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CLASSIFICATION OF QUICK CLAY ZONES TO PINPOINT AREAS OF HIGH RISK – RESULTS AND EXPERIENCES

Erik Endre [1], Tharan Fergus [1], Ragnar Moholt [2]

ABSTRACT

There is risk of severe accidents caused by quick clay slides in Norway. Flooding and erosion may initiate quick clay landslides with a potential for loss of lives and huge damages. Mapping of areas with a potential for quick clay slides carried out during the last two decades show that the majority of these areas border to watercourses. The Norwegian Water Resources and Energy Directorate (NVE) is 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 method is developed by NGI. Results so far indicate that 20 % of the total areas with a potential risk of clay slides have a higher risk than acceptable. A strategy for cooperation with municipalities involved has been developed as well as an information strategy for presenting maps and results. This to ensure their use in land use and contingency planning. Knowledge and awareness is the most efficient way to reduce risk and prevent hazards caused by quick clay slides.

Key words: Risk classification, natural hazard, watercourse management

INTRODUCTION/BACKGROUND

The responsibility for water resources management in Norway is divided between the national, regional and local levels. At the local level, municipalities prepare water resource plans concerning water supply and quality, land use, sewage, water pollution and fishing as part of their ordinary planning work. At the regional level, county planning is used as a tool for the management of rivers and lakes. Both long-term and corporate plans are statutory and represent important tools for both municipalities and counties. The County Governor has the mandate to ensure that safety and environmental issues are given the proper attention in the plans made on the local level.

The Norwegian Water Resources and Energy Directorate (NVE) is a directorate subordinate to The Ministry of Petroleum and Energy. The Ministry is responsible for the following legislation regarding water resources management: The Watercourse Regulation Act, The Industrial Conscession Act and the Water Resources Act. NVE has a central role in flood prevention work,

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1 Norwegian Water Resources and Energy Directorate, P.O. box 5091 Majorstua, N-0301 Oslo, Norway, (+47 2295 9098, een@nve.no)
2 Norwegian Geotechnical Institute, P.O. box 3930 Ullevaal Stadion, N-0806 Oslo, Norway (+47 2202 3000)

to prevent accidents in watercourses, and has the overall responsibility for maintaining national power supplies. NVE aims to prevent damage and improve safety within river basins by implementing safety measures against flooding, landslides and erosion along watercourses and by mapping of flood prone areas. To pinpoint quick clay areas of high risk, NVE has initiated a program to classify all known quick clay zones by risk, probability and by consequence. Results and experience from this work is presented in this article.

Flooding and erosion being natural processes in water courses, they are not always given the necessary attention according to natural hazards. Through ancient times population has been established near watercourses, and especially where rivers meets the sea. In Norway many of these areas once was below sealevel due to the weight of the ice covering the country. Clay minerals were deposited in this marine environment. In periods of flooding and larger sediment transport in rivers, layers of silt and fine sand were deposited upon the layers of clay. Due to upheave of the country as the ice melted away, these areas are now the best land for agricultural use. The long coast of Norway made the sea a natural choice for transportation, making these rich areas a natural choice of a growing population.

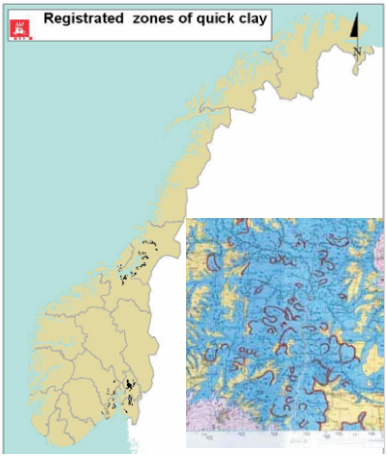


Fig. 1: Map of Norway showing mapped areas. Zones of quick clay larger than 10.000m^2 were registered. All areas with marine clay deposits are potential areas for quick clay. Quarternary maps gives a good indication of where to find marine sediments (blue colour), here partly covered by riverine sediments (yellow). Red markers indicate historical slides.

Through time the saline content in the marine clays above sea level, has slowly been reduced by fresh water infiltrating the clay. The reduction in the saline content has a dangerous effect on the clay. Salt (Na^+ and Cl^-) gives an electric load to clay mineral grains (flocculation), making the grains build up a structure which encapsulates water in the clay. As the salt is washed out, the clay gradually becomes more and more unstable. If the structure eventually collapses, the clay will suddenly liquify and act exactly like muddy water. This is called quick clay. Quick clay slides may take on huge dimensions, and are through history responsible for the loss of several hundreds of lives in Norway. The most recent huge slide in Norway is the Rissa slide in 1978. The Rissa slide triggered a national mapping program funded by the Ministry of Environment and the Ministry of Agriculture to point out areas prone to quick clay slides (so called danger zone mapping), and approximately 1200 zones covering 500 km^2 has been identified. The aim of this mapping was to identify 90% of the areas with the potential of quick clay slides. The mapping was executed by NGI.

Fig. 2: The Rissa slide was triggered by deposition of mass near the lake shore. The farmer had planned to build a new barn. The weight of the deposited mass made the quick clay collaps, triggering a slide 1.5 km long!

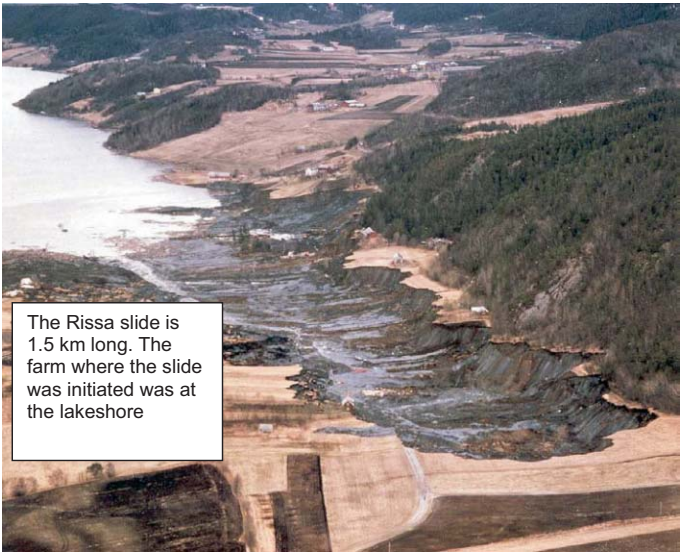


Fig. 3 The Rissa quick clay slide

NVEs PROGRAM TO ENHANCE SECURITY AGAINST CLAY SLIDES

The Rissa slide was triggered by human impact and shows very clearly the necessity for precautionary attention both to human activity and to natural processes such as erosion and flooding in quick clay areas. It is very difficult to foresee that even the smallest action either by human activity or erosion even in the smallest creek may trigger a quick clay slide given the right circumstances.

The mapping of quick clay zones was an important and necessary step forward to identify areas that should be given special attention in land use planning on the local level (municipalities). This work was unfortunately not given the right attention in the municipalities, and the reports were

often put in a drawer or archived without any further notice. Areas identified with a potential of a quick clay accident were regulated for building, industry and other development.
With an increasing locus on land use planning and precautionary measures in watercourse management, it was deemed necessary to develop a tool to distinguish between unstable and more stable zones of quick clay. The aim was to locus attention in land use planning and precautionary measures to the areas with a largest risk of dangerous slides.
A program to enhance safety against quick clay slides was proposed in 1999, and has since been focused on also on the Governmental level.

THE PROGRAM'S FIVE MEASURES

Classification of known quick clay zones with a potential of sliding

To get an overview, the zones previously identified will be reexamined and a first evaluation based on existing information available will be performed for each zone. In addition each zone will be examined in the field, and parameters that influence on stability registered are registered (see description of the method in a later paragraph). This information is coupled with the parameters in the consequence evaluation, giving the risk evaluation of the zone.

Our knowledge should be others knowledge - Information of the results

Results should be accessible and handed to those who need this information in their work. An information strategy has been developed to bring this information forward in the best possible manner. Results, and how to use this information is presented in local council meetings, directly to administrative/technical personnel on the local level and in meetings with the County Governor on the regional level. Press conferences are also arranged in agreement with the local authority. On the technical level results are accessible as thematic maps for land use and area planning programs in standard GIS formats. Results are also accessible through a national internet database for natural hazards being established at the Geological Survey of Norway.

Mapping of chosen watercourses not included in the former mapping program

The purpose of the national mapping program was identify areas with a potential risk of a quick clay slide. To manage this task, restrictions were given to the mapping and registration. The zone should be minimum 10.000m^2 and certain topographic criterions fulfilled; more than 10 meter difference of height or a terrain gradient steeper than 1:15. This program has identified approximately 90% of the potential dangerous areas. The northern part of Norway was not included. NVE will contribute so that areas of potential risk along watercourses in this part of the country are classified using the same method.

Safety measures

Along watercourses, the majority of slides are triggered by erosion on the river bank and/or the bottom. Due to a general maturation of the landscape, it is in small creeks and small rivers the erosion is most active, leading to a more rapid change in the stability of the embankments. The most common method to enhance the stability is to place a counterweight of rock on the

embankments. The river bottom is often raised, and the terrain gradient of the embankment often reduced.

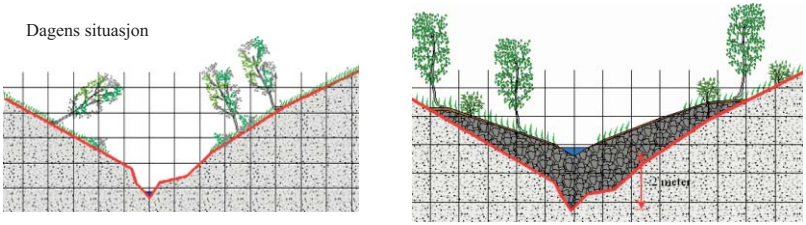


Fig. 4: Stabilization of quick clay terrain by reducing shear forces in the clay on the embankment and stopping further erosion by the running water

Surveillance of danger of a quick clay slide

The need for a surveillance system will be evaluated as part of the program. Surveillance could, in some places be crucial to give an early warning for evacuation and other contingency actions to be activated.

STEPWISE PROCESS TO REDUCE RISK THROUGH ENHANCED KNOWLEDGE

Classification of the zones is executed in several steps. The purpose is to achieve sufficient knowledge on each zone to ensure that an acceptable level of risk is maintained. Firstly each zone is examined as already mentioned, and given the first evaluation on risk, probability and consequence according to the described classification method.
Based on the points for the zone concerning probability and consequence and hence risk, zones in high risk classes (4 and 5) and/or in the class ”High probability” need to be given extra attention. For these zones an additional investigation program is put forward in cooperation with the municipality involved in order to get a sufficient level of accuracy to decide if the zone is a zone with an unacceptable risk or not. If the zones are still classified in either risk class 4 or 5 after the supplementary information is accounted, it is documented that there is need for safety measures to ensure that the risk of the zone can come to an acceptable level. A stability analysis is then performed to dimension the extent of the measures that have to be taken. Normally the cost for safety measures is divided 20% on the municipality or others that will benefit from the safety measures, and 80% by the Government channelled through NVEs annual budget for safety measures along watercourses. The work concerning stability calculations of the zones is done by geotechnical experts. The extent of the zones is adjusted according to this new information with a higher level of accuracy.

METHODOLGY

Risk is defined as the multiple of probability and consequence. Evaluation of both probability and consequence is carried out for a certain number of factors that are thought to contribute most to the risk for landslides. The factors are weighted, after their relative importance, and given a score for each zone (0-3). A value that represents the influence of each factor is then obtained by

multiplying the score and the weighting number. A consequence and a probability score is derived as the sum of all affecting factors.
Topographical and geotechnical factors influence on the probability for landslides to occur. Pore pressure is thought to contribute most of the geotechnical factors, and is therefore given highest weighting (3). Erosion in brooks and rivers often initiates landslides by removing soil from the bottom of slopes, making the slopes higher and/or steeper. Direct human impact includes mass

Table 1: Evaluation chart, probability for landslides

Factors	**Weighting**	**Probability (score)**			
		3	2	1	0
Activity of slides	1	High	Medium	Low	No
Slope height, m	2	>30	20-30	15-20	<15
OCR: (Present/former terrain level)	2	1,0-1,2	1,2-1,5	1,5-2,0	>2,0
Pore pressure Artesian Less than hydrostatic	3 -3	>+30 <-50	10-30 -(20-50)	0-10 -(0-20)	Hydro-Static
Thickness of quick clay layer	2	>H/2	H/2-H/4	<H/4	Thin layer
Sensitivity	1	>100	30-100	20-30	<20
Erosion	3	Active	Some	Little	No
Direct human impact worsening Improvement	3 -3	Big	Some	Little	No
Sum		51	34	16	0
% of total score		100	67	33	0

movements such as fillings, excavations and building of roads. Deforestation or changes of natural drainage conditions are also defined by this factor. The zones are ranged after their total probability score and classified as possessing “High”, Medium”, or “Low” probability for landslide occurrence.

Table 2: Evaluation chart, consequence of landslides

Factors	**Weighting**	**Consequence**			
		3	2	1	0
Dwellings, number	4	Dense	Spread >5	Spread <5	None
Commercial buildings	3	>50	10-50	<10	None
Other buildings	1	High	Considerable	Limited	None
Road, average no. cars/day	2	>5000	1001-5000	100-1000	None
Railway, track priority	2	1-2	3-4	5	None
Powerline	1	Central	Regional	Distribution	None
Floods/inundation	2	Serious	Medium	Little	None
Sum		45	30	15	0
% of total score		100	67	33	0

Loss of lives and injuries are considered to be the worst consequences of landslides. As people spend most of their time at home, the number of dwellings inside a zone is weighted highest. Also taken into account, though less weighted, is damage to social infrastructure like roads, railways and electricity. Damage to human lives and property may also be the result of landslides damming up rivers, causing rise of the water level and inundation of inhabitated areas. The subsequent breaking of dams, in such cases, may also lead to inundation of areas where people live. The zones are divided in three classes “Very serious”, “Serious”, or “Less serious”

with respect to consequence in the same way as with respect to probability. Classification of risk is divided in five classes (1 – 5) from the nominal value the zone acquires after multiplying consequence and probability.

EXAMPLES

Trondheim.

Trondheim is the third largest city in Norway. Parts of the city is known to have areas with quick clay. Results from the first evaluation of the formerly mapped zone (fig. 5A) is shown as probability and as risk maps (fig 5B and C). There is a great need for more exact knowledge on the probability for zones with highest probability (red coloured zones). NVE and the municipality are collaborating on a program for further supplementary ground investigations. The darker the colour the higher the risk on the risk map.

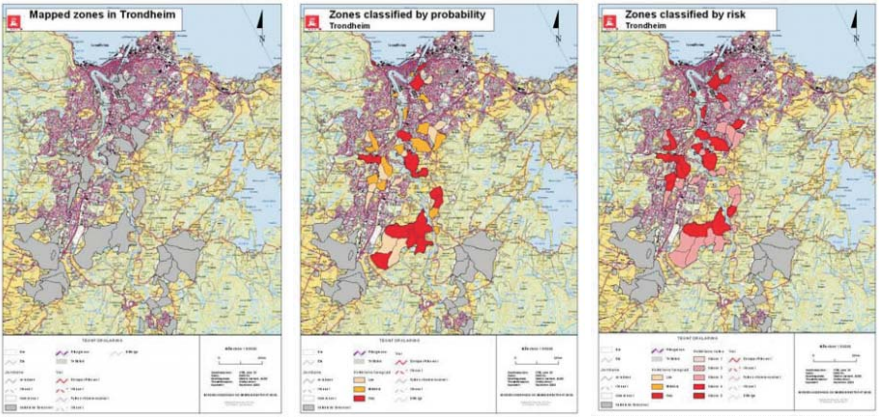
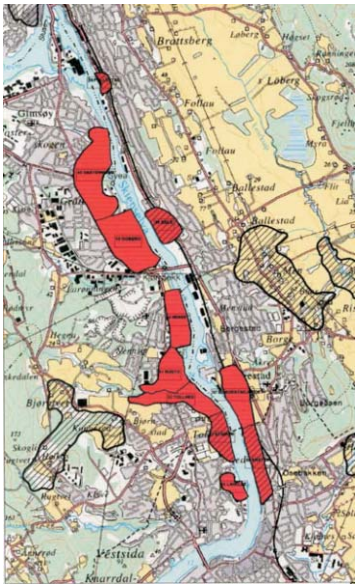


Fig 5: A: Zones with a potential danger of quick slide. The zones have no ranging and there was no routine for sending the reports to the municipalities. This work therefore did not become the tool as was intended for the municipality in their planning of land use. The knowledge of these maps was sparse and often random in the municipalities.
B & C: During NVEs program for enhanced security against clayslides these zones are classified by consequence, probability and risk. NVE has developed an information strategy to make these new maps known on a broad level in the municipalities involved, both the political side and the administrative/technical side. These new maps have been very well accepted, and there is a general desire to make these maps formalized as a regulation connected to the Norwegian Planning & Construction Act

Skien and Porsgrunn

Skien and Porsgrunn in South Norway are the first two municipalities where results and experiences of all steps in the stepwise process are available. It was clear after the first evaluation that several thousands people in these two municipalities had their homes on ground which could collapse and flow into the river. This is visualized in the two maps below. Fig 6A 2001 shows the results from the first evaulation, Fig 6B is from 2003. Fig 6B is the result after a supplementary

programme including geotechnical ground investigations and photographing the river bed. The results from the supplementary investigations are visible by comparing the two maps.



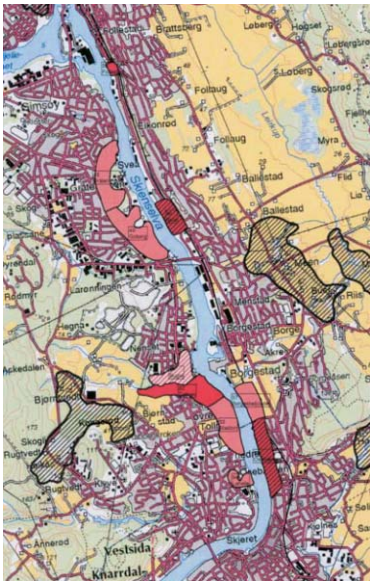


Fig 6 A: First evaluation of the zones presented in 2001.
Fig 6B: Result after supplementary program in 2003. Zones are now more correctly classified and have a more correct extension. (Less information leads to more uncertainty and a more conservative interpretation regarding both extension and probability of a slide). Zones upper left side border no longer directly to the river. This means that flooding and erosion in the river will have less impact/influence on the stability for these zones. The knowledge put forward during the process has pointed out zones which is at an unacceptable high risk, and where necessary measures to stabilize these zones have to be taken. Contingency plans are revised and adapted to this knew knowledge. The areas along the river are very attractive. Plans for land use and exploitation are now revised. Governmental funding is applied for to work out necessary measures to enhance stability on the embankments and stop erosion in the river

EXPERIENCES

Knowledge.

The comprehension of knowledge as the most important sole factor to reduce risk and vulnerability in the society pervades the program. For that reason much effort is put down to share and transfer knowledge to those who need it as background for their own work and decisions with special focus on the local level which is the main responsible administrative level for land use and area planning according to the Planning and Building Act. Comments and expressed opinions so far clearly states the value of the work being done in classifying the zones with regard to both land use and area planning and contingency planning.

Ownership

The local authorities play a central role in securing the local communities. It is therefore vital that they have attention and interest in the work being done and the results being produced. Any decision of putting tasks into handling is therefore based on the cooperation between the local authority and NVE to ensure the local ownership. The cooperation is established before the zones are classified. Local ownership is also achieved through sharing of expenses regulated by a White Paper which says that "Normally should the local authorities apply for 20% of the cost to ensure local ownership"

Process to reduce risk

The process to reduce risk and vulnerability chosen has been an efficient and cost effective way to sort out zones which must be given special attention, and those for which there is sufficient knowledge after the first evaluation. Results so far have sorted out 20% of the zones for which there is need for a supplementary investigation program. Results emerging from the supplementary investigations, points out areas with an unacceptable risk with a higher level of accuracy. The most exact knowledge is applied for those zones which still are classified as high risk zones. A stability analysis is the most exact method for deciding if the stability is sufficient or not, and is executed for these zones to achieve the necessary certainty about stability.
This process is an efficient tool for NVEs to give priority to applications for funding and expert assistance to accomplish safety measures in and along watercourses funded by Governmental means.

There are several important results from the supplementary investigation program. Zones are now more correctly classified and have a more correct extension. (Less information leads to more uncertainty and a more conservative interpretation regarding both extension and probability of a slide). An important distinction is to decide if running water and hence flooding and erosion is an active parameter or not and if a zone borders to a river/creek or not. The knowledge put forward during the process has pointed out zones which is at an unacceptable high risk, and where necessary measures to stabilize these zones have to be taken. Contingency plans are revised and adapted to this knew knowledge. The areas along the river are usually very attractive. Plans for land use and exploitation are now revised. Governmental funding is applied for to work out necessary measures to enhance stability on the embankments and stop erosion in the river.

Accordance with political goals

Recent White Papers concerning risk vulnerability points out the need to reduce risk and vulnerability in the society, and encourage the different administrative levels to take action to identify under what circumstances the society is vulnerable to unwanted incidents and how to prepare countermeasures to reduce the probability of unwanted incidents. The method evolved and the results produced have made some municipalities work out risk analysis based on this information.

CONCLUDING REMARKS

1. The method described is a valuable tool to give priority to applications for funding and expert help by NVE.
2. The County Governor intends to use this method to ensure proper handling of plans for land use and area planning in the municipalities.
3. There is a demand to formalize the method and make it a regulation connected to the Planning and Building Act.
4. The information strategy chosen has given good results and ensured the local ownership to the work being done.
5. The method and the maps help to point out responsibility between municipality, private owner, insurance companies, and the Government
6. Risk is reduced!