Internationales Symposion
INTERPRAEVENT 2004 – RIVA / TRIENT

CONSTRUCTION WORKS AND THEIR TECHNICAL-ECONOMIC EXPEDIENCE RIVER SAFETY MEASURES IN QUICK CLAY AREAS, THE MERÅKER PROJECT IN NORWAY

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ABSTRACT

The Norwegian Water Resources Directorate (NVE) started a major project mapping the risk of landslides in quick clay areas in collaboration with the Norwegian Geotechnical Institute (NGI) in 2000. Several areas with a high probability of landslides and risk of severe damage and loss of lives have been uncovered. The Kråkstadmarka area in the Meråker municipality in Central Norway is such an area. This situation here was considered alarming regarding the danger of initial sliding and high probability that this could initiate a major landslide though the populated area. The Norwegian government allocated extraordinary funding for river safety measures here. The measures in the main river consist of constructing a heavy stabilising embankment along the river bank and stabilising and securing the river bed against scour. Safety measures along the tributary consist of raising the river bed 3 meters and relieving the top of slopes along the tributary. A major concern, both during construction and in the final safety measures is to minimise the impact on the natural river environment.

Key words: quick clay, landslides, stabilization

INTRODUCTION

Due to geographical constraints most available land for housing, infrastructure and farming in Norway lies on either marine or alluvial deposits and many areas are exposed to a risk of either flooding, erosion or landslides. Many rivers in Central Norway experience degradation. Degradation in the lower parts of these rivers is to a large extent caused by both gravel extraction and excessive erosion protection works of the banks. In the upper areas of these rivers there is a naturally low supply of gravel and these areas are degrading in the long term. This degradation is especially dangerous in areas along the river that are bordered by quick clay underlying housing and infrastructure. Erosion of the river bed and banks has been the main cause of many large quick clay slides in Norway (Andersen, 1996). Quick clay landslides are especially dangerous in that they may cause great damage with a high risk of loss of life within a very short time span and with no initial warning signs.

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The Norwegian Water Resources and Energy Directorate (NVE) are presently funding a project performed by The Norwegian Geotechnical Institute (NGI) to classify quick clay areas by probability, consequence and risk within 2000-2005. The project and methodology used is presented under the congress theme *Risk analysis and assessment*: (Classification of quick clay zones to pinpoint areas of high risk, Endre, E & Fergus, T). During the project several areas with a high risk of severe damage caused by quick clay slides have been exposed along both large rivers and minor streams. Flooding and erosion is often the triggering factor in initiating a quick clay landslide. The development and application of river safety measures to stabilise the situation and reduce risk is part of the program. This paper describes the technical and ecological aspects of these safety measures in the case of Kråkstadmarka, in the municipality of Meråker in Central Norway.

LOCATION, HYDROLOGY AND NATURAL ENVIRONMENT

Meråker lies within the watercourse of the Stjørdal river which is one of the major rivers in Central Norway (figure 1). It lies in the county of South Trøndelag with some minor parts of the catchment lying in Sweden. The size of the catchment area is 2112 km^2 at the outlet in the Trondheim fjord and. The highest point within the catchment is 1249 masl. and the mean height of the catchment is 505 masl. In the upper part of the catchment 5 rivers join to form the main river, the Stjørdal river at Meråker. The main river flows from east to west and Meråker lies approximately 50 km from the main rivers outlet. The marine level at Meråker is at approximately 180 m.

Fig1: Map of the Stjørdal watercourse

Kråkstadmarka is situated approximately 2 km downstream of Meråker and forms an adjacent plateau to the right hand side of the river looking downstream. The catchment area upstream of Kråkstadmarka is 815 km^2. The height of the plateau upon which Kråkstadmarka is situated is approximately 115 masl. The plateau is intersected by the small stream Smemobekken

(catchment area 1.4 km^2) and this has its outlet to the main river at 85 masl. This stream is steep with no storage area within its catchment. The mean annual flood in this small stream is calculated to 2.7 m^3/s. A housing scheme consisting of about 50 houses, farms, power lines and a main road are all situated within the Kråkstadmarka area.

The upper parts of the Stjørdal catchment is strongly regulated for hydropower and the annual hydropower production is 590 GWh. Regulation of the upper catchment is shown in red on figure 1.

The mean annual discharge in the Stjørdal river at Kråkstadmarka is 32 m^3/s and the mean annual flood is 250 m^3/s. The largest recorded flood occurred 1947 and the discharge was recorded to 850 m^3/s.

The Stjørdal river is among the 5 best salmon rivers in Central Norway. The national Wild Salmon Committee has proposed it to be a national salmon river. The mean annual salmon catch is approximately 9 tons. No salmon fry have been registered in the Smemobekken stream but trout fry have been registered in the lower 200 m.

MAPPING OF QUICK CLAY DEPOSITS AT KRÅKSTADMARKA

Before the development of the Kråkstadmarka housing scheme a soil drilling programme was carried out privately. The depth (less than 10 m) and range of the programme was not sufficient to uncover the large quick clay deposits underlying the planned housing scheme.

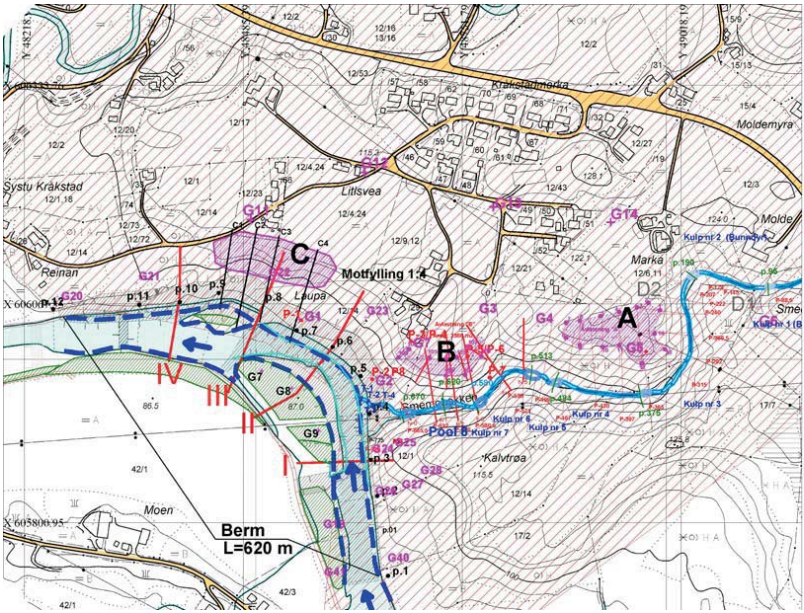

Fig2: Mapped quick clay deposits at Kråkstadmarka

A drilling programme to map the extent of quick clay and to plan the dimensioning of safety measures in this area was started in the autumn of 2001. This was part of the ongoing program to enhance security against clay slides initiated by NVE in 2000. The drilling exposed a much more dramatic situation than was expected from previous investigations. It was found that quick clay underlies the whole area that has been built upon and that the deposit has an incline towards the Smemobekken stream and the main river. The thickness of the quick clay layer is more than 10 m. Drill points along the river banks show that the quick clay layer lies about 1 m below the low flow level. A 4 m deep scour hole in the river bed was also uncovered during these investigations. The calculated stability towards the Smemobekken stream and the main river was alarmingly low. Geotechnical expertise deemed the situation critical in regard to the danger of initial landslides and a deeper larger landslide being triggered by further erosion. Approximately 90 people would be in danger in the event of a landslide. Figure 2 shows the Kråkstadmarka area with mapped quick clay deposits.

RIVER SAFETY MEASURES AND REMEDIAL ENVIRONMENTAL MEASURES

Emergency measures

Planning of emergency measures were initiated shortly after the results of the drilling were known. Technical, legal and environmental aspects were important issues that had to be dealt with swiftly during this phase of the project. A close collaboration with the county environment authorities was established early on in the project and concerns regarding salmon habitat were taken into consideration during construction. This contact has also been valuable in planning the permanent safety measures.

The primary aim of the emergency measures was to stop the ongoing erosion of the bed and banks of the main river and thereby reduce the danger of a major quick clay slide. These initial emergency measures were carried out during the autumn months of 2002 and were funded by an extraordinary funds provided by the government.

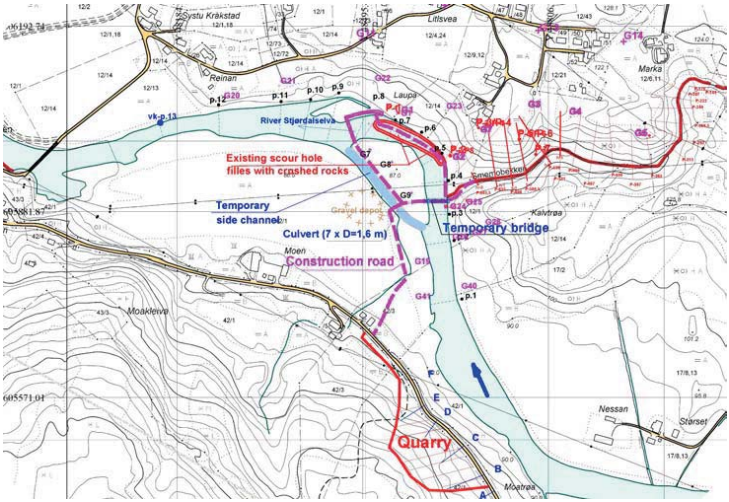

Fig3: Sitemap showing location of quarry, road, dam and emergency measures

A quarry was established not far from the site on the left hand side of the river (figure 3). Blasting was kept to a minimum for security reasons (due to its vicinity to the quick clay area) and vibrations were monitored on both sides of the river. The ground water level was also closely monitored during this period as this is a crucial factor in the release of an initial slide. One main reason for establishing the quarry close to the construction site was to minimise the environmental costs and the strain on local roads.

The emergency measures consisted of filling in the 4 m deep scour hole and securing the river bed by plastering it along a 130 m reach with a width. Figure 3 shows the location with quarry, road, river diversion and emergency measures. A total of 3000 m^3 of rock was used to secure the river bed at the scour hole. The main river was dammed 50 m downstream of the scour hole. The dam was used as a bridge to transport rock for the bed plastering. Part of the road built in the river on the right hand side will be used as part of the permanent safety measures. The flow of the river was diverted through a natural flood way that had been closed previously and a culvert using 7 turbine pipes was used to construct a bridge here. The power station kept the flow at a minimum (12 m3/s) during the construction period of 3 weeks.

In placing the dam and transport roads it was taken care to avoid disturbing a registered spawning habitat for salmon. The dam was remover immediately after the emergency measures were completed and a bridge up steam the location was established. This bridge is in use for constructing further stabilisation works. The emergency safety measures took 3 weeks to complete.

Further river safety measures

Further river safety measures were deemed necessary both to hinder erosion with a risk of puncturing the quick clay layer and to stabilise slopes. This was necessary in both the main river and minor stream Smemobekken. Figure 4 shows stabilisation works in the main river in September 2003.

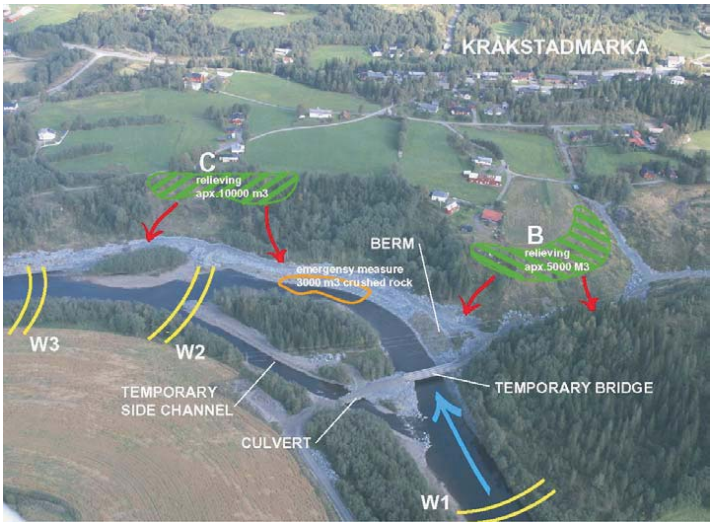

Fig4: Stabilisation works in main river, September 2003

The stabilisation measures in the main river consist of erosion protection and berm along the right hand side of the bank and widening the river, securing the bed by plastering and building 3 weirs. The slope down to the river has also been relieved by removing mass at the top of the slope. The flood way to the left of the river that was previously closed will be reopened and this will also relieve pressure on the river bed.

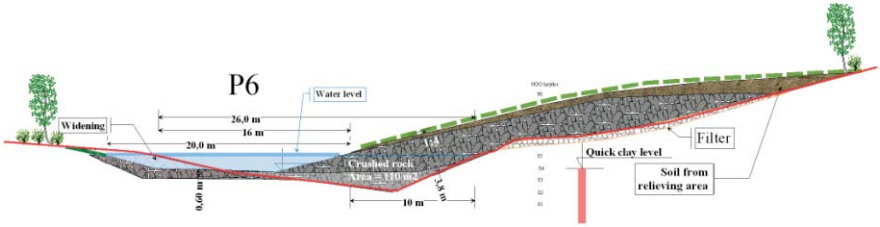

Fig5: Profile of main river with berm and widening at p6

The river bank has been extended into the river by 10-12 meters between p8 and p5 (figure 3 and figure 5). This was done to create a counterweight to the quick clay layer along the right bank. The extension of the bank has been compensated by removing the outer part of the vegetated bank along the left side and the river has in effect been widened. The total length of the berm is 620 m and the volume of rock used here is 50 000 m^3. The total length of erosion protection along the right bank is 1100 m. The bed has been secured by plastering along a reach of 400 m and a total volume of 10 00 m^3 of rock has been used for this purpose.

A total volume of 25 000 m^3 of soil has been removed to relieve pressure and reduce the gradient of the slope at 3 areas along the top of the slope to the main river and stream (figure 4 and 7). This soil will be used to cover the counterweight berms along the main river and stream. The slope to the river will after removal of soil have an inclination of 1:2.5.

Stabilisation and erosion protection measures in the stream consist of raising the river bed level by covering this with rock (figure 6) as well as relieving slopes. The river bed is raised 3 m from the outlet of the stream into the main river and to 550 m upstream.

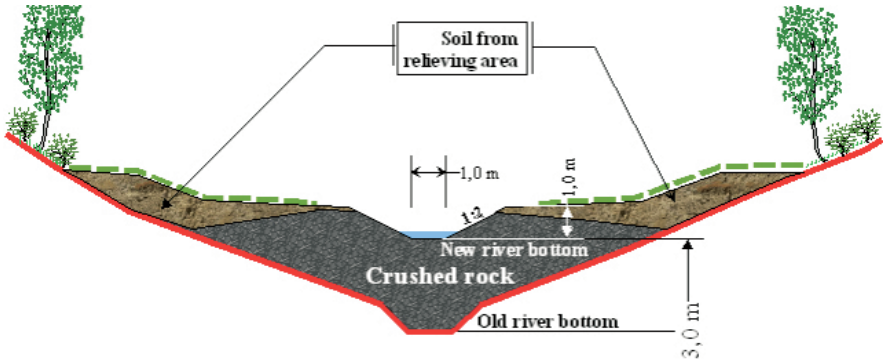

Fig6: Profile of stream showing raised stream and valley bed

The raising of the river bed will gradually be reduced from this point until 720 m from the outlet. A total volume of 30 000 m^3 rock will be used here.

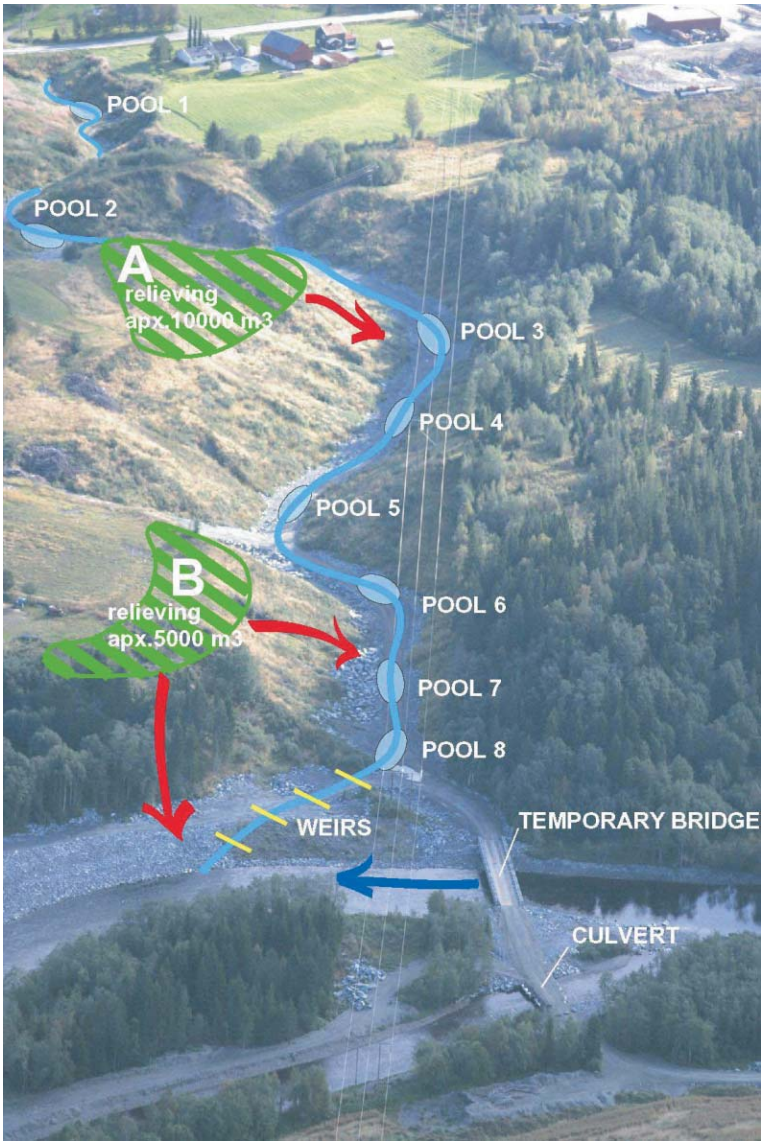

Fig7: Stabilisation works in stream, September 2003

The temporary bridge across the river will be removed when construction work is finished.

Remedial environmental measures

The conservation of salmon and trout habitat is a major concern in the Stjørdal river. There has before and during the project been a good dialog and cooperation between fish scientists, river owners and river engineers. The river safety measures will result in a loss of spawning grounds, rearing areas and habitat for both juvenile and adult salmon. A number of remedial measures are planned to compensate for this.

- The stone berm along the right bank will be formed so as to copy a natural river bank as closely as possible. This will be done by setting out stones and the main line of the bank in an irregular way. Mass and roots removed from the slopes will be placed on these berms and this will ensure that these are rapidly vegetated. This is of importance for creating habitat for juvenile fish especially.
- Large stones and deflectors in the main river will be set out to create habitat for adult fish.
- 3000 m^3 of gravel will be introduced both to improve habitat and if possible restore spawning grounds.
- A series of weirs at the outlet of the main stream together with four pools further upstream will ensure that rearing habitat in this stream is not lost.
- Gravel will also be introduced here.

The cost of the remedial measures are calculated to be approximately 10% of the total costs of the construction works.

CONCLUSIONS

The construction works will reduce erosion and increase stabilisation of the Kråkstadmarka area. We do not yet know if the remedial measures will have the required affect upon biological life along the effected stretch of river, but this will be monitored. We do know that other areas in Norway have the same risk of damage from quick clay slides initiated by erosion. Both the legal, technical and environmental and experience gained in carrying out the emergency measures, further river safety measures and remedial measures will be useful in equivalent situations.

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