*Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)*
*Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5*
*https://doi.org/10.53243/ICSMGE2026-690*

# Optimizing ground stabilization in quick clay prone areas while enhancing sustainability for the Fv. 770 county road project in Mid-Norway

**Anuj Thapa Magar,** Johannes Gaspar Holten, Åsmund Elgvasslien, Helene Alexandra Amundsen
*Sweco AB, Trondheim, Norway, anuj.magar@sweco.no*

ABSTRACT: County Road Fv. 770 Kolvereid-Nakling, located in the mid-western part of Norway, serves as a vital transportation route for transporting salmon from the town of Rørvik in Trøndelag County. The Fv. 770 project aims to modernize this road, which goes through a coastal area which is exposed to extreme weather conditions due to its proximity to the arctic circle. This work examines the challenges and possible solutions for sustainable ground stabilization for a road development project through large marine quick clay deposits of low plasticity along mountainsides. The initial results from slope stability calculations suggest that large areas of the ground need to be stabilized to comply with the safety requirements. The most used ground improvement method in Norway is lime-cement stabilization using deep-mixed technology. The method requires a large quantity of lime and cement, which have both economic and environmental implications, including increased $CO_2$ emissions. Strategies have been developed to reduce $CO_2$ emissions while ensuring both local and global slope stability. This road project aims to conserve the undisturbed natural areas; therefore, minimizing environmental impact has been a priority. This paper discusses how optimizing ground stabilization in the Fv. 770 road project has enhanced overall sustainability.

KEYWORDS: Quick clay, ground stabilization, sustainability

## 1 INTRODUCTION

County Road Fv. 770 Kolvereid-Nakling, located in the mid-western part of Norway in Nærøysund municipality, serves as a vital transportation route for transporting salmon from the town of Rørvik in Trøndelag County. The Fv. 770 project aims to modernise this road, which passes through a coastal area alongside a mountainside exposed to extreme weather conditions due to its proximity to the Arctic Circle, see Figure 1. The project entails detailed zoning plan for a about 5 km long stretch of two-lane county road between «Kolvereid» and «Nakling». The planned county road is designed for a speed limit of 80 km/hr with an average daily traffic (ADT) of 3500. The current stretch of the county road is small, winding and highly prone to traffic accidents. It goes through large marine quick clay deposits of low plasticity.

Many natural slopes along the planned stretch of the county road Fv.770 have severely critical stability (Amundsen *et al.*, 2026). All the alignment alternatives for the planned county road goes through several cuts and fills. To comply with the safety requirements as per The Norwegian Public Road Authority (NPRA), an extensive safety measurement or ground improvement/stabilization is required.

The most commonly used ground improvement method in Norway is dry deep soil mixing. This technique enhances the strength and stiffness of weak soils by mixing them with a dry binding agent. Lime and cement, which have huge environmental implications, such as increased $CO_2$ emissions, are common binding agent. This method is often referred as a lime-cement stabilization. The binding agent reacts with the weak soils and shear strength and stiffness increases because of chemical reaction between minerals, pore water and binding agent. This ground stabilization method is highly effective in quick clays.

This road project aims to conserve the undisturbed natural areas; therefore, minimizing environmental impact has been a priority. This paper discusses possible sustainable solutions for ground stabilization in the Fv. 770 road project.

## 2 SUSTAINABILITY

Sustainability and environmental impact considerations are key objectives of this project. The Trøndelag County Authority (TRFK), the project owner, defined their premise for the environment and sustainability criteria to $CO_2$ emission or greenhouse gas (GHG) budget and preservation of marshland (Jahan, 2025) . Marshland in and around the project area, primarily in part 3, was identified and mapped during the early planning phase. Consequently, all the alternative alignments were designed to avoid and preserve the marsh- and wetland in the project area.

From the onset, it was clear that extensive safety measures in terms of ground stabilization were required to comply with the safety requirements. These ground stabilizations efforts are costly. One of the alternatives that included a tunnel, was disregarded in an early phase assessment due to lack of economic viability. The tunnel line is indicated by green dotted line in Figure 2. Therefore, sustainability for this project also involves finding a cost-efficient alternative that requires minimal safety measures while ensuring minimal environmental impacts, especially reducing $CO_2$ emission. Strategies to reduce $CO_2$ emissions have been developed based on NPRA methodology (Statens vegvesen, 2022), while ensuring slope stability has been a major focus of this project.

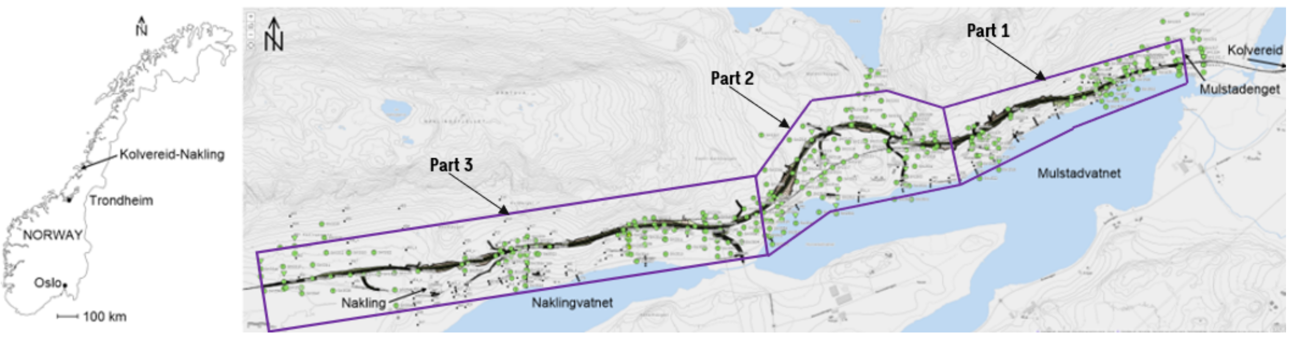


Figure 1. Location of the Fv. 770 Kolvereid-Nakling. Additional ground investigations are marked with green boreholes.

Building this stretch of the road is essential and highly prioritized by TRFK due to its critical importance for traffic safety as well as its socioeconomic and industrial significance. Consequently, reducing construction cost and $CO_2$ emissions are given equal consideration in the project's sustainability efforts, while minimizing or avoiding encroachment on existing infrastructures. Other factors, such as total area encroached, mass balance and impact on the agricultural lands, are considered but are given less weight.

## 3 QUICK CLAY AND SAFETY REQUIREMENTS

Marine clay deposits in Norway, which were sedimented in salt water, have been leached by fresh water since the melting of glacier ice and the uplift of the land. Marine clay in the area where Fv. 770 Kolvereid-Nakling is planned consists of thick quick clay layers with an undrained shear strength of 20-40 kPa and a remoulded undrained shear strength of 0.1-1.27 kPa. A more detailed presentation of the engineering characterization of the site is summarized by Amundsen et al. (2026).

The Norwegian Water Resources and Energy Directorate (NVE, 2019) requires slope stability calculations for short-term (undrained total stress analysis, $\gamma_{m,UDR}$) and long-term stability (drained effective stress analysis, $\gamma_{m,DR}$) in the mapped hazard zones with strict construction regulations.

- For slopes in the hazard zone for quick clay landslides that are outside the influence area of the measure, the safety requirement $\gamma_{m,DR} \geq 1.25$ and the robustness requirement $\gamma_{m,UDR} \geq 1.20$ apply.
- NVE, Norwegian Public Roads Administration (NPRA), and Bane NOR (Norwegian rail infrastructure) have additional requirements for both $\gamma_{m,UDR}$ and $\gamma_{m,DR}$ that are triggered in connection with construction measures:
  - If the measure worsens stability, an absolute safety factor of $\gamma_{m,UDR} \geq 1.6$ and $\gamma_{m,DR} \geq 1.25$ shall be required.
  - For measures that do not worsen stability, the safety requirement is $\gamma_{m,UDR} \geq 1.40$ and $\gamma_{m,DR} \geq 1.25$.
  - When lower safety than required for the measures that do not worsen stability, $\gamma_{m,UDR}$ and $\gamma_{m,DR}$ must be increased proportionally according to the guidelines for quick clay (NVE, 2019). Applicable only for change in terrain or by using light weight aggregates.
  - A safety factor of $\gamma_{m,UDR} \geq 1.40$ and $\gamma_{m,DR} \geq 1.25$ must be achieved after the ground stabilization measure is implemented.
- The safety factor requirements ($\gamma_{m,UDR}$ and $\gamma_{m,DR}$) are independent from each other.

Regulations given by NPRA allow a total settlement of 45 cm for a road with design speed limit of 80 km/hr, while also maintaining a differential settlement in the longitudinal direction of maximum 0.75% within 60 m long stretch or a differential settlement of 45 cm for 60 m or longer road stretch (Statens vegvesen, 2024).

## 4 SLOPE STABILIZATION TECHNIQUES USED IN NORWAY

The most common slope stabilization methods used is Norway are as follows:

- Lime-cement stabilization (a)
- Counter fill (b)
- Mass displacement (c)
- Terrain relief (d)
- Preloading with vertical drains (e)
- Light weight aggregates (f)

Lime-cement stabilization techniques are often used in quick clay-prone areas where other ground stabilization techniques, whether individually or in combination, fail to meet the safety requirements.

Lime-cement piles are established by rotating and pressing a mixing tool at the tip of a drill rod down into the ground to the lowest level of the lime-cement pile. When the mixing tool reaches the desired level, the injection of the binding agent are injected while the mixing tool is rotated and raised until the top level of the lime-cement pile. The curing process starts immediately.

The strength of the lime-cement piles is often documented during the first week after the installation by in-situ tests such as reversed pile soundings, lime-pile soundings or cone penetration tests.

## 5 ASSESSMENT OF ALTERNATIVES

### 5.1 *Early phase assessment*

Four different alternatives for the Fv. 770 Kolvereid-Nakling, alongside the current stretch of the county road, were evaluated through a desk study utilizing existing available data (see Figure 2). This data included road models and previous ground investigations, primarily rotary soundings from the 1980s along the current county road, and a limited number of total soundings along the stretch of alternative *17000* between part 1 and 2, shown in Figure 1. Consequently, the strength and stiffness parameters of the soil in the project area were relatively unknown.

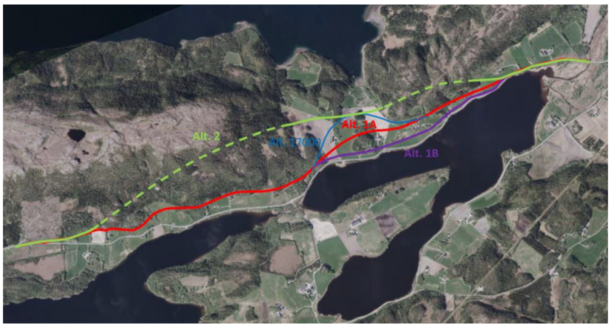


Figure 2. Early phase assessment with four alternatives.

An alternative with a tunnel, indicated by green dotted lines in Figure 2, was disregarded due to high construction costs. Improvement of the existing road was not feasible due to poor slope stability near the lakes along the current stretch. This would result in enormous costs for ground stabilization and significant environmental impact on the water bodies in the area. *Alt. 1B* (purple line followed by red line) was also not viable because of high construction costs due to extensive lime-cement stabilization required along the naturally unstable slopes, and its consequent environmental impact.

A corridor between the two alternatives *alternative 17000* and *16000* (*Alt. 1A),* shown in Figure 2 and Figure 3, was chosen to be investigated further with a new set of ground investigations and stability calculations. In addition to be less expensive than the other alternatives, these two alternatives were also the two open terrain alternatives with the lowest GHG emissions, much due to the reduced amount of lime-cement stabilization needed here compared to the other open terrain alternatives.

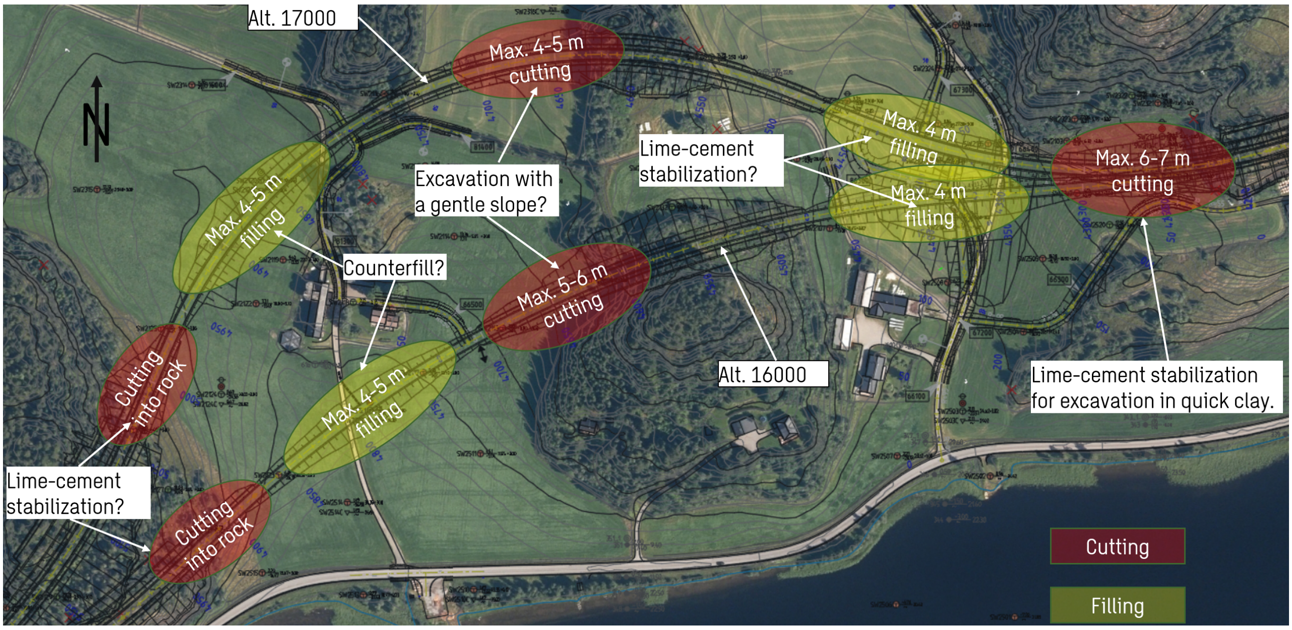


Figure 3. Evaluation of ground stabilization between Alternative 16000 and 17000 in Part 2.

## 5.2 *Final phase assessment*

A critical area where significant differences between the alternatives occur were identified in Part 2 of the road project, as shown in Figure 3. This segment of the planned county road lies within profiles 4200 to 5100, spanning from right to left in Figure 3. Alternative *16000* is nearly 100 meters shorter than Alternative *17000* and appeared to be the best option during the initial phase assessment.

For the final phase assessment during the detailed zoning phase, extensive ground investigations were conducted over the course of a year, followed by laboratory tests on a substantial number of undisturbed piston samples (54/75 mm).

The criteria for evaluating the alternatives were:

- Construction expenses
- $CO_2$ emissions, with a focus on minimizing lime-cement stabilization
- Mass balance
- Impact on agricultural land.

It is also essential to preserve the farm buildings within Part 2.

## 5.3 *Evaluation of safety measures*

Figure 3 illustrates the process of evaluating safety measures for two road alternatives, *16000* and *17000*. Parts of the road lie on a fill above the current terrain, and some parts must go through rock and soil cutting below the current terrain. The ground conditions in part 2 consists of a thin dry crust over quick clay extending to depths of up to 25 meters where ground stabilizations are planned. The quick clay has low plasticity and low to medium undrained shear strength.

Stability analysis for terrain interventions due to the planned road indicated much lower factor of safety than the safety requirements. The ground stabilization is necessary to comply with the safety requirements for both fills above the terrain and deep cuttings in the quick clay along many sections in part 2 (Figure 1). Fills above original terrain must also comply with the maximum and differential settlement limits. Possible ground stabilizations for sections of the alternatives are mentioned in Figure 3 and summarized in Table 1.

Table 1. Safety measures for Alternative 17000 and 16000, as shown in Figure 3.

| Alternative 17000 | | Alternative 16000 | |
|---|---|---|---|
| Profile | *Safety measures | Profil | *Safety measures |
| 4240 – 4320 | (a) | 4240 – 4320 | (a) |
| **4320 -4460** | **(b) combined with (f)** | **4320 – 4460** | **(a)** |
| 4640 – 4720 | “Excavation | 4620 – 4700 | “Excavation |
| 4800 – 4920 | (b) | 4720 – 4850 | (b) |
| 4960 – 5020 | (a) | 4890 – 4950 | (a) |

*Notations as described in chapter 4.
“Excavation with a gentle stable cutting slope of 1:2 or lower.

Both Alternative *17000* and *16000* required similar methods and quantity of safety requirements apart from the section between profile 4320 – 4460 (Table 1). In this section, Alternative *16000* required lime-cement stabilization, whereas Alternative *17000* only required a sufficient safety measure of counter fill combined with light weight aggregates under the base layer of the road. Restrictions caused by the farm buildings implies that it is not possible to create a counter fill to achieve safety requirements for Alternative *16000*. Light weight aggregates are used to minimize the settlement due to road fills over original terrain and to reduce the load on the driving side.

In total, Alternative *17000* required nearly 60 000 $m^3$ less lime-cement stabilization than Alternative *16000*. However Alternative *17000* required 7800 $m^3$ more counter fill and 2500 $m^3$ more light weight aggregate. The increased counter fill resulted in additional land area encroachment of approximately 7 600 $m^2$. These counter fills are designed with a gentle slope of 1:8 or lower, which allows for more arable area compared to Alternative *16000*, indicated by yellow in Figure 5.

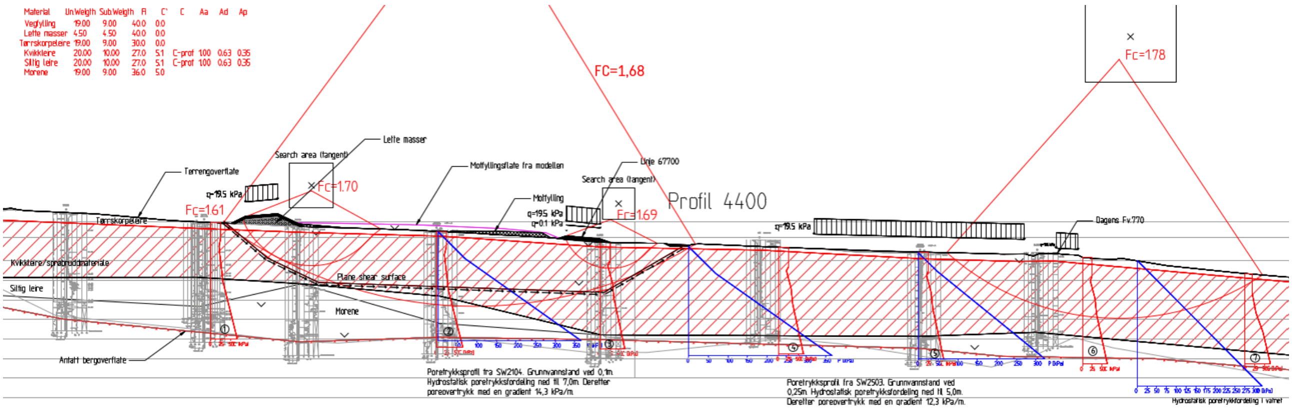

Figure 4. Stability analysis with safety measures for profile 4400 in part 2 of the Fv. 770 road project.

The overall construction expenses were estimated to be 57.5 MNOK cheaper for Alternative *17000.* Greenhouse gas emissions from Alternative 17000 were estimated to be reduced by approx. 811 tons $CO_2$e compared to Alternative *16000.* ***Alternative 17000*** was chosen as the final alternative based on these assessments. Figure 4 shows the safety measures in one of the calculations in profile 4400. The calculation presented use a safety measures, both light weight aggregates and counter fill to achieve the safety requirements. All the safety measures in part 2 presented in a detailed map in Figure 5, previously shown as part in Figure 1 and in Figure 3.

## 6 DISCUSSIONS

The average annual greenhouse gas emission for Nærøysund municipality is estimated to be around 99 000 tons. The municipality has set a goal to reduce its annual greenhouse gas emissions by 30% by 2030 and by 90% by 2050. The overall $CO_2$ emissions for this road project is estimated to be nearly 33 000 tons which is almost one-third of Nærøysund municipality's annual greenhouse gas emissions. Therefore, reducing of $CO_2$ emissions in detailed zoning plan significantly contributes to achieving its sustainability goals.

There has been a significant focus on sustainability when deciding safety measures for ground stabilization in the early phases of the Fv. 770 Kolvereid-Nakling road project. Initially, the $CO_2$ emissions due to lime-cement stabilization were estimated to be about 12 000 tons after the early phase assessments. However, $CO_2$ emissions in the completed detailed zoning plan were reduced to only 3 200 tons, due to alternative stabilization measures.

Extensive optimization of the road alignment was carried out to minimize or eliminate the need for lime-cement stabilization, especially in connections between adjacent local roads to the planned county road. For example, in Figure 3, the early phase iteration of joining of the local roads to the planned county road is shown. This proposed connection would have required lime-cement stabilization for this section for Alternative *17 000* as well. After several iterations and calculations, a new alignment for the local roads was proposed with slightly elevated local road as illustrated in Figure 5. This

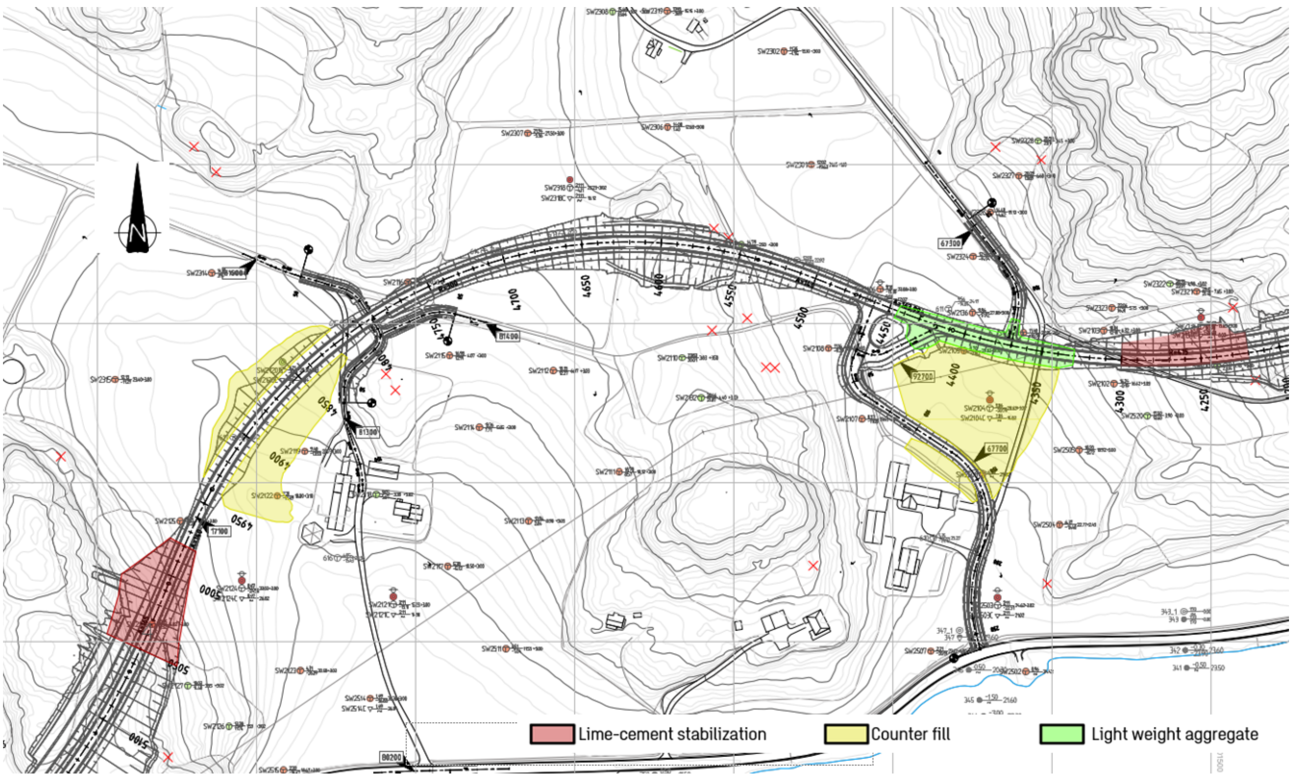

Figure 5. Safety measures in part 2 of the Fv. 770 road project. Red indicates the area with lime-cement stabilization, yellow indicate areas with counter fill and green indicate areas with light weight aggregates in filling.

modification ensured the slope safety requirement, thus avoiding the lime-cement stabilization. Optimizing terrain intervention from adjoining local roads significantly reduced the necessity for lime-cement stabilization. Similar measures were also taken in Part 3 of the project area.

Eliminating several infeasible alternatives in the early phase assessments allowed the limited budget for the ground investigation to be maximized solely focused on the chosen alternatives. It was well known from the early phase that all the alternatives will provide extra cut volumes for the project. To reduce these extra cut volumes certain sections of the road alignment in part 1, for example profile 3200 – 3500, were elevated to reduce the cut in the slope upwards. Adjustment in the road alignments were done ensuring no extra lime-cement stabilization in that section. Similar road adjustments were done in Part 3 (Figure 1) to reduce the cut volume. Counter fills are designed with a gentle slope of 1:8 or lower such that the agricultural land encroached by terrain intervention could be used again for cultivation. Figure 6, Figure 7 and Figure 8 and shows the safety measures for the Kolvereid-Nakling road project for Part 1, 2 and 3 respectively.

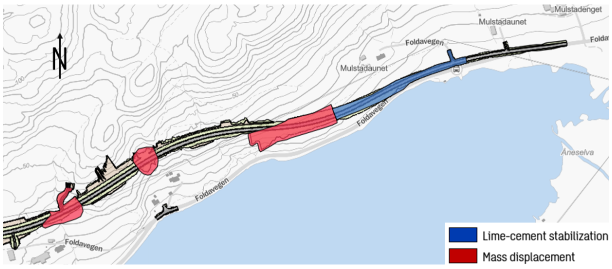


Figure 6. Safety measures for the Fv. 770 road project, Part 1.


Figure 7. Safety measures for the Fv. 770 road project, Part 2.

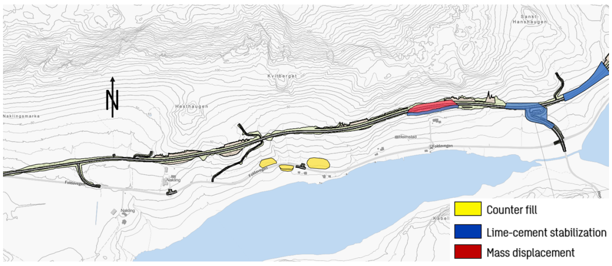


Figure 8. Safety measures for the Fv. 770 road project, Part 3.

Furthermore, Amundsen et al. (2026) highlighted that changes to current regulatory assessment frameworks for the quick clay slope stability in Norway have substantial economic and environmental consequences. The number of critical slopes requiring stabilization for this project could be reduced by over 50%. Following SAUNA recommendations (Watn *et al.*, 2024), combined with assessments done by Amundsen et al. (2026), would eliminate the need for four counter fills and two lime-cement stabilization for this project. The final guidelines from the SAUNA project are estimated to arrive at the beginning of 2026. Further analysis of critical slopes in accordance with the new SAUNA guidelines could significantly reduce construction costs as well as $CO_2$ emission for the project.

## 7 CONCLUSIONS

The Fv. 770 Kolvereid-Nakling road project is a challenging project due to its proximity near to the coastal area with mountainous terrain and prone to ground condition with large areas of marine quick clay deposits and many slopes with severely critical stability. This project demonstrates how geotechnical assessments from a very early phase of the project could shape and lead to solutions adhering to sustainability.

It was apparent from the beginning that the project will require large quantity of safety measures including lime-cement stabilization. Detailed calculations for the possible alternatives followed by an extensive optimization of the road alignments have facilitated to finalize the best alternative which led to reduction in $CO_2$ emission, from 12 000 tons to 3 200 tons, by almost 4 times than that was estimated after initial phase assessments. The final phase assessments in the detailed zoning phase also resulted in cost reduction of 57,5 MNOK.


## 8 ACKNOWLEDGEMENTS

The authors are grateful to Trøndelag County authorities (Trøndelag fylkeskommune), especially planning project manager Bernt Arne Helberg, for allowing us to publish the results from the Fv. 770 road project. The authors wish to acknowledge the support from Sweco Norway, especially team manager of the geotechnics group in Trondheim, Guri Venvik, for encouraging the publication of the results, and the project manager Mari Sagbakken for continuous support.

Engineers Oddbjørn Rønning, Morten A. Pettersen and André Bakken are gratefully acknowledged for their skills and knowledge that made challenging ground investigations possible. The authors would also like to show appreciation to Magnus Inderberg Vestrum for his contribution for the calculation of $CO_2$ emission due to ground stabilization. The authors are also grateful for the good collaboration with the geotechnical laboratory at Multiconsult and ground investigations team at Rambøll for carrying out ground investigations in the lakes for this project.


## 9 REFERENCES


Amundsen, H.A. et al. (2026) 'Slope stability in low plasticity quick clay – Fv. 770 road project in Norway', in Proceedings of the 21st International Conference on Soil Mechanics and Geotechnical Engineering. Vienna.

Faria Jahan (2025) 'A systematic review of blue carbon potential in coastal marshlands: opportunities for climate change mitigation and ecosystem resilience', Frontiers in Applied Engineering and Technology [Preprint].

NVE (2019) Sikkerhet mot kvikkleireskred. Veileder Nr. 1/2019. Available at: https://publikasjoner.nve.no/veileder/2019/veileder2019_01.pdf.

Statens vegvesen (2022) Veileder for klimapassberegninger i infrastrukturprosjekter.

Statens vegvesen (2024) 'Håndbok N200 - Vegbygging'.

Watn, A. et al. (2024) SAfety of Urbanized NAtural slopes (SAUNA) - Stabilitet av naturlige skråninger i kvikkleire - Rapport fra Work-shop 2024-10-22. Trondheim.