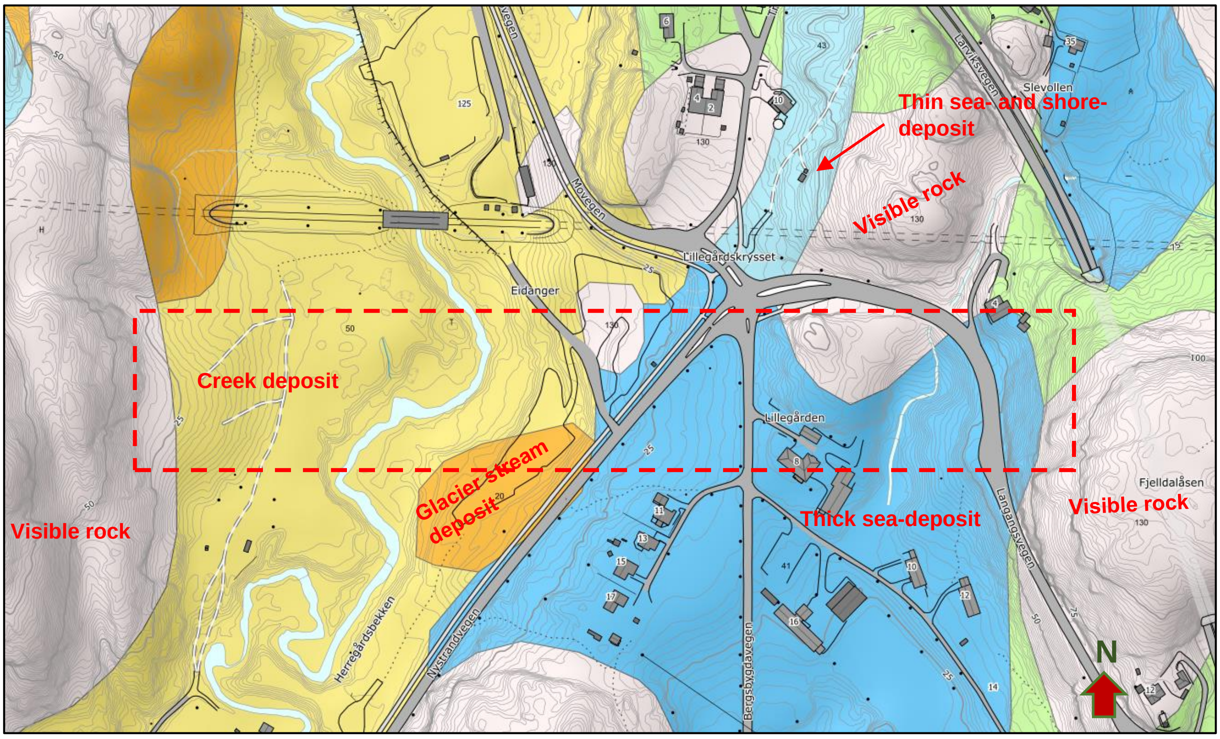

Figure 4 soil deposit map from NGU

4.3 SKJELSVIKDALEN

The main infrastructures in Skjelsvikdalen are highways E18 and Rv36 and industrial businesses in the valley. There are large settlers in the area but outside the planned area. The terrain level varies, from +30 to +40 in the valley to +70/+110 outside the valley. A terrain map from Kartverket for the area can be seen in figure 4.5.

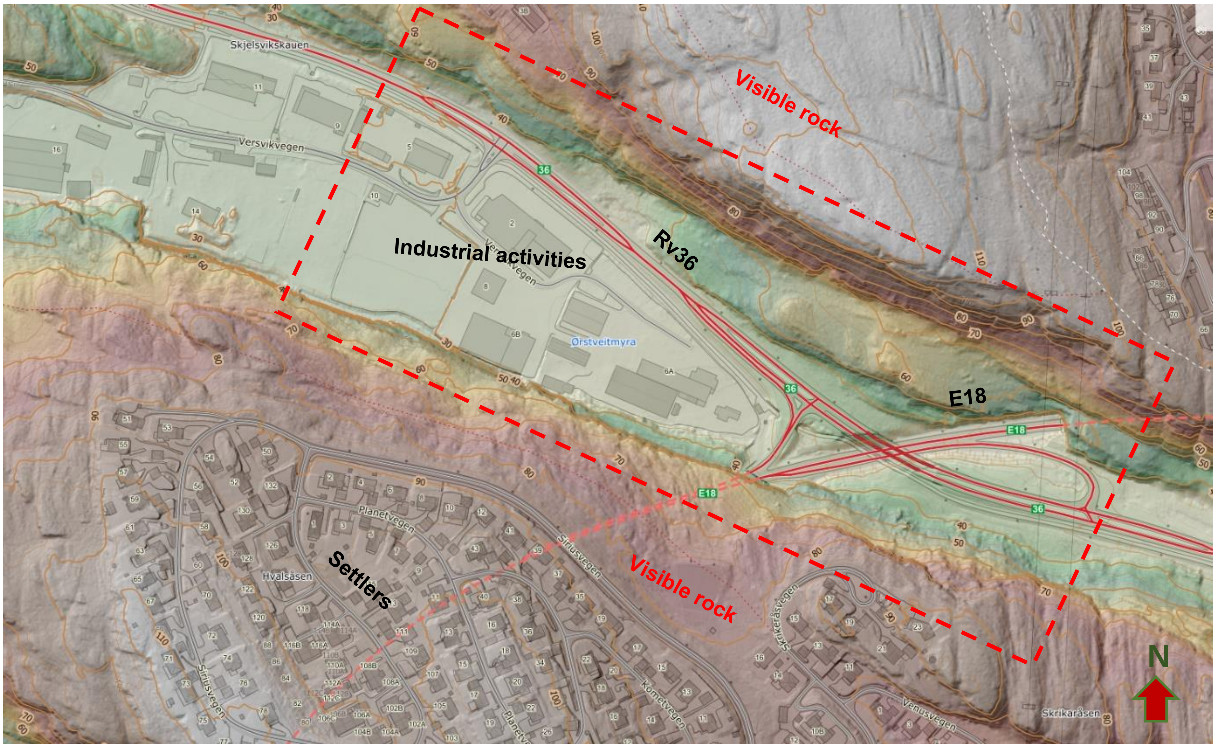

Figure 5 terrain map from hoydedata.no

Soil deposit maps from NGU in Figure 6 implies that the soil types in the area may consist of visible bedrock/weathered material, marine deposit, bog/ organic deposit, and fill masses.

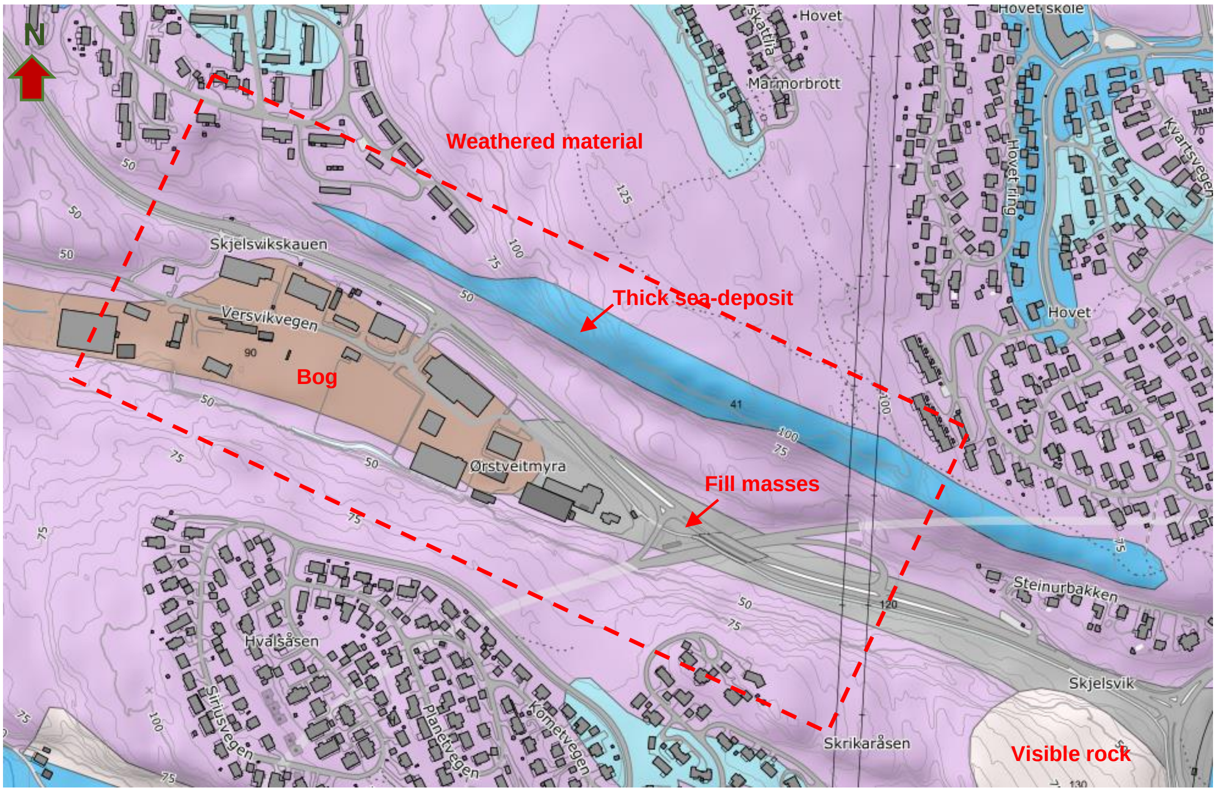

Figure 6 soil deposit map from NGU

4.4 KJØRHOLT

The main infrastructures in Kjørholt are E18, state highway Rv354, traffic junction Kjørholt, industrial businesses, local roads, and settlers. Terrain level varies, from +40 to +50 in the low-lying areas to +60/+80 in the high-lying areas. Terrain map from Kartverket for the area can be seen in Figure 7.

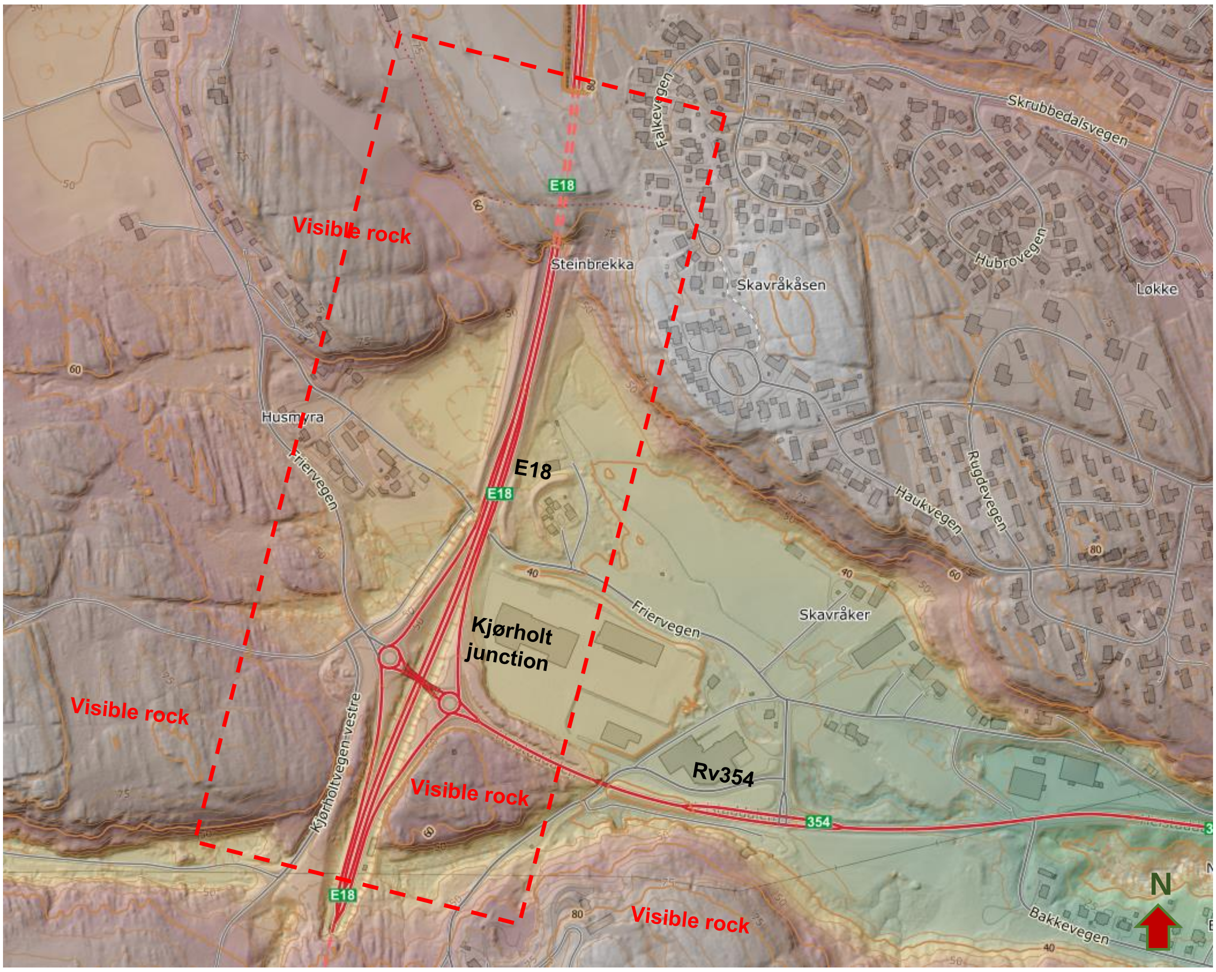

Figure 7 terrain map from hoydedata.no

Soil deposit maps from NGU in below figure implies that the soil types in the area may consist of visible bedrock/weathered material, marine deposit, and fill masses.

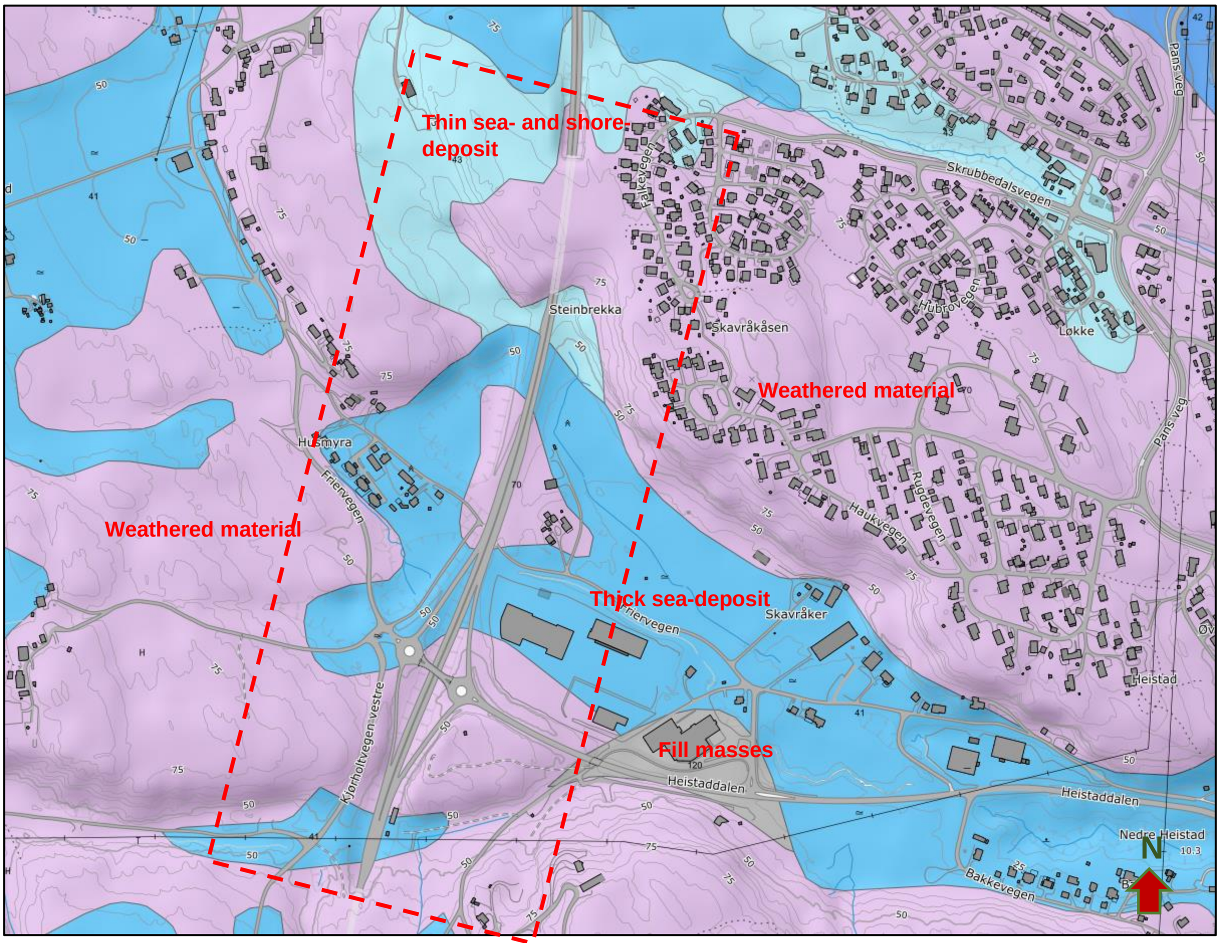

Figure 8 soil deposit map from NGU

5. SOIL CONDITIONS

5.1 LANNER

In the first part of the line, ch. 3450 – 3700, the soil conditions consist of limited depth to rock, 0 – 3m.

From ch. 3700 to ch. 4100, the soil conditions vary. On the north side of the road line, the soil consists of organic soil at the top on soft clay on sand on bedrock with depth to bedrock, approx. 2,4 – 8m. Also, visible rock can be expected. In the south side of the road line, the depth to bedrock varies in general from 2m – 10m but in some local places, the depth increases to 19m. The soil consists of organic deposits on soft clay on till/sand on bedrock. Some of the organic masses could have been substituted with fil material when existing E18 was constructed. The soft clay in the south of the road line could be quick or brittle material ("sprøbruddsmateriale"). Supplement GI must be carried out to find out if the clay is brittle material/ sensitive or just soft.

From ch. 4200 to 4400, depth to bedrock varies between 2,4 – 9,8m. Soils are 0,3 – 2,6m top-layer of fill, dry crust, and vegetation on 1 – 7m soft clay on 1,1 – 2,5m sand on bedrock. Quick clay has been detected in one borehole.

From ch. 4400 and onward there are no previous performed investigations but further up from ch. 4400, visible rock can be seen so presumably the first part of ch. 4300 could be a thick soil (0-3m) laid on bedrock.

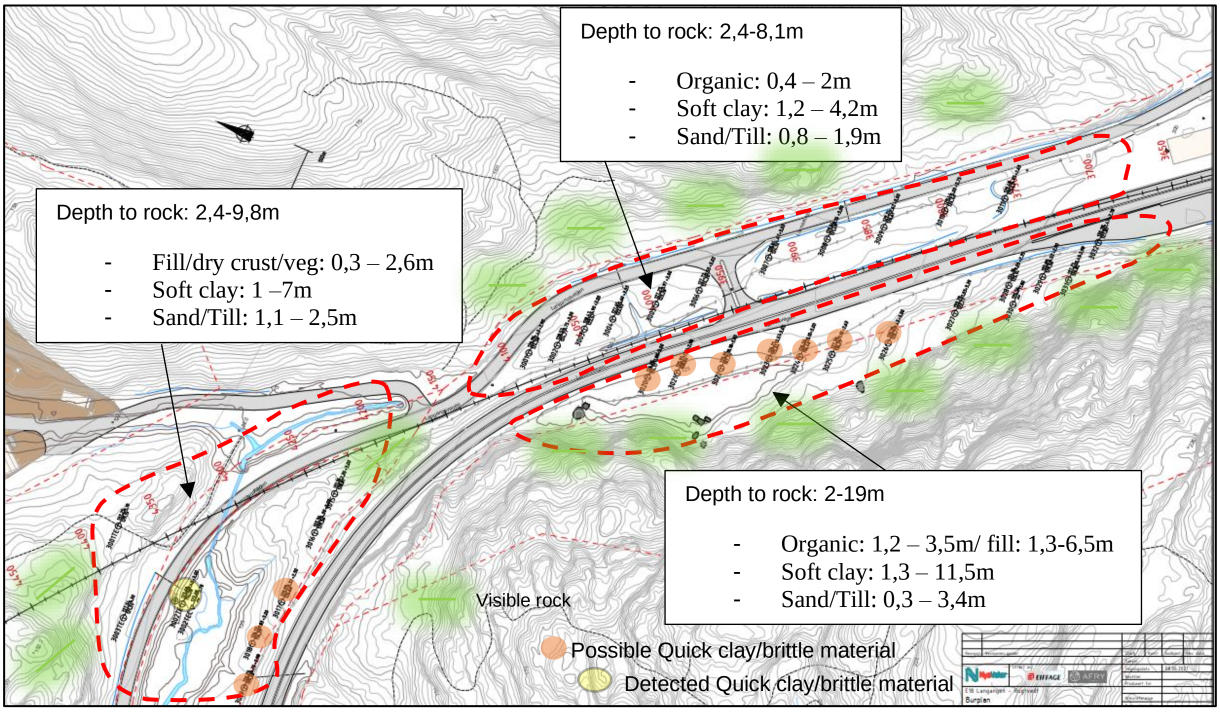

Figure 9 Soil conditions Lanner

5.2 HERREGÅRDSBEKKEN

At the start of ch. 6/800 (east of Langangsvegen) there is visible rock or rock below a thick soil layer. Slightly west of Langangsvegen (around ch. 6/810), the bedrock slowly descent with depth to bedrock 5 – 7m. The soil consists of moraine or fractured rock.

At ch. 6/860 there is a lowering in the topography with a valley and a small creek going through the valley. There are done investigations in the valley with depth to rock from 2 to 17m. Also here can be discussed, regarding the large depth to bedrock, if the soil is moraine or maybe fractured rock.

After the valley (between the valley and Bergsbydavegen,) there is an area with visible rock (ch. 6/870 – 6/970.)

After Bergsbydavegen and onwards to Herregårdsbekken (between 6/970 and 7/160) the depth to rock varies between 1,5 to 25,1m below terrain. The soil conditions are mostly sand and gravel but also some softer material local in some places.

After Herregårdsbekken and to the end of the line (ch. 7/180 – ch. 7/400) the soil conditions are at the top, 3 – 15m with soft soils (clay/silt) and below that hard moraine to bedrock where bedrock is at 40 – 60m below terrain.

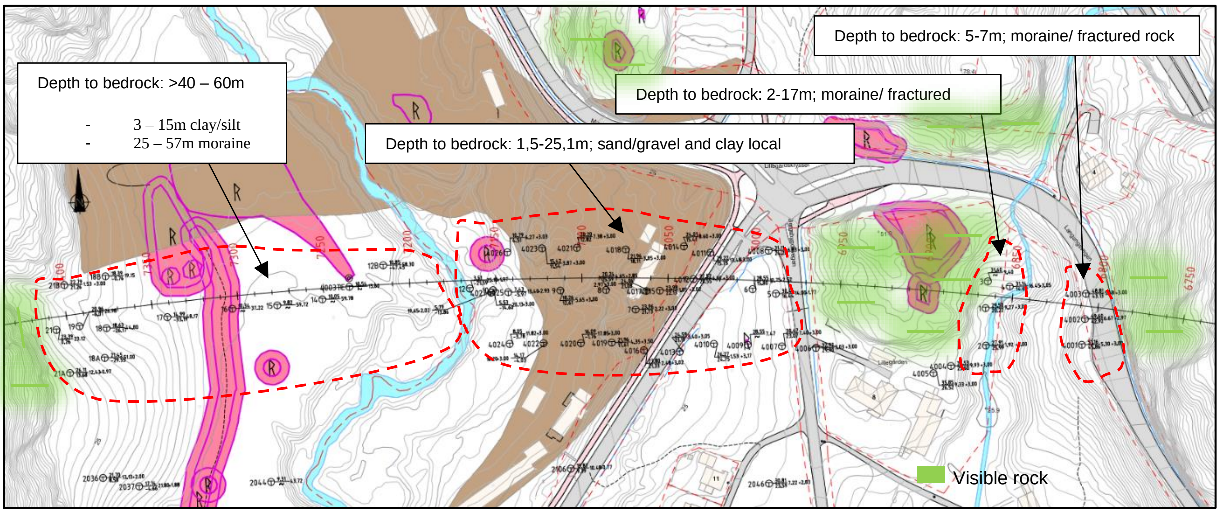

Figure 10 Soil conditions Herregårdsbekken

5.3 SKJELSVIKDALEN

The depth of bedrock at Skjelsvikdalen varies from 1m to a bit over 30m. Performed GI:s indicates that the rock surface level is highest at the middle of the valley and falls off to the south and north.

For much of Skjelsvikdalen and its industry – area, the soil condition is believed to consist of deposited contaminated masses. The occurrence of these masses is somewhat blurry but seems to lie in depth from 2-3m down towards 10m. The contaminated masses are covered with fill masses. Additionally that, the soil in the area appears to be very varied, and occasionally quite soft in some places.

There are some uncertainties regarding depth to bedrock in Skjelvsvikdalen. From GI:s, where it is interpreted as soil, it could likely be fractured rock. Some new GI:s are suggested to better clarify this issue.

Based on conditions in Skjelsvikdalen, we can conclude that the ground conditions are quite similar in the area except for depth to rock, but as mentioned before, the depth to rock interpreted from performed GI:s can be discussed.

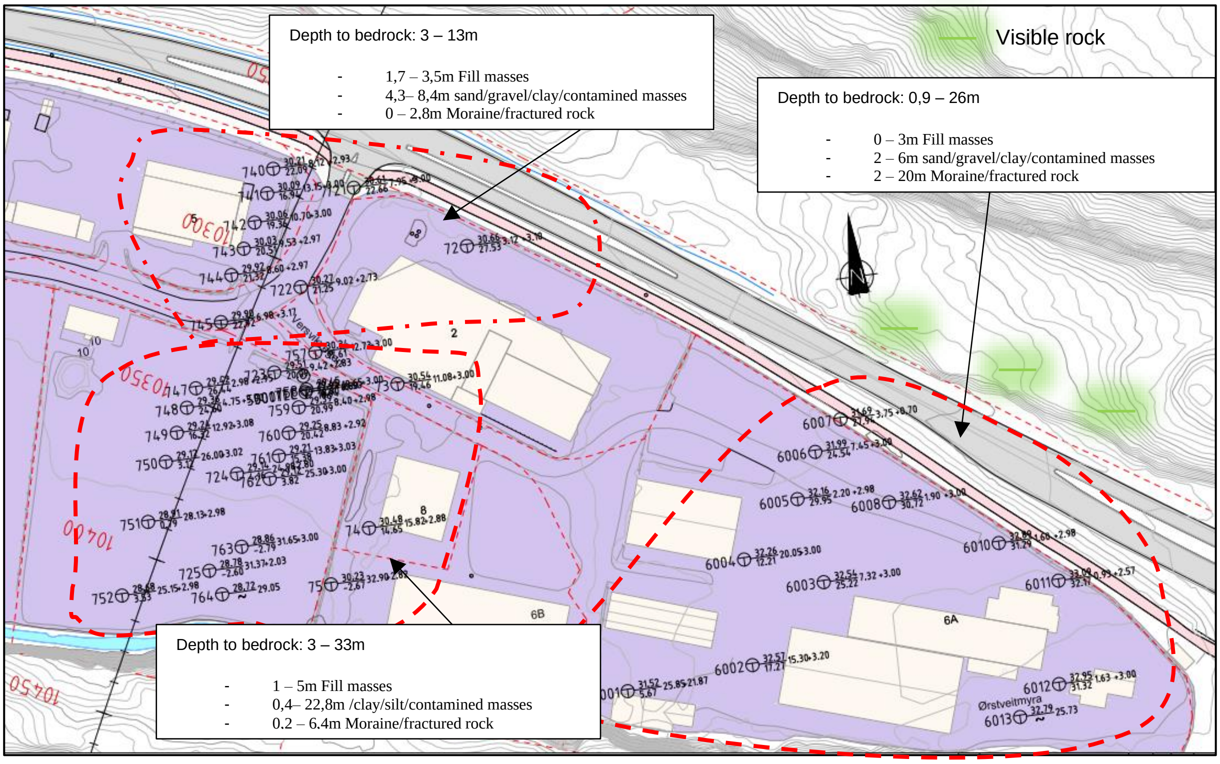

Figure 11 Soil conditions Skjelsvikdalen

5.4 KJØRHOLT

Around ch. 12/680 – 12/950, north of Friervegen, boreholes are indicating soft clay that could be sensitive and quick but with limited depth. After Friervegen the soil conditions gradually improve with more solid soil and visible rock to the end of the line at ch. 13/500.

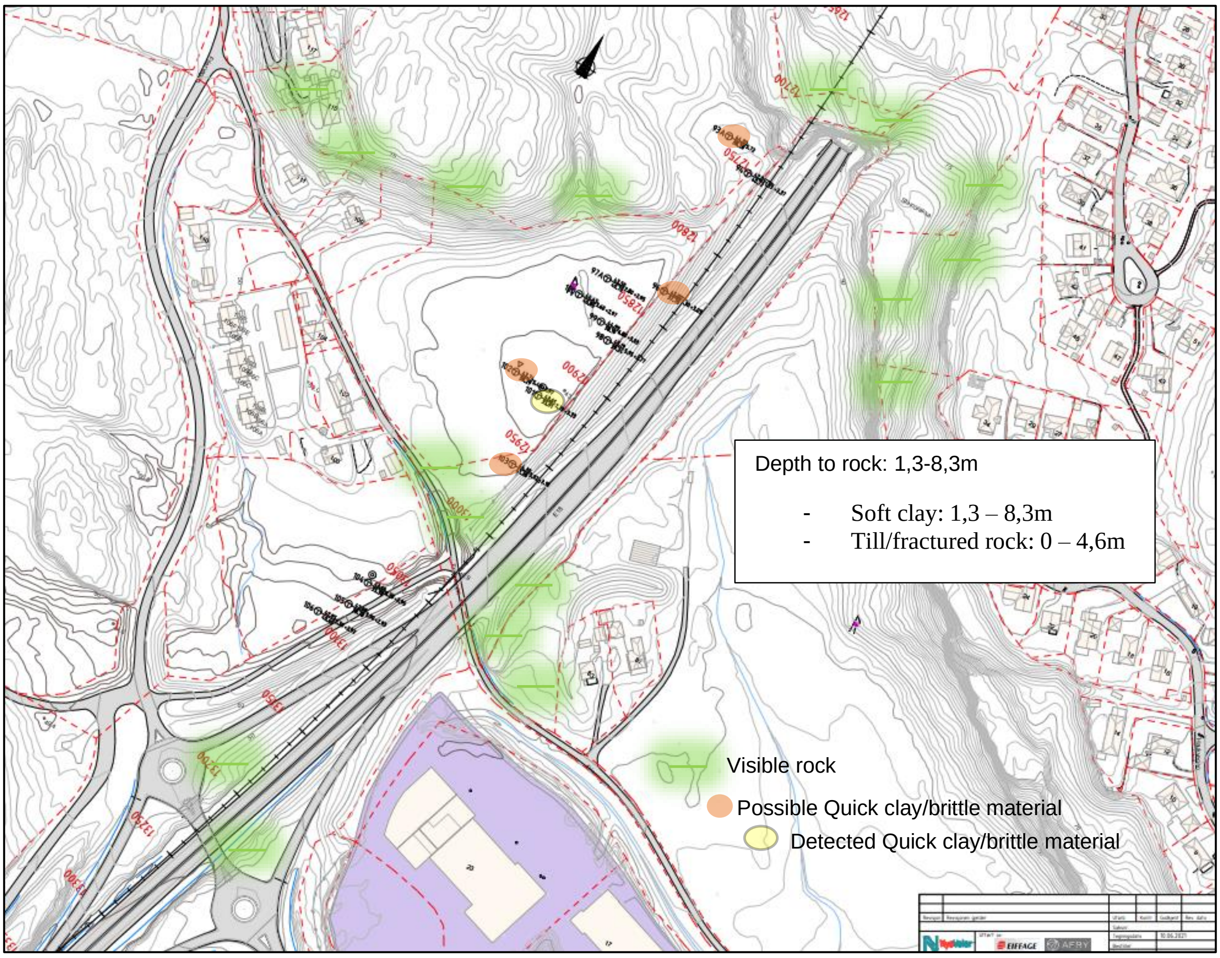

Figure 12 Soil conditions Kjørholt

6. PROPOSED CONSTRUCTION

6.1 LANNER

E18
The road line will stretch on fill from ch. 3450 to ch. 4300 and cutting from ch. 4300. The fill height is minor at the start of the line but increases to approx. 5m at ch. 3850 and again degreases afterward and goes into cutting at 4/300.

Fv.30/e18 ramp
The road line will stretch on fill with height 0 – 4,5m in the first 350m followed by cutting between ch. 0350 and 0540, followed by fill (0 – 10m height), followed by a small cutting and fill again from ch. 0/770 to the end of the line.

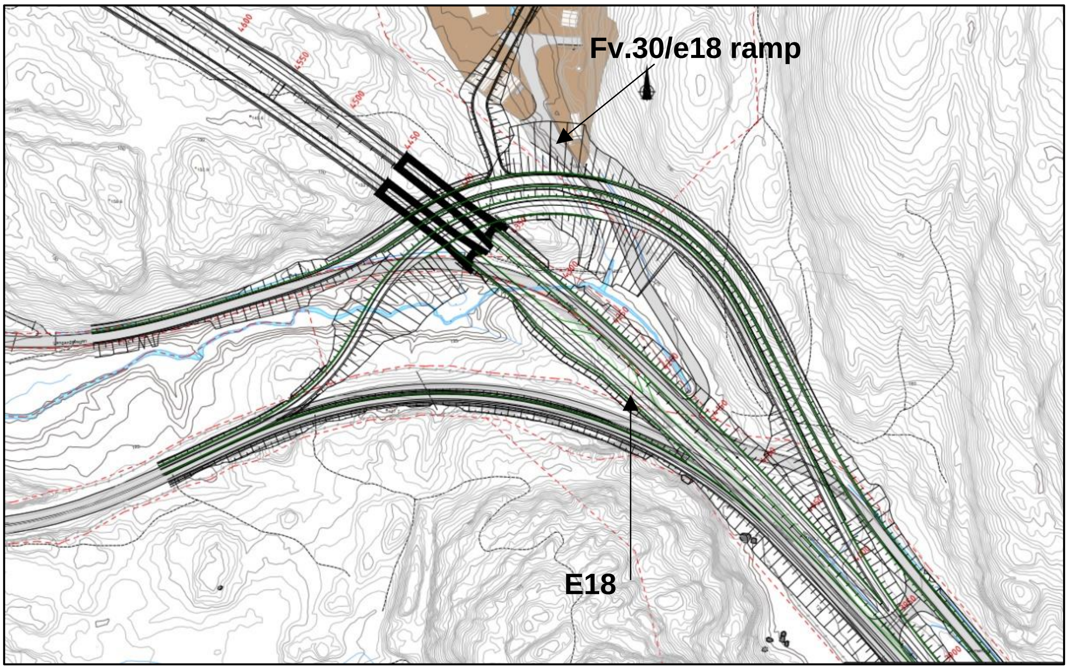

Figure 13 Planned road Lanner

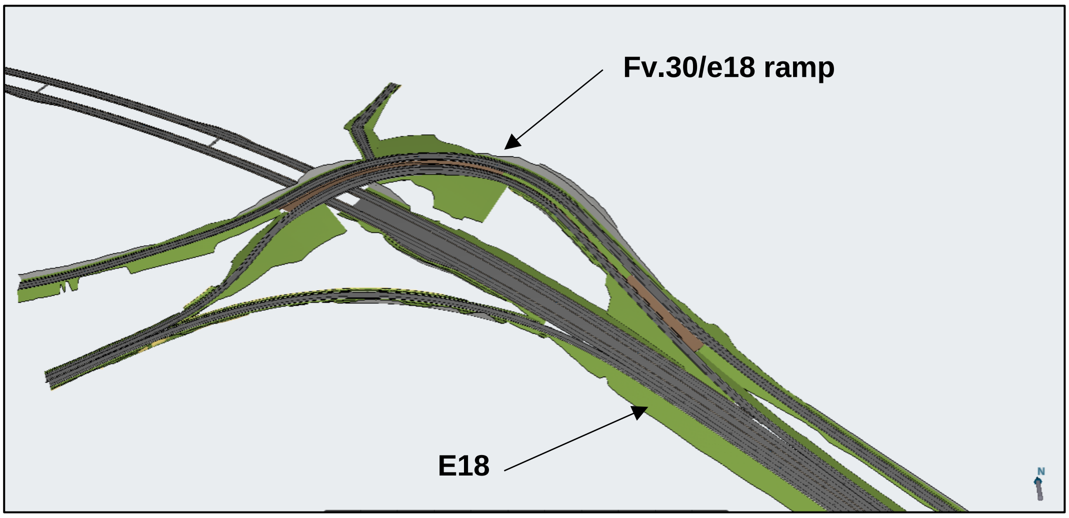

Figure 14 Planned road Lanner – 3D model

6.2 HERREGÅRDSBEKKEN

The line from Bjønnås tunnel comes out in portal in daylight at ch. 6970 (slightly around Bergsbygdavegen). The z-level at the bottom of the line is +11 and the terrain level is +32 - +33. The line will go in cutting until it reaches Herregårdsbekken creek. The road will go on a bridge over the creek. The z-level of the line around Herregårdsbekken is around +9. After Herregårdsbekken the line continues in cutting until it reaches the end of the line at ch. 7400.

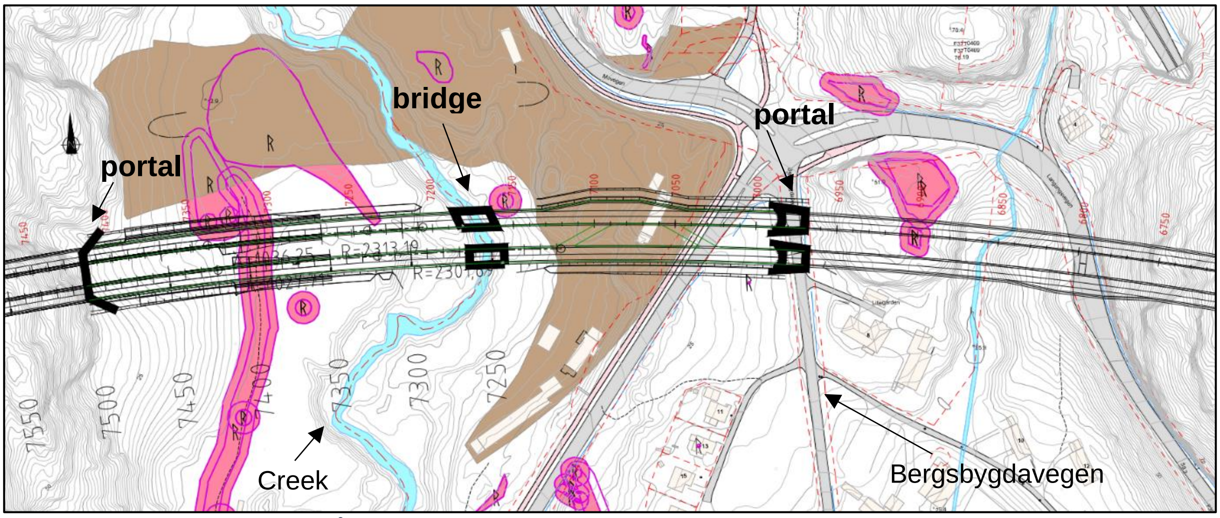

Figure 15 Planned road Herregårdsbekken

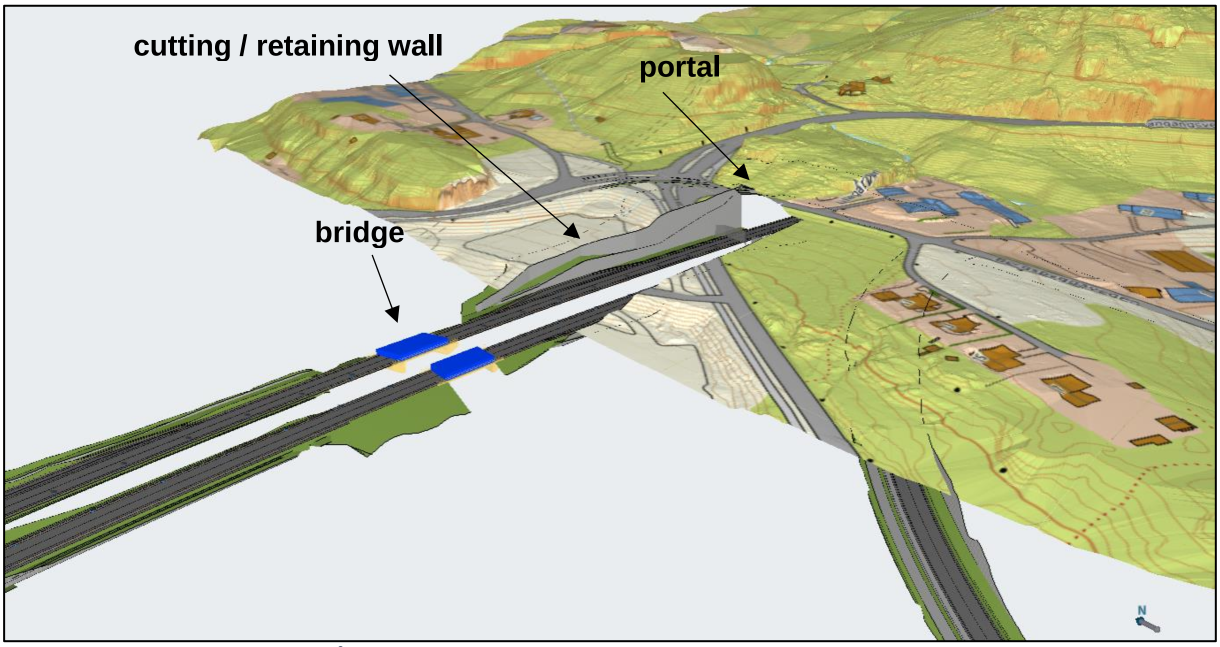

Figure 16 Planned road Herregårdsbekken – 3D model

6.3 SKJELSVIKDALEN

E18 goes in a tunnel with the bottom level of the tunnel at around -10 i.e. 40m below terrain. At level -10, the rock should be of good quality. New E18 connects with existing rv36 with ramps in tunnels and/ soil/rock cuttings and roundabouts in connection at the ground.

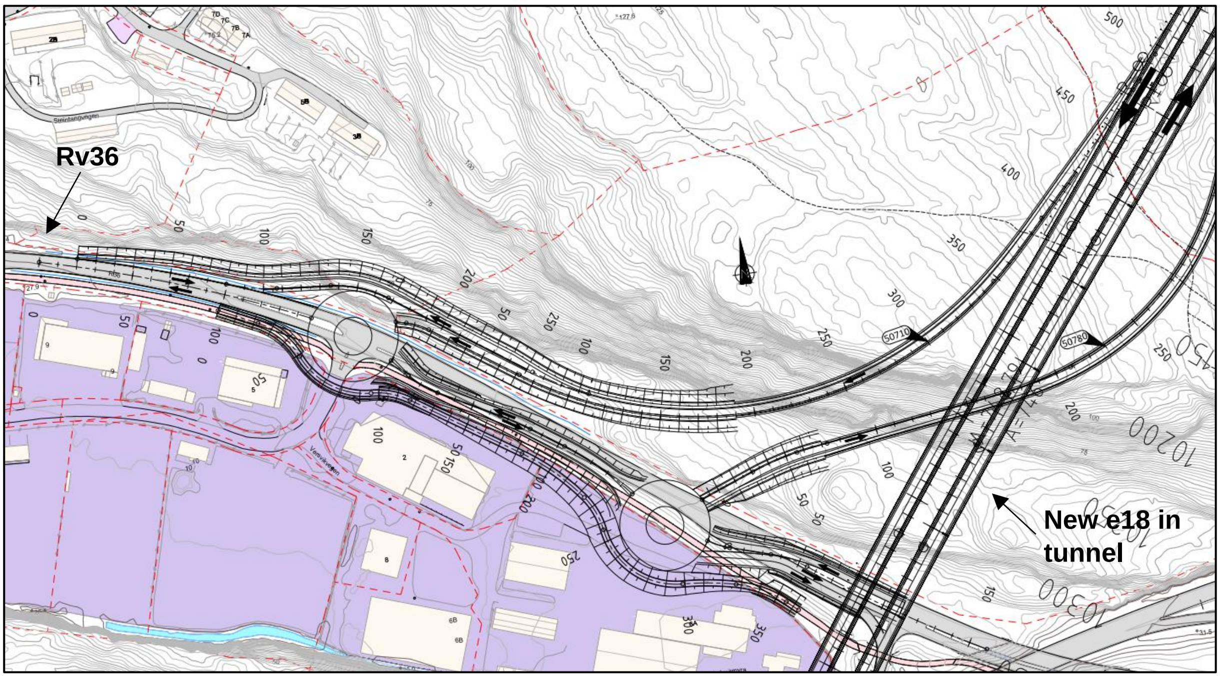

Figure 17 Planned road Skjelsvikdalen

Figure 18 Planned road Skjelsvikdalen – 3D model

6.4 KJØRHOLT

The line from Grenland tunnel comes out in daylight at 12/710. The new E18 is on fill, height 0 – 1m, between 12/710 and 13/110, and cutting, height 0 – 2m between 13/110 and 13/500.

The old E18 will also be shifted and new-constructed with a different stretch than the previous. It will stretch slightly to the right in a curve on fill with the height of 10m at most. It will be connected to the new E18 in a culvert and large fills. To the surrounding areas, it will be connected with a culvert and bridge.

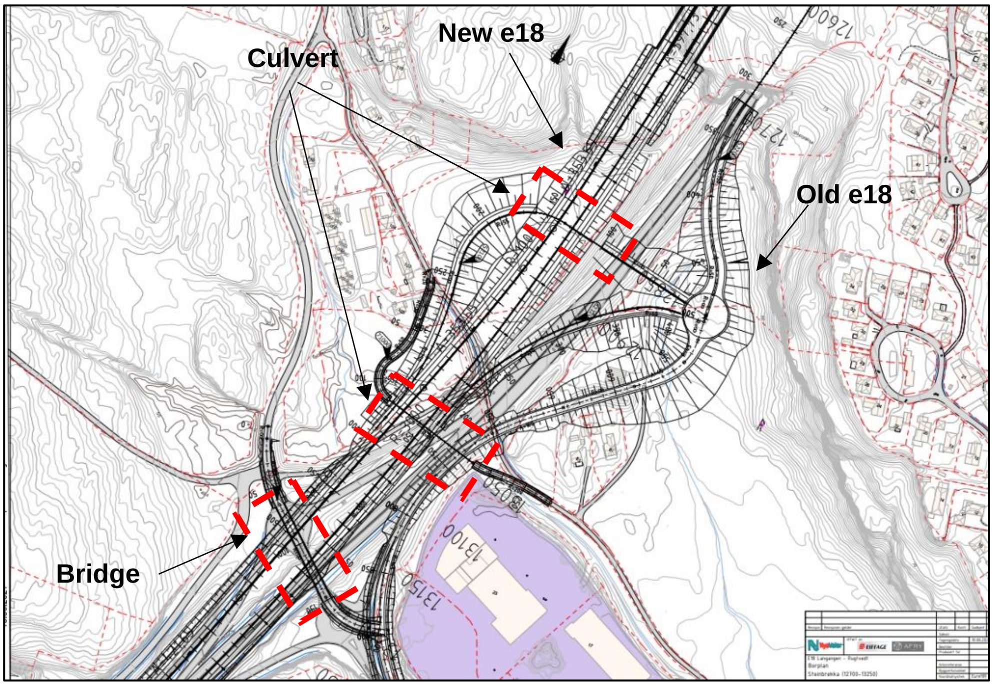

Figure 19 Planned road Kjørholt

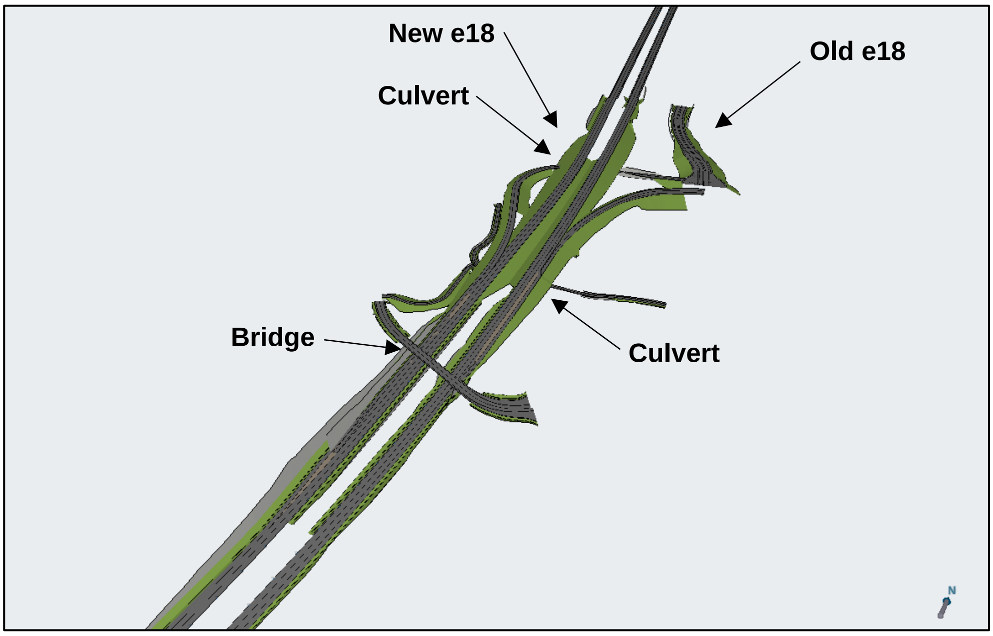

Figure 20 Planned road Kjørholt – 3D model

7. AREA STABILITY

7.1 GENERAL

According to section 28-1 of the *Planning and Building Act*, land can only be built, or property is created or changed if there is sufficient safety against hazard or significant inconvenience as a result of natural or environmental conditions.

Landslide risk is one of the topics that will be included in the risk and vulnerability analyses, as described in Section 4-3 of the *Planning and Building Act*.

In TEK17, it is specified in section 7 *Safety against natural disaster*, that buildings shall be placed, designed, and carried out in such a way that acceptable safety is achieved against damage or significant inconvenience from a natural disaster such as floods, storm surges, and landslides.

NVE's guide 1/2019, *Safety against quick clay landslides*, describes how landslide risk can be investigated. Investigating and documenting the risk in agreement with this guide satisfies the applicable legal requirements. The aim of the study per NVE guidelines at the zoning level is to clarify the real risk for quick clay landslides where planning is development. When investigating real landslide risk, the hazard areas shall be delimited, described, and assessed with given safety requirements depending on the zone's hazard level and category of action.

According to NVE quick clay map (NVE Atlas), the planned road line does not pass through or near previously mapped quick clay zones (*faresoner*), see Figure 21. However, there are observed quick clay / sensitive soil in boreholes (purple points in the figure – called "SVV kvikkleireområder" in the NVE Atlas). This is the information that has already been interpreted from the boreholes received from Nye Veier (most likely it is the same basis that has been used to detect "SVV kvikkleireområder".)

From available GI it can be confirmed that quick clay / sensitive soil is detected at Lanner and Kjørholt and possible quick clay / sensitive soil at Rød (but Rød is not anymore a part of this mission since the line goes in a tunnel in rock at Rød and there are no actions in the soil at Rød).

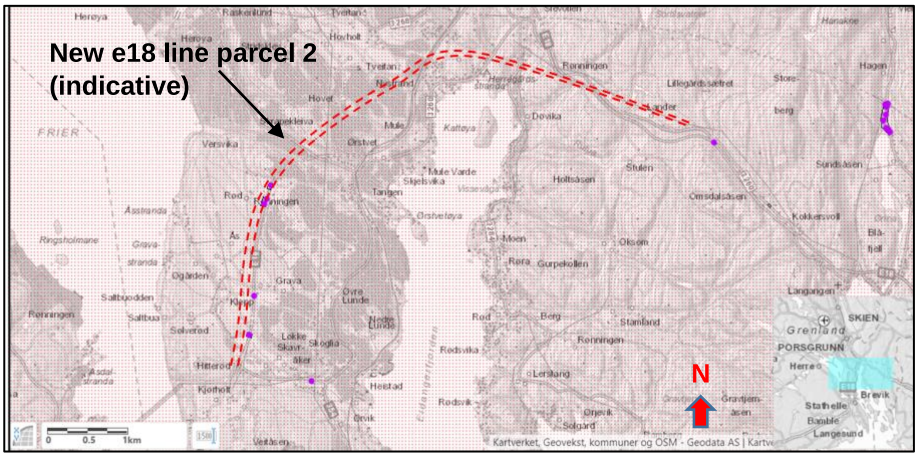

Figure 21 Quick clay zones

7.2 PROCEDURE FOR INVESTIGATING AREA STABILITY

The procedure for investigating area stability is described in NVE's guideline 1/2019. It is a step-by-step procedure that can be seen in Table 3. In general, if it is not detected sensitive soils, it will be sufficient to only fulfill a survey from levels 1 to 3. But if this first part of the procedure indicates that there could be a risk for area stability for the planned action, then this must be investigated further (level 4 – 10.)

Level	**Requirements**
1	Check for quick clay zones in the area / *Undersøk om det finnes kartlagte faresoner for kvikkleireskred i området*
2	Delineate areas with marine clay / *Avgrens områder med marin leire*
3	Delineate areas with terrain that indicates a possible risk of landslides / *Avgrens områder med terreng som kan være utsatt for områdeskred*
4	Determine measure category / *Bestem tiltakskategori*
5	Review of background data – identification of critical slopes and possible loosening *area /* *Gjennomgang av grunnlag – identifikasjon av kritiske skråninger og mulig løsneområde*
6	Site visit / *Befaring*
7	Conducting ground investigations / *Gjennomfør grunnundersøkelser*
8	Consider current landslide mechanisms and delineate loosening- and discharge- areas / *Vurder aktuelle skredmekanismer og avgrens løsne- og utløpsområder*
9	Classify quick clay zones / *Klassifiser faresoner*
10	Document satisfied security factor / *Dokumentér tilfredsstillende sikkerhet*

Table 3 Procedure NVE guide 1/2019

7.3 AREA STABILITY LANNER

1. Check for quick clay zones in the area

No previous quick clay zones in the area.

2. Delineate areas with marine clay

The area is below the marine limit. Also, marine clay is detected from ground investigations. Possible delineate areas are Lanner 1 and Lanner 2 as in Figure 22.

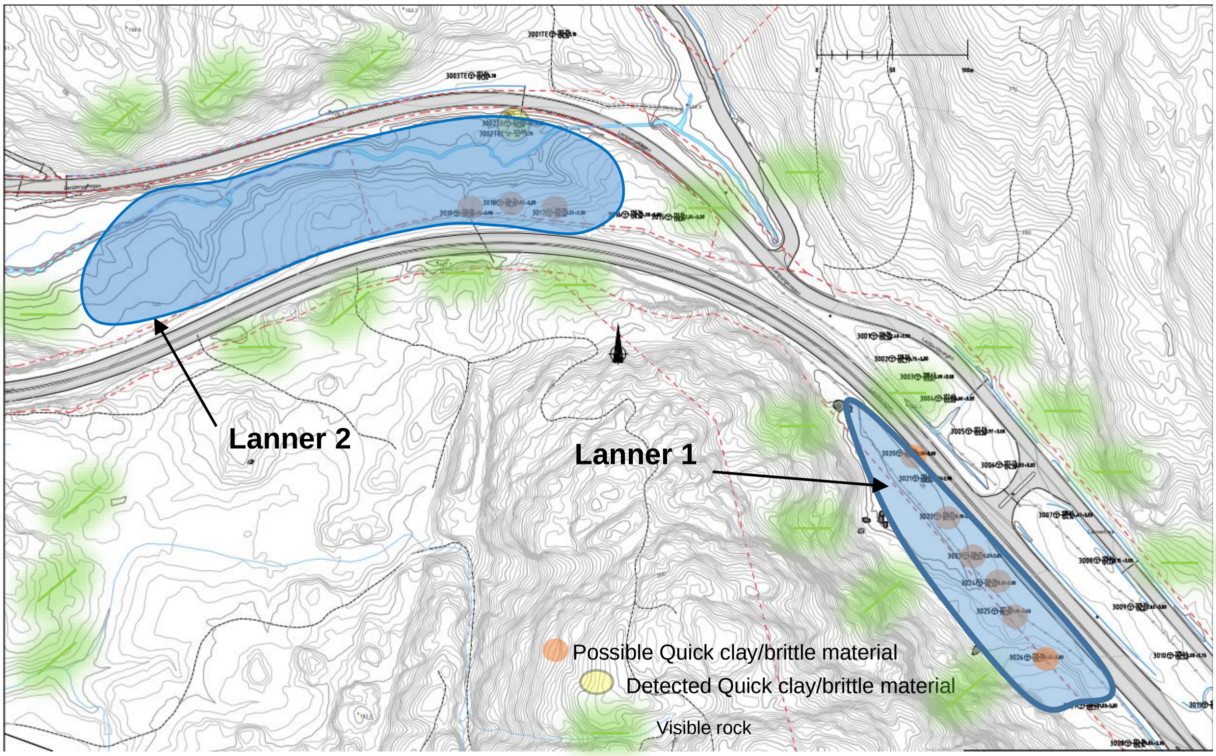

Figure 22 Possible areas with marine clay

3. Delineate areas with terrain that indicates a possible risk of landslides

Requirements for terrain that indicates a possible risk of landslides is:

- Total slope height (in soils) over 5 meters, or
- Evenly sloped terrain steeper than 1:20 and elevation difference over 5 meters

To identify the possible risk of landslide due to terrain levels (and soil conditions) a couple of cross-sections over the areal have been generated. Cross-sections in plan and profiles (together with relevant boreholes) can be seen in Figure 23 – Figure 29. There are giving notes to each cross-section regarding the risk of landslide.

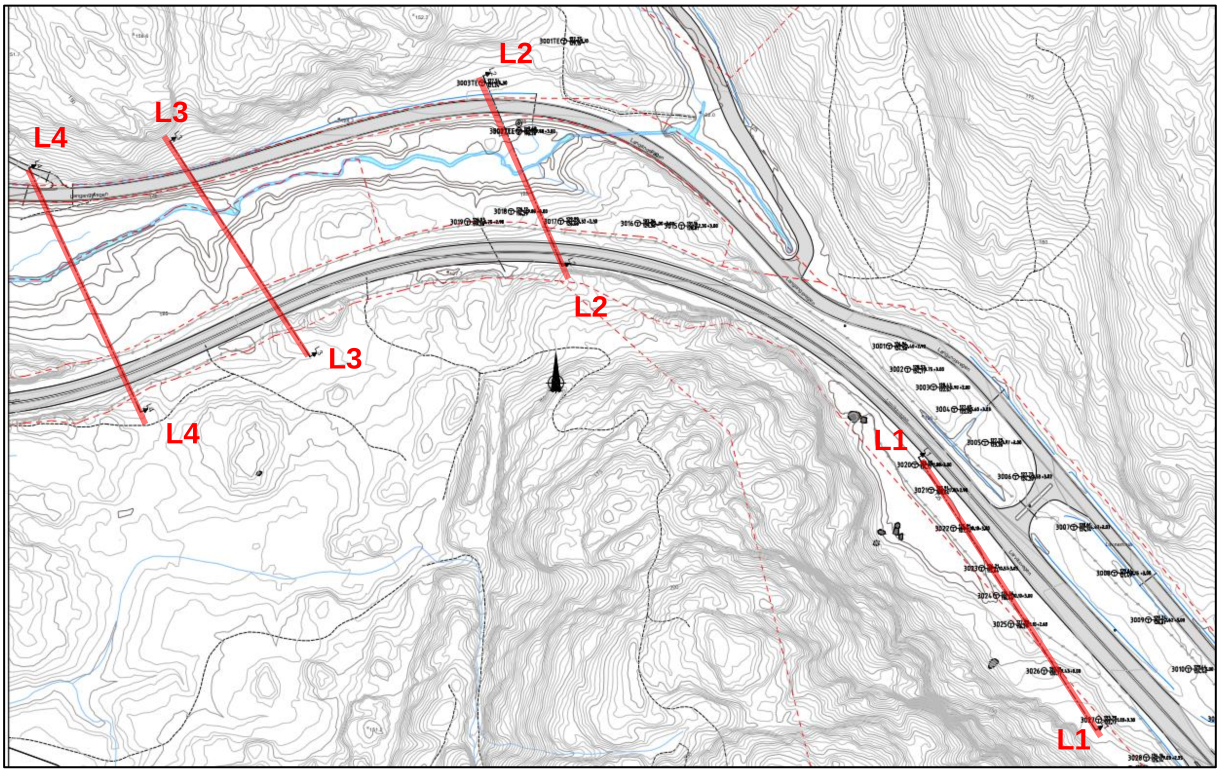

Figure 23 Plan over representative cross-sections in Lanner

Cross-section L1-L1

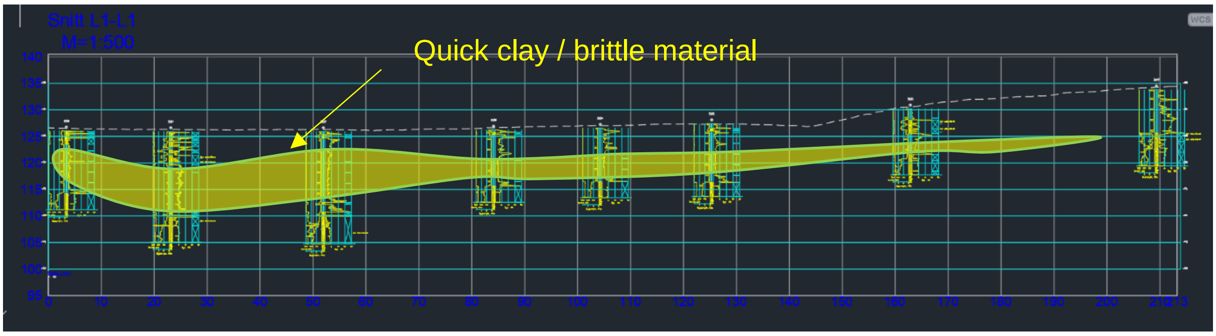

Figure 24 Profile cross-section L1-L1

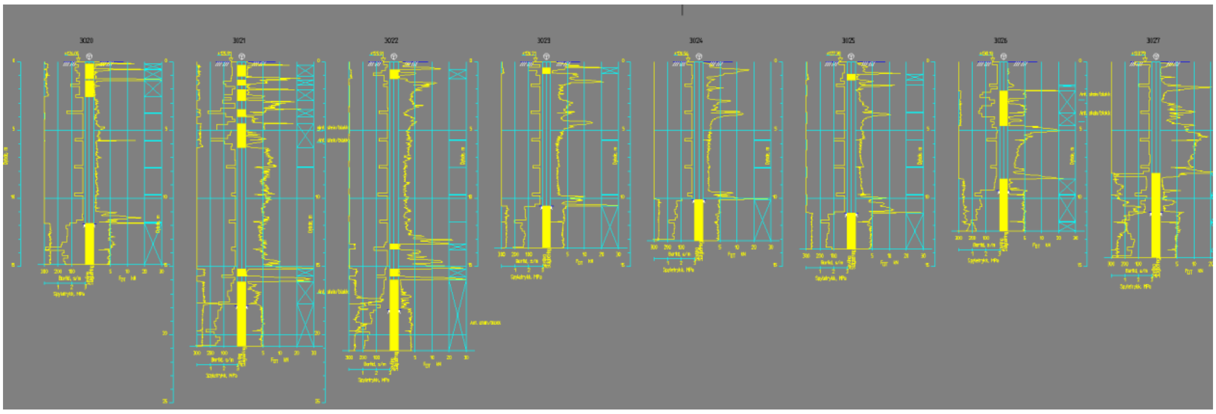
Figure 25 Boreholes cross-section L1-L1

Terrain slopes are relatively flat but less flat than 1:20 in the last part. This cross-section will be investigated further.

Cross-section L2 – L2

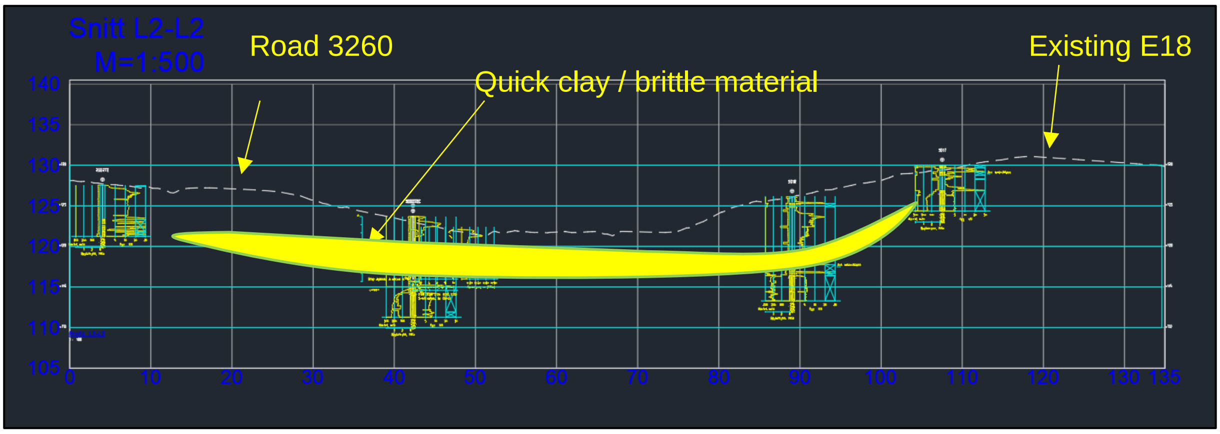

Figure 26 Profile cross-section L2-L2

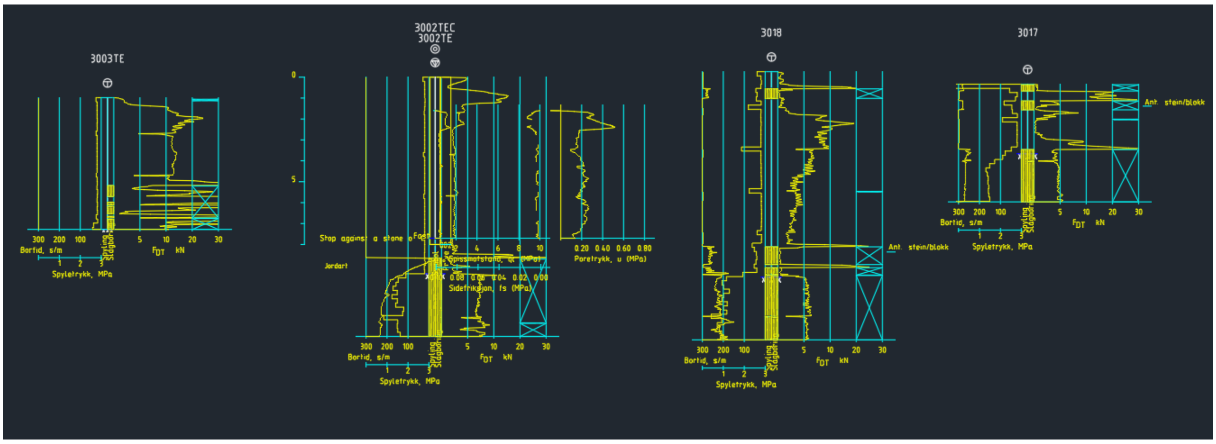

Figure 27 Boreholes cross-section L2-L2

Terrain slopes are less flat than 1:20. This cross-section will be investigated further.

Cross-section L3 – L3

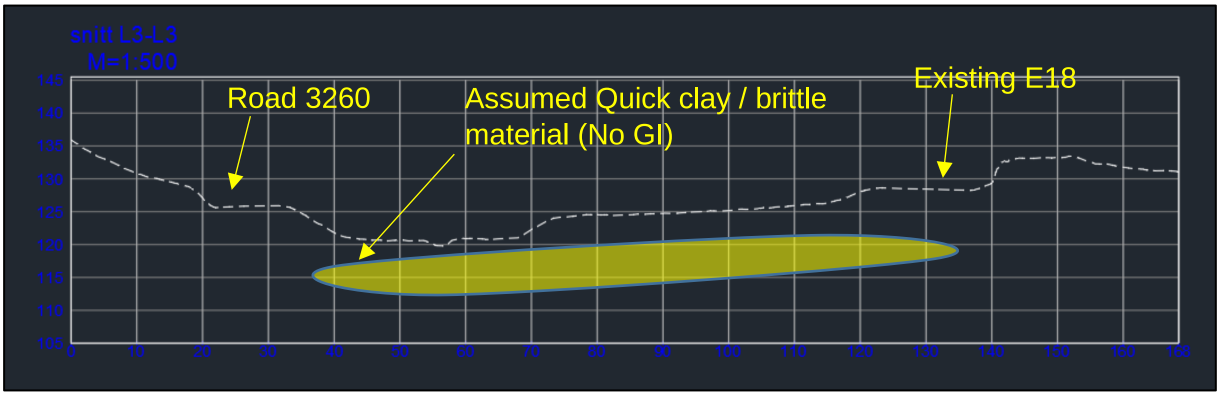

Figure 28 Profile cross-section L3-L3

Terrain slopes are less flat than 1:20. No GI in the cross-section but assumed quick clay based on GI in the area.

Cross-section L4 – L4

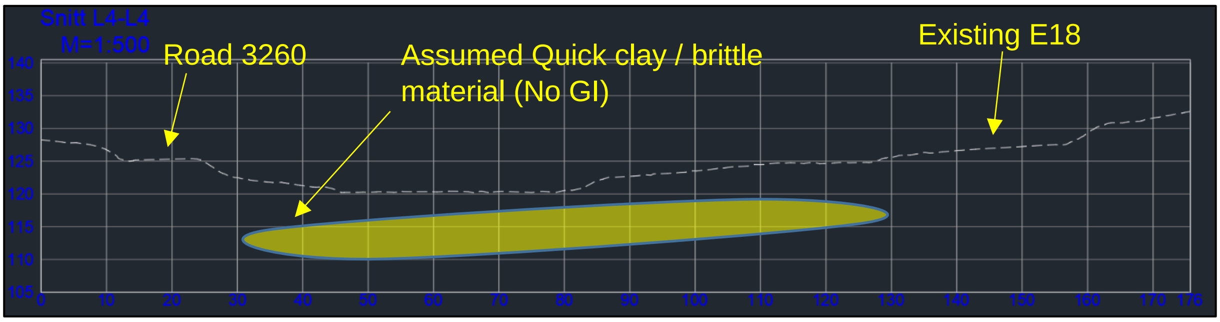

Figure 29 Profile cross-section L3-L3

Terrain slopes are less flat than 1:20. No GI in the cross-section but assumed quick clay based on GI in the area.

4. Determine measure category
The road is defined into category K4 per chapter 0.5 in manual V220.

5. Review of background data – identification of critical slopes and possible loosening area

A review of background data and identification of critical slopes has already been carried out. Possible loosening areas will also be shown in the coming parts.

6. Site visit
A site visit has been carried out. Mapping of rock surface outcrops has been done. A possible sign of erosion in the creek that goes through Lanner 2 could trigger landslides. Geotechnical measures for the creek need to be sorted out.

7. Conducting ground investigations
Ground investigations, supplement to previously performed investigations will be performed later. Area stability needs to be checked again when this information is available at a later stage.

8. *Consider relevant landslide mechanisms and delineate loosening- and discharge areas*

The relevant landslide mechanism is a flake landslide for Lanner 1 and a retrogressive landslide for Lanner 2.

Loosening and discharge areas as in Figure 30. For Lanner 2, the existing rv3260 works like a loading berm and reduces the discharge area. It is mostly the same case for Lanner 1 where the existing e18, the ground below road supercharge, has been excavated according to background data.

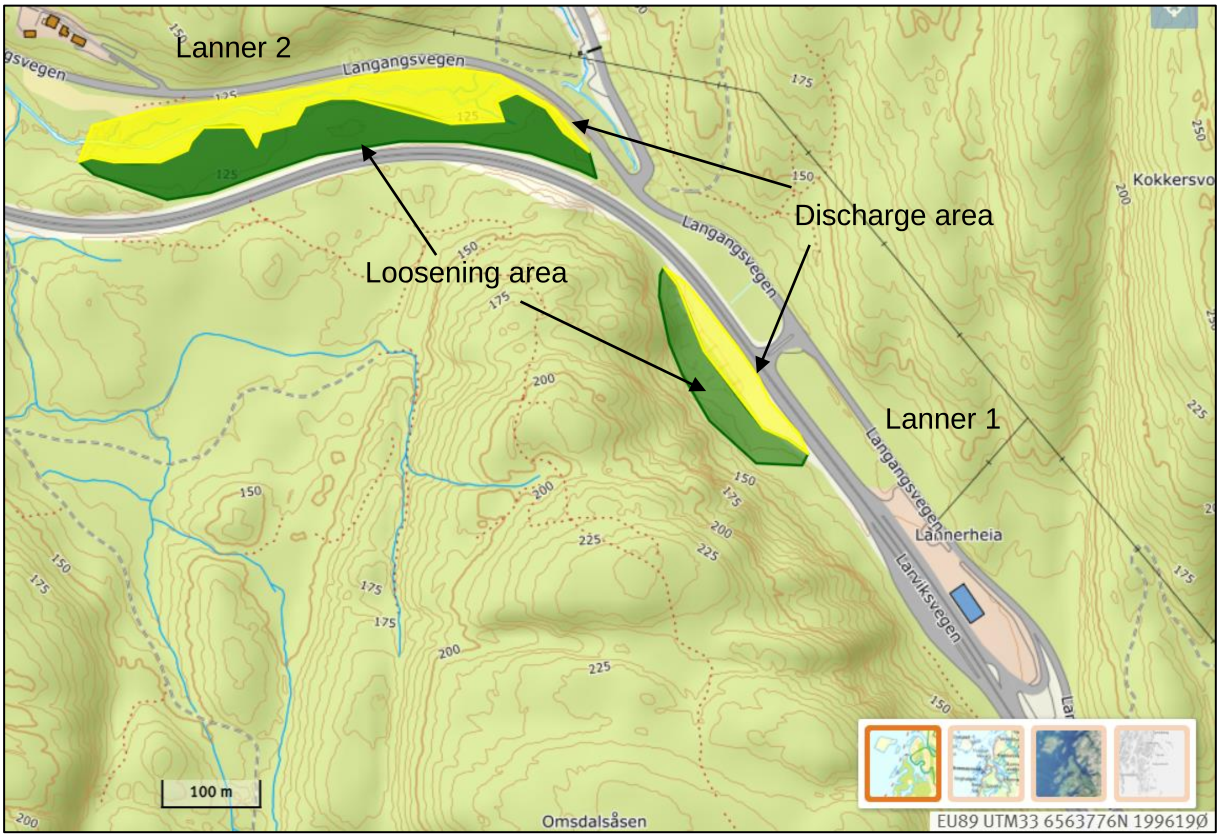

Figure 30 Loosening and discharge areas Lanner

9. Classify quick clay zones
See Annex A.

Lanner 1
For the *damage consequence class,* the score found in the rating is 6 out of 45, which corresponds to 13% of the maximum score. The area is categorized in the damage consequence class <u>less seriously.</u>

For *quick clay grade class*, the evaluation for the zone gives a score of 6 out of 51, which corresponds to quick clay grade class <u>low</u> and a percentage of 12% of the maximum score.

Risk is equal to damage consequences class multiplied by quick clay grad class. The quick clay zone gets a score of 13 x 12 = 156. The zone is thus placed in risk class 1.

Lanner 2
For the *damage consequence class,* the score found in the rating is 6 out of 45, which corresponds to 13% of the maximum score. The area is categorized in the damage consequence class <u>less seriously.</u>

For *quick clay grade class*, the evaluation for the zone gives a score of 7 out of 51, which corresponds to quick clay grade class <u>low</u> and a percentage of 14% of the maximum score.

Risk is equal to damage consequences class multiplied by quick clay grad class. The quick clay zone gets a score of 13 x 14 = 182. The zone is thus placed in risk class 2.

10. Document satisfied security factor

Requirements
$F_{c,u}$ >1,4 (assumes no worsening of stability because the planned action will work as loading berm and improve the stability) and F_{phi} = 1,25.

Cross-section for calculations
Cross-sections L1-L1 and L2-L2 in Figure 23 will be performed with stability calculations. Cross-sections L3-L3 and L4-L4 are similar to L2-L2 and therefore not relevant to repeat.

Material parameters

A compilation of undrained shear strength, direct in the area is shown in Figure 31.

Strength parameters used in the calculations are shown in Table 4. The calculation parameters are assessed based on ground investigations and experience values.

Material parameters in sensitive clay are based on undisturbed samples and CPTU in boreholes 3002.

Where there are no investigations in the immediate area of the calculation sections or at the deepest levels where no samples have been taken, undrained shear strength for clay derived from the following context has been used:

$$S_{UA} = \alpha \cdot \rho_0 \cdot OCR^m$$

where

s_{uA} = active undrained shear strength

ɑ = constant, normal 0,3

p_0' = in situ effectiv vertical stress

OCR = overconsolidation ratio. Chooses 1,2 which means it's normally consolidated which is on the conservative side

m = swelling module, chooses 0,68

The relationship shown above goes by the designation SHANSEP strength model (Stress History And Normalized Soil Engineering Properties) and was first presented by Ladd and Foott in 1974.

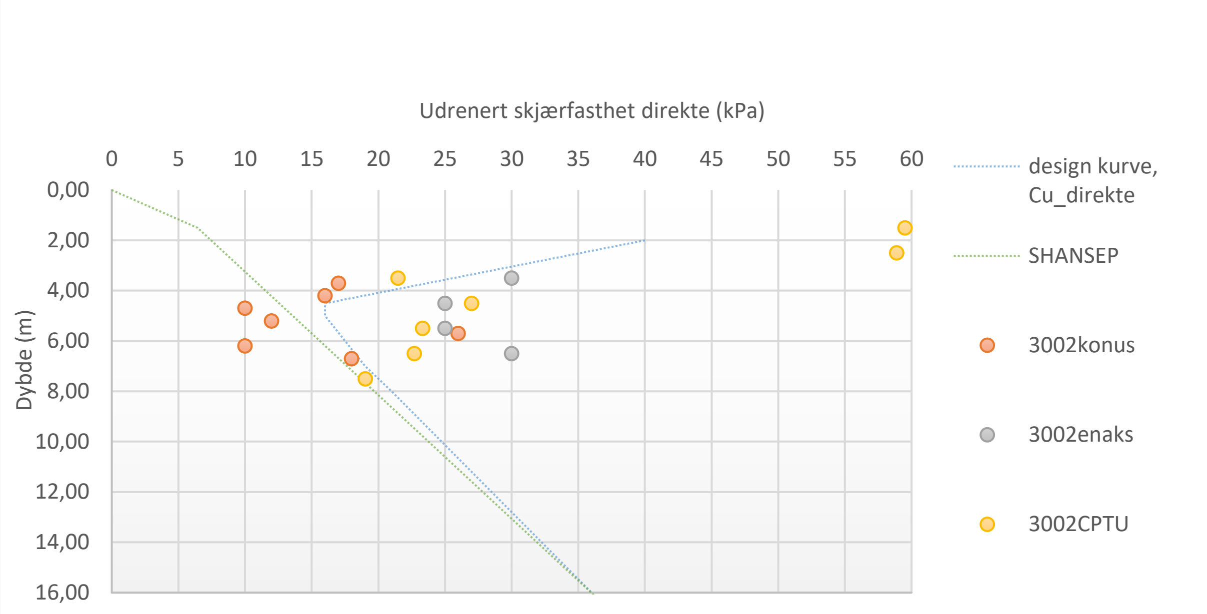

Figure 31 Undrained shear strength

<table>
<tr><th>Material</th><th>Strength parameters</th><th>Bulk density [kN/m³]</th></tr>
<tr><td>Fill</td><td>$\varphi'_k = 40°$
a = 0kPa</td><td>$\gamma_k = 19; \gamma'_k = 11$</td></tr>
<tr><td>Sand/silt</td><td>$\varphi'_k = 34°$
a = 0kPa</td><td>$\gamma_k = 19; \gamma'_k = 11$</td></tr>
<tr><td>Quick clay (most likely not all the clay layer is quick but this is on the safe side!)</td><td>Drained
a=2kPa
$\varphi'_k = 24°$

Undrained
<table>
<tr><th>Z (m)</th><th>C_{uk} DIREKTE SKJÆRFASTHET, (kPa)</th></tr>
<tr><td>2</td><td>40</td></tr>
<tr><td>4</td><td>20</td></tr>
<tr><td>4,5</td><td>16</td></tr>
<tr><td>5</td><td>16</td></tr>
<tr><td>7</td><td>19</td></tr>
<tr><td>8</td><td>21</td></tr>
</table></td><td>$\gamma_k = 19; \gamma'_k = 9$</td></tr>
<tr><td>Till/Sand/Gravel</td><td>$\varphi'_k = 36°$
a = 0kPa</td><td>$\gamma_k = 19; \gamma'_k = 11$</td></tr>
</table>

Table 4 Material parameters in calculations

The groundwater level is estimated to be approx. 1,5m below terrain.

The choice of anisotropy factors is made in accordance with report no. 14/2014 *"Naturfareprosjektet Dp. 6 Kvikkleire. En omforent anbefaling for bruk av anisotropifaktorer i prosjektering i norske leirer".*

The following table specifies how these factors are calculated:

I_p	c_{uD}/c_{uC}	c_{uE}/c_{uC}
$I_p \leq 10$ %	0,63	0,35
$I_p > 10$ %	$0{,}63+0{,}00425*(I_p-10)$	$0{,}35+0{,}00375*(I_p-10)$

The following anisotropy factors are used for ADP calculations:

Ad = 0,67 and Ap = 0,39

Results

The results from the calculations are presented in Annex B1-B4 and briefly summarized in Table 5. The results show that both undrained and drained safety factors are over requirements. It can be added that drained analysis is the most valid case here since there are no new loads applied on terrain (long-term situation.)

Area stability			
Cross Section	***Undrained analyse Fc***	***Drained analyse Fcϕ***	***Annex***
L1-L1	1,48	2,51	B1-B2
L2-L2	1,42	1,73	B3-B4

Table 5 Results stability calculations

7.4 AREA STABILITY HERREGÅRDSBEKKEN

1. Check for quick clay zones in the area

No previous quick clay zones in the area.

2. Delineate areas with marine clay

The area is below the marine limit and the NGU map indicates the possible occurrence of marine clay. Ground investigations in the area do not detect the occurrence of sensitive soil / quick clay. Area stability is therefore adequate in the area.

7.5 AREA STABILITY SKJELSVIKDALEN

1. Check for quick clay zones in the area

No previous quick clay zones in the area.

2. Delineate areas with marine clay

The area is below the marine limit and the NGU map indicates the possible occurrence of marine clay. Ground investigations in the area do not detect the occurrence of sensitive soil / quick clay. Area stability is therefore adequate in the area.

7.6 AREA STABILITY KJØRHOLT

1. Check for quick clay zones in the area

No previous quick clay zones in the area.

2. Delineate areas with marine clay

The area is below the marine limit. Also, marine clay is detected from ground investigations. Possible delineated areas are shown in below figure.

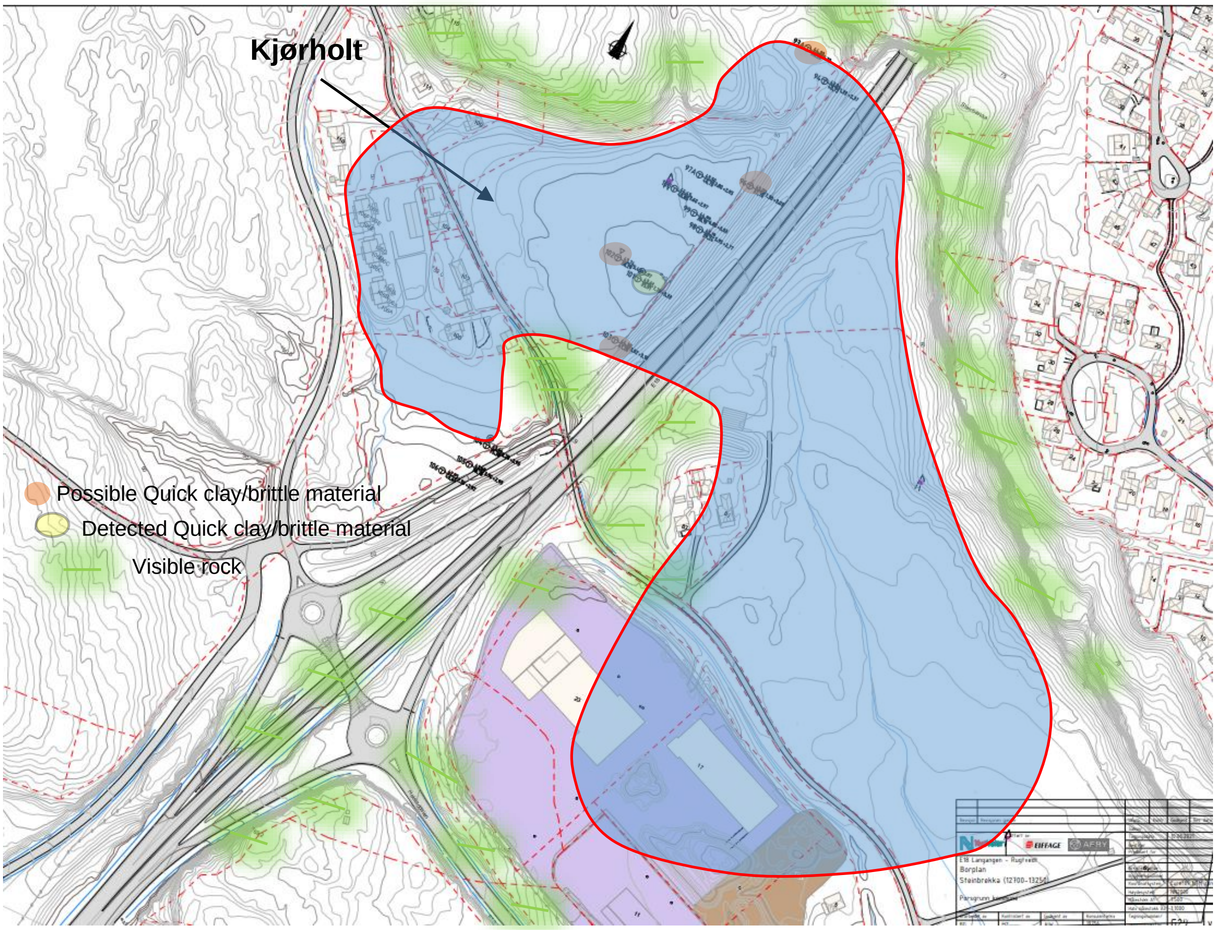

Figure 32 Possible areas with marine clay

3. Delineate areas with terrain that indicates the possible risk of landslides

Requirements for terrain that indicates the possible risk of landslides is:

- Total slope height (in soils) over 5 meters, or
- Evenly sloped terrain steeper than 1:20 and elevation difference over 5 meters

To identify the possible risk of landslide due to terrain levels (and soil conditions) a couple of cross-sections over the areal have been generated. Cross-sections in plan and profiles (together with relevant boreholes) can be seen in Figure 33 – Figure 45. There are giving notes to each cross-section regarding the risk of landslide.

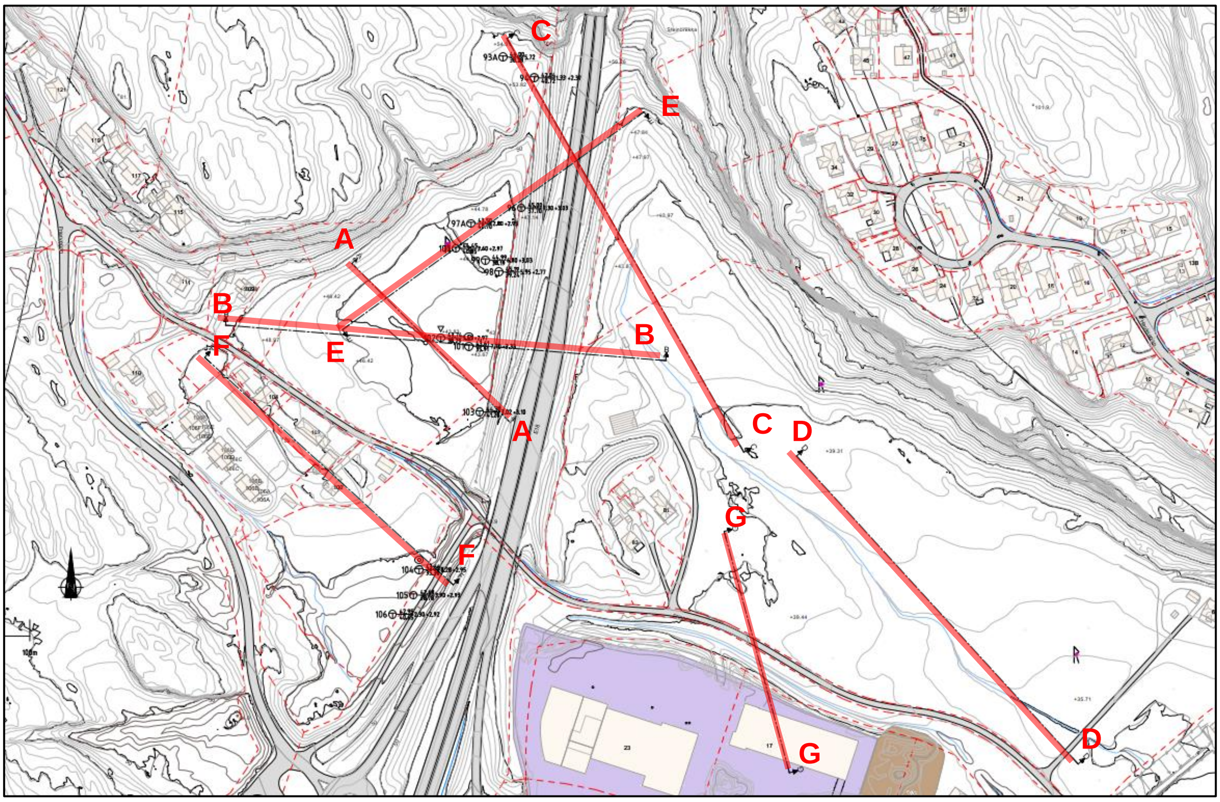

Figure 33 Plan over representative cross-sections in Kjørholt

Cross-section A-A

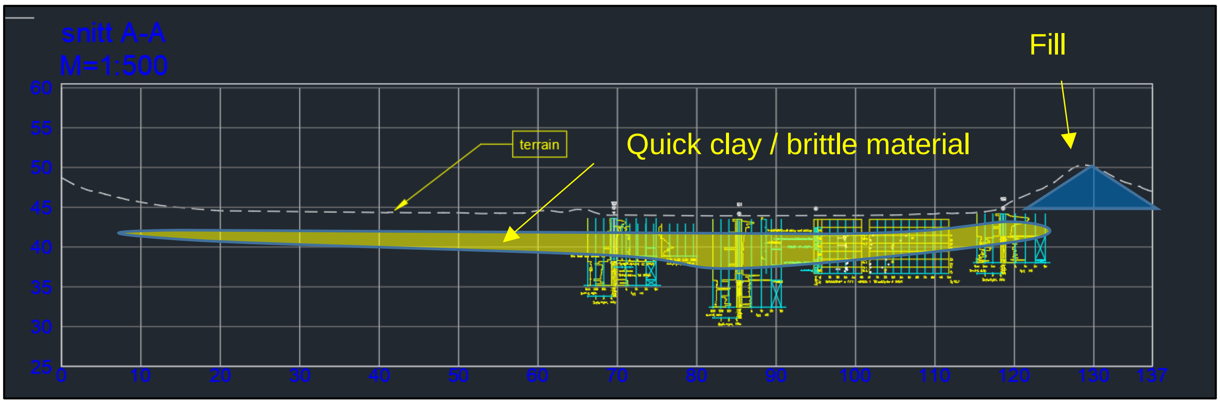

Figure 34 Profile cross-section A-A

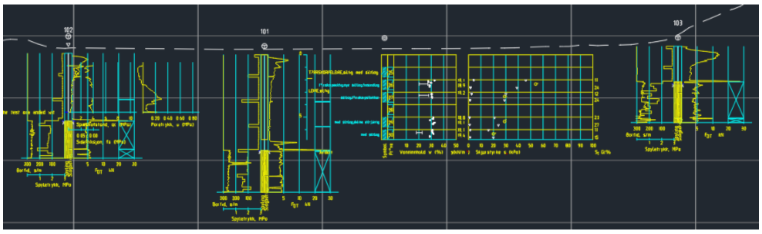

Figure 35 Boreholes cross-section A-A

Detected quick clay / brittle material in borehole 101 and possible quick clay / brittle material in boreholes 102 and 103. Terrain slopes are relatively flat so no risk for landslides due to terrain conditions.

Cross-section B-B

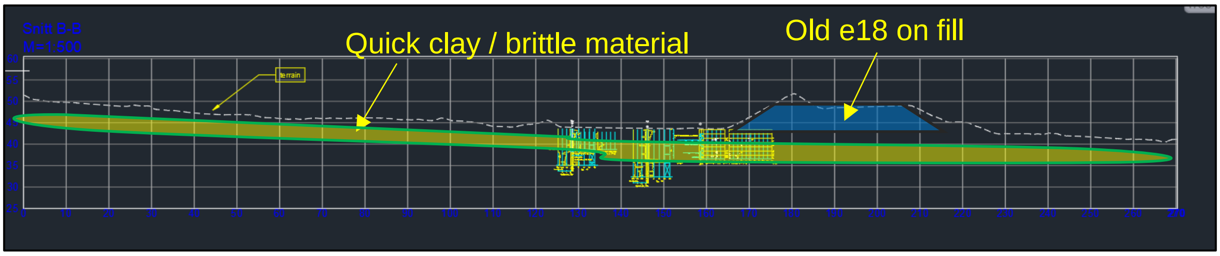

Figure 36 Profile cross-section B-B

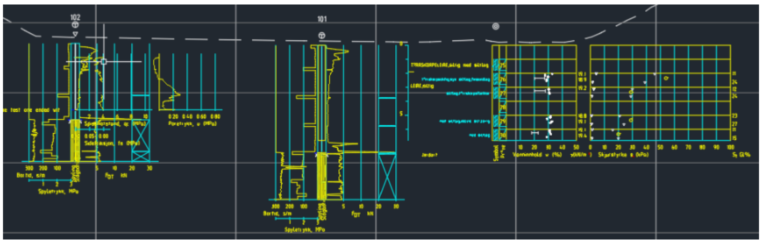

Figure 37 Boreholes cross-section B-B

Detected quick clay / brittle material in borehole 101 and possible quick clay / brittle material in borehole 102. Terrain slopes are less flat than 1:20. This cross-section will be investigated further.

Cross-section C-C

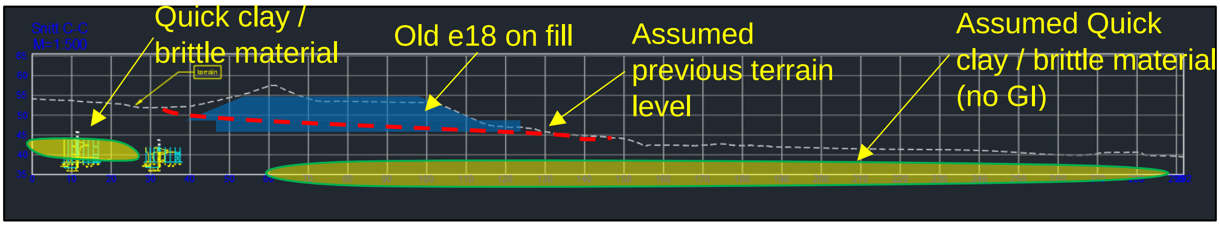

Figure 38 Profile cross-section C-C

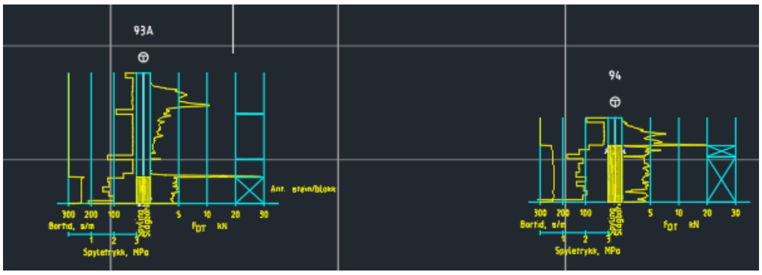

Figure 39 Boreholes cross-section C-C

Possible quick clay / brittle material in borehole 93A. But closest borehole, 94 does not conclude sensitive clay so most likely sensitive local around 93A. After that, the surface level is flatter than 1:20 so no risk for landslides due to terrain conditions. Height difference in the surface due to construction of the existing E18 in the area.

Boreholes 93A and 94 have measured terrain levels at + 42 - +44, however, at the same spot, the terrain levels from the 3D model are + 53 - +54 so a difference of 10m. There is no information at the moment why there is this difference.

Cross-section D-D

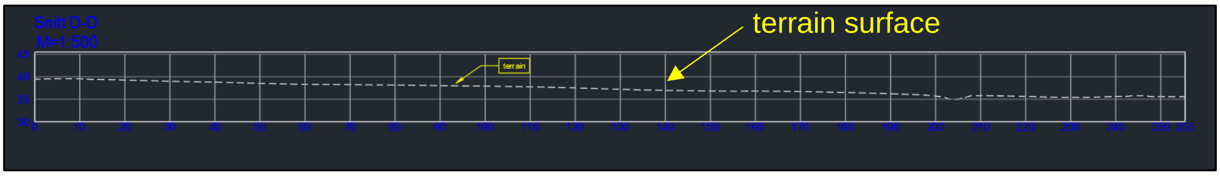

Figure 40 Profile cross-section D-D

Terrain slopes are relatively flat so no risk for landslides due to terrain conditions.

Cross-section E-E

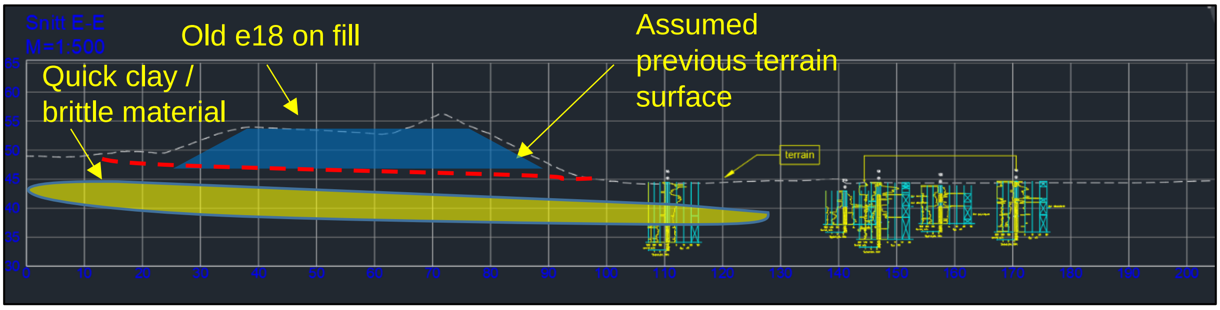

Figure 41 Profile cross-section E-E

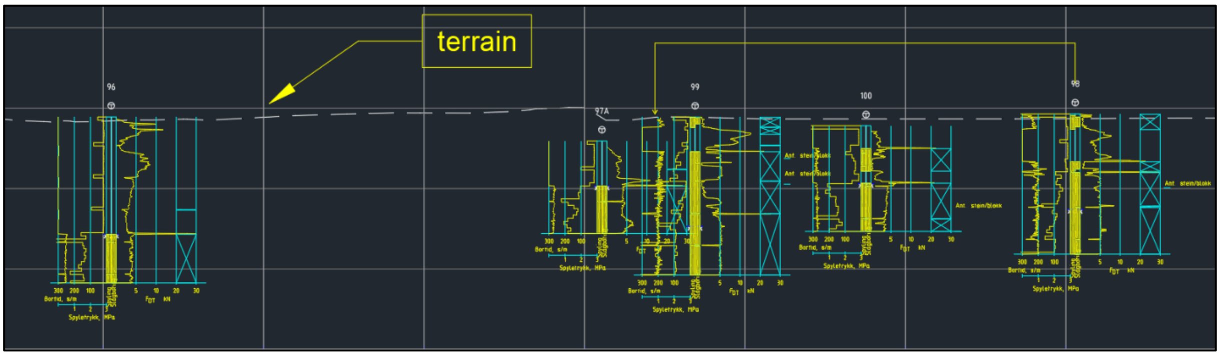

Figure 42 Boreholes cross-section E-E

Possible quick clay / brittle material in borehole 96. Height difference in the surface due to construction of the existing E18 in the area. Surface levels are slightly less flat than 1:20 but the existing E18 works like a loading berm and improve the stability. The surface level after existing E18 is flatter than 1:20. No risk for landslide due to terrain conditions.

Cross-section F-F

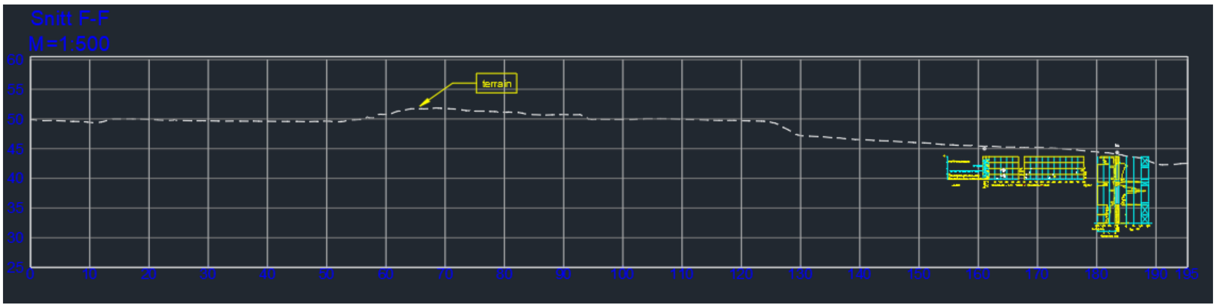

Figure 43 Profile cross-section F-F

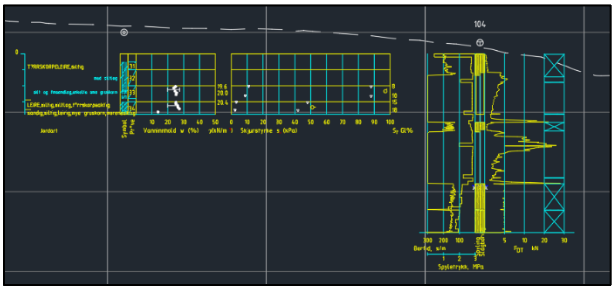

Figure 44 Boreholes cross-section F-F

Sensitive is >15 and stirred shear strength >2kPa in borehole 104 so no brittle material. No other investigations in the close by. However, the surface level is flatter than 1:20 west of borehole 104 so no risk for landslide due to terrain conditions.

Cross-section G-G

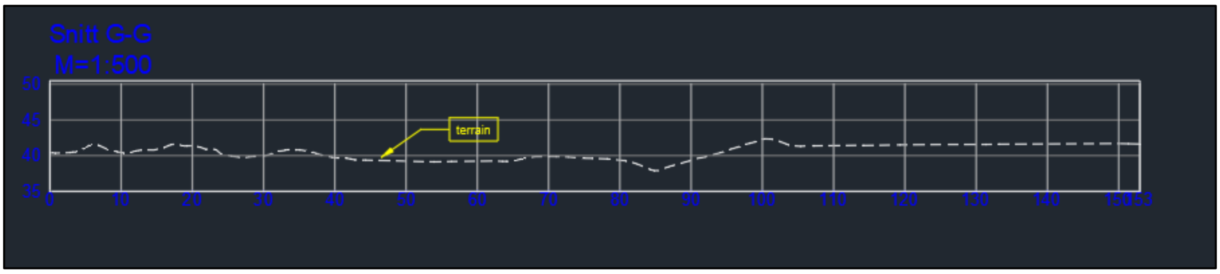

Figure 45 Profile cross-section F-F

Terrain slopes are relatively flat so no risk for landslides due to terrain conditions. Local height differences due to human intervention.

4. Determine measure category
The road is defined into category K4 per chapter 0.5 in manual V220.

5. Review of background data – identification of critical slopes and possible loosening area

A review of background data and identification of critical slopes has already been carried out. Possible loosening areas will also be shown in the coming parts.

6. Site visit
A site visit has been carried out. Mapping of rock surface outcrops has been done. There is a small creek going in the east part of Kjørholt. No sign of ongoing erosion although.

7. Conducting ground investigations
Ground investigations, supplement to previously performed investigations will be performed later. Area stability needs to be checked again with the background of new ground investigations.

8. *Consider relevant landslide mechanisms and delineate loosening- and discharge areas*

The relevant landslide mechanism is the flake landslide.

Loosening and discharge areas as in the following figure:

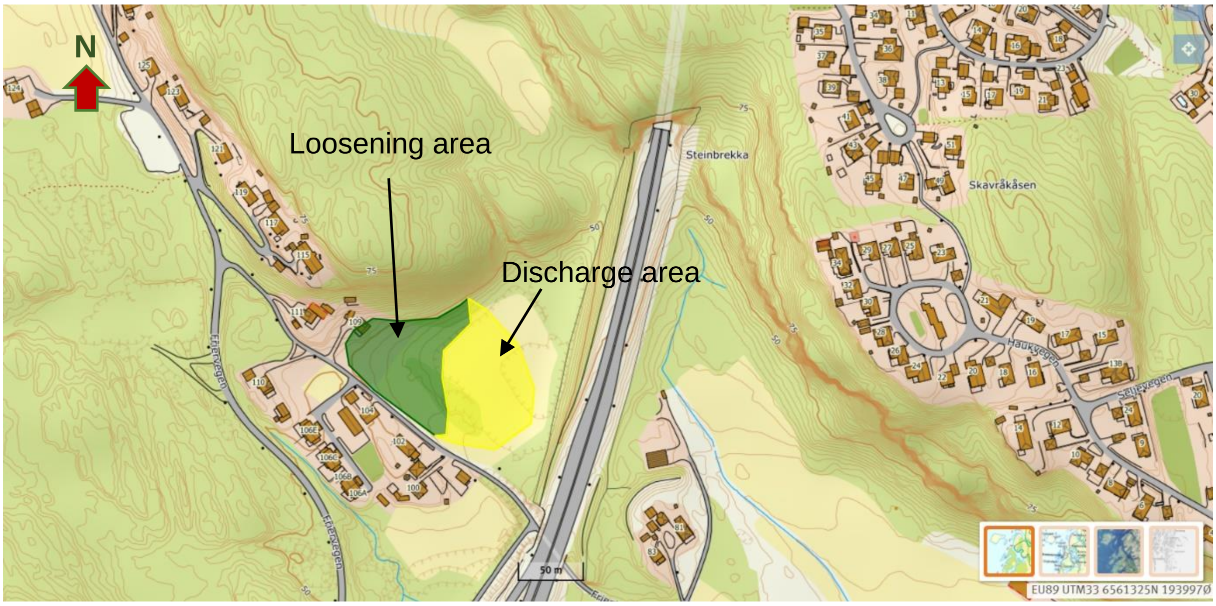

Figure 46 Loosening and discharge areas Kjørholt

9. Classify quick clay zones
See Annex A.

For the *damage consequence class,* the score found in the rating is 6 out of 45, which corresponds to 13% of the maximum score. This category the area in the damage consequence class <u>less seriously.</u>

For *quick clay grade class*, the evaluation for the zone gives a score of 6 out of 51, which corresponds to quick clay grade class <u>low</u> and a percentage of 12% of the maximum score.

Risk is equal to damage consequences class multiplied by quick clay grad class. The quick clay zone gets a score of 6 x 6 = 36. The zone is thus placed in risk class 1.

10. Document satisfied security factor

Requirements
$F_{c,u}$ >1,4 (assumes no worsening of stability because the planned action will work as loading berm and improve the stability) and F_{phi} = 1,25

Cross-section for calculations
Cross-sections B-B in figure 7.12 will be carried out with stability calculations due to the risk of a landslide.

Material parameters
A compilation of undrained shear strength, direct in the area is shown in Figure 47.

Strength parameters used in the calculations are shown in Table 6. The calculation parameters are assessed based on ground investigations and experience values.

Material parameters in sensitive clay are based on undisturbed samples in boreholes 101 and CPTU in borehole 102.

Where there are no investigations in the immediate area of the calculation sections or at the deepest levels where no samples have been taken, undrained shear strength for clay derived from the following context has been used:

$$S_{UA} = \alpha \cdot \rho_0 \cdot OCR^m$$

where

s_{uA} = active undrained shear strength

α = constant, normal 0,3

p_0' = in situ effectiv vertical stress

OCR = overconsolidation ratio. Chooses 1,2 which means it's normally consolidated which is on the conservative side

m = swelling module, chooses 0,68

The relationship shown above goes by the designation SHANSEP strength model (Stress History And Normalized Soil Engineering Properties) and was first presented by Ladd and Foott in 1974.

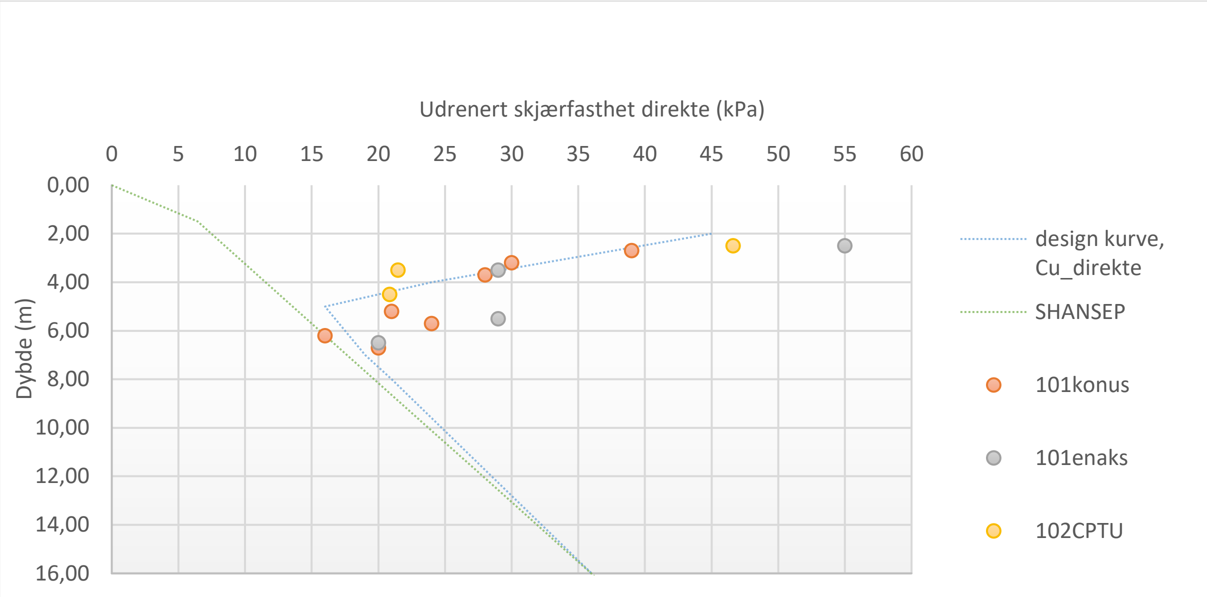

Figure 47 Undrained shear strength

Table 7.4 Material parameters in calculations

<table>
<tr><td>Material</td><td>Strength parameters</td><td>Bulk density [kN/m³]</td></tr>
<tr><td>Fill</td><td>$\varphi'_k = 40°$
a = 0kPa</td><td>$\gamma_k = 19; \gamma'_k = 11$</td></tr>
<tr><td>Sand/silt</td><td>$\varphi'_k = 34°$
a = 0kPa</td><td>$\gamma_k = 19; \gamma'_k = 11$</td></tr>
<tr><td>Quick clay (most likely not all the clay layer is quick but this is on the safe side!)</td><td>Drained
a=2kPa
$\varphi'_k = 24°$

Undrained
<table>
<tr><td>Z (m)</td><td>C_{uk} DIREKTE SKJÆRFASTHET, (kPa)</td></tr>
<tr><td>2</td><td>45</td></tr>
<tr><td>4</td><td>24</td></tr>
<tr><td>5</td><td>16</td></tr>
<tr><td>7</td><td>19</td></tr>
<tr><td>8</td><td>21</td></tr>
<tr><td>16</td><td>36</td></tr>
</table></td><td>$\gamma_k = 19; \gamma'_k = 9$</td></tr>
<tr><td>Till/Sand/Gravel</td><td>$\varphi'_k = 36°$
a = 0kPa</td><td>$\gamma_k = 19; \gamma'_k = 11$</td></tr>
</table>

Table 6 Material parameters in calculations

The groundwater level is estimated to be approx. 1,5m below terrain.

The choice of anisotropy factors is made in accordance with report no. 14/2014 *"Naturfareprosjektet Dp. 6 Kvikkleire. En omforent anbefaling for bruk av anisotropifaktorer i prosjektering i norske leirer".*

The following table specifies how these factors are calculated:

I_p	c_{uD}/c_{uC}	c_{uE}/c_{uC}
$I_p \leq 10$ %	0,63	0,35
$I_p > 10$ %	$0{,}63+0{,}00425*(I_p-10)$	$0{,}35+0{,}00375*(I_p-10)$

The following anisotropy factors are used for ADP calculations:

Ad = 0,67 and Ap = 0,39

Results

The results from the calculations are presented in Annex B1-B2 and briefly summarized in Table 7. The results show that both undrained and drained safety factors are over requirements. It can be added that drained analysis is the most valid case here since there are no new loads applied on terrain (long-term situation.)

Area stability					
Cross Section	*Undrained analyze Fc*		*Drained analyze Fcϕ*		*Annex*
	Circular surface	*Plan surface*	*Circular surface*	*Plan surface*	
B-B	2,26	>5	1,98	>4	B1-B2

Table 7 Results stability calculations

7.7 SUMMARY QUICK CLAY ZONES

For parcel 2, a total of 3 quick clay zones have been identified. The zones are delimited based on topography, soil maps, available ground investigations, and assessment of loosening and discharge area. The zones are divided into three different classes; "low", "middle" and high". All three identified sones have "low" grades.

In Annex A, the background for determining the grade for each zone is presented. Information from ground investigations varies and there is therefore slightly different grades accuracy in the quick clay classification. Where there are few ground investigations, conservative assumptions are made. For an example of now, there is very little information about factors such as OCR, pore pressure, quick clay, and sensitivity.

There is relatively high uncertainty associated with the assessment of discharge area for the landslide. The material properties of clay such as sensitivity and stirred shear strength are of great importance. The topography of the discharge area is also very central. The slope of the discharge area and how well the discharge area "canalizes" are important topographic factors.

7.8 CONCLUSION

Lanner

Detected quick clay from samples. Possible quick clay/ brittle material from total and CPTU soundings. Stability calculations show safety factors over current requirements. No need for stability measurements to handle area stability.

There will be performed supplement ground investigations. Area stability needs to be updated concerning supplement ground investigations.

Geotechnical actions are needed for the creek in Lanner. Since the new E18 ramp will stretch over the creek there are likely already planned actions for that.

Herregårdsbekken

No quick clay / brittle material was detected or interpreted from boreholes at Herregårdsbekken.

Skjelsvikdalen

No quick clay / brittle material was detected or interpreted from boreholes at Herregårdsbekken.

Kjørholt

Detected quick clay from samples. Possible quick clay/ brittle material from total and CPTU soundings. Stability calculations show safety factors over current requirements. No need for stability measurements to handle area stability.

There will be performed supplement ground investigations. Area stability needs to be updated concerning supplement ground investigations.

8. FOUNDATION DESIGN RECOMMENDATIONS

Geotechnical solutions that have been compared with aspects on cost, environment, and time: lime cement stabilization, preloading, vertical drains, and lightweight fills.

8.1 LANNER

8.1.1 E18 CH. 3/450 – 4/300

Ch. 3450 – 3700

No need for special geotechnical action except excavation of top layer, 0 – 2m.

Ch. 3700 – 4300

The proposed solution is lime cement stabilization on the south side of the road (between ch. 3700 – 4100). From ch. 4100 to 4300 it is rock outcrops south of the line. No sign of rock outcrops to the north side of the line. Rock cutting to the south and fill on the north. The fill could be established with preloading to reduce the settlements. From ch. 4300 the road goes in a tunnel.

8.1.2 FV. 30/ E18 RAMP

Ch. 0 – 200

The proposed geotechnical solution is excavation at the top layer, 0 -2m.

Ch. 200 – 350

The depth to bedrock is less than 6m but soft soil in most of the boreholes. Excavation and preloading are proposed. Vertical drains can also be used to speed up the settlements.

Ch. 350 – 550

Cutting in rock.

Ch. 550 – 700

The road will be on fill with 10m fill height at the top. Preloading and vertical drains are proposed. No ground investigations but the most likely limited depth to bedrock.

Ch. 700 – 760

The road goes over the tunnel.

Ch 760 – 900

There is possible quick clay in this part so lime cement stabilization is proposed. Where quick clay is not representative, it could be used preloading as an alternative.

8.2 HERREGÅRDSBEKKEN

8.2.1 E18

Since the road line from ch. 6/970 to 7/400 will be in cutting there is no settlement problem. So, no geotechnical actions are needed to handle settlements for earthworks. There is no indication of sensitive clay in this part so excavation can be carried with general procedures. Also, the groundwater table has to be checked but because the soil is mostly sand and gravel, the groundwater table is in direct contact with air. Possible groundwater lowering can be carried out without harming the existing environment.

Stability in cuttings will be satisfied as long as the open slopes are established with slope 1:2. Since the soil magnitude (from terrain level to bedrock level) will be 10m at most in some places, the scale of open cuttings will be quite significant in the landscape. To reduce height differences and the scale of open cutting, one can use retaining walls or as alternative soil nailing. Both methods should be achievable.

Height differences (more than 5m) are observed in the following sections;

- between ch. 6/970 to 7/020 (both sides of the road; height differences; 5 to 10m)
- between ch. 7/080 to 7/130 (north side of the road; height differences; 5 to 10m)
- between ch. 7/330 to 7/400 (both sides of the road; height 5 to 15m)

8.2.2 BRIDGE OVER HERREGÅRDSBEKKEN

The bridge will most likely be founded on friction piles. Spread footing is also an alternative that needs to be checked closely concerning bridge loads and foundation level.

8.3 SKJELSVIKDALEN

The tunnel will stretch in bedrock and connects with existing rv36 in ramps in tunnels and soil/rock cuttings and roundabouts in connection at the ground. The soils in the area where planned action will be carried are solid masses so no need for geotechnical actions for settlements and stability.

8.4 KJØRHOLT

Ground investigations at Kjørholt are limited yet there is proposed a lot of constructions; embankments with a height of 10m, culverts, and a bridge. Some boreholes indicate sensitive soil, others not. The proposed geotechnical solution for embankments (after new supplement investigations have been available) are lime cement stabilization (sensitive soil), excavation (if the depth to bedrock are limited and soils are weak), and preloading with vertical drains (soft soil – not quick).

Constructions such as culverts and bridges most likely need to be founded on piles to bedrock.

9. EXCAVATION AND FILLING

All fill under the road construction should be built up with blasted rock. Other material than that should be avoided because of the risk of different settlements and trickier compaction works. Masses from terrain and road cuts can be used in fills outside the road body such as in agricultural plans or as loading berms as part of the geotechnical action. All fills must be built, layered, and compressed according to normal compression according to process 25.1 in Manual R761. Settlements in the fillings are expected to be in the order of 0,5-1% of filling height. It will be beneficial if fillings (especially the high fillings) are laid out early in the construction period so that as much as possible of the settlements are done before the ballast is laid out. In general, the majority of the settlements in compressed fillings of blasted rock to be completed within 6 months after laying. Settlements are closely followed up with settlement measurements during the construction period.

Organic and humus-containing masses under road fills must be removed and a horizontal filling foot must be established in sloping terrain. This could otherwise cause poor contact with underlying masses and provide poor support for compression when building up fill masses. Furthermore, a separation layer must be laid between natural ground and fill.

Soil slopes during excavation phases should not be steeper than slopes assessed from geotechnical calculations. The stability of the excavation slopes will depend on the groundwater. In general, the slopes above groundwater levels are stable, while below groundwater level, problems with soil loosening and slip out of the masses can occur.

Several small creeks are going through the planned road line that needs to be taken care of. The water must be directed through pipes under the road fills. The water should not enter the road supercharge due to the risk of leakage and soaking.

10. CRITICAL MOMENTS

In areas with quick clay with little cover, minor / initial slides can somehow trigger a larger slide. Excavation and filling in the construction phase in areas with quick clay must therefore have a high focus so that minor / initial slides can be avoided. Also, intermediate storage of masses is generally not permitted in these areas unless this has been clarified in advance by the geotechnical engineer. The use of heavy equipment must also be reduced to a minimum in these areas.

This type of slides can occur during the following moments in construction and also permanent phase and need to be addressed correctly:

- Temporary excavation slopes
- Excavation and filling works
- Stability in the construction phase
- Erosion
- Pore pressure build-up when installing lime cement columns
- Difference settlements.

11. FURTHER WORKS

Further works that must be taken care of in the construction phase are:

- Supplement ground investigations
- Update of area stability based on supplement ground investigations
- Pore pressure measurements
- Mapping and building inspection of nearby infrastructure and buildings
- Stability calculations for the construction phase
- Detailed design of lime cement columns
- Detailed design of preloading and vertical drains
- Detailed design of permanent retaining walls
- Detailed design of bridge foundations on piles
- Develop control plan for the construction work
- Stability calculations for RIG areas.

12. DRAWINGS

Ground Investigations plan Lanner	P2-G01
Ground Investigations plan Herregårdsbekken	P2-G02
Ground Investigations plan Skjelvsvikdalen	P2-G03
Ground Investigations plan Kjørholt	P2-G04
Ground investigations field and lab profiles	P2-G11

13. ANNEXES

Annex A	Damage consequence class and quick clay grade class (Separate document)
Annex B	Calculations area stability (Separate document)