Slope processes and strength of material in silt rich ravines in Säterdalen, Sweden

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Sammanfattning


Resultaten varierar, shear ring-apparaturen bestäms som väl fungerande med undantag från vissa utförda tester, där svårigheter uppstod då jordproverna var störda eller mindre representativa. Vissa av laborationerna på jorden misslyckas med att ge bra värden, vilket ofta är ett resultat av dåliga eller störda prover. Laserscanningar av raviner med LIDAR bestäms som ett bra sätt att studera utvecklingen i sluttningar samt att mäta erosion.

Abstract

Slope processes are important to understand if we are to protect fragile environments. Every year slope development in weak soils put nearby infrastructure in risk zones of sliding and ravine erosion takes away field areal from farmers as they grow even larger. Many methods for doing a risk analysis of a slope and its soil are complicated and require a lot of equipment. A simple way to do a slope investigation is explained in this report, along with its advantages and disadvantages. The authors construct a shear ring, an apparatus to measure peak shear stress of soils before fracturing. LIDAR scanning of two small ravines are also made to illustrate how laser scanning can be used to accurately measure denudation in slopes.

The results vary, the shear ring is mostly a success aside from errors caused by difficulty in taking representative samples and disturbance. Some of the laboratory work made to determine material properties fail at giving good results, often a result of bad samples or disturbance in the tests. The LIDAR is determined to be a good instrument when working with slope development.
1. Introduction

Ravines occur in loose materials where a water flow has cut through the materials over time. Different slope processes, conditions and material properties later determine the angle of the walls in the ravine. These formations are usually active and change valley shapes rapidly with a substantial amount of material in motion. This makes them a difficult environment to predict and therefore also problematical to use for infrastructural purposes. Many ravines in Sweden are national parks, often popular recreational areas with rich vegetation and animal life. However in some areas infrastructure is placed close to these ravines, which make it imperative to understand these ongoing processes to minimize material loss and unnecessary costs to ensure safety. Already in 1712 records tell of farmers having their fields diminished by ravine erosion, leading to requests for compensation from the government (Bergqvist, 1986). This was in Säterdalen, a large ravine system in the middle of Sweden. The area is one of the most well-known in Scandinavia, famous for its long, well developed main ravine with strong relief. Säterdalen with its many side ravines is measured to be 9 kilometers in length (Bergqvist, 1986). Every year more of the adjacent land to the ravine is eroded as a result of slope processes. Some areas nearby which accommodate infrastructure are in the risk zone of laying on a slip surface which could at any time force the landmass down. The many conditions which act as factors when talking about slope stability are important to have an understanding about. To collect data about all these factors often requires complicated and expensive methods. This report experiments with the option of building a shear ring, a test apparatus used to test different soils ability to resist shear stress, an important factor when investigating the stability of slopes.

Figure 1. Recent ravine erosion on a field adjacent to Säterdalen. (Pontus Westrin, 2/5-2013)
This report is focused on four different parts; the first part is discussing general knowledge about slope stability and silt, second is a construction of a laboratory device called Shear Ring and third is a 3D-modelling done with LIDAR made as a preliminary study of denudation rates (the article will not cover a second study due to lack of time). The fourth part will bring the three others together in a discussion, putting them into context and comparing it with modern methods.

1.1 Area Description

Säter, which houses the ravine system this article focuses on, is located in the region Dalarna in Sweden. The ravine system is the biggest in Sweden, measuring a depth up to 40-50 meters and a length of 9 kilometers (Bergqvist, 1986). Säterdalen is located above the limes norrländicus, a natural border which divides Sweden in two distinct climate zones mainly based on the vegetation (SNA, 2013). This indicates that the area has a colder climate with vegetation mainly composed of pine trees which can survive the cold winters. Säter has around 700 mm of annual rainfall, where 25 - 30 % of that is estimated to be snow (SMHI, 2013). This means that the area will gather up a large amount of snow during the winter, and when it melts during the spring it will cause a spring flood (in Swedish called “Vårflod”). Large amounts of water is released in the area and the frozen ground that during the winter supported and held the ravines together is melted (SMHI, 2013), causing high erosion rates during the beginning of the spring season. This is enhanced by the fact that the soils are mostly very silt rich, which will be explained later.

The area where Säterdalen has been created in is a result of a glacial river during the latest ice age. The river eroded away large parts of the bedrock, which later resulted in a water filled fjard. Sedimentation occurred in calm water after the ice age and resulted in a sediment basin mostly dominated by loose material with a high percentage of silt (Bergqvist, 1986), giving it perfect conditions to accommodate a ravine.

2. Theory

2.1 Ravines

Ravines form in loose materials which over time are eroded along a water flow. The shape of a ravine can differ. Some are U-shaped with a flat bottom, whereas others are v-shaped with a sharp bottom, though most ravines lay somewhere in between the two. The shape is determined by several different controlling factors, such as water content in the soil, water flux of groundwater, surface runoff, precipitation, material grading, grain size and vegetation etc. (Bergqvist, 1986). Thus, variations in these parameters depend on both local and climatological circumstances, leading to different ravine shapes. In Sweden several types of ravines have formed, for example in southern Sweden small ravines with low relief are created in soils with a high percentage of clay while bigger are created in materials like silt in the northern parts of the country. The reason why silt rich ravines grow deeper and steeper is mainly that negative pore pressure builds up in the material. This negative pore water pressure binds the grains of the material together, making the particles stick like glue to each other. As the ravine grows deeper the ground water surface will lower towards the riverbed as water flows out in the lower parts of the slopes, resulting in a negative pore pressure
which increases further up the slopes (Bergqvist, 1990). The material will on the other hand become more fluid like if the water content is increased or if the material is disturbed, i.e. increasing the pore water pressure. Distortion may result in the material becoming less subsumed leading to failure. This can mainly be explained by two concepts. The first one is simply the fact that material in motion, which leads to spreading of forces within the material, could make the material fracture due to a loss of strength. Secondly soil liquefaction can occur, which explains loss of strength as the distortion of fine wet material leading to the negative pore pressure easing its strain on the grains. In extreme cases even a positive pore pressure can build up as water will leave the surrounding material due to compression (Das & Ramana, 2011). This will result in a rubber like consistency of the material that will flow more easily (Walker, Fell, 1987).

As earlier mentioned there are several types of ravines, which form in different material with different grain size, under varying water flux and climatic conditions. In the northern parts of Sweden the steep kind mainly discussed in this article, consisting of silt rich material, is commonly occurring. These form from the highest shoreline and below, usually with coarser material in the top layers that works as an antipode towards the transportation of material from the top of the ravine (Bergqvist, 1990).

2.2 General Slope Stability

This section highlights the many factors and variations that drive the topic of slope stability, an important issue in the field of geotechnics and geomorphology. This report only give an overview of the subject. It is over 100 years of research in the field that have yielded advanced techniques and theory in testing of slopes, techniques that often need greater resources and skilled supervision. This report aims to give an overview explanation and use simple tools for slope investigation by constructing an own shear ring testing apparatus. This laboratory equipment is used to determine the strength of material as well as the angle of repose, the steepest angle a material can be piled without failure. These two properties are vital components when looking for instability in slopes.

Some variations of slope erosion are also discussed, mostly common ones from typical silt rich ravines as Säterdalen.

2.2.1 Controlling Factors and Conditions

Strength of the material is referred to the materials ability to resist deformation, either by compression, tension or shear stress. The potential slip, or shear deformation, is controlled by many conditions acting on the slope. As written by Selby (1993) in *Hillslope Materials and Processes*, an equation of the matter may become very complex:

*A complete equation might take the form:

$$
\tau_f = f(e, \Phi, C, \sigma', c', H, T, \varepsilon, \dot{\varepsilon}, S \ldots),
$$

In which:
- \(\tau_f\) is the shearing resistance
- \(e\) is the void ration
- \(\Phi\) is the frictional property of the material
- \(C\) is the composition
\( \sigma' \) is the effective normal load holding materials in contact
\( c' \) is the effective cohesion of the material
\( H \) is the stress history
\( T \) is the temperature
\( \varepsilon \) is the strain
\( \dot{\varepsilon} \) is the strain rate
\( S \) is the structure of the material

(Selby, 1993)

Instead many earth scientists often focus on maybe the most important factors; cohesion, angle of repose and the peak shear strength the material can resist. These are numbers possible to obtain from tests like the shear box/ring, the ring shear or triaxial test. The shear box/ring will be explained in more detail in 3.3 and 3.4.1.

Other very important factors to remember are water content and grain size, which depends on climate and geological environment. Of course the climate changes over the year, but the soils stay the same from a geological perspective. Various soils react differently to a change in water content. For example; water saturated silt is very susceptible to erosion while clay is quite resistant to the same treatment. The behavior of soils with a high silt percentage will be further discussed in 2.3, as well as processes occurring in silt rich ravines.

2.2.2 Mass Wasting

Total mass wasting of a specific area can be called the denudation of that area. The denudation happens due to erosion and weathering processes, like fluvial erosion, ice fracturing of material, wind etc. Denudation describes not only the weathering of solid materials but also the transport of the loose product to another site (Selby, 1993). In this article we will focus on the transport of soil materials that already have been separated from their source rock and undergone earlier stages of transport. The material in place in Säterdalen has been transported there during the last glaciation, called Weichsel, that took place between 115,000 and 11,000 years ago (Eriksson et al., 2011). The soils in the area is well sorted fine grained silt which indicates deposition over a long period of time in a relatively low energy environment. Within such a loose material fluvial erosion may initially form a cut that will grow by time if the flow is continuous as more material is transported away. As the cut is further eroded ground water flux becomes a major factor as water starts to escape the ravine walls. Before a loose material can undergo movement a force larger than the containing strain condition must be induced on each of the grains that are to be transported. Before shear of a soil negative pore water pressure, surface tension between the grains and the water, as well as chemical bonding will also keep the grains from moving (Selby, 1993). When motion already has occurred, less energy will be required to keep the grains in motion. Movement in silt rich ravines are chiefly initiated by water flux where the bonding between grains are broken, which can happen in several ways. The first and most obvious way is water with enough kinetic energy to strip grains from the mass. But it could also be due to water first saturating the material and with increased water pressure expanding the material by increased separation of the grains until the water will distribute the overlying pressure on the water below and so forth and the containing weight of the material on itself will be negligible and the soil will start to deform (Walker & Fell, 1987). Also the high
pore water pressure on grains can be released by draining of soil water through ground water flow. During rainfall the drops will also have high energy on impact compared to the area they affect, making it likely some material will be removed and then transported away by the surface runoff (Selby, 1993). For further reading of specific processes that is present in forming of ravines in silt materials, see 2.3, 2.3.1, and 2.3.2.

2.3 Silt

Silt is classified as a grain size where grains have a diameter between 63 - 2 micrometers and is further categorized into fine silt (2 – 6.3), medium silt (6.3 - 20) and coarse silt (20 - 63) (IEG, 2010). Silt comes with many special attributes, especially when combined with water. These attributes have given silt rich soils many different names in Sweden, ranging from quick soil to yeast soils (directly translated from the Swedish words kvickjord and jäsjord). Silt soils have a strong capillary bond with water that binds the material together. The soils consisting of finer silts are hard to drain of their water due to these strong bonds. This also makes them keen to absorb water very quickly. Silts are classified in between friction soils and cohesion soils, making them hard to categorize. They still have cohesion between grains as clays do, but this is easily taken away by increasing the pore water pressure, i.e. by saturating the soil with water. This can cause the soils to quickly go from having quite strong solidity to acting as a fluid, giving them the nickname “Flytjordar” in Swedish (directly translated to floating soils). (Eriksson et al., 2011).

Bulk density for silt is expected to be between 1300 kg/m³ and 1400 kg/m³ for silt, with an assumed porosity of approx. 50%, whereas particle density is expected to be between 2600 kg/m³ and 2700 kg/m³ (USDA, 2013). The bulk density will be dependent on the particle density as well as of the porosity of the material. Porosity for silt is expected to be between 35 % and 50 % (EVS, Argonne National Laboratory, 2014), which would put the bulk density between 1300 kg/m³ and 1755 kg/m³ for a particle density between 2600 kg/m³ and 2700 kg/m³, as bulk density is the weight of the material in dry state, with air filling the pores.

2.3.1 Mudslides

As mentioned before, silt and clay receive their solidity and strength from the cohesion and friction between the grains, determined by the availability of water and the contact surfaces of the grains. If too much water enter the soil the grains will be pushed apart so that water can move more easily within the materials resulting in lowered cohesion, and eventually enter suspension. As this happens the materials are enabled to behave as a liquid as the properties gradually move towards those of a liquid (Brunsden & Prior, 1984). As opposed to clay, silt absorbs water very easily even after having its pores filled, why this phenomenon is very common in silt rich soils. This is because of the lower capillary forces in silt. Triggers to a mudslide can be heavy rain, melting of snow or a rise of the ground water level for some reason (Bergqvist, 1986).
2.3.2 Tunneling

When material is transported away from the slopes of a ravine several different features can be formed. One of these are tunnels where material is removed from the subsurface. The overlaying material collapse into the tunnel forming sink holes in the ground. As the process goes on the new material will also follow out with the groundwater, forming a tunnel underground as the “ceiling” of the tunnel consist of dryer material that will stick together. This happen above where the ground water flows out of the slope, and the saturated material to some degree will be transported with it, called ground-sapping (Bergqvist, 1986). As the water content is high the grains will not be very strongly bound together by surface tension, but the overall constitution of the material will rather behave like a liquid (Bromhead, 1986). As the material is removed laterally from the slope from sapping a void will form inside the ravine side. Besides from that the support for the overlying material is removed, the water flow will also create a suction by reduced pore pressure that will create a stress on the soil above. When the overlying material has caved into the tunnel more material from above will follow. Less work is needed to transport more material where fracturing has already happened than untouched areas like the sides of the tunnel. The negative pore pressure suction will have its highest magnitude in the tunnel as the water is also allowed to travel faster through these disturbed layers. This will result in water in the surrounding layers moving toward the tunnel increasing the difference in strength within the material. The
moving soil in the tunnel will become more liquefied whereas the wall material will be fortified when the surface tension within it increases (Selby, 1993). The process may continue as long as there is a water flux and material that can be transported, but will often be restricted rather quickly as these structures occur shallow and erosion processes are working rapidly (Bergqvist, 1986).

Figure 3. Tunneling in Säterdalen (Pontus Westrin, 2/5-2013)
3. Method

3.1 LIDAR

LIDAR is an optical remote sensing technology which is used in many ways, for example in fields like archaeology, geology, geomorphology, forestry and geography. The acronym LIDAR stands for Laser Imaging Detection And Ranging, or Light Detection and Ranging, which indicates that it uses laser beams to detect and measure distance to surfaces (Cracknell & Hayes, 2007). The device used in this article is a model which is capable of measuring 360 degrees around its base, making it useful for mapping archaeological dig sites or caves. It is also useful for measuring steep ravines a long way over its base position, which is what it’s used for in this project. The result gives is a 3D-model over a ravine with detailed data of even the most subtle topographical features and their angles. With a ground based instrument like LIDAR it is possible to create a very detailed DEM (Digital Elevation Model), though on a limited area, which is why the project is restricted to work on a two small parts of the ravine system.
3.1.1 Preparation and Execution

The LIDAR equipment used in this report is a ground based laser scanner called Focus 3D by FARO. The Focus 3D comes with three white spheres which are a little smaller than a handball. The spheres are placed in plain sight on different elevations and angles from the LIDAR and their location is measured with advanced GPS equipment, in this case the Trimble R7 GNSS was used which give coordinates down to centimeters (Trimble, 2013). When in post processing the spheres can be located by the program and the coordinates from the GPS is used as input and work as geographic reference for the LIDAR scan. As there are three spheres, triangulation can be used to determine the Focus 3Ds, as well as the scans, location.

Figure 5. The Focus 3D by FARO with scale. The LIDAR is maneuvered with a touchscreen. (Pontus Westrin, 2/5-2013)

Figure 6. Measuring GPS coordinates of spheres (Pontus Westrin, 2/5-2013).
LIDAR scanning was made at two separate sites, where on both several scans were made along the slope from the top and downwards to get a clear view of the formations. At the first site a sully was scanned that started at the very top of the slope next to a farm field and ended almost down at the water stream at the bottom of the valley. This had clearly been recently formed, which could be determined by a lot of vegetation that had been covered by sediment. This survey consist of five scans, the first one at the top and the following ones in order down the slope. This was considered interesting as it could eventually develop into a new side ravine. These side ravines act as several limbs that reach out to the sides of the main ravine.

The second survey was made in a larger sully where the ravine sides had developed to the characteristic slopes you find in these silt rich ravines. This was a more open space and only three scans were considered necessary to capture the area. The ravine was still expanding with silt flows along the slopes of the limb, with a lot of material moving away. It was however developed much further than the potential forming of a limb structure at the site for the first scan and there could therefore be compared between respective projection to give a clearer view of how these form over time. This together with laboratory work of the material and field investigation of slopes, complemented with literature studies are altogether carried through to expand the understanding of how these ravines develop and in what rate this development occur.

The data were processed through an open source software called Cloud Compare. With it the multiple scans from the same area could be linked to each other with the spheres and their exact GPS coordinates. As some of the same spheres are used in several of the scans of the same area they can be used as geographic reference and the scans can be “puzzled” together. The result is the whole area as one 3D-model. The model can then be used to calculate different things like elevation and angle of slopes. The primary use for this model will be to calculate change in slopes and material from another scan taken later, something that will not be discussed here.

3.2 Sampling

Sampling of the materials were made with cylindrical tubes with sharp ends that were put into the ground to minimize disturbance of the material. The tube walls are also thin, an attribute that minimizes displacement during sampling (Brunsden & Prior, 1984). When the cylinder had been pushed down in the material a lid was put on top of it so it could be lifted up without the sample just falling out of the tube, as vacuum forms under the lid preventing the material to fall out. Material was sampled at several elevations above the water stream to measure how the properties of the material differ with water content. Samples were taken just above the waterline where the material was saturated with water, about one meter above the waterline where the material was less fluid-like and more cohesive, around 3 to 4 meters above the water and about ten meters up the slope where the material was expected to have even less water content. A recent silt sully was also sampled to see how the material had been affected by the event. Several samples were also taken in the uppermost part of the slope where a recent silt flow had exposed a fresh surface. This silt flow had transported a lot of material almost all the way down to the water stream, an event that was documented with photographs and some sampling of a hanging wall and foot wall in a fault that was most likely associated with the silt flow.
Disturbance of the samples is hard to avoid, often due to lack of resources and time to perform bore holes to take samples from. Sources that is known to yield disturbance in this case are:

1. The tubes, that when forced down in the soil generate compression
2. Pore-water pressure reduction when a sample is taken from its surroundings, an action that may cause gas to fill pore space and directly damage the soil structure
3. Vibration during transport of the samples
4. Time interval between sampling and test, which cause drop in water levels if not properly sealed
5. The transfer from sample tubes into the shear ring apparatus (Brunsden & Prior, 1984)
A term called area ratio can be used to determine the quality of the sampling tubes. The area ratio is determined by the equation:

\[
\text{Area ratio} = \frac{D_o^2 - D_i^2}{D_i^2} \times 100 \text{ per cent}
\]

Where \(D_i^2\) is the inner diameter and \(D_o^2\) is outside diameter (Brunsden & Prior, 1984). The sample tubes used in this report are made in a hard plastic with relative low friction on the inside, minimizing any compression when pushed down in the soils. The tubes inner and outer diameters are 5.1 and 5.4 centimeters. If put into the equation the answer given is 12 per cent. As written by Brunsden and Prior (1984) a value of 10 is optimal, while a value over 25 is considered to yield a severe amount of disturbance. This puts the sampling equipment in a good place around 10 percent, yielding only a small degree of disturbance.

The disturbance in the samples are to be deemed acceptable due to the fact that every sample is expected to experience the same amount of disturbance. The laboratory work is mainly to raise the discussion around what the changes in material properties and water content does with the strength and angle of repose of the silts in Säterdalen, as long as the samples are equally disturbed this is not a problem.

### 3.3 Shear Ring Construction

As part of this project the choice was made to build a shear ring apparatus to estimate angle of repose, cohesion and the ability to resist shear stress for the silt material with different water content. The shear ring was built on a flat woodblock as foundation to ensure that the whole construction was as stable as possible. A shear ring consist of two cylinders, one attached to the woodblock and another placed directly above it. The top cylinder is attached to an arm that rolls on several ball bearings, so that the top cylinder can move in a horizontal trajectory in frictionless mode. The two cylinders are put as close as possible to one another without touching. This way the material will be sheared along a horizontal plane at the gap between the two cylinders. The arm that is attached to the top cylinder is pulled by a string that lies horizontally toward the arm with the other end of the string hanging vertical under a spinning wheel. When a specific weight is put on the string it will equal the shear stress (\(\sigma_1\)) put on the plane of the material that lies between the two cylinders. The top cylinder will be open on both sides so that a confining pressure (\(\sigma_3\)) can be applied on the sample. As you control both confining pressure and shear stress you can alter the confining pressure and see how the shear stress needed to fracture the sample differentiate. When the procedure is repeated several times for the same material but with different confining pressure you will be able to plot a Mohr diagram with the respective circles correlating to the different confining pressures. The shear ring apparatus was made with references to the shear box explained in Slope Instability by Brunsden and Prior (1984) and careful observation of an old shear ring at the Department of Earth Science in Uppsala.
Figure 10. The four ball bearings holds the upper cylinder 2 millimeters over the lowest one. They also makes it possible for the upper cylinder to move in a frictionless fashion horizontally. (Pontus Westrin, 25/4-2013)

The shear ring/box have a number of error sources that can be observed, particularly;

1. The samples are hard to install into the shear ring, often due to the fact that the soil stick to the walls of the tube
2. Complex stress distribution in the apparatus
3. The sample has only one spot to generate failure (the few millimeters between the tubes)
4. During the test the contact area is reduced, leading to less stress (Brunsden & Prior, 1984)

Despite the above-mentioned error sources this might not play an important part in this report. As explained under 3.2 this is acceptable due to the fact that every sample undergoes the same test with the same conditions, and only the relative values between the samples are to be used.

3.3.1 The Mohr Diagram and Envelope

The Mohr diagram is a plot over acting stresses on an object presented on two axes, confining pressure and shear stress. The two values are taken at a point where deformation is observed in the object, for example a confining pressure (σ₃) of 1 kilo Pascal acting on a specific sand would need 4 kilo Pascal of shear stress to bring it to failure. When plotted into a Mohr diagram we get a Mohr Circle, where σ₃ is where the circle cuts the x-axis on the left
side and $\sigma_1$ on the right. As we are able to increase the confining pressure on an object the shear stress needed to bring it to failure increases too. A test of this sort will give us more Mohr Circles to put in our diagram, resulting in smaller circles followed by larger circles to the right of the diagram (increasing $\sigma_1$ & $\sigma_3$). By drawing a straight line across the connecting tops of the circles (if imagined as a clock face often around 10-11 hours) we get a linear function. This function, or line, is known as the Mohr Coulomb Envelope. This will help us predict further failure points in Mohr Circles of the same material. It will also help us determine the cohesion and angle of repose of the material, given by the linear function $y = kx + m$ where $m$ represents the cohesion and $k$ the angle of repose (Brunsden & Prior, 1984).

Before the data collected from the testing can be put into the Mohr diagram to build up the plot it has to be converted from specific weight (kg) to Pascal (N/m$^2$). The area of the fracture plane is calculated and the weight needed for fracturing is converted to Newton and distributed of the area of the cylinder (m$^2$).

Equations used:

- Circle area (cm$^2$): $C_a = \pi \times r^2$
- Pascal (N/m$^2$): $Pa = \frac{W \times a \times (10^3/C_a)}{10^3}$

Where:
- $r$ = Radius of tube
- $W$ = Weight need for fracture
- $a$ = Acceleration constant, in this case gravity (9.82 m/S$^2$)

In this report the theory is applied with the constructed shear ring to determine valuable information about the soils in Säterdalen to help with understanding the movement and development of the land.

### 3.4 Laboratory Work

All laboratory work were done as quickly as possible after sampling to minimize loss of water from the soil specimens. The tubes were sealed shut with rubber caps and held in the same direction as their original position in the ground to ensure the smallest amount of disturbance as possible.

The shear ring was used to find out more about the soil’s angle of repose and strength and how it differed when other properties changed. To determine the different properties and how to classify the soils a number of other tests were made. The properties determined most important were grain distribution, porosity and natural water content.

#### 3.4.1 Shear Ring

Shear ring testing was performed with equipment specifically built for this study (see 3.3). The tests with the constructed shear ring apparatus were made before the material labs as the shear ring needs undisturbed samples and the material properties tests does not. Therefore the same samples could be reused after going through the shear ring tests. The shear ring tests were done by gently pushing the soil sample through the tube down in the two separate, smaller tubes laying directly on top off each other. The sample was then exposed to stress by hanging weights from the side, making the cylinder on top act as a
When the maximum weight the sample could endure was reached it deformed and the amount of weight added was recorded and put in the results. The sample was put in a labeled plastic bag and the shear ring cleaned. Another sample was then inserted into the shear ring from the same location, but this time a weight was added on top of the two cylinders representing \( \sigma_3 \), the confining pressure. The confining pressures added to the samples were 0, 200 and 400 grams. The sample was then exposed to a shear stress in the same sense as the previous sample, this time with a higher weight required to bring it to a shear deformation.

### 3.4.2 Water Content and Porosity

The natural water content in the collected samples were measured using a technique that slowly evaporates the water in the material. Metal tubes were first measured precisely to calculate their internal volume, they were then weighed in grams with two digits. The material to be examined was put into the tubes carefully to ensure the material filled the whole tube and no air pockets formed inside. The tubes were then weighed again before they were put to dry in a drying cabinet in 105° C. After 18 hours when completely dry they were put into an exicator with a desiccant inside of it to make sure they were kept dry when cooling down. The weight was then measured again. From these measurements natural water content can be measured (See calculations below).

Porosity was measured in the same soil samples after natural water content measurement was done. Porosity was also measured by evaporation of moisture in the material. The soil samples were put into small oven safe bowls that had been weighted, and the clods that had formed during the first drying were softly grinded so that the grains were carefully separated into a fine powder. The bowls were filled with more water than needed to saturate the soil, after the soil were thoroughly saturated with water the waterline were approximately 1 cm above the coarser material that settled instantly. The bowls were left for sedimentation of the finer phases for 6 hours, then the excess water was removed extremely carefully to not disturb the saturated soil. When all excess water has been evaporated the remaining water will completely fill the pores. The samples were then weighed before put in the drying cabinet at 105° C for 12 hours to dry. The samples were weighed again in their dry state. As the weight of the water in the saturated sample can be calculated by the difference in weight and the density of water is known, the porosity can be calculated. The particle density (bulk density) can also be calculated as the volume was known during the testing of the natural water content and the percent air (porosity) in those dried samples are now known (see calculations below).
Used Equations:

Water content (%) \( W = \frac{(S_w - S_d)}{S_d} \)

Porosity (%) \( P = \frac{(S_{ws} - S_d)}{C_v} \)

Bulk Density (kg/m\(^3\)) \( D_b = \left[ \frac{S_d}{(C_v - P)} \right] \times 10^3 \)

Where:

- \( S_w \) = Wet sample (g)  
- \( S_d \) = dry sample (g)  
- \( S_w - S_d \) = Water (g)  
- \( S_{ws} \) = Fully water Saturated sample (g)  
- \( C_v \) = Cylinder volume (cm\(^3\))

(Brunsden & Prior, 1984). Note that 1 g water equals 1 cm\(^3\), for bulk density and porosity it is the volume the water in the saturated samples we are interested in.

Figure 11. The samples used when determining natural water content. (Nils Melin, 14/5-2013)
3.4.3 Grain Size Distribution

To determine the soil’s grain size distribution a sedimentation analysis was made with a hydrometer. The hydrometer used is a tool which measures the density of the solution versus the density of water on a scale of -5 to 60 g/l.

100 grams of soil were taken from the sample bag and weighted with two decimals of accuracy. The soil was then put in a jar with 200 ml of distilled water and 100 ml of dispersant, in this case 0.05 moles of $Na_4P_2O_7$. The soil is then dispersed continuously for 15 minutes. The jar is then kept sealed until the next day.

The jar is dispersed again on the beginning of day two. After 15 minutes the jar is taken out and its contents are put in a high, glass sedimentation cylinder. The cylinder is filled with distilled water, bringing the water level up to 1000 ml. The contents are then put in motion with a stirrer. When all the grains seem to be in suspension the stirring is stopped and a stopwatch is started. At 1, 2, 4, 10, 20, 50, 100, 200, 400 and 1440 minutes the hydrometer is lowered carefully into the solution and a value is noted. When in-between measures the hydrometer is kept in a jar of distilled water to not hinder the sedimentation in the cylinder (Bouyoucos, 1926; Eijkelkamp, 2009).

The hydrometer analysis was done for two samples, 019 and 024, description of these can be found in 4.1.

![Figure 12. Hydrometer test. (Nils Melin, 14/5-2013)](image-url)
4. Results

4.1 Sampling

A list over the sample names and locations are given in Table 1. All the samples were taken directly north of Uggelbo, a small village west from Säter. Not all samples were used.

Table 1. The sample names and locations.
* means that the sample was taken at the same spot as the one above

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Meters over the stream</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>119</td>
<td>0.1</td>
<td>Right by the stream at the shoreline.</td>
</tr>
<tr>
<td>042</td>
<td>0.1</td>
<td>*</td>
</tr>
<tr>
<td>107</td>
<td>0.1</td>
<td>*</td>
</tr>
<tr>
<td>020</td>
<td>0.5</td>
<td>A half meter above the stream on the shoreline.</td>
</tr>
<tr>
<td>019</td>
<td>0.5</td>
<td>*</td>
</tr>
<tr>
<td>106</td>
<td>2</td>
<td>Taken from the mudslide shown in Figure 2.</td>
</tr>
<tr>
<td>101</td>
<td>2</td>
<td>*</td>
</tr>
<tr>
<td>116</td>
<td>2</td>
<td>*</td>
</tr>
<tr>
<td>112</td>
<td>8</td>
<td>Taken from the middle of the ravine (no sign of recent movement).</td>
</tr>
<tr>
<td>040</td>
<td>8</td>
<td>*</td>
</tr>
<tr>
<td>104</td>
<td>6</td>
<td>Taken where material recently had been transported.</td>
</tr>
<tr>
<td>081</td>
<td>6</td>
<td>*</td>
</tr>
<tr>
<td>103</td>
<td>6</td>
<td>*</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
<td>Taken in the fault zone in Figure 8. Dry part.</td>
</tr>
<tr>
<td>033</td>
<td>20</td>
<td>*. Moist part</td>
</tr>
<tr>
<td>017</td>
<td>20</td>
<td>*. Moist part</td>
</tr>
<tr>
<td>024</td>
<td>30</td>
<td>Taken at the top of the ravine, seen in Figure 1.</td>
</tr>
<tr>
<td>047</td>
<td>30</td>
<td>*</td>
</tr>
<tr>
<td>011</td>
<td>30</td>
<td>*</td>
</tr>
</tbody>
</table>

4.2 LIDAR
The results of the LIDAR 3D scanning is presented in the appendix.

4.3 Laboratory Results
Here follows the results from the laboratory work to find out more about the material in Säterdalen.

4.3.1 Shear Ring Test
The results for the shear ring test are presented below in Table 2 - 6 and Figure 13 - 14. Only sample numbers are shown below, readers are referred to Table 1 for more information about the samples. Note that some samples were big enough to be used twice.

The results are two-fold, first a table of the values, second a Mohr diagram of the test. The results are discussed in 5.1.2.
Table 2. Values given from the shear ring tests. The second, third and fourth tests were unsuccessful which is the reason for absent Mohr diagrams for these tests.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Confining pressure (σ3) (gram)</th>
<th>Confining pressure (σ3) (Pa)</th>
<th>Peak shear stress (σ1) (gram)</th>
<th>Peak shear stress (σ1) (Pa)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>119</td>
<td>0</td>
<td>0</td>
<td>400</td>
<td>1923</td>
<td>First test.</td>
</tr>
<tr>
<td>119</td>
<td>200</td>
<td>961</td>
<td>660</td>
<td>3173</td>
<td>Mohr plot shown in Fig. 13.</td>
</tr>
<tr>
<td>107</td>
<td>200</td>
<td>961</td>
<td>620</td>
<td>2980</td>
<td></td>
</tr>
<tr>
<td>042</td>
<td>400</td>
<td>1923</td>
<td>950</td>
<td>4567</td>
<td></td>
</tr>
<tr>
<td>019</td>
<td>0</td>
<td>X</td>
<td>700</td>
<td>X</td>
<td>Second test.</td>
</tr>
<tr>
<td>019</td>
<td>0</td>
<td>X</td>
<td>700</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>020</td>
<td>200</td>
<td>X</td>
<td>1000</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>020</td>
<td>400</td>
<td>X</td>
<td>1200</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>019</td>
<td>0</td>
<td>X</td>
<td>600</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>019</td>
<td>0</td>
<td>X</td>
<td>680</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>019</td>
<td>200</td>
<td>X</td>
<td>540</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>019</td>
<td>0</td>
<td>X</td>
<td>360</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>019</td>
<td>100</td>
<td>X</td>
<td>350</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>019</td>
<td>200</td>
<td>X</td>
<td>420</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>011</td>
<td>0</td>
<td>0</td>
<td>660</td>
<td>3173</td>
<td>Fifth test.</td>
</tr>
<tr>
<td>024</td>
<td>200</td>
<td>961</td>
<td>940</td>
<td>4519</td>
<td>Mohr plot shown in Fig. 14.</td>
</tr>
<tr>
<td>047</td>
<td>400</td>
<td>1923</td>
<td>1150</td>
<td>5528</td>
<td></td>
</tr>
<tr>
<td>047</td>
<td>400</td>
<td>1923</td>
<td>1200</td>
<td>5769</td>
<td></td>
</tr>
</tbody>
</table>

Figure 13. Mohr diagram plot of the first shear ring test.

Where:
- $\tau$ = Shear stress
- $C$ = Cohesion
- $\sigma_n$ = Normal net strain
- $\alpha$ = Internal angle of friction
- $\Theta$ = Angle of repose
Figure 14. Mohr diagram plot of the fifth shear ring test. Explanation of symbols above.

4.3.2 Water Content and Porosity

Table 7. Volume and weight of the test cylinders used, needed for further equations.

<table>
<thead>
<tr>
<th>Cylinder number</th>
<th>Correlates to sample:</th>
<th>Volume ($cm^3$)</th>
<th>Weight incl. Jars (gram)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>019</td>
<td>32.20</td>
<td>44.73</td>
</tr>
<tr>
<td>2</td>
<td>024</td>
<td>32.20</td>
<td>44.69</td>
</tr>
<tr>
<td>3</td>
<td>116</td>
<td>31.58</td>
<td>36.41</td>
</tr>
<tr>
<td>4</td>
<td>040</td>
<td>31.99</td>
<td>35.88</td>
</tr>
<tr>
<td>5</td>
<td>020</td>
<td>32.41</td>
<td>33.45</td>
</tr>
<tr>
<td>6</td>
<td>112</td>
<td>32.20</td>
<td>44.77</td>
</tr>
<tr>
<td>7</td>
<td>047</td>
<td>32.20</td>
<td>36.59</td>
</tr>
<tr>
<td>8</td>
<td>011</td>
<td>31.58</td>
<td>33.22</td>
</tr>
<tr>
<td>9</td>
<td>042</td>
<td>31.99</td>
<td>35.88</td>
</tr>
<tr>
<td>10</td>
<td>119</td>
<td>32.41</td>
<td>44.70</td>
</tr>
</tbody>
</table>
Table 8. Volume of water and bulk density.

<table>
<thead>
<tr>
<th>Cylinder number</th>
<th>Weight incl. Cylinder and bucket – wet (grams)</th>
<th>Weight incl. Cylinder and bucket – dry (grams)</th>
<th>Water in the tubes before drying (grams)</th>
<th>Weight of wet material in the tubes (grams)</th>
<th>Weight percentage of water (%)</th>
<th>Weight percentage of water (%)</th>
<th>Volume percentage of water (%)</th>
<th>Bulk Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>104.69</td>
<td>90.29</td>
<td>14.40</td>
<td>59.96</td>
<td>24.01</td>
<td>44.72</td>
<td>1.415</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>104.96</td>
<td>91.21</td>
<td>13.75</td>
<td>60.27</td>
<td>22.81</td>
<td>42.70</td>
<td>1.445</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>95.74</td>
<td>81.66</td>
<td>14.08</td>
<td>59.33</td>
<td>23.73</td>
<td>44.59</td>
<td>1.433</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>91.28</td>
<td>75.17</td>
<td>16.11</td>
<td>55.40</td>
<td>29.08</td>
<td>50.36</td>
<td>1.228</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>92.65</td>
<td>79.31</td>
<td>13.34</td>
<td>59.20</td>
<td>22.53</td>
<td>41.16</td>
<td>1.415</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>101.98</td>
<td>86.67</td>
<td>15.31</td>
<td>57.21</td>
<td>26.76</td>
<td>47.55</td>
<td>1.301</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>95.66</td>
<td>81.70</td>
<td>13.96</td>
<td>59.07</td>
<td>23.63</td>
<td>43.35</td>
<td>1.401</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>91.27</td>
<td>77.01</td>
<td>14.26</td>
<td>58.05</td>
<td>24.57</td>
<td>45.16</td>
<td>1.387</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>96.16</td>
<td>82.56</td>
<td>13.60</td>
<td>60.28</td>
<td>22.56</td>
<td>42.51</td>
<td>1.459</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>105.27</td>
<td>91.45</td>
<td>13.82</td>
<td>60.57</td>
<td>22.82</td>
<td>42.64</td>
<td>1.442</td>
<td></td>
</tr>
</tbody>
</table>

Table 9. Porosity and particle density.

<table>
<thead>
<tr>
<th>Bowl Number (correlates to cylinder number)</th>
<th>Correlates to sample: Weight of bowl (g)</th>
<th>Weight of bowl with fully water saturated material (g)</th>
<th>Weight of bowl with dry material (g)</th>
<th>Porosity (%)</th>
<th>Particle Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>019</td>
<td>59.25</td>
<td>117.23</td>
<td>102.55</td>
<td>45.59</td>
</tr>
<tr>
<td>2</td>
<td>024</td>
<td>62.33</td>
<td>126.31</td>
<td>107.09</td>
<td>59.69</td>
</tr>
<tr>
<td>3</td>
<td>116</td>
<td>64.92</td>
<td>128.42</td>
<td>109.15</td>
<td>61.02</td>
</tr>
<tr>
<td>4</td>
<td>040</td>
<td>68.09</td>
<td>126.42</td>
<td>104.25</td>
<td>69.30</td>
</tr>
<tr>
<td>5</td>
<td>020</td>
<td>66.36</td>
<td>126.29</td>
<td>111.30</td>
<td>46.25</td>
</tr>
</tbody>
</table>

Note that the samples put in the bowls were the same and all of the material in the cylinders from the previous experiment and the volume therefore is the same.
4.3.3 Grain Size Distribution

Table 10. Hydrometer analysis for 019 and 024.

<table>
<thead>
<tr>
<th>Time (minutes: seconds)</th>
<th>Hydrometer value (μ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>019</td>
</tr>
<tr>
<td>1:15</td>
<td>33</td>
</tr>
<tr>
<td>2:00</td>
<td>27</td>
</tr>
<tr>
<td>4:00</td>
<td>20</td>
</tr>
<tr>
<td>10:00</td>
<td>13</td>
</tr>
<tr>
<td>20:00</td>
<td>10</td>
</tr>
<tr>
<td>50:00</td>
<td>7</td>
</tr>
<tr>
<td>100:00</td>
<td>5</td>
</tr>
<tr>
<td>200:00</td>
<td>4</td>
</tr>
<tr>
<td>400:00</td>
<td>3</td>
</tr>
<tr>
<td>1440:00</td>
<td>2,5</td>
</tr>
</tbody>
</table>

Due to unknown reasons this test did not bring satisfying results, leading to the exclusion of the analysis. Discussion of this can be found in 5.2.

5. Discussion

5.1 Sampling Methods And The Making And Use Of A Low-Cost Shear Ring Apparatus

This project aimed to further investigate simple methods for examining the properties of slopes and loose materials in whole but also to investigate the material properties in soils where active parties are present to understand slope properties better.

Building of a shear ring has to be done extremely precise if the results from the experiments are to be representative, qualitative measurements of properties for the soil samples. Due to its low cost it could however be applicable in several cases, such as for educational purposes, or as part of a pre study of an area to decide if further measuring of the area is needed. If construction, sampling and measuring is made with extreme precaution the results will theoretically correspond to reality and be very close to the data that would be
achieved with more expensive automated equipment. However it is not possible to sample without any disturbance, or move samples between sampling equipment and the measuring device etc. which will be further discussed.

5.1.1 Error Sources

There are several error sources needed to be accounted for when doing a shear ring test. Some of which will be more apparent when working with simpler equipment as the one used for this project, but also some that are applicable for all testing of loose material strength. As mentioned in the text above there are several error sources to take into consideration when sampling and handling the samples. The tubes used for this project had an area ratio of 12.1 percent which is considered to be good for sampling without disturbing the soil too much through compression toward the center of the sample along the central axis of the tube. Also the pore-water pressure reduction was kept to a minimum by concealing the sample directly after collection in the field. Preferably testing in the shear ring equipment should be done as close in time as possible after sampling is made. During this project the time between sampling and tests were more than a week apart which potentially could have affected the outcome of the experiment. However the samples were properly stored without any movement during this time and tightly sealed to ensure no leaking could occur. The two most sensitive steps in the procedure implemented during this study transport of the samples from Säterdalen back to Uppsala where the shear ring testing was performed, as well as the process of moving the samples from the sampling tubes to the apparatus in which the experiment was performed. The samples were however handled as careful as possible during transport in an upright position and transported by train which were considered a more stable way of transporting them than by car. When the samples were to be applied into the shear ring apparatus it was done carefully and the experiment was performed instantly after the material was in place in the apparatus. The equipment was constructed in such a way that compaction of the material from buildup of pressure in the air pocket below the sample during insertion was avoided, and specially built tool for the purpose of extracting the samples from the sampling tubes were used to minimize disturbance during the whole process of placing the samples in the shear ring apparatus.

A shear ring has some sources of error that is difficult to compensate for. The most apparent is the one that the soils can only fracture along a specific plane between the two shearing cylinders and the result is just representative for this part of the soil. Sampling was made at sections of the sample where the material was considered homogenous. This way the peak strength can be appreciated to roughly represent all potential fracture planes of the soil. Biological material like grass residues and roots were avoided, as this will affect the strength of the material. Obviously material oriented along the sample perpendicular to the shearing plane will counteract the initiation of shearing if it crosses the shearing surface, while randomly oriented objects within the sample and especially that laying parallel to the shearing plane was considered a source that could potentially lower the peak strength of the material as the binding forces between the grains will be compromised. It is difficult to tell exactly how mixed randomly oriented organic residues will affect the result but as this study focused on the properties of the pure soil it was considered best to sample homogenous material to ensure that’s what the results represent.
5.1.2 Shear Ring Results In Detail

The shear ring test which results are presented in 4.3.1 are explained in this section with references to the previous section about the error sources overall when dealing with the shear ring as an instrument.

The first test performed well, when plotted into a Mohr diagram it produces reasonable values that are representable for the soil. The samples were the ones located right at the stream, with high water content and very fine grained particles. The test also generates similar values with repeated measurements, proving that the constructed shear ring, or at least the concept of it, indeed works. It also proves that similar samples are obtainable from the same site, with the same amount of disturbance. The behavior of two samples tested twice with similar or exactly the same results can also be seen in the second and fifth shear ring test, further proving that the constructed shear ring is functioning.

The second test was a failure and was therefore aborted due to a large root in the middle of the 020 sample. As explained in 5.1.1 the tests were arranged for non-organic matter only, and as the root compromised the results it was aborted and put in the report to explain the many difficulties with testing and sampling.

The third and fourth tests had similar reasons for being aborted. These samples were all taken in recently transported material in the form of mudslides of different characters. The samples were believed to be taken from similar sources in the field, but testing shows values that does not generate a reasonable Mohr diagram. When samples were taken out of the tubes some showed signs of having a higher water content or slightly different composition than others, two important factors contributing greatly to the ability to resist shear stress.

The fifth test generated reasonable values that can seem representable for the soil and was considered a success. The soil’s ability to resist shear stress was greater than the soils in the first test. When comparing the first test with the fifth we see that the soils from the top of the ravine (the fifth test) require approximately 30 - 50 percent more weights to come to failure. This is likely to be a result of the lower water content in the soils from the top of the ravine. The relation to the different compositions are also important

5.2 Laboratory Work Determining Material Properties

The natural water content does not seem to differ as much as one would expect, as sampling was made at different sites with expected difference in water content. This could be explained by water loss during shear ring testing and transportation, and states the fact that it is imperative to carry out every step in the process of testing with extreme caution. However the results show that the properties that were measured were correlated in the result from the shear ring testing, where the slightly dryer material sampled in the top of the slopes had higher cohesion than the wetter material sampled in the ravine bottom. Angle of repose does not seem to be different for different sampling sites which confirm that water content mainly will affect the angle to which the ravine sides can steepen as long as the negative pore pressure remains, but the angle at which the material will settle when sliding is uniform at the sample sites and is similar for the different water contents. The low angle of repose tell us that the material is a fine angular material where the separate grains when dry or set in motion easily move past one another. This helps to prove that the steep angles the ravines have are mainly due to the
negative pore pressure in the material as well as vegetation binding the material along the slopes, and not the angle of repose of the material.

The values obtained for bulk density are all within plausible limits (1228 – 1459 kg/m$^3$) for silt soils, but the values obtained for particle density are differing very much. The expected value is 2600 – 2700 kg/m$^3$, which means two of the values obtained is probably close to the real particle density. However three values are outliers with far too great densities expressed. A probable source of error is faulty preparation of the samples in the bowls before drying. Even though prepared cautiously it was very sensitive to disturbance. Also the effect of pore expansion may have played a role, since a higher value for porosity for the same bulk density would put the value for particle density in a higher region.

The hydrometer analysis also failed due to unknown reasons. The values for sample 019 seemed to point towards 35 % of clay, but was too unclear to read out. The values for sample 024 did not correspond with the nomogram at all, leading to the exclusion of the analysis from this report.

5.3 LIDAR as an Instrument for Studies of Slope Denudation Rates

Often calculations of erosion rate of a slope are based upon the level of water flux and precipitation in the area as well as other contributing factors such as vegetation cover and soil composition. These calculations are often supported with illustrations and photographs showing a change over a period of years. With several LIDAR images over a slope taken from different times we not only get a perfect illustration of the slope but also a good qualitative measure by comparing different scans. With careful GPS-positioning and georeferences in post-processing the rate of movement over a period of time (provided you have several scanning’s from different times) can be given.

A problem that was encountered with the GPS equipment was signs of multipathing. This is when the signals from the satellite to the handheld GPS receiver can’t go in a straight path. In this case the multipathing were likely produced by the vegetation in the area, the ravines that were mapped had many trees that may have interfered with the GPS receiver, causing signals to bounce. This caused problems when, in post-processing, trying to georeference the spheres used to triangulate the position of the scan. However it did not affect the relative georeferencing when putting the different scans together, which is for example important when analyzing morphological properties of the slope. The GPS-errors could cause a problem when trying to correlate with a second scan later, as the scans then need to be compared with their absolute position. The option is to relate the scans to easily recognizable trees or other landmarks, though this is not a perfect method in any means. The conclusion to be drawn from this is that to avoid multipathing in the GPS measurement more careful scanning has to be made with the use of antennas put higher than potential vegetation causing interference.
6. Conclusion

The importance of slope development is significant in regions with weak soils. Methods to avoid slope retreat from getting out of hand are many, but the first step is to characterize the physical properties of the slope and understand how these affect the slope retreat. This study introduce a way to investigate soils with simple methods.

The results from the study vary with each step. One of the most difficult stages is the retrieval of sample material from the region that is studied. A major reason for the problems that arose was lack of good sample sites, mainly due to vegetation disturbing samples used in the shear ring apparatus. Another reason for the difficulties were transportation of samples with varying water content, i.e. keeping the water content equal as when sampled.

The shear ring apparatus, when handling good samples, performed very well. The results given were consistent with literature and seemed representable for the soils in Säterdalen. The results from the LIDAR survey were also good, though harder to evaluate as this study only took part in a preliminary scan, which is to be used as comparison with later scans. Discussion about the method reveal possibilities with LIDAR as an investigation tool.

In conclusion, it can be necessary to do further research in the area, build upon the first shear ring and refine the sampling methods. The last point is important as the samples themselves stand for a lot of the knowledge about the area. Factors as shear strength, grain size and water content are all vital for if a slope will fail, resulting in a fault, or hold.

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Slope processes and strength of material in silt rich ravines in Säterdalen, Sweden

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Slope processes are important to understand if we are to protect fragile environments. Every year slope development in weak soils put nearby infrastructure in risk zones of sliding and ravine erosion takes away field areal from farmers as they grow even larger. Many methods for doing a risk analysis of a slope and its soil are complicated and require a lot of equipment. A simple way to do a slope investigation is explained in this report, along with its advantages and disadvantages. The authors construct a shear ring, an apparatus to measure peak shear stress of soils before fracturing. LIDAR scanning of two small ravines are also made to illustrate how laser scanning can be used to accurately measure denudation in slopes.

The results vary, the shear ring is mostly a success aside from errors caused by difficulty in taking representative samples and disturbance. Some of the laboratory work made to determine material properties fail at giving good results, often a result of bad samples or disturbance in the tests. The LIDAR is determined to be a good instrument when working with slope development.