The Quick Clay Landslide in Rissa, Norway.
The Sliding Process and Discussion of Failure Modes

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SYNOPSIS
The paper gives a detailed description of the Rissa land-slide. This has been possible due to eyewitnesses and films taken of the actual sliding process. Attention is given to events of special importance to the understanding of quick clay failure modes. Failure mechanisms of the Rissa-slide are discussed.

Ground conditions, determination of the soil strength parameters and results of stability calculations are described.

INTRODUCTION
Rissa is situated just north of the city of Trondheim, Central Norway. The «Trondheim region», together with the «Oslo region», are the two large marine clay areas in Norway.

The Rissa land-slide, which took place April 29, 1978 is the biggest in Norway in this century. The slide area covers 330,000 m² and the slide debris is of the order of 5–6 million m³. The slide area was a typical Norwegian farming community, made up of small farms and single family homes. All together 7 farms and 5 single family homes were taken by the slide or had to be abandoned for safety reasons. About 40 people who were within the slide area when the sliding started, only one was killed. The others escaped, many under extremely dramatic circumstances.

The slide is exceptionally well documented. A large number of people actually saw the slide taking place, and amateur films were also taken showing the most dramatic scenes. Due to these fortunate and unique circumstances, we today have all necessary information on why and how the slide took place. For illustration a model has been made of the slide area, and the whole sequence of events has been reconstructed. The most interesting stages are shown and discussed in this paper.

Figure 1 shows the model with location of buildings and road and final slide boundary. The surface topography has a gentle slope from the foot of the mountain range, elevation 30–35 metres, towards Lake Botnen, elevation 0.5 metres. For a profile through house B this represents an average slope of 1:10.

THE SLIDE WAS A 2-STAGE PROCESS
The landslide was initiated at farm A, located at the very edge of the final slide area, see Fig. 1. It was caused by a 700 m³ earth fill placed down by the shore of Lake Botnen. For two days excavation works for a new wing to the existing barn had been carried out, and the surplus masses had been placed down by the shore line to extend the land area of the farm. These earth works had just been terminated when suddenly 70–90 m of the shore line slid out into the lake, including half of the recently placed earth-fill (Grande 1978). The size of this slide is illustrated in Fig. 2. The slide edges were 5–6 m high and extended 15–25 m inwards from the water line.

The slide now developed retrogressively in the south western direction, i.e. successive minor slides took place over a relatively long period (stage 1). Each
Fig. 2. The initial slide.

Fig. 3. Retrogressive slide pit.

Fig. 4. The main slide (flake-type).

Fig. 5. Gate opening after main slide.

Fig. 6. Farm C slides out.

Fig. 7. Final slide area.
slide resulted in a complete liquefaction of the quick clay, and the debris was literally pouring into the lake like streaming water. This process went on for about 40 minutes. (The time elapsed can be established fairly accurately due to recordings made when electric cables were broken). By that time the slide area had the shape of a long and narrow pit with a narrow gate towards the lake as shown on Fig. 3. It was expected that the slide would not proceed much further. The length was now 450 m covering an area of 25-30 000 m² (6-8% of the final slide area). If the sliding now had come to a standstill, the slide would have been registered amongst our many minor quick clay slides.

However, it was at this point that the real catastrophe started (stage 2). Almost immediately after the retrogressive sliding had reached the boundaries shown in Fig. 3, a large flake-type slide started. (Gregersen 1979). An eye witness watching the sliding from a position in the mountain in the background explains: «Suddenly an area of about 150 × 200 m including building B sank down and moved monolithically towards the lake, not through the existing gate opening but in the direction of the terrain slope (see Fig. 4). The downstream end of the lake, where the soil was coming up through the surface crust, was down by the bottom road. The debris flowed down the sloping surface partly on top and partly by ploughing into undisturbed ground on its way towards the lake. The speed of motion was moderate, of the order 10-20 km per hour. An other eye witness positioned at the downstream end of the slide, described: «The surface rose about 4 m and came towards me like a sea wave». Most of the slide debris flowed into the lake while some came to a stop in the compression zone between the lake and farm E. A new large gate had now been opened into Lake Botnen, Fig. 5.

Immediately afterwards a new large flake-type slide started, taking farm C as shown on Fig. 6. The size of this flake was almost as big as the first. On an amateur film the housing area of the farm can be seen floating as an intact unit down the quick clay river at a speed of 30-40 km per hour. The owner of farm C, watching his home being destroyed from a standing place facing the slide area, tells: «A minute after the first large slide was over a crack developed round my farm. It looked as if a brown belt had been placed on the ground. In the next instant the whole area was moving towards the lake at a high speed».

Now a series of slides took place over a short period of time. In matter of a few minutes the slide propagated along the mountain side and up to farm D where the sliding stopped. Fig. 7 and 8. The distance from this point to the site where the initial slide occurred is 1.5 km. From the first flake-type slide took place until the sliding came to an end at farm D (making up 92-94% of the total slide area) the time taken was about 5 minutes.

THE INITIAL STATE OF STRESS IN THE QUICK CLAY GOVERNS THE MODE OF FAILURE
Quick clay slides occur in two ways, either retrogressively or as flake-type slides. A study of recent slides clearly demonstrates this (Bjerrum 1973).

The factor which first of all governs the mode of failure is believed to be the state of stress that existed in the quick clay prior to instability. When loading a clay undrained beyond a «critical shear stress level» τ₉₀, a tendency for a volumetric decrease take place, resulting in pore pressure increases. Thus, to obtain an increase in shear strength the effect of increased mobilized φ'-angle must be greater than the effective stress reduction due to the increase in pore pressure. For a quick clay, loaded undrained beyond τ₉₀, the pore pressures will increase explosively as the unstable «card house» clay particle structure will start collapsing, resulting in a net decrease in shear strength. Consequently, failure takes place almost instantaneously and long before the angle of internal friction is fully mobilized (Aas 1981). In Fig. 9 this behaviour is illustrated schematically for a quick clay under drained and undrained condition.

![Fig. 8. Final slide area. Photo Aftenposten.](image-url)

![Fig. 9. Shear strength mobilization for quick clays under drained and undrained conditions.](image-url)
At stress levels below \( \tau_{cr} \) the clay is in its «elastic» state. When loaded, only small pore pressures are set up, resulting in a net increase in strength mobilization of the clay. Not until \( \tau_{cr} \) is reached will failure take place.

Transferring the above reasoning to slides in natural quick clay slopes leads to the following:

a) For flake-type slides to occur (take place instantly), the initial stress level in the quick clay must be close to «the critical stress level», \( \tau_{cr} \). A small stress increase will result in a failure of a larger area simultaneously.

b) A slide will develop retrogressively (relatively slowly) if the initial stress level in the quick clay is well below \( \tau_{cr} \). After an initial slide, shear stresses will build up, reaching the highest level close behind the slide edge. If \( \tau_{cr} \) is reached, a slide will take place. This phenomenon will repeat itself and the slide propagate backwards in many small slides until the maximum shear stress level behind the slide edge no longer exceeds \( \tau_{cr} \).

ANALYSIS OF SLIDE DEVELOPMENT

Stage 1 of the Rissa slide was a retrogressive process. The situation after the initial slide is shown in Fig. 2 and the final situation, reached 40 minutes later, in Fig. 3. Site investigations show that the long and narrow slide pit was a result of topographical restraints. Between the pit and Lake Botnen the soil was not sensitive, while along the upper edge the depths to bedrock were small. The slide was «forced» into a long and narrow shape. Prior to the initial slide the stability of this area was good, i.e. the shear stress level in the quick clay was relatively low. Hence, the sliding developed retrogressively.

The retrogressive sliding was immediately followed by a flake-type slide. This was the main individual slide in the whole process and was the actual start of the real slide catastrophe, see Figs 4 and 5. How could this slide happen and why did the sliding from now on take place so dramatically fast and reach such large dimensions?

It was, of course, the existence of the retrogressive slide pit that had affected the stability of the «flake» and caused its failure. The «flake» was physically a direct continuation of the existing pit. Therefore no side forces were acting along the common face, an area of about 50 metres length and 5–10 metres height. Also the effects of vibrations due to the previous sliding may have had an influence on the soil strength, at least locally. However, together these effects only make up a very small average increase in stress level over the failure surface. Accordingly, the stress level in the quick clay must have been close to
the critical level $\tau_{cr}$, before any sliding started. This small stress increase resulted in reaching $\tau_{cr}$ and the failure took place instantly. That this area, and the area that slid out afterwards, had an inherent low factor of safety explains the fast occurrence of the sliding from this stage on.

Back calculations of the stability of the «flake» has been carried out, supporting the claim that the stability was low prior to the sliding. An explanation of the determinations of soil strength parameters and the stability analysis is given in the following.

THE SEDIMENT IS A MASSIVE MARINE CLAY DEPOSIT, LEACHED IN A ZONE ALONG THE MOUNTAIN SIDE

An extensive soil investigation program has been carried out, in and around the slide area, consisting of soundings, vane borings and undisturbed soil sampling. In addition to routine laboratory investigations, triaxial tests and direct simple shear tests have also been carried out.

The investigations showed that the clay deposits were massive. With a few exceptions, the clay was 20-30 m deep below the slide bottom. Outside the slide area the clay deposit had equivalent or greater thickness.

![Graph](image)

**Fig. 12.** Characteristic stress-strain curves.

Of particular interest was the mapping of the quick clay formation, to explain the slide, its extent and somewhat peculiar shape. The map and cross-section X-X in Fig. 10 show a reconstruction of the quick clay distribution prior to the slide. Quick clay existed in a 200 to 400 m wide zone along the entire mountain side. The zone had its maximum thickness, up to 25 m, close to the rock face. Fresh water under artesian pressure has flowed slowly from the bed rock, up through the clay sediment and along horizontal pervious layers. The quick clay has been formed by leaching of the marine clay. (Bjerrum et al. 1969, Rosenvist, 1977).

Figure 11 shows a boring profile from the quick clay zone, located by farm D, just behind the slide scar. The material is a silty clay with numerous thin layers of silt. The sediment is quite homogeneous over the depth examined. From 4 to 15 m depth the clay is quick with sensitivities measured as high as 100. The plasticity index is only some 5%, and the water content is 10% higher than the liquid limit. The shear strength, determined by the field vane test is seen to increase linearly with depth at a rate equal to 0.1 times the effective overburden pressure.

![Graph](image)

**Fig. 11.** Typical boring profile of quick clay.

UNDRAINED SHEAR STRENGTHS HAVE BEEN DETERMINED FROM TRIAXIAL TESTS AND DIRECT SIMPLE SHEAR TESTS

It has been known for some years that simple field and laboratory tests do not always give good estimates of the shear strengths of clays. In the Norwegian silty, sensitive clays, the values determined by those methods are generally too low. At the Norwegian Geotechnical Institute, the strength determinations for such materials are carried out by triaxial and direct simple shear tests. The clay is consolidated to the in-situ stresses and the tests are run undrained. For a slope stability analysis three types of tests are run, triaxial active, direct simple shear and triaxial passive, each representative for different parts of the failure
plane. The method is explained in more detail in the literature (Bjerrum 1973, Berre 1975, Aas 1981).

Characteristic stress-strain curves for the three different types of tests for the Rissa clay are shown in Fig. 12. The stress paths in the active and passive triaxial tests are given in Fig. 13. It is seen that the maximum shear stress level for the active tests are reached at an axial strain of only 0.2%. Fig. 14 presents the shear strength variation with depth for the three test types, determined at 1.5% strain. The strength increases linearly with depth for all three types, i.e. there is a constant ratio between the undrained shear strength and the effective overburden stress. The ratios are 0.3, 0.2 and 0.1 for active triaxial tests, direct simple shear tests and passive triaxial tests, respectively.

These shear strength profiles were used for the stability calculations. For the potential slip surface shown in Fig. 10 the factor of safety was calculated to be 1.10. This shows that the stability of the area was low before any sliding had taken place, i.e. the mobilized shear stress was close to «the critical level». Similar results have been obtained by back calculating other well documented flake-type quick clay slides as presented by Aas (1981) in an accompanying paper to this conference.

CONCLUSION

The Rissa land slide is extremely well documented, with a number of eye witnesses. Even amateur films were taken of the slide development.

The first phase was retrogressive; going on for about 40 minutes and made up 6-8% of the final total slide area.

Retrogressive sliding took place where the sliding itself changed the stability condition from good to un-

stable. This occur locally behind the slide edge, resulting in relatively small slides, each taking a certain time to develop.

The remaining 92-94% of the sliding took 5 minutes or less, and was made up of large flake-type slides.

Flake-type slides occurred where the factor of safety was low prior to the sliding process. A stress increase, even small, led to instant structural collapse in the quick clay and subsequently to failure of the area.

REFERENCES


