Landslide risk assessment in the Göta river valley: effect of climate changes

L'évaluation des risques de glissement de terrain dans la vallée de la rivière Göta : effet des changements climatiques

Tremblay M., Svahn V., Lundström K.
Swedish Geotechnical Institute, Linköping and Gothenburg, Sweden

ABSTRACT: The predicted effects of the ongoing climate change such as increased precipitation and longer dry periods are expected to result in an increased frequency of landslides in Sweden. In order to meet this challenge, the Swedish Government commissioned the Swedish Geotechnical Institute (SGI) to investigate and assess the landslide risk in the Göta river valley, which is one of the Swedish valleys with the highest landslide frequency and where consequences of a landslide could be severe due to the number of large industrial sites as well as residential areas and infrastructure. A mapping of the landslide risk considering both present conditions and the effects of a future climate change has been performed. The investigation shows that climate change will increase the risk of landslides in the valley. However, it also shows that high level of risk is already estimated in many areas which can be affected even in today's climate.

RÉSUMÉ : Les effets prévus du changement climatique en cours, comme l'augmentation des précipitations et des périodes sèches plus longues devraient se traduire par une augmentation de la fréquence des glissements de terrain en Suède. Afin de relever ce défi, le gouvernement suédois a chargé l'Institut suédois de géotechnique (SGI) d'étudier et d'évaluer le risque de glissement de terrain dans la vallée de la rivière Göta, qui est une zone à haute fréquence de glissement de terrain et une zone particulièrement vulnérable en raison du nombre de grands sites industriels ainsi que des zones résidentielles et des infrastructures. Une étude des risques de glissement de terrain considérant à la fois les conditions actuelles et les effets d'un changement climatique à venir a été effectuée. L'étude montre que le changement climatique augmente les risques de glissements de terrain dans la vallée, mais elle montre aussi que le niveau de risque est déjà élevé dans de nombreuses parties de la vallée, même dans le climat actuel.

KEYWORDS: lanslides, risk assessment, climatic changes, mapping.

1 INTRODUCTION

The Göta river valley is situated in the southwest of Sweden and runs from Lake Vänern in the north to Gothenburg in the south, Figure 1. It is one of the areas in Sweden which is most frequently affected by landslides. Each year, several landslides of various size and character occur in this region. The landslides are generally small and shallow, however, a number of large landslides have occurred during the past century, some of them with human casualties and extensive property damages (e.g. Alén et al. 2000; Hultén et al. 2007). One reason for the high frequency of landslides in the Göta river valley is its geological history. The deep clay layers were formed during and after the latest glaciation period and in some parts reach a thickness up to 100 meters. The Göta river has overtime cut deep into the clay, forming the prerequisites for landslides. As the clays were mainly deposited in a marine environment, quick clay is therefore widespread in the area. The total length of the river is about 100 km.

The valley has a long history of human activities resulting in settlements, industries, shipping and harbours. Roads and railroads of national importance follow the river bank for kilometres, and environmentally hazardous activities and contaminated sites are common. More than 100,000 people live in the valley and the river is also the fresh water source for about 700,000 people. Due to the relatively high exploitation of the area, the consequences of a landslide in the Göta river valley can therefore be very severe.

The Göta river has suffered from many landslides over the years that have been documented. Parts of the most populated areas in the valley have earlier been investigated for mapping the risk of landslides, but in order to predict the effect of climate changes, the Swedish Government has commissioned the Swedish Geotechnical Institute to investigate and map landslide risks in the whole valley.

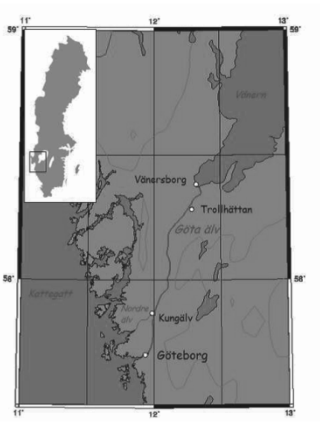

Figure 1. Location of the Göta river

2 METHODOLOGY OF RISK MAPPING

The concept of risk used in these investigations refers to a combination of the *probability* that an event might happen in a given area and the *consequence* of this event occurring.

Risk is defined as a combination of these two parameters:
Risk = Probability x Consequence

A landslide risk analysis thus includes three separate parts:

- the estimation of the probability for a landslide to occur,
- the determination of the consequences of such a landslide,
- the combination of these two factors resulting in a risk map.

Landslide probability is based on the calculation of the safety factor using conventional stability analysis. By studying the uncertainties in a number of parameters used in the calculation of the safety factor in a given area, the probability of a failure occurring in this area is estimated. The probability is therefore directly dependent on the safety factor and the variation in different parameters such as slope geometry, shear strength and density of the soil, etc. The probability of landslide occurrence is divided into five probability classes from "negligible probability of landslide" (probability class S1) to "substantial probability of landslide" (probability class S5).

The impact of a landslide in an area, i.e. damage to life, property and environment, is also defined in five consequence classes, from "minor damages" (consequence class K1) to "catastrophic damages" (consequence class K5). The assessment of the consequences of a landslide takes into account the damage that a possible landslide would cause. Extent of the damage is assumed to be in proportion to how the land is used for dwelling, industries, infrastructure and other facilities and activities. Of course, the size of the landslide is important for the assessment of the consequences, both on land and in the river, and it is affected by the presence of quick clay in the area as well as the topography of the slope. In earlier investigations, the consequences were described following a scale with incremental effects, but in the present project the financial aspects have been added on the impact assessment in order to more systematically compare the consequences of landslides in different areas, affecting different functions in the society.

The combination of landslide probability classes and landslide consequence classes results in an expression of the risk of landslide. Landslide risk class is expressed as a pair of numbers that reflects the consequences of a landslide (K) and its probability to happen (S). A total of 25 risk classes may be obtained from the risk matrix, see Figure 2, and they are clustered into three risk levels (low, medium, high) in order to simplify the risk mapping. The different levels of risk of landslides involve different requirements for geotechnical actions including the need of detailed stability investigations and eventually protective measures.

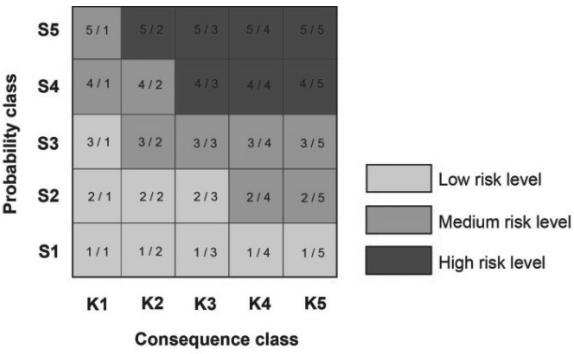

Figure 2. Risk matrix used in the present investigation.

The landslide risk map is obtained by overlaying the probability map and the consequence map and combining them into risk levels. The results of the risk analysis is finally presented in colored maps representing the three risk levels (low, medium and high) as shown in Figure 3. Areas with no landslide risk, e.g. areas with visible bedrock, are omitted from the risk map.

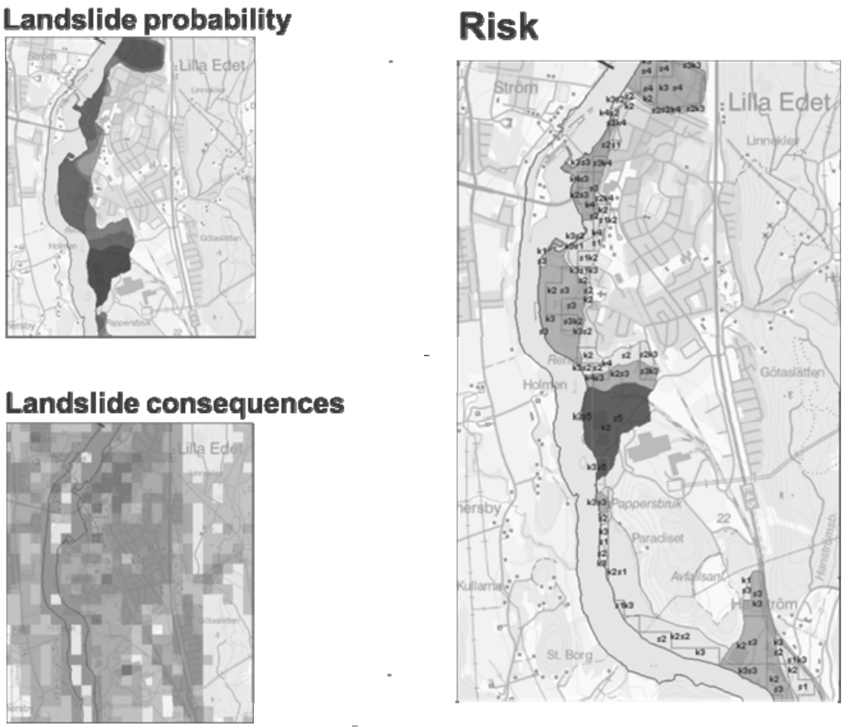

Figure 3. Principle of landslide risk mapping: probability map and consequence map are combined into a risk map.

3 EFFECTS OF CLIMATE CHANGE

Climate change is generally expected to result in increased frequency of natural disasters. In order to limit the damages and meet the new threat that a changing climate will mean for society, it is necessary to work both proactively to identify risks and to protect exposed areas by improving the quality of planning with regard to the new situation. SGI has for several years and on several occasions drawn attention to the geotechnical impacts of climate change. The analysis was summarized in an action plan for climate adaptation work and reported in various publications including the report "Geotechnical conditions for an increased flow of lake Vänern to the Göta River", SGI Varia 565 (Hultén et al, 2006).

Expected climate change in the Göta river valley over the coming 100 years includes gradually increase of yearly mean temperature and precipitation, see Figure 4 and 5, resulting in a higher mean water level in the river. The climate change will also result in an increase in most intensive rainfall events, an increased number of high and low discharges from the Lake Vänern due to increased inflow during autumn/winter and decreased inflow during spring/summer, and finally increased 100-year flows in Göta river tributaries (Bergström et al., 2011).

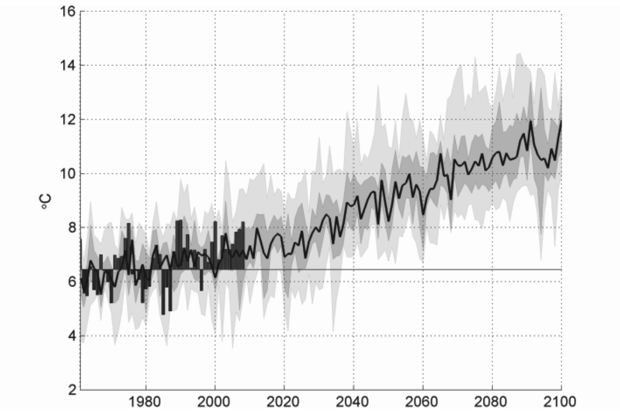

Figure 4. Calculated increase in temperature in the Göta river valley, based on 16 climate scenarios. The historical observations are shown as bars. The dark shaded area shows the 25-75 percentiles and the light shaded area the maximum and minimum values. The black line is the median value (after Bergström et al, 2011).

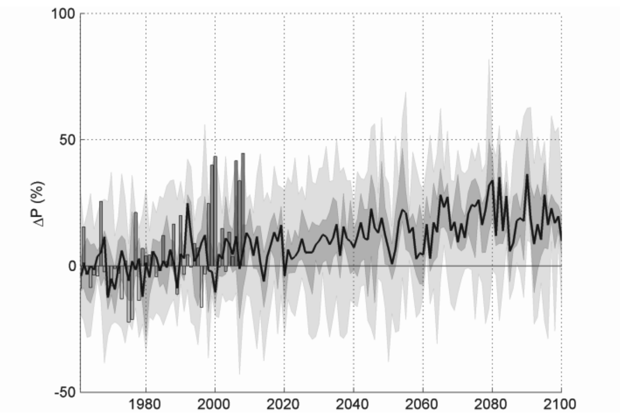

Figure 5. Calculated increase in precipitation in the Göta river valley, based on 16 climate scenarios. The historical observations are shown as bars. The dark shaded area shows the 25-75 percentiles and the light shaded area the maximum and minimum values. The black line is the median value (after Bergström et al, 2011).

A closer study of the results from the different climate scenarios which were performed in the present investigation shows a significant increase in precipitation during the autumn/winter period, which means that the amount of water coming to the Göta river through discharge from the lake Vänern will increase, increasing the risk of erosion and the risk of landslides along the river.

The forecast produced by the different climate scenarios also shows reduced quantities of water during the drier spring/summer periods in the Vänern basin. This means that a lower water level is expected in the Göta river during these periods and thus an increased risk of landslides due to the decreased stabilizing effect of the water in the river. However, the water level in the Göta river is controlled by the presence of electric power plants along the river and is regulated by court statements and different agreements between the electricity producers and the authorities. Therefore, only minor changes of the highest or lowest water levels are expected to occur due to climate change. However, the mean water flow will increase over longer period, causing erosion along the river.

Studies of the changes in groundwater levels have shown that the expected variations are about 0,5 m in the area which means a minor effect on the total stability (see Blied and Persson, 2011).

An extensive study of the impact on the erosion process has also been conducted in this project. The results show that a number of river sections will be affected by the increase of flow in the valley resulting in an increase of erosion (see Rydell et al., 2011).

4 WORK DONE IN CURRENT INVESTIGATION

4.1 *Stability conditions*

To improve the basis for stability calculations, a detailed topographical model of the area has been set up. The model includes topography from a laser scanning on land and a multibeam scanning of the topography of the river bottom.

Existing studies, surveys, maps, charts and other relevant material were collected from various stakeholders and analyzed. Inventory was also made regarding the older material from a stability study in 1962, and other SGI investigations.

To get an overview of ongoing work and a reasonable amount of stability studies, the river valley has been divided into 10 different areas. For all of these areas, a number of sections were chosen and studied using traditional methods to estimate the stability conditions in the current situation. Thereafter, the impact of climate change on the stability was assessed and quantified. A total of 240 sections along the river have been studied including over 2500 field investigation tests and laboratory testing on about 4000 soil samples.

Erosion of the Göta River is a very important factor associated with increased risk of landslides. Cooperation with universities, government agencies and other appropriate bodies was established early in the project in order to plan the study and investigation work necessary for the implementation of the mandate.

Mapping of quick clay areas has also been a major topic studied in this project since it is a primordial parameter needed for a better prediction of the size of expected landslides. Improved investigation methods have been tested and implemented in the project.

4.2 *Consequences of landslides*

In order to perform a complete risk analysis, elements that may be affected by a possible landslide have been analyzed and taken into account. Among the major elements included in the study are human life, residential properties and infrastructures as well as contaminated soils. Extensive work has been performed for inventory, compilation and report of the selected elements for impact assessment (see Andersson-Sköld et al, 2011).

4.3 *Data processing and databases*

Information, data and results from different studies must be organized in an orderly manner to allow for quick access to all materials. For this purpose, a GIS database was built up to simplify data processing and to enable work with the large amount of information acquired during the project.

5 R&D IN CURRENT INVESTIGATION

The investigation included a comprehensive risk analysis to be performed in a rather large area with many factors to be taken into account. The methodology chosen for the investigation using a risk matrix was developed and used in previous landslide analysis.

The commission stipulates that the investigation is expected to result in a complete risk analysis along the Göta river together with a general increase of knowledge regarding landslide analysis and risk mapping. A number of working studies were therefore initiated to study and improve different methods used in this kind of analysis. The Research and Development efforts have mainly been concentrated on mapping of input parameters, understanding of the erosion process, the estimation of probability of landslide and new routines for assessment and presentation of impact of landslides in different areas.

The assignment, which in addition to studying the current situation should also take into account increased flow and runoff conditions in the river valley, asked for a study of the climate changes at a regional level.

The research and development linked to the commission was mainly needs-driven and provided direct assistance in the investigation. Research on mapping and handling of quick clay is an example of efforts which provided valuable knowledge for the investigation. A method based on field measurements has been improved and implemented in the project for classification and mapping of sensitive and quick clays.

Efforts have also been made to try to understand and predict the impact of climate changes on prevailing groundwater conditions. These changes are expected to affect both the mean value of the groundwater level and its variations in time.

Even though it has been the object of a number of earlier analysis and studies, the ongoing erosion in the Göta river valley is still incompletely known. Better knowledge has been acquired and improved models have been developed for both the bottom erosion and erosion of the slopes at the waterline. Analysis and measurements of erosion and sediment transport coordinated with the determination of bathymetric and topographic conditions have been performed in this project. The R&D-work has also included studies of boat related erosion and the use of advanced numerical models.

6 RESULTS AND REPORTING

The results of the project are presented in two different forms:

- a series of 34 reports in which the results from the different R&D groups are presented including study of groundwater, erosion, methodology of probability analysis, methodology for estimation of consequences, mapping of quick clay, etc.

- a final report in three parts including general discussions and recommendations, a complete presentation of the methods used in the investigation and finally risk maps covering the whole valley, see Swedish Geotechnical Institute (2012) or SGI's website: www.swedgeo.se.

As expected, the investigation shows that climate changes will increase the risk of landslides in the Göta river valley. However, it also shows that high level of risk is already estimated in many areas which can be affected even in today's climate. Both the risk for landslide in the present climate conditions and the effect of the climate change in form of new estimation of risk in the future are presented in the final report.

The investigation also leads to a general presentation of protective and preventive measures which could be taken in different parts of the valley. Examples of practical measures that have to be considered are excavations, backfills, soil reinforcement and erosion protection. Besides a rough estimation of the costs of protective measures, the report also includes recommendations regarding different monitoring activities which should be regularly performed along the river.

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