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A risk-based approach to the quick clay landslide at Flatanger, Norway – comparison of national regulatory guidelines

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Abstract. The quick clay landslide that struck Flatanger in Mid Norway on March 10, 2023, posed significant challenges for the safe reopening of County Road 6928. Key concerns included the risk of additional slide debris reaching the road, potential for new retrogressive failures from the shoreline, and the stability of the road itself. According to Norwegian Public Roads Administration regulations N200, the safety levels for repairing roads are in general the same as required for building new roads. For Flatanger, this would have implied extensive stabilization measures with substantial environmental, climatic, and economic impacts. Through an analysis of relevant legislation, regulations, and guidelines, this study explores how safety requirements can be interpreted and adapted while maintaining public safety. At Flatanger, a design strategy was chosen that prioritized addressing triggering factors rather than imposing large-scale interventions to achieve absolute safety factor requirements. The post-slide work highlights the importance of a flexible approach to regulatory interpretation and risk management in complex quick clay environments. This paper investigates and compares the regulatory guidelines for Norway, Sweden and Finland in light of the Flatanger landslide. To what extend does these different guidelines open for a risk-based approach, and under which prerequisites? The key findings show that Norway and Sweden have similar guidelines which would have led to the same solution at Flatanger. But also, it is evident that the Swedish regulations are more consistently founded on probabilistic principles. As Finland has less issues with sensitive clays and poor stability, their regulations are to a lesser extent adapted to situations like the one at Flatanger, resulting in massive stabilizing measures if applied.

1 Introduction

Regulatory design guidelines aim to balance levels of risk with the costs required to achieve them. For the stability of slopes and embankments, design requirements are often expressed as absolute criteria, such as prescribed partial factors. However, in cases involving soft and sensitive clays, the measures needed to meet these absolute safety levels can lead to disproportionately high costs. In addition, many existing structures were designed under less stringent regulations, raising the question of whether, and to what extent, their stability should be upgraded to meet current standards.

This paper investigates how the design guidelines in Norway, Sweden and Finland addresses these challenges. Specifically, it explores whether lower safety levels may be acceptable under certain conditions and whether risk-based design approaches offer a viable alternative to the specification of absolute safety thresholds. The discussion is based in insights drawn from the quick clay landslide that occurred in Flatanger, Mid-Norway, in 2023.

2 The Flatanger landslide

On Friday, 10 March 2023, a landslide occurred at Innervika, crossing County Road 6928 in the municipality of Flatanger. The location of the landslide is shown in Fig 1, together with a drone image of the event. Fig 2 shows an overview of the landslide area. The landslide was triggered approximately 100 m upslope from the county road, and the slide material flowed like a liquid river across the road and onwards into the sea. The landslide volume is estimated at approximately 43,000 m³, and the scarp is up to about 150 m wide and 12-15 m high. No people were caught or injured by the landslide, but approximately 100 people were isolated after the road was cut.

The terrain rises westward from the shoreline, continuing uphill past the county road and further upward toward and beyond the landslide area. A stream runs through the entire landslide zone before discharging into the fjord.

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Fig. 1. Location of landslide in mid Norway. Capture from a drome-video of the landslide (Flatangernytt). Video is found here: https://vimeo.com/806840967.

3 Acute phase and early investigations

Soon after the landslide occurred, one of the main goal of the road authorities and local municipality was to open the road as soon as possible for local traffic. From a geotechnical perspective a set of issues had to be resolved to reach a conclusion to ensure safety. These included a combination of site investigation, stability analyses and mitigation work as presented below.

Seabed mapping was performed using multibeam echosounder about one week after the landslide. No noticeable erosion of the seabed was registered. However, results showed that parts of the landslide debris had accumulated on the submarine slope where quick clay was identified.

In March and April 2023, ground investigations were carried out both on- and offshore in the landslide area. Borehole locations were selected based on accessibility for drilling equipment and safety assessments. A total of 22 boreholes were completed onshore and 10 offshore.

The site investigations identified a continuous layer of quick clay[†] extending from the seabed up to the landslide scarp (Fig 3). The quick clay normally consolidated and with low plasticity (plasticity index around 5-6 %). The clay layer generally has a thickness of 5–15 m and is overlain by a coarser sandy material.

To evaluate the impact of debris accumulation on the stability of the submarine slope, and to address whether such a failure mechanism could endanger the road along the shoreline, stability analyses were performed. The analyses were carried out in a profile through the submarine slope where quick clay was identified (Fig. 3). The results indicated that the submarine slope has sufficient stability and that no mitigation measures were required (Fc = 1.41).

Following the landslide event, 5 topographical surveys were performed using a LIDAR equipped AUV from march to June 2023. The last survey was performed on 7 June 2023 (i.e. less than three months after the landslide). Review of the digital elevation model (DEM) revealed ongoing erosion in the stream channel. The stream bed was now 2 m deeper compared to the situation before the landslide. The level of the stream bed was approaching the level of the quick clay, and locally steep and high banks had formed.

There was concern that further erosion could lead to new slope failures and potentially another landslide. Resources were therefore allocated to design and implement erosion protection measures in the stream. The erosion protection was completed in late August 2023.

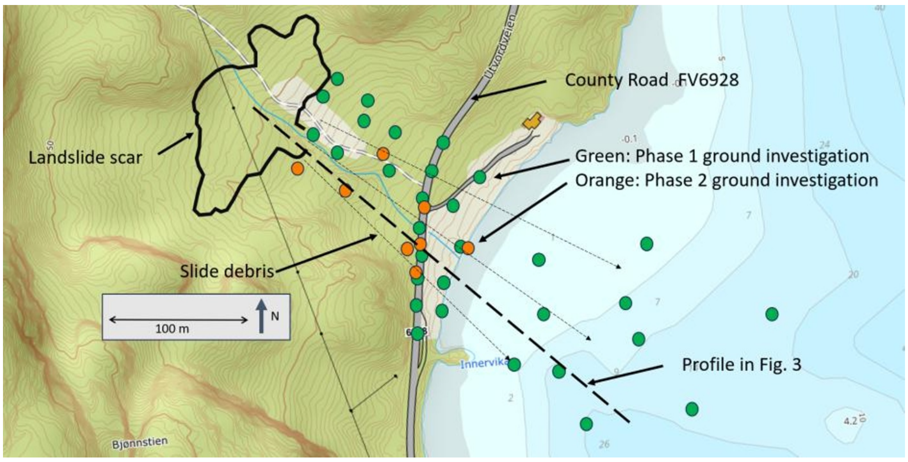

Fig. 2. Overview of the landslide area with location of borings and the cross section in Fig. 3.

[†] Quick clay is defined as clay with a remoulded shear strength below 0,33 kPa (using fall cone ISO 17892-6:2017)

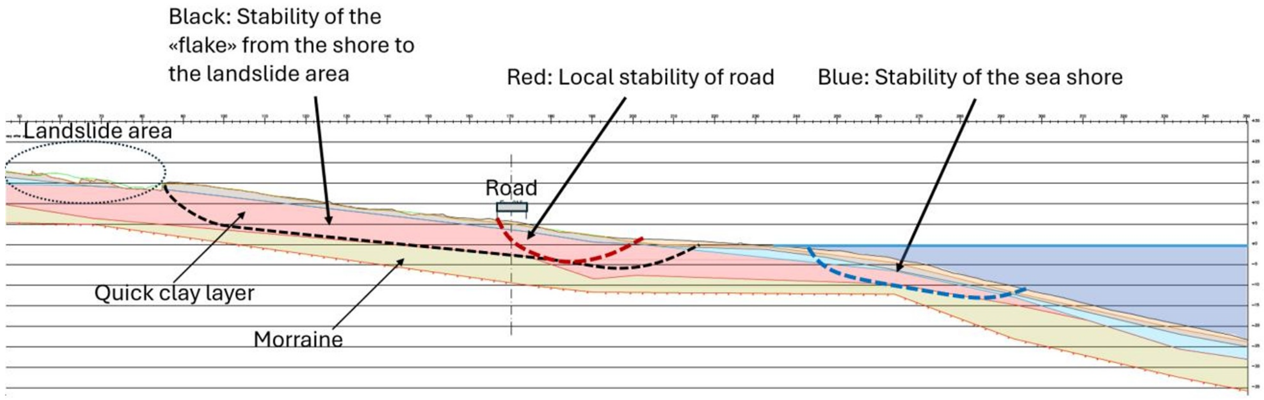

Fig. 3. Section through the bay, with the landslide area upslope to the lest in the profile, and the sea to the right. The figure defines three stability situations.

4 Long-term solution

Once the acute factors had been managed, the focus turned to assessing the stability of the remaining slopes affected by the landslide to determine a long-term solution for the road and adjacent terrain.

Parameters for stability evaluations were derived from CPTU-soundings and a set of triaxial- and oedometer-tests. The main concern was undrained stability, and hence this is the focus in the paper. Undrained safety factors (F_{cu}) were evaluated for both translational (black) and semi-circular slip surface (red) in the vicinity of the road (see Figures 3-4). The calculation tool was GeoSuite/BEAST which uses a limit-equilibrium approach. One profile was calculated using FEM/Plaxis for verification of the LEM-results. Both methods gave similar results.

4.1 Stability – Phase 1

Stability analyses were performed along five profiles using parameters derived from Phase 1 investigations [12].

The analysis concluded that:

- The road's local stability ($F_{cu} \approx 1.1$-1.2) falls below the thresholds specified for new road projects in quick clay areas according to current national guidelines (Section 6.1).
- Overall stability of the slope between the sea and the landslide area is also very low ($F_{cu} \approx 1.0$-1.1).
- Mitigation measures intended to lower driving forces (such as unloading) or increase resisting forces (such as counterfill) at one location along the road leads to reduced stability at other locations on the slope. This behaviour is typical for long, uniform near-shore slopes where the infinite-slope conditions dominate.
- All drained analyses showed safety factors above absolute criteria

Consequently, the situation could not be considered satisfactory, and realistic improvement options were limited to extensive measures such as major ground reinforcement, bridge construction, or road realignment.

A second round of ground investigations was launched to refine the selection of geotechnical parameters and support informed decisions on a permanent solution.

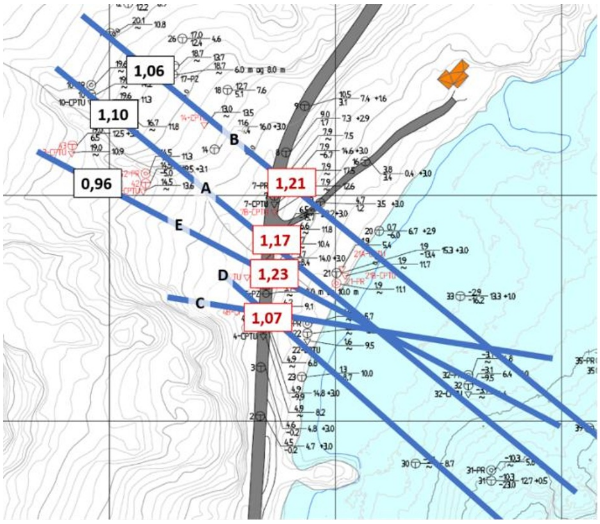

Fig. 4. Summary of F_{cu} for the remaining slopes after the landslide based on data from Phase 1 site investigation.

4.2 Stability – Phase 2

Supplementary investigations in Phase 2 were planned to obtain higher-quality parameters for stability analyses. High-quality block samples were planned at two boreholes, along with additional CPTU soundings. During the fieldwork, it became clear that block sampling was impracticable due to the high silt content in the clay and because the material contained large fragments of shells and stones, which damaged the sample. The investigation programme was therefore adjusted to include additional CPTU soundings and conventional 54 mm piston sampling. The improved parameter basis was thus achieved through increased data quantity.

Calculated stability for the road and shoreline slope is summarised in Fig 5. In all cases, safety factors for drained analyses are well above 1.6. For total stress analysis (i.e. undrained) the following results were obtained:

- Local stability of the road is F_{cu} ≈1.3-1.4
- Analyses using a planar or translational slip surface black) shows that the overall stability of the slope between the sea and the landslide area is F_{cu} ≈1.0-1.16
- Stability of the shoreline slope is close to 1.5

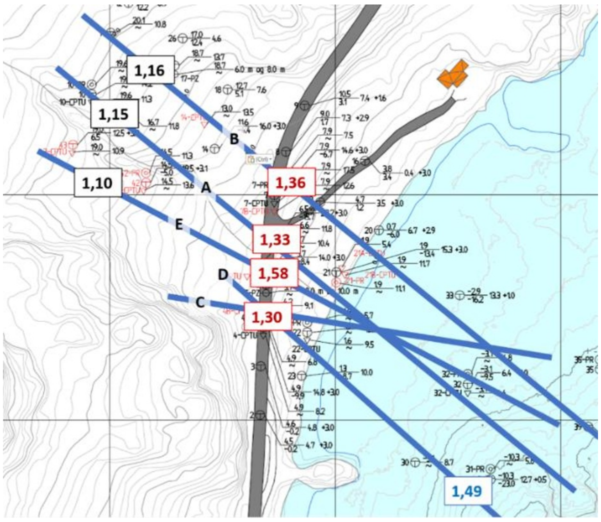

Fig. 5. Summary of F_{cu} for the remaining slopes after the landslide based on data from Phase 2 site investigation.

5 Assessment of mitigation measures

Several mitigation strategies have been examined to improve stability in the landslide area at Flatanger. The options differ significantly in terms of effectiveness, cost, construction risk, and environmental impact. The following subsections outline the key considerations for each measure.

5.1 Bridge or relocation of road

A bridge over the landslide area is a feasible solution, but it would come with a high economic and environmental costs. It should also be noted that this bay is one of many similar bays with quick clay in the region. If this area is deemed too hazardous for road traffic, should the same high-cost remediation measures then be required at all comparable locations?

Relocation of the road would imply construction of a totally new road through a rocky and steep mountainous area. This is a last-resort high-cost solution.

5.2 Counterfill in the shore zone

By placing masses in a counterfill on the downslope side of the road, a stabilizing effect is achieved for both local and overall stability.

The challenge with this measure is that it increases the driving forces along a critical slip surface passing through the quick clay and exiting in the fjord. Stability in the nearshore slope decreases from F_{cu}= 1.49 to 1.34 after the counterfill is placed. This significant reduction leads to a requirement for a F_{cu}≥ 1.6 under NVE guidelines 1/2019 [3]. Meeting the requirements of NVE 1/2019 and ensuring sufficient road stability cannot be achieved solely through the use of a counterfill. Additional measures such as ground improvement would be required in such case.

5.3 Mass replacement in the road with lightweight fill

By replacing the existing materials in the road body with lightweight fill, a weight reduction is achieved that improves local stability. In this case, a solution has been considered where approximately 2 meters of the road body is excavated and replaced with lightweight material. For the road, it is possible to meet the Norwegian regulatory requirement of F_{cu} ≥1.6 with mass replacement. At the same time, while the road gains improved stability, the overall area stability (black planar slip surface in Fig. 2) is reduced.

5.4 Ground improvement

Ground improvement using, for example, lime-cement technology can improve local stability of the road and provide some improvement in overall area stability. The challenge with this measure is that stability worsens during the construction phase due to build-up of excess pore pressure, as well as the cost implications. During construction, local stability can be improved with a counterfill, but as shown in section 6.2, this leads to a deterioration of stability in the shoreline/slope, which should not be done. Furthermore, the effect on the stability of the planar slip surface (black in Fig. 2) is largely theoretical, as there is poor interaction between the relatively soft clay and the stiff cement.

5.5 Terrain relief

Decreasing the driving forces in the slope by removing soil in the remaining masses near the landslide area would improve overall stability along the planar slip surfaces shown in Fig. 2 (see black line). This measure can be combined with, for example, mass replacement of the road.

The challenge with this measure is that extensive excavation is required to achieve an effect. Calculations indicate the need to excavate around 3.5 m over a length of 50 m close to the landslide area. Ground investigations show very soft soils and quick clay in the subsurface, and an extensive construction phase with significant mass transport will pose a risk of triggering a landslide event. Excavating 3.5 m means digging down into the quick clay. At the same time, a large amount of the natural environment would be destroyed.

6 Comparison of national guidelines

This chapter compares national guidelines in Norway, Sweden, and Finland regarding stability requirements for roads affected by quick clay landslides, focusing on safety factors, treatment of existing roads, and the use of risk-based approaches for a situation following the Flatanger landslide. The main concern is the undrained failure mode since the drained analysis fulfils all requirements at the case of the Flatanger landslide.

6.1 Norway

There are currently no Norwegian regulations that specifically address cases where a road is affected by a quick-clay landslide and is not subsequently rebuilt. The most relevant guidance available is Section 1.4.4 of the National Public Road Administration (NPRA) Road Standard N200, which outlines safety requirements for existing roads. This section states that "existing roads should, as a general rule, meet the same safety requirements as new roads", but that deviations may be permitted following an overall assessment. A translation of the text that opens for an exception from the general rule is "*For minor improvements to existing roads, it may in some cases, subject to agreement with the client and based on socio-economic considerations, be accepted that the safety level in geotechnical design does not meet the same requirements as for new roads. In such cases, the project shall undergo an extended design review*."

Depending on the planned measures, area/quick clay stability requirements under NVE Guideline 1/2019 [3] may apply.

NPRA Circular 2014/08, Guidelines for risk acceptance criteria for landslides on roads [2], is also pertinent to this assessment. The latter presents a risk-based approach for e.g. rockfalls, debris blows and snow avalanches stating that an acceptable risk level for an existing road can be achieved by implementing measures that reduce the likelihood of a new landslide event. Although the guideline explicitly states that quick clay landslides are not covered by the risk acceptance criteria, the principle in the safety philosophy is relevant.

Finally, it is also relevant to highlight SVV Report 801 "Handling of Critical Ground Conditions" [5]. For existing roads in quick clay areas, an approach is recommended that focuses on triggering causes and their removal, rather than deterministic requirements of safety factors.

In sum, the Norwegian requirements for calculated stability for a new road in the Flatanger area includes:
i) Local stability of the road
- $F_{cu} \geq 1.60$

ii) Local stability of any stabilizing counterfill
- $F_{cu} \geq 1.61$ (1,4*brittleness factor (1,15))

iii) Overall stability of remaining quick clay slopes in the landslide area
- $F_{cu} \geq 1.40$ or percentage improvement.
- $F_{cu} \geq 1.61$ for measures that worsen stability.
- $F_{cu} \geq 1.20$ for slopes outside the intervention area. Requirement for erosion protection.

6.2 Sweden

The main regulations in Sweden for stability requirements of slopes and infrastructure are presented in the IEG report 4:2010 [9] which describes requirements for natural slopes and slopes with existing buildings. SGI report 8 [7] is also an important document for assessing the stability of slopes. The Swedish Transport Administration Publ 2009:46 [6] gives requirements for the stability of roads and railways. Recently the Swedish Transport Administration released a report giving recommendations for the use of percentage increase for roads and railways; Publication 2025:165 [8].

Based on the above, the Swedish requirements for calculated stability for a new road in the Flatanger landslide area would be:
i) Local stability of the road
- $F_{cu} \geq 1.65$

ii) Local stability of any stabilizing counterfill
- $F_{cu} \geq 1.65$

iii) Overall stability of remaining quick clay masses in the landslide area
- $F_{cu} \geq 1.40$ or percentage improvement

According to SGI report 8 [7] and Publication 2025:165 [8], a percentage-improvement methodology may be applied in cases involving existing infrastructure where stability is inadequate, but where conventional reinforcement measures would be disproportionate relative to the achievable safety benefits. This situation commonly arises when contemporary design requirements are imposed on older road or railway structures.

SGI report 8 [7] further indicates that deviations from prescribed safety-factor requirements may be acceptable when justified by technical, economic, or environmental conditions. However, such deviations are contingent upon demonstrating a reduction in failure probability, supported by appropriate risk and probability analyses.

6.3 Finland

The regulations in Finland mainly point to the requirements of Eurocode 7 where the national Transport agency requires $F_{cu} \geq 1.4$ while the environmental ministry (housing) require $F_{cu} \geq 1.5$ for undrained analysis [10, 11].

If the factor of safety of an existing railway is below the current requirement, but remains above 1.3, the regulations allow this safety level to be accepted provided that the site is monitored (usually inclinometers). A $F_{cu} < 1.3$ is not permitted. In such cases, stability must be improved to meet the same requirements that apply to new construction. By convention, this practice is applied to roads as well.

Hence, regulations in Finland include some level of risk-based design through requirement of monitoring, but only with an explicit lower limit of the factor of safety. No concept of percentage improvement is mentioned.

Finnish requirements for calculated stability for a new road in the Flatanger landslide area would include:
i) Local stability of the road
- $F_{cu} \geq 1.4$ or minimum 1.3 with monitoring

ii) Local stability of any stabilizing counterfill

- $F_{cu} \geq 1.4$

iii) Overall stability of remaining quick clay masses in the landslide area

- $F_{cu} \geq 1.4$ or minimum 1.3 with monitoring

7 Selected mitigation strategy at Flatanger and comparison with Sweden and Finland

7.1 Norway

The current slope stability at Flatanger is below regulatory safety-factor requirements but not critically low. Road stability is acceptable event though it does not meet new construction standards. While the area as low undrained stability, its drained stability is high, and a major trigger would be required to activate an undrained failure surface across the entire area. Even the previous landslide event did not achieve this. Thus, despite low calculated undrained values, the area can be regarded as robust.

As it was challenging to find mitigation measures that address both local and area stability in both the permanent and construction phases, a strategy aligned with NPRA 2014/08 [2] and NPRA Report 801 [5] was recommended. This focused on reducing actual risk by addressing triggers rather than strictly meeting quantitative stability requirements. Because regulations do not set specific criteria for this approach, professional judgment was required to evaluate acceptable safety levels.

For the road and the nearshore slopes as a whole, three main triggering mechanisms were evaluated, along with measures designed to reduce the likelihood of such events.

i) Traffic load on the road

- Scenario: High traffic loads could theoretically lead to a local instability, which in turn could trigger a quick clay landslide.
- Risk-reducing measure: Narrowing the road to a single lane to reduce traffic load.

ii) Erosion in the stream

- Scenario: Erosion in the stream could trigger a new landslide event in the quick clay.
- Risk-reducing measure: Erosion protection for the stream.

iii) Landslide along the shoreline slope

- Scenario: A landslide along the shoreline could propagate backward through the quick clay, involving the road and remaining quick clay in the entire bay.
- Risk-reducing measure: No measures necessary. The shoreline slope has calculated stability that meets N200 and NVE 1/2019 requirements for overall area stability.

Note that the guidelines in Norway have no requirement for quantitative analyses of how the mitigation measure affects any probability of failure, only qualitative.

7.2 Sweden

The Swedish regulations are somewhat similar to the Norwegian ones for the Flatanger-case. The requirement for the F_{cu} for the road and involved stability mechanisms is 1.65, and thus higher than current stability. It would have been difficult to reach any of the required F_{cu} using the measured presented in section 5.

Sweden opens for the use of a risk-based approach in the guidelines. However, if a risk approach was adopted, the Swedish regulations would require stricter requirements than in Norway to document and quantify the impact of the risk reduction measures, both in terms of the response of the soil on the measures, and risk/probability analyses.

It is worth noting that the Swedish regulations have a consistent base in probabilistic and risk principles with regards to safety factors and percentage improvement. With more detailed investigations, the requirement for safety factor for existing slopes is lowered. The levels of percentage increase is a result off probabilistic analyses related to a comparison of probability of failure.

7.3 Finland

Local stability of the road meets the minimum requirement for $F_{cu} \geq 1.3$, so that one can accept the situation given that a monitoring program is implemented. However, the stability of the “flake” is well below 1.3. The Finnish regulations do not open for a risk approach to this stability situation, and an increase of F_{cu} up to the same level as a new road is required, i.e. $F_{cu} \geq 1.4$.

Of the possible mitigation measures listed in section 6, only soil improvement has the potential to raise the safety to such a level. The stabilization measures would most likely be extensive in the whole area of the bay. But given the low initial stability it not obvious that the area is robust enough to handle the destabilizing effect of the installation phase of e.g. lime cement columns. A bridge, or relocation of the road, would be the alternatives.

8 Discussion and conclusions

The Flatanger landslide proves is an interesting case to compare geotechnical regulations at the national level. Table 1 summarizes the regulations in Norway, Sweden and Finland together with the resulting measures applied at Flatanger.

The Finnish regulations stand out in this comparison as being the “strictest” as it does not open for percentage improvement. The background for this is most likely that in most cases it is possible to achieve the required safety levels without extensive measures in Finland. In Norway and Sweden however, slopes with soft and sensitive clays with low initial stability is a common issue. Both countries have addressed this issue in a similar fashion with percentage improvement and openings for risk-based approaches. Still, the Swedish regulations stand out in the sense that they are more

Table 1. Summary of requirements and safety measures.

	Norway	Sweden	Finland
F_{cu} local stability, new	1.6	1.65	1.4
F_{cu} local stability, existing	1.6	1.65	1.3-1.4
F_{cu}, area stability	1.2-1.4	1.4	1.3-1.4
Is percentage improvement method allowed?	Yes	Yes	No
Risk approach method allowed?	Yes, but not explicitly	Yes, explicit requirements	Partially. Monitoring if F_{cu} is between 1.3 and 1.4
Mitigation solution at Flatanger	Risk based approach. *Qualitative* documented reduction of probability of failure. Remove triggering agents (chosen solution)	Risk based approach. Documented *quantitative* reduction of probability of failure. Remove triggering agents	Extensive soil stabilization
Cost of mitigation (1 to 5 scale)	2	1 (quantified risk analyses can give more optimal mitigation measures vs. Norway)	5

explicitly and consistently based in probabilistic principles compared to regulations in Norway.

Concerning safety levels, all national guidelines are relatively similar, with Finland on the lower side. However, in the case of slopes where no quick clay is involved, the safety requirement is similar between all three countries. It is further noted that the Norwegian regulations operate with a requirement of $F_{cu} \geq 1.2$ for slopes outside the design area, where an initial landslide could evolve into a retrogressive landslide involving the design area.

Norway has thousands of kilometres of existing roads constructed according to standards from an earlier era. Some of these roads are located in areas with poor ground conditions. Given the current policy emphasis on upgrading existing roads rather than constructing new ones, it is necessary to develop a consistent approach for dealing with inadequate stability conditions.

Bringing all existing roads up to the same safety level required for new road construction would result in very high socioeconomic costs. Therefore, adopting a risk-based approach is essential. In this context, it may be valuable to draw inspiration from the Swedish regulatory framework, which already incorporates risk-based principles for similar challenges.

The Norwegian Building Technical Regulations (TEK17) address natural hazards, including landslides, using requirements based on annual nominal probability. However, quick clay landslides differ from hazards such as snow avalanches or floods because they are onetime events without meaningful return periods. To enable more risk-based approach to quick clay hazard assessment, this discrepancy must be resolved. A central question arises: *What is the annual nominal probability for a landslide in a natural slope?* To further evolve Norwegian guidelines, it is recommended to address this issue and to look to Swedish regulations for examples on how to implement a consistent probabilistic framework.

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