HAZARD MAPPING OF LANDSLIDES, A COMPARISON OF THREE DIFFERENT OVERVIEW MAPPING METHODS IN FINE-GRAINED SOILS.

Karin Lundström
Swedish Geotechnical Institute, S-581 93 Linköping, Sweden, karin.lundstrom@swedgeo.se
Mattias Andersson
Swedish Geotechnical Institute, S-581 93 Linköping, Sweden

RÉSUMÉ
L´objectif de ces études était d´appliquer des méthodes de cartographie de l'aléa utilisées en Suède, en Norvège et au Canada, sur des sols à grains fins, dans la zone test Åby, et d'évaluer les différences entre ces methodes. Les conditions des sols sont assez similaires dans ces pays. Pendant et aprés la dernière déglaciation, de l'argile molle a été déposée en bordure des littoraux, dans des lacs et dans des vallées où beaucoup de glissements de terrains se sont produit. On peut trouver dans ces trois pays des argiles particulièrement très sensibles. La zone test de Åby est située dans la partie sud-ouest de la Suède prés de la rivière Göta. Les principaux objectifs des méthodes étudiées sont de circonscrire les zones d'aléa de glissements de terrain et d'identifier celles pouvant exiger des études plus détaillées. Les critères utilisés dans les méthodes sont dans l´ensemble basés sur les conditions géologiques et topographiques existantes, les glissements antérieurs et les conditions d´érosion. Selon les conditions relevées, toutes ces méthodes classent les secteurs étudiés en différentes zones d'aléa ou de susceptibilité aux glissements de terrain. La présente étude démontre que toutes les méthodes indiquent qu´il y a des aléas de glissements de terrain et que certaines zones requièrent des études géotechniques plus détaillées dont des analyses de stabilité. Les plus grandes différences entre les résultats des différentes méthodes concernent la forme, la surface et le nombre des zones d'aléa.

ABSTRACT
The aim of the study was to apply hazard mapping methods which are used in Sweden, Norway and Canada for fine-grained soils, on the Åby test site and to evaluate the differences in-between them. In these countries the soil conditions are quite similar. During and after the latest deglaciation soft clays were deposited along coastlines, lakes and valleys in which many large landslides have occurred. A special type of sensitive clay, quick clay, may be found in the countries studied. The chosen test site, Åby, is located in the south-western part of Sweden close to the Göta River. The main purposes of all of the studied methods are to identify areas with a hazard for landslide and to point out areas which need further investigations. The studied methods use criteria mainly based on geological and topographical conditions, earlier events and the possibility for erosion. Based on these conditions and the criteria set up, all methods divide the investigation area into different hazard zones. The application show that all methods indicate that there is a hazard for landslides and a need for further, more detailed geotechnical investigations and stability analyses in some part of the area. The largest differences between the results are the shape, the size and the number of hazard zones

1. INTRODUCTION

Conditions important for a landslide hazard zonation include geomorphology, geology, geotechnical parameters, hydrology, topography, meteorology and botany. The hazard may be determined through a deterministic or a probabilistic approach. Methods used for hazard zonation differ among countries but also depending on the aim of the study. Some methods are performed in different levels of detail and in some methods not only the hazard but also the vulnerability and the risk of landslides are assessed. The first step may involve a mapping in which areas, in need for a more detailed investigation, are pointed out. This paper describes the results from landslide mapping using the overview mapping methods used in Norway, Quebec province (Canada) and in Sweden applied on the Åby test site, situated in south-western Sweden. The work is one part of the results from the EU-project "Lessloss", which is described in more detail by Lundström and Andersson (2007).

The geology in northern Europe and Northern America is strongly affected by the latest glacial time, the Pleistocene epoch. Along coastlines, lakes and valleys deep deposits of soft clays[1] may be found in which many large landslides have occurred. A special type of clay, quick clay, may be found in deposits which are situated below the highest coastline in these parts of the world. The designation "quick-clay" refers to a clay whose structure collapses completely at remoulding and whose shear strength thereby is reduced to almost zero. Quick clay is formed through geological processes. They are found mainly in northern Russia, Norway, Sweden, Canada and Alaska (Brenner et al, 1981). These areas have been affected by isostatic uplift causing soil, which were deposited in seawater, to be located above sea level. The exposed clay deposits have then been subjected to leaching, whereby the ion concentration in the pore water has changed, leading to the formation of quick clays. The sensitivity, S_t, is the relation between the undisturbed and the fully remoulded undrained shear strength. Quick clay is in Sweden defined as a clay with a sensitivity of 50 or more, and a fully remoulded shear strength of less than 0.4 kPa (Karlsson & Hansbo, 1989). In Canada, sensitive clays

[1] The definition used is the same as used by Brenner et al (1981), a soft clay is a clayey soil with an undrained shear strength of less than 40 kPa.

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are defined as clays with a remoulded shear strength of less than 1.0 kPa and with a liquidity index of more than 1.2 (Lebuis *et al.*, 1983). In Norway, quick clays are defined as clays with a remoulded shear strength of less than 0.5 kPa (Norwegian Geotechnical Society, 1982). Almost all landslides in clays in Sweden, Norway and Canada with significant consequences can be designated as quick (or highly sensitive) clay slides (Viberg, 1984). Quick clay is therefore a significant factor for the risks involved with low stability slopes.

2. TEST SITE ÅBY

The Åby test site is located about 50 km north of Göteborg, in a side valley to the Göta River. The Göta River valley is the area with the highest frequency of landslides in Sweden. The test site is an area of farmland with about 15 dwelling houses, see Figure 1. The topography consists of a rough terrain, with outcropping bedrock in the northern part of the area and eroded clay valleys in the rest. Two brooks, which pass through the area from north towards south-east, have formed 10–15 m deep gullies with a slope inclination of 1:1.5 to 1:2 in the steepest parts. Along the brooks erosion is ongoing and scars from small landslides can be found in the valleys and up towards the mountain Bergåsen in north-east. Geotechnical investigations carried out in the area show that the soil profile consists of glacial clay with the greatest thickness, up to 35 m, in the central parts of the valley covering till deposited on bedrock. The thickness of clay and till decreases towards the sides of the valleys. The clay was deposited in marine environments during or after the deglacitation of the latest inland ice (around 12000 years ago). The highest coastline is situated at 125 m above sea level in the area. Since all clay deposits are situated below this level there are prerequisites for quick clay occurrence.

Figure 1**.** Åby test site (April 2006). The brook Rörstorps-bäcken, some dwellings and the hill Bergsåsen.

3. THE SWEDISH LANDSLIDE HAZARD ZONATION METHOD

In Sweden general overview mapping is executed individually for each municipality. The work started in 1978 and is still ongoing. There are two different mapping techniques, one for areas built up by clay and/or silt and one for areas in till and other coarse grained soils. The methods are described by Berggren et al (1991) and by Lundström and Andersson (2007). In this paper only the method use for clay and/or silt areas is presented.

The mapping starts with a *preparatory study*, in which a selection of areas to be mapped within the municipality is done. The study is based on contact with municipality staff, examination of geological and topographical maps and field inspections. The preparatory study also includes an inventory of aerial photographs and earlier geotechnical investigations. The actual general overview mapping is divided in two sub-stages – stage 1a and stage 1b.

Stage 1a aims to distinguish between areas which have or have not prerequisites for landslides. Studies are made of geological and topographical maps, earlier geotechnical investigations and of aerial photographs. Field inspections and in some cases soundings are made. The division is based on soil type and topography. Three different stability zones, numbered I-III, with or without prerequisites for landslides, are defined as described in Figure 2. Stability zone I involves land areas where there are prerequisites for initial landslides (areas which may be primarily affected by an initial slide or slip) Stability zone II involves land areas where there are no prerequisites for initial landslides but the zone may be affected secondarily by landslides acting backwards or forwards while Stability zone III involves areas with bedrock outcrops and soils not containing clay or silt.

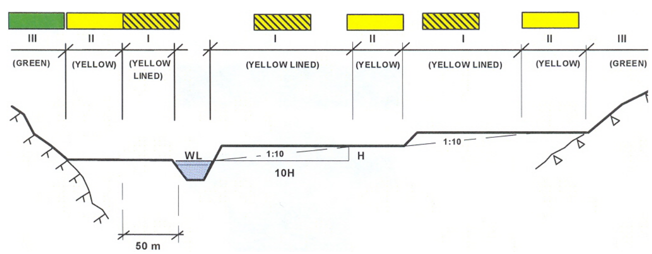

Figure 2. Criteria for the division into stability zones where the soil consists of clay.

The division into stability zones is shown on a map in colour on a scale of 1:5,000. In addition to the stability zones, the map shows earlier slides and slips, ongoing erosion etc. Observations made during field inspections are documented according to a standard structure and aerial photographs of each inspected site are analysed.

Stage 1b comprises an evaluation of the stability conditions under prevailing conditions. The evaluation is made with the aid of simplified calculations according to the "Directives for Slope Stability Investigations" issued by the Swedish Commission on Slope Stability (1995). The calculations are based on a few field and laboratory investigations in selected sections and, if existing, earlier performed stability investigations in nearby areas. The results of Stage 1b consist of areas considered to have satisfactory stability and areas considered having unsatisfactory stability. Safety factors below 1.5 in a combined analysis or 2.0 in an undrained analysis, are used as criteria in overview calculations. Areas with unsatisfactory stability conditions are marked orange on a map on the scale of 1:5 000. Other information of interest, such as investigated sections, earlier landslides, ongoing erosion, is shown on the same map. Areas where a detailed investigation is judged to have high priority are also marked on the map (orange hatched), together with a comment.

3.1 Results from mapping of the Åby test site according to the Swedish method

The studied area was pointed out in the preparatory study of the municipality of Lilla Edet. In stage 1a the soil- and topographical conditions were evaluated in three sections on the east side of the brook Rörstorpsbäcken. Field investigations comprised: levelling of sections, static pressure soundings, field vane tests, auger sampling, water levelling of the brook, ground water level measured in bore holes. Type of soil, bulk density, natural water content and liquid limit were examined on soil samples. The investigations showed that the soil profile consists of a dry crust followed by more than 30 m of soft clay. Below the layers of clay a coarse grained soil (unknown thickness) is deposited on bedrock. In some part of the studied area more than 35 meters of clay was found. The pressure soundings indicate that quick clay may be found in some depths in all three sections. The shear strength is around 15-20 kPa below the dry crust and is then increasing with depth (around 1.4 kPa/m). The groundwater table is found 1-2 meters below the ground surface. The inclination of the slopes have a mean value of around 14 degrees with steeper parts close to the brook (up to 22 degrees). The results form the basis for the production of the hazard map in Stage 1a. The main part of the area was mapped into stability zone I (clay with an inclination equal or higher than 1:10). Also stability zone II (clay situated on a longer distance than 10 times the slope height from the brook or area with silt/sand) and stability zone III (bedrock) are found.

In stage 1b stability calculations were performed in three cross sections situated in hazard zone I. Undrained and combined analyses for circular and plane slip surfaces were studied. The calculations indicated low safety factors (below 1.0) in the southern part of the area. Also in the other sections the calculated safety factors are lower than the required values. Therefore large parts of the studied area were designated to be in need for further investigations. The results from Stage 1b, see Figure 4, show that the whole area mapped into Stability zone I is classified to have unsatisfactory stability. In the south-eastern part detailed stability investigation is particularly recommended (marked orange hatched) while in the rest of the area detailed stability investigation is recommended (marked orange).

4. THE NORWEGIAN LANDSLIDE HAZARD ZONATION METHOD

According to statistics after 1945, a large quick clay slide (a slide covering a land area of more than 10 hectare or involving a volume over 1 million cubic meter soil) has occurred with an interval of four years in Norway (Gregersen, 1989). Nationwide mapping of quick clay areas was started in 1981. The mapping is performed in two main stages. Firstly, mapping of quick clay areas with prerequisites for landslides, according to simple topographical criteria, was performed for around 80 % of the areas with marine deposits. In Norway around 5000 km^2 of clay were deposited below the highest shoreline. Secondly, risk zonation of the mapped quick clay deposits is performed. This work is still in process. The methods are described by Gregersen (2002) and by Lundström and Andersson (2007).

Deposits of marine clay were detected with the help of geological maps. These areas were then divided into smaller zones after the principle that one zone is equal to one potential landslide area. Each zone was classified based on one topographical and one soil criteria. Gullies with a height difference of more than 10 meters are marked. For sloping terrain inclinations steeper than 1:15 are marked. Occurrence (verified by a defined scheme, see below) of quick clay is marked. The occurrence of quick clay is verified by studying the penetration force to depth curve using rotary pressure soundings. Rotary pressure sounding is a Norwegian method developed in the 1960´s (see Statens Vegvesen, 1997). In quick clay the penetration force will remain almost constant with depth or even decrease. For sloping terrain without gullies, the sounding is placed in the middle of the slope and to a depth equal the total slope height. In terrain with gullies the sounding is placed 1.5 times the height of the gully behind the crest and to a depth of 1.5 times the height of the gully.

If quick clay is found, the area is classified as a potential hazard area. If quick clay has not been found supplementary soundings are performed. Based on these properties hazard maps will be produced in the scale 1:20,000 or 1:50,000 with 5 meter elevation curves. The zones with marine clay were divided into three different subzones: (1) areas where quick clay has been found and where stability investigations have not been performed or given low stability, (2) areas where quick clay has been found and the stability conditions have been evaluated showing an acceptable safety factor for the present condition and (3) areas where rotary pressure soundings not have been performed or the result are difficult to evaluate.

To classify the marked zones, a quick clay risk zonation method is then performed. The method has been described by Gregersen (2002). Potential slide areas are given "engineering scores" based on geotechnical parameters, local conditions, persons or property exposed and engineering judgement. Hazard classes are described as low, medium and high. Consequence classes are discussed as not severe, severe and highly severe. The resultant risk, based on engineering evaluations and experience, is divided in five risk classes. The hazard level depends on topography, geological and geotechnical conditions, and human activities influencing the stability. The hazard is evaluated by studying scores times weights for the following parameters: earlier sliding, height of slopes, OCR, pore pressure, thickness of clay layer, sensitivity, erosion and human activity. Highest weights are given for pore pressure, erosion and human activity. The evaluation of scores and the weight given to each hazard describes its importance relative to the stability of the slope. Zones mapped as "low hazard", have low probability of failure by sliding. The zones mapped as "medium hazard", have a higher, though not critical, probability of failure. The zones mapped as "high hazard", have a relatively high probability of failure.

Consequences are evaluated by studying number of dwellings, persons in industrial buildings, number and importance of roads and railways, power lines, buildings (values), and consequence of flooding. Highest weights are given for closely spaced dwellings and persons in industrial buildings. The evaluation of the consequences is done with the help of three consequence classes; highly severe, severe and not severe. In zones mapped as "not severe", there are few or no permanent residents. In zones mapped as "severe" and zones mapped as "highly severe", there are a large number of persons, either as residents or temporarily on the premises. The risk score to classify the mapped zones into a risk class is obtained from:

$$\text{risk} = \text{hazard } (H_{ws}) \times \text{consequence } (C_{ws})$$

where H_{ws} = hazard weighted score in % of maximum value, C_{ws}= *con*sequence weighted score in % of maximum value

To make decisions on the need for additional soil investigations, stability analyses or other remedial actions, the mapped areas are divided in five risk classes. In risk class 1-2 no more soil investigations are necessary and the area is classified as stable. For risk class 3 further investigations are necessary and for risk class 4-5 further investigations are necessary, stability analyses are required and remediation work to get the area stable is probably needed.

4.1 Results from mapping of the Åby test site according to the Norwegian method

The test site Åby is situated below the highest shoreline and thus has marine deposits. Rotary pressure sounding is not used in Sweden, but according to static pressure soundings and fall cone tests, quick clay is found in the area. There are sloping terrains with inclinations steeper than 1:15, why the test site should be investigated further, according to the first stage of the Norwegian mapping method.

Parameters used for the risk zonation are based on prior information produced for the mapping according to the Swedish method, i.e. no supplementary investigations have been performed. Topographical maps, produced in the Lessloss project, in the scale 1:1 000 and with an equidistance of 0.5 m based on laserscanning have though been used. The test site, Åby, was divided into seven zones. One zone is equal to one possible landslide area, see Figure 5. To define the borders of one potential landslide zone, studies of natural depressions in the terrain, such as gullies, streams and old landslides scars are performed. For each zone the hazard, consequence and risk classifications have been performed. The chose of parameters for the classification is given in this paper only for zone number 5. In the Norwegian mapping procedure usally no field investigation are performed except rotary pressure soundings. The evalutation is therefore based on geological and topographical maps, field inspections, information available from nearby areas and experiences from similar areas. The hazard scores given for zone 5 in the Åby test site are shown in Table 1. Different kind of human activities have either a worsening or an improving effect on the stability depending on the activity. For example excavation in the toe of the slope can be an initiating factor for a landslide and in areas with quick clay huge areas can be affected of backwards propagating landslides. Improving activities can for example be erosion protection.

To judge the consequences of a landslide in the investigated area things like human lives, infrastructure, buildings and properties of special importance for the society like hospitals, churches and historical or cultural heritages are studied. An evaluation of the economical consequences of flooding caused by soil movements in a landslide is also performed. The consequence scores given for zone 5 in the Åby test site is presentd in Table 2.

Table 1. Example of hazard scores for zone 5 in Åby, see also Figure 5.

Hazard	Weight	Value	Score	Weight * score
Earlier sliding	1	Few	1	1
Height of slope, H	2	<15m	0	0
Overconsolidation ratio, OCR	2	1,5-2	1	2
Pore pressure				
-in excess	3	10-30	2	6
-suction	-3	-	-	-
Thickness of quick clay layer	2	H/2-H/4	2	4
Sensitivity, S_t	1	30-100	2	2
Erosion	3	Active/sliding	3	9
Human activity				
-worsening effect	3	None	0	0
-improving effect	-3	None	0	0
Sum of weight times scores, (max = 51)				24

Table 2. Example of consequence scores for zone 5 in Åby, see also Figure 5.

Consequence	Weight	Value	Score	Weight * score
Number of dwellings	4	>5 closely spaced	1	1
Persons in industrial buildings	3	0	0	0
Roads (traffic density)	2	Low	1	2
Railways (importance)	2	None	0	0
Power lines	1	Local	0	0
Other buildings, value	1	0	0	0
Consequence of flooding	2	Small	1	2
Sum of weight times scores, (max = 45)				16

The risk class, R_{ws}, is determined as the weighted hazard score (in percent of the maximum value) times the weighted consequence score (in percent of the maximum value). For zone 5 that gave:

$$R_{ws} = H_{ws} \cdot C_{ws} = (24/51) \cdot 100 \cdot (16/45) \cdot 100 = 1673$$

A calculated risk score of 1673 is classified as risk class 3 (risk score from 629 to1905 is equal to risk class 3).

For zones 2, 4 and 5 the risk class 3 was determined, see Figure 5. According to the Norwegian method additional in situ tests and pore pressure measurements are recommended in risk class 3 areas. Stability analyses should be considered and remedial measures could be necessary. For the zones 1, 3, 6 and 7 the risk class 2 was determined and no more preventive work is nessecary.

5. THE QUEBEC PROVINCE LANDSLIDE HAZARD ZONATION METHOD

In the Province of Quebec, Canada, problems with landslide are mostly found along the St.Lawrence valley and its side valleys where the majority of population is settled on post glacial marine soils. These soils are characterized by their high sensitivity, frequently above 50, with some values larger than 1000, and by the occurrence of very large retrogressive landslides, which can occur very rapidly. Consequently, the hazard mapping is mainly done for soils consisting of clay and silt. Built-up areas, land-used planned areas as well as areas which are attractive for building are mapped. The main steps in the mapping procedure are the establishment of a hazard map (Cartographie des zones de susceptibilité relative aux glissements de terrain) and a constraint map for land use management (Carte de zones de contraintes). The method is described by Robitaille et al, (2002). The hazard mapping information is presented on two maps: the information map and the susceptibility map.

5.1 Information map

The information map comprises data such as type of soil, topography, limits (top and toe) of slope, height and inclination of slope, scars of landslides, slope classes and geomorphologic elements like erosion, field inspections, location of the boreholes, etc. Aerial photographs analyse and soundings (CPTU) are used to identify and map the soils on a depth equal to the height of the adjacent slopes. Piezometers are installed to define regional ground water conditions since artesian pressures are one main factor causing the development of large retrogressive landslide. Clay and silt slopes with a height equal or higher than 5 meters and with an inclination of 14^{o} or more are mapped. The slopes are divided into steep slopes, with an inclination equal or greater than 20^{o}, and moderate slopes, with an inclination between 14^{o} and 20^{o}. In steep slopes landslides can occur naturally. In areas with coarse grained soils (sand, gravel or till), slopes with a height equal or higher than 5 m and with an inclination of 27^{o} or more are mapped.

5.2 Susceptibility map

On the susceptibility map the land area is divided into different hazard (or susceptibility) zones. The degree of susceptibility depends on the geological, geomorphological and geotechnical characteristics of the site and the soil.

Two different main hazard zones are classified. These are the moderate to high susceptibility zones (MHSL), and the low susceptibility (LSL) zones for landslides. The two main zones are divided further into ten subzones based on the type of soil, the inclination of the slope, the presence of sensitive clay, the presence or absence of erosion at the toe of the slope and the type of danger. Zones containing sensitive clay are first found by identifying old landslide earthflow scars by aerial photography analysis and further confirmed using boreholes and by laboratory tests on soil samples (Swedish cone and Atterberg limits).

For clayey and silty soils the classification of hazard zones is made with the help of a special flow chart, which is given in Figure 3. The dimensions of the zones prone to large retrogressive landslides are determined by an empirical approach, based on the comparisons of adjacent scars (Lebuis *et al.*, 1983). During the mapping program, if houses seem to be in danger, more detailed investigations are carried on to evaluate the risk. For areas that, in the detailed investigations, are found to be in danger of a slide, the slope stability has to be increased by preventive measures or the buildings in danger have to be removed.

5.3 Results from mapping of the Åby test site according to the Quebec province method

A susceptibility map according to the Quebec province method has been produced for the Åby test site. Since most of the soil in the area consists of clay the flow chart given in Figure 3 has been followed. Erosion is ongoing along both brooks and slopes adjacent to the brooks with an inclination of more than 22 degrees are therefore mapped as red zones with number 1. Sensitive soil has been found in the area and therefore those slopes which are higher than 10 meters have an area behind the crest of the slope mapped as grey-yellow and numbered 3. Two zones are mapped as orange zones with number 5, which are steep slopes not affected by neither erosion nor worsening factors. Other areas along the brooks have inclinations less than 22 degrees but higher than 14 degrees. Of these, areas affected by erosion are mapped as orange zones with number 6 while areas not affected by erosion are mapped as blue zones with number 9. Behind zones mapped as orange and numbered 5 or 6 the extension of an area with low susceptibility for earth flow should be marked if sensible soils are present and the slope height is more than 10 meters. The borders of these zones are marked with a green line with arrows. The extension is based on studies of largest adjacent earthflows scars. South of the mountain Bergsåsen two areas consisting of sand have been mapped as blue zones with number 10. The resulting susceptibility map is given in Figure 6. The map shows that there is a need for further, more detailed geotechnical investigations in and that the largest part of the investigation area is mapped into zone 6. Some zones with the highest degree of susceptibility for landslide (HSL) are found next to the dwellings in the southern part of the investigation area.

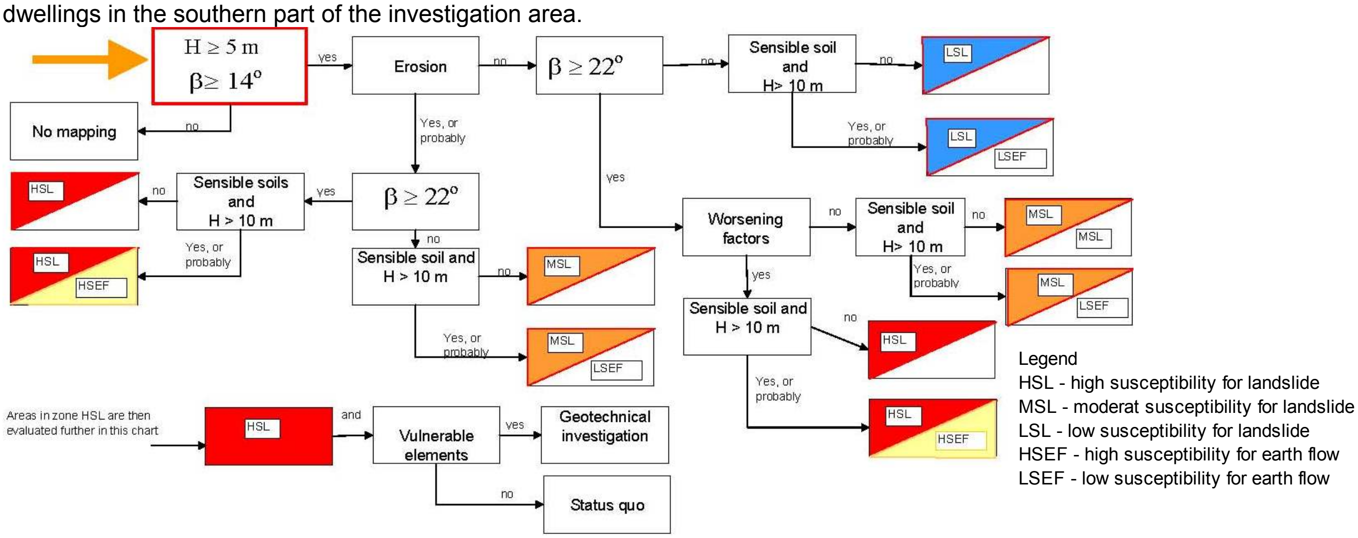

Figure 3. Flow chart used for susceptibility in areas with clay and silt deposits

6. COMPARISON OF RESULTS

6.1 Main differences between methods

The countries studied have a similar geology due to the fact that they were all glaciated during the latest glacial epoch, and therefore, there are many similarities between the methods studied. Anyhow there are geological differences, like strength of clay sediments and occurrence of quick clay, which affect the mapping techniques. For instance the Canadian clays have generally higher shear strength values, compared with the Swedish and Norwegian once, which makes it possible for steeper slopes to be stable. The lowest inclination criterion used in the Quebec province method for areas to be mapped is 14° while the inclination criterion used in Norway is 1:15 (~4°) and in Sweden 1:10 (~6°).

Quick clay is the main reason for the development of large landslides in Norway and thus the Norwegian method is only applied to areas where quick clay is found. In the Quebec province method the division of areas into different zones of susceptibility is affected by the presence of sensible soils but areas may get the highest degree of susceptibility even if sensible soils are not present. In Sweden there is no requirement for investigations of quick clay occurrence or sensitivity. The Quebec province method divides the hazard area into many small zones, for instance depending on the type of mass movement that could occur; areas with prerequisites for initial rotational or superficial landslides and areas in which an earth flow could be initiated by a down-slope landslide. In the Norwegian method, the area is divided in larger zones, each one corresponding to a potential landslide zone including earth flows. In the Swedish method, a hazard zone is not equal to a potential landslide zone, the results only indicate that more investigations are necessary.

In both the Swedish and the Quebec province method geotechnical investigations are required. The only requirement for investigation in the Norwegian method is rotary pressure soundings for verification of quick clay occurrence. In the Norwegian method not only the hazard but also consequence and risk are studied. In the Quebec province method, risks are also mapped but this information wasn't available at the time of our study.

6.2 Main similarities and differences between the results from mapping in Åby

Since there are differences between the principles of the methods the results should also differ and a very strict compilation is therefore not meaningful. In contrary, the focus has been held on similarities and differences which have effects on the final results of the mappings.

The comparison between the results of the application of all methods, are made between the Swedish hazard map 1B, the Quebec province susceptibility map and the Norwegian risk map presented in Figures 4-6. The choice of the Norwegian risk map is based on the fact that this map, gives recommendations on the need for additional soil investtigations, stability analyses and remedial measures in a similar way as the Swedish map 1B and the Quebec province susceptibility map.

All methods show that there is a hazard for landslides and a need for further, more detailed geotechnical investigations and stability analyses in some parts of the Åby test site. They also show that some of the dwellings are situated in the most critical zones, although not exactly the same dwellings are pointed out. The erosional processes along the brooks influence the results from all methods. The largest differences between the methods are the shape, the size and the number of hazard zones. This is because the methods have different criteria and techniques for critical zones which gave different location, shapes and sizes of zones. In the area around the buildings situated south of the mountain Bergsåsen, the results from the different methods show different houses to be in areas which have a need for further actions.

Both the Norwegian and the Quebec province methods show a hazard for landslide or earth flow in a larger area south-east of the mountain Bergsåsen, compared to the results from the Swedish method.

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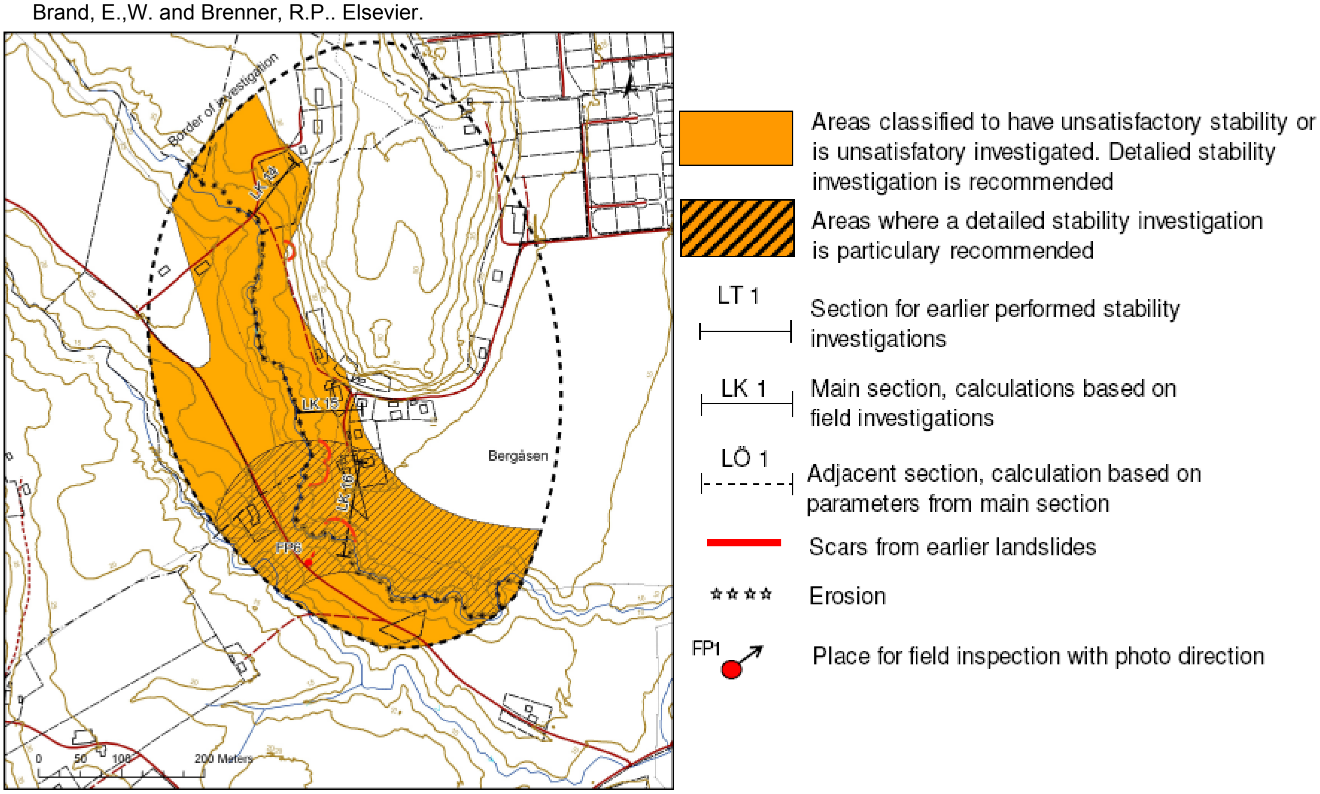


Figure 4. Hazard map 1B for the Åby test site, according to the Swedish method.

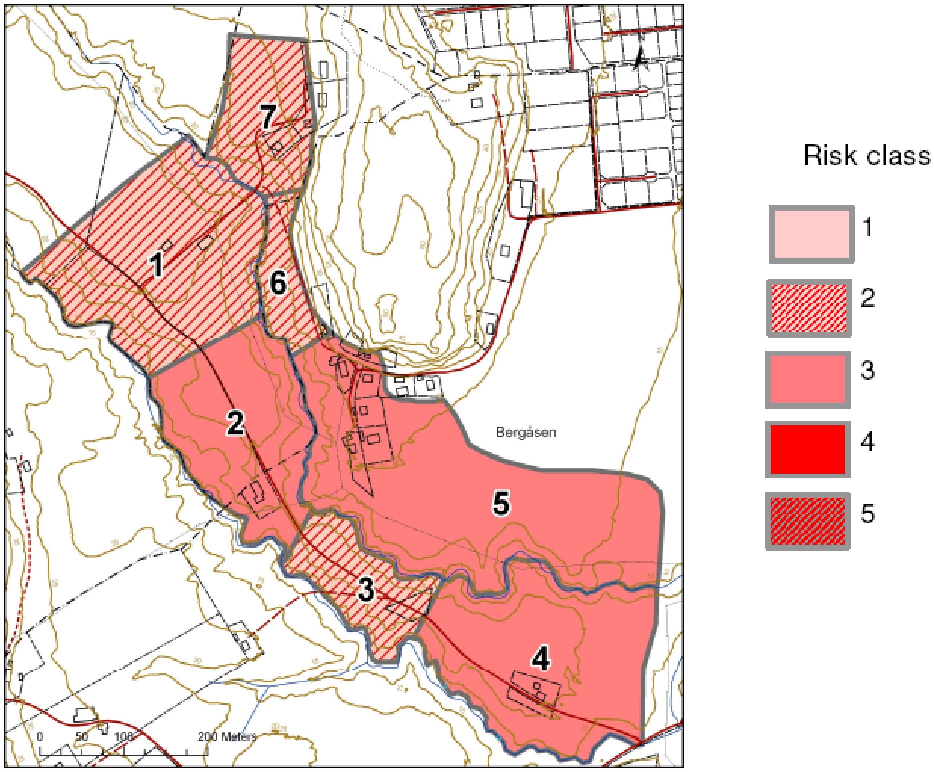
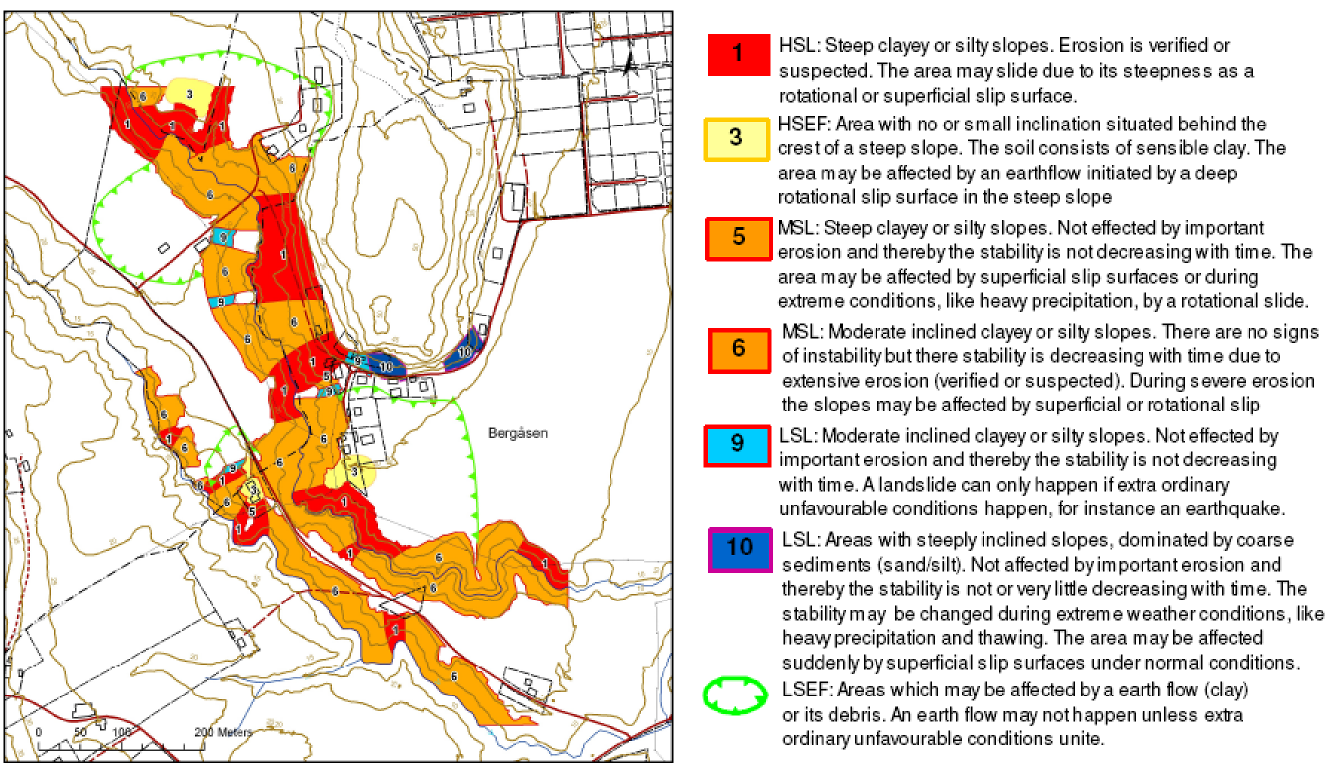


Figure 5. Risk class map for the Åby test site, according to the Norwegian method



.Figure 6. Susceptibility map for the Åby test site, according to the Quebec province method.