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RESULTS FROM SURVEY MAPPING OF THE RISK FOR LANDSLIDES AND DEBRIS FLOWS IN TILL AND COARSE-GRAINED SOILS IN SWEDEN

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ABSTRACT

Up to now, mapping of the risk for landslides and debris flows* in long slopes and gullies in till and coarse-grained soils in Sweden, has only been done in a few limited areas. By commission of the Swedish Rescue Services Agency, the Swedish Geotechnical Institute has recently developed a method for survey mapping of such risks. The aim of the mapping is to identify urbanised areas where there are prerequisites for landslides and/or debris flows. After identification, the areas are classified into four groups with respect to how important it is to investigate them more thoroughly. In 2002 the method was tested in the middle part of Sweden. Two municipalities with different geological histories were chosen for the test, one in a typical mountainous area and one in a bedrock fault area. The investigation shows that the survey mapping method developed is a useful tool.In the test, areas were mapped into all four different levels of need for further investigation.

Key words: Survey mapping, natural hazards, landslides, debris flow, early planning stages, till, coarse-grained soil

INTRODUCTION

Sweden is subjected to different kinds of natural hazards such as landslides, floods, debris flows, avalanches and rock falls. Most of the hazards with severe consequences have been landslides in fine-grained soils. Consequently the research on natural hazards in Sweden have

* In this article debris flow will be referred to as an event where a large volume of a highly concentrated viscous water-debris mixture flows through a stream channel (definition used by Coussot and Meunier, 1996)

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focused on slope stability in fine-grained soils. A survey mapping method for the stability conditions in slopes and gullies in fine-grained soil has been carried out in Sweden since the beginning of the 1980´s with good results. Fallsvik and Viberg (1998) have described the method.

In the Swedish mountainous area, Fjällen, and in other areas covered by till and coarse material incidences of debris flows and landslides occur. Most of the incidences occur, though, outside urbanised areas. Due to the extensive development of ski resorts and increasing heavy precipitation the problems have increased during the last years. In 1997 some large debris flows and landslides occurred in the counties of Värmland and Dalarna which effected roads and settlements, see Fig 1. These events was the starting point for the discussion of the need for a survey mapping method for the stability conditions in slopes and gullies in till and coarse grained soils in Sweden.

Fig 1. Landslide in a deforested slope covered by till. Sysslebäck, County of Värmland. Photo: E., Ottosson, SGI

DESCRIPTION OF THE SURVEY MAPPING METHOD

The Swedish Geotechnical Institute in co-operation with Chalmers University has developed a survey mapping method for the stability conditions in slopes and gullies in till and other coarse soils. The development was done by commission and financing of the Swedish Rescue Services Agency. The method was described in detail by Fallsvik et al. (2003) and is therefor only shortly described within this article. The aim of the survey mapping is to find areas with prerequisites for debris flows and/or landslides and to classify the areas into four groups with respect to how important it is to investigate them more thoroughly.

The survey mapping starts with a pre-study of a whole municipality, with the aim to find urbanised areas, which have prerequisites for debris flow and/or landslides. Only build-up areas come in question in the investigation. The selection of areas is based on geologic and topographical conditions and also on the knowledge of earlier events. The selection is carried out in co-operation with the municipality.

The areas found to have prerequisites for soil movements are then analysed and mapped in two steps (step 1a and 1b). Step 1a comprises survey mapping of the topography, the soil conditions, the hydrological conditions, the vegetation condition, signs of earlier events (land-

slide, erosion, alluvial fan, debris cone), the impact of human activities and existing preventive measures. The investigation is done both by desk studies and by field investigation. The field investigation only involves an ocular inspection of the situation in each area and is not a detailed investigation.

In step 1b is an assessment of the stability conditions in the gully and the slope carried out. All parameters assessed are presented in Tab. 1. For instance, a calculation of the factor of safety for selected possible shear surfaces in a slope is carried out. Step 1b results in a classification of the need for detailed investigation, into four judgement classes. The classification is based both on measured and calculated factors as well as a relative method where the need for investigation is based on a comparison with earlier events. The judgement classes are presented in Tab. 2.

The results of the survey mapping are presented on maps and in a report.

Tab. 1. Parameters assessed in step 1b.

Mapping condition	*Elements to be mapped and calculated*
Landslide – open slope	Height of slope, length of slope, inclination (mean and max), soil type, groundwater conditions, density, safety factor
Topographical conditions – gully	Height difference, length, inclination, width, stability of side slope, gully erosion
Hydrological conditions – gully	Size of catchment area, brook, groundwater erosion, drainage, risk for damming
Soil and rock conditions – gully	Soil type, bare rock, presence of talus and bolder, amount of loose sediments, length of soil cover
Field conditions	Type of vegetation, vegetation cover, road, culvert, ski pist
Earlier events	Debris flow, landslide, erosion, alluvial fan, levees, debris cone, large water flows
Preventive measures	Presence, function, maintenance

Tab. 2. Classification of the need for detailed investigation.

Judgement class	Need for investigation
1	Urgent need for detailed investigation
2	Need for detailed investigation. Need for observation.
3	No need for detailed investigation. Need for observation.
4	No need for detailed investigation and no need for observation under prevailing conditions.

TEST SITES

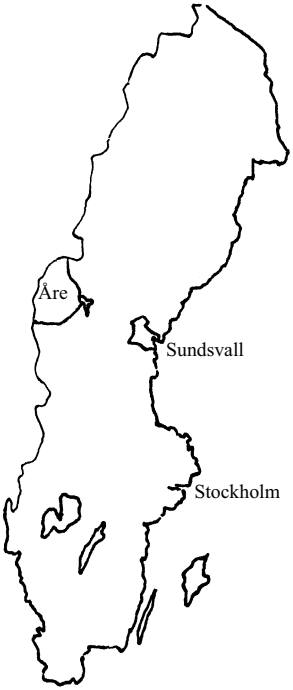

Fig 2. Location of the two test sites; the municipalities of Åre and Sundsvall.

The survey mapping method developed has been applied and tested in 2002. Two municipalities, Åre and Sundsvall in the middle part of Sweden, were selected as test areas, see Fig 2.

Åre

The municipality of Åre is situated in the western part of the county of Jämtland and covers an area of around 7000 km^2. The area is characterised by the mountain ridge, Fjällen. Both mountain peaks as well as mountain plains are found. The highest peak reaches up to 1700 m above sea level

The mean temperature is –10° in wintertime and +13° in summertime. The mean precipitation is around 1000 mm/year in the lower areas and in higher areas the precipitation can reach levels of 1500 mm/year.

The main soil types are silty or clayey till and peat but also a large amount of bare rocks exist. In former ice lakes, sediments consisting of clay and silt, have been deposited and alluvial materials are found in watercourses below.

The bedrock of the Fjällen mountain ridge, consists mostly of sandstone, limestone, schist, glimmer, mica and amphibolite. In some parts the underlaying Precambrian crystalline basement appears. The vegetation consists mostly of coniferous forests up to 650-800 m above sea level (Nationalencyklopedin, 1995). At higher altitudes forests of downy birches (Betula Tortuosa) are growing up to the timberline (around 950 m above sea level). Above the timberline heather and sprigs moors are found.

The village of Åre is the most well known Swedish ski resort. A large development of the village and the ski system has taken place during the last 20 years. A railroad and a European mainroad pass through the village of Åre. Many recurring problems connected to debris flows and landslides have affected Åre. After investigation of the situation, in the beginning of 1990´s, the first preventive measures for debris flows in Sweden were built in Åre.

Sundsvall

The municipality of Sundsvall is situated in the eastern part of the county of Medelpad and covers an area of around 3200 km^2. The area, which border on the southern part of the Gulf of Bothnia, is characterised by a Precambrian rock plateau with rivers flowing in deep valleys from the west side towards the sea. The western part of the municipality is a largely hilly forest-terrain with till slopes above the sediments in the bottom of the valleys. Many peat-lands and bare rock areas are also found in this area. The area close to the Gulf of Bothnia is a lowland area with many bare rocks but also deltas, sand and gravel deposits. The main part of the bedrock consists of granite, granite like rocks, gneiss and transformed sediments and rocks formed by volcanic activity (Nationalencyklopedin, 1995).

The river Ljungan flows in a wide and fertile valley from the south-western part of the municipality towards the east. The river Indalsälven flows in a steep and narrow valley from the north-western part of the municipality towards the east.

The mean temperature is -10° in wintertime and $+15^o$ in summertime. The mean precipitation is 6-800 mm/year. The area is part of the so called nordic coniferous forest region dominated by coniferous trees, pine and spruce, but with an abundantly contribution of birches (Betula Pubescens), aspen (Populus tremula), greyalder (Alnus incana) and rowan (Sorbus aucuparia).

RESULTS

The test of the method was done during September 2002. Three days for field investigation were used on each municipality.

Åre

The pre-study of the whole municipality of Åre indicated 20 built up areas with gullies and slopes, with prerequisites for debris flows and/or landslides. The gullies and slopes were distributed among 7 areas. All these areas were investigated according to step 1a and step 1b. Many evidences of earlier incidences, mostly shallow erosion, landslides and debris flows, were found during the field investigation.

Two of the investigated areas, Fjällhalsen and Bydalen, will be presented more thouroghly in this article. Both areas are situated on the south side of the mountain Västfjället that reaches up to 1159 m above sea level, see Fig 3. The upper part of the mountain is bare rock and further downhill the soil consists of erodible silty till. Six brooks bring water from Västfjället through the areas. The inclination of the slope has a mean value of around 17 degrees and the highest values of around 34 degrees.

In the area of Fjällhalsen the brooks have formed two deep gullies. The largest gully in Fjällhalsen has a catchment area of around 2 km^2. The brook in the bottom of the gully has at some places eroded its way down to bare rock. Many levees, debris cones, inclined trees and some traces of landslides where found in this gully, see Fig 4 and Fig 5.

In Bydalen a ski area is situated and in the pists erosion had occurred at some places. Some cottages were under construction in the lower part of the slope. Problems with erosion were obvious at places where the vegetation cover had been removed, see Fig 6. An old scare from a landslide was also found. The factor of safety against a planar shear surface parallel to the

ground surface, was calculated to be unsatisfied. At Bydalen an alluvial fan is also situated where two brooks discharge into a small lake.

The largest gully in Fjällhalsen was classified to have an urgent need for detailed investigation. The slopes in both Fjällhalsen and Bydalen and the gullies in Bydalen were all classified to have a need for detailed investigation. The results from the investigation in Fjällhalsen and Bydalen are shown on a map in Fig 3. In Tab 3 is shown the legend used for showing the results on the map.

The results from the classification for all investigated areas in Åre, show that two gullies, but no slope, were found to have an urgent need for detailed investigation, The results also showed that of 20 areas investigated 15 (75%) were classified to have a need for detailed investigation. One slope was classified not to have any need for further investigation or observation under prevailing condition.

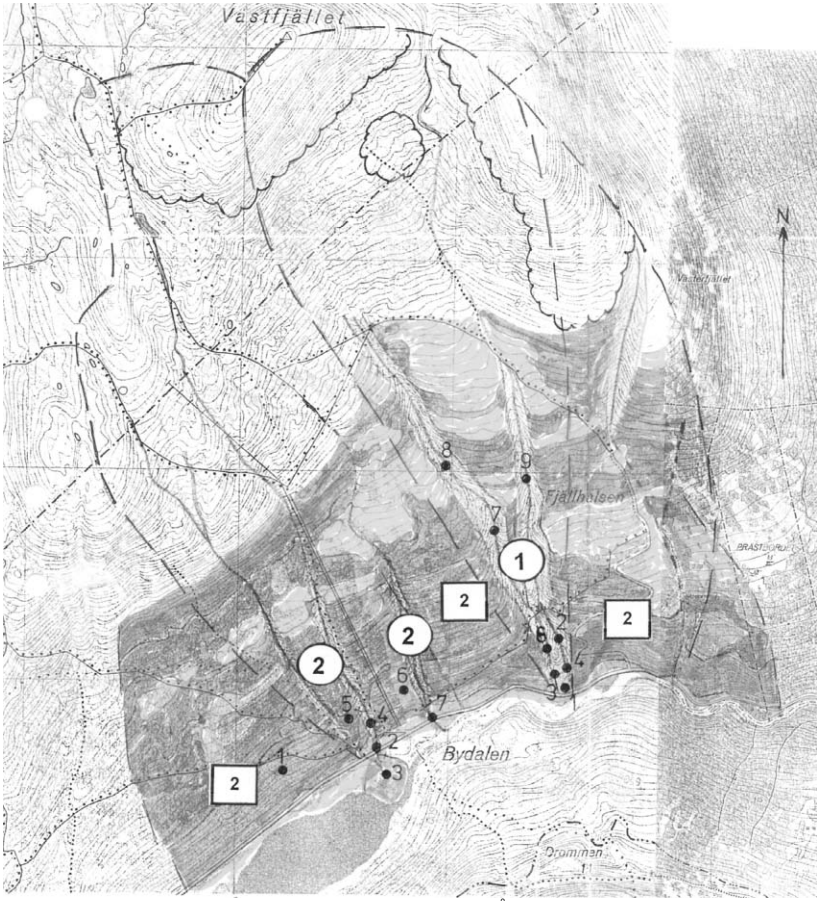

Fig 3. Map showing the test areas in Fjällhalsen and Bydalen, Åre. The results from the classification in step 1 are also shown.

Fig 4. Erosion at the side slopes in the largest gully in Fjällhalsen. Photo: K., Rankka, SGI.

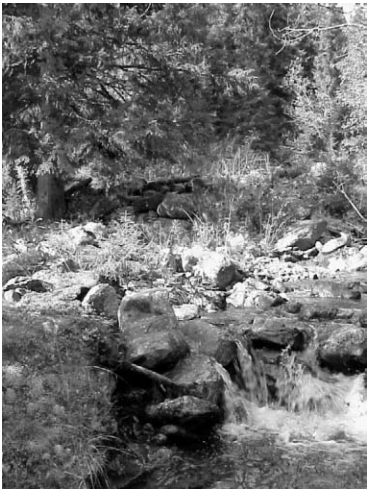

Fig 5. Old debris in the largest gully in Fjällhalsen. Photo: K., Rankka, SGI.

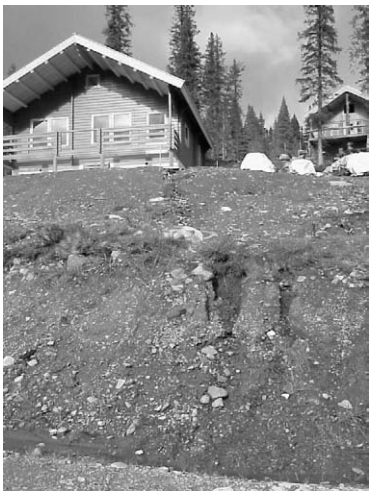

Fig 6. Erosion in silty till in connection with construction of some new cottages in Fjällhalsen. Photo: K., Rankka, SGI.

Tab 3. Legend for showing results on map in step 1.

Symbol	Description	Criteria
	Bare rock	
	Border of catchment area	
Red	Landslide, debris flow, erosion, weathering	
Green	Deposit from mass movements, for instance alluvial fan, debris cone, levees, talus etc.	
Violet	Gully, brook, watercourse	
Blue	Prerequisites for initial landslide or debris flow in an open slope	Inclination >17°
Orange	Prerequisites for transportation and deposition of soil by progressive landslide, debris flow	17°>inclination>10°
Yellow	Prerequisites for deposition of water transported material, mostly gravel, sand, silt and clay	10°>inclination >2°

Tab 4. Classification of the need for detailed investigation in the municipality of Åre.

Area	Need for detailed investigation Judgement class	
	Gully	Slope
Höglekardalen	1-2	2-3
Bydalen	2	2
Fjällhalsen	1	2
Mårdsunds-bodarna	2-3	3
Ottsjö	2	4
Åre-Duved	2-3	2-3
Åre-Mörvik	2	3
Duved-Björnänge	2	2
Edsåsdalen	2-3	2
Undersåker	2	2

It should be noted that no evaluation of the existing preventive measures in the village of Åre was done. The slopes and gullies were classified to have a need for detailed investigation and to have a need for observation.

Sundsvall

The pre-study of the whole municipality of Sundsvall showed 15 gullies and slopes, with pre-requisites for debris flows and/or landslides. The gullies and slopes were distributed among 11 areas.

One of the investigated areas, Järkvissle, will be presented more thouroghly in this article. The area is situated on the eastern side of the Indal River in the west looking slope down the hill of Vithällberget, see Fig 7. The highest point of the hill is 423 m above sea level. The soil consists of erodible silty or sandy till. One brook brings water from the Vithällberget through the area down to the Indal River. The inclination of the slope has a mean value of around 7 degrees and the highest values of around 18 degrees.

The brook has a catchment area of around 3 km^2. In the brook levees and debris cones from old incidents where found, see
Fig 8. The brook is lead through a culvert below the national main road connecting Sundvall and Östersund. The risk for damming in the culvert, due to clogging by transported debris material, was estimated to be high.

For the open slope, the factor of safety against a planar shear surface parallel to the ground surface was calculated to be unsatisfied.

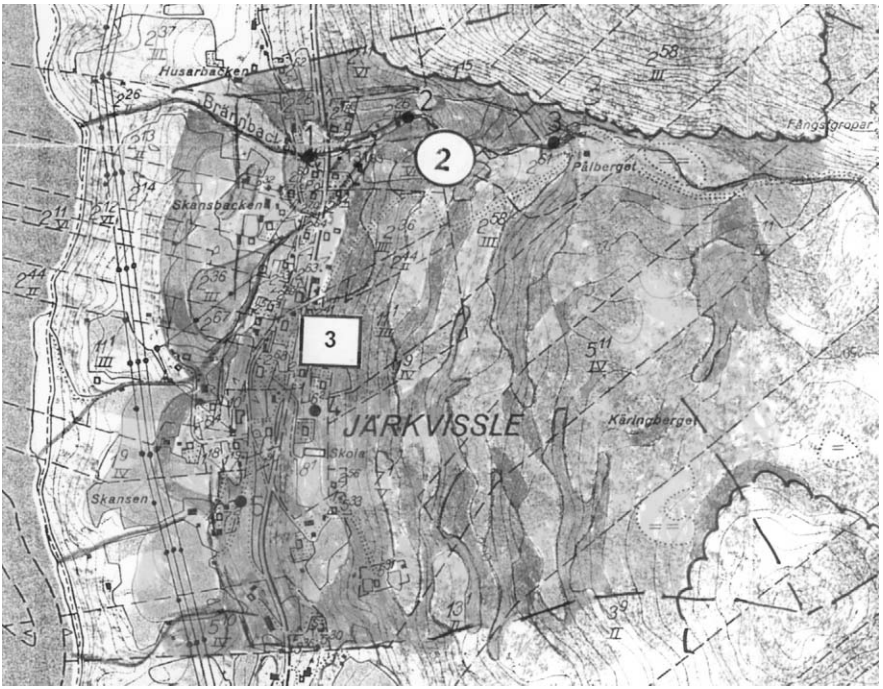

Fig 7. Map showing the test area and the results from the classification in step 1, in Järkvissle, Sundsvall. .

Fig 8. Levees at the side of the brook in Järkvissle, Sundsvall. Photo: J., Fallsvik, SGI.

The area around the brook was classified to have a need for detailed investigation. The slope was classified not to have a need for detailed investigation but a need for observation. The results from the investigation in Järkvissle are shown on a map in Fig 7.

The results from the classification for all investigated areas in Sundsvall, show that none of the investigated gullies or slopes, have an urgent need for detailed investigation, Tab. 5. Moreover, the results also showed that of 15 areas investigated 6 (40%) were classified to have a need for detailed investigation. Three slopes were classified not to have any need for further investigation but a need for observation.

Tab. 5. Classification of the need for detailed investigation in the municipality of Sundsvall.

AREA	Need for detailed investigation Judgement class	
	Gully	Slope
Stöde V	-	2
Österlo	2	4
Lucksta	-	4
Matfors	-	4
Klingsta	2	-
Kvissleby	-	2
Sundsvall, Skönsmon	3	-
Sundsvall, N Stadsberget	-	3 3
Indal	2	-
Järkvissle	2	3
Liden	3	3

CONCLUSIONS

The investigation shows that the survey mapping method developed is a useful tool to indicate gullies and slopes in need of detailed investigation.

The investigation also shows that even in comparatively small catchment areas and low inclined slopes, there are possibilities for mass transport. Many of the incidents of mass transport have occurred due to human activities such as changes in vegetation cover (clear cutting, ski pists) and water flow (underdimensioned road culverts, forest roads). The many unusual heavy precipitation events during the last years have lead to rapid mass movements. There are areas where incidents of mass transport always have occurred and always will occur due to erodible soils, high waterflow, low vegetation cover and high precipitation.

A general survey mapping of municipalities in Sweden, by use of the developed method, will show where prerequisites for landslides and/or debris flows are high. Thereby subsequent suitable action will mitigate the consequences of mass transport.

PLANNED NEW ACTIVITIES

A project has started at the Swedish Geotechnical Institute, which aims to develop a method for detailed investigation of Experiences from other European countries will act as a base for the development but the method will be adapted to the Swedish mountainous and hilly areas. In another ongoing project the municipalities in need for a survey mapping of the stability conditions in slopes and gullies in till and coarse-grained soil are identified. In the future, these municipalities will all be mapped according to the method developed.

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