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Monitoring the hydro-mechanical effects of vegetation cover on shallow landslide triggering: Preliminary results from a case study in western Norway

Surveillance des effets hydromécaniques de la couverture végétale sur le déclenchement de glissements de terrain superficiels: Résultats préliminaires d'une étude de cas dans l'ouest de la Norvège

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ABSTRACT: Rainfall-induced shallow landslides are amongst the most common gravitational mass movements on slopes in steep terrain. The use of vegetation as a nature-based solution for shallow landslide risk reduction is receiving increased attention in the scientific community. Until now, no studies on the effects of vegetation on slope stability have been conducted for Nordic conditions. Additionally, direct comparison between the hydrological conditions in a forest and a neighbouring open field has never previously been carried out in this region. To contribute to filling this knowledge gap, a monitoring program is installed, and field investigations are conducted in a natural slope in the Flåm valley, located in western Norway. The case study site is situated on a slope partially used as hayfield, and partially covered by deciduous forest. Both the hayfield and the forest are assessed to compare the effects of the presence of vegetation on slope stability. Herein, preliminary results are presented. A detailed analysis of the monitored variables and the laboratory test results must be carried out before to conclude on the effectiveness of the existing forest as a shallow landslide mitigation measure at the case study site.

RÉSUMÉ: Les glissements de terrain peu profonds induits par les précipitations sont parmi les mouvements gravitationnels les plus courants sur les pentes en terrain escarpé. L'utilisation de la végétation comme solution fondée sur la nature pour la réduction du risque de glissements de terrain peu profonds suscite un intérêt croissant au sein de la communauté scientifique. Jusqu'à présent, aucune étude des effets de la végétation sur la stabilité des pentes n'a été menée dans des conditions nordiques. De plus, aucune comparaison directe entre les conditions hydrologiques dans une forêt et un champ ouvert voisin n'a jamais été réalisée dans ces conditions. Pour contribuer à combler cette lacune de connaissances, un programme de surveillance est mis en place et des investigations de terrain sont menées sur une pente naturelle dans la vallée de Flåm, située dans l'ouest de la Norvège. Le site d'étude est situé sur une pente partiellement utilisée comme champ de foin et partiellement recouverte par une forêt caduque. Le champ de foin et la forêt sont tous deux évalués pour comparer les effets de la présence de végétation sur la stabilité de la pente. Dans ce document, des résultats préliminaires sont présentés. Une analyse détaillée des variables surveillées et des résultats des tests en laboratoire doit être effectuée avant de conclure sur l'efficacité de la forêt existante en tant que mesure d'atténuation des glissements de terrain peu profonds sur le site d'étude de cas.

Keywords: Monitoring; nature-based solutions; hydromechanical root-reinforcement; shallow landslides.

1 INTRODUCTION

Rainfall-induced shallow landslides are amongst the most common gravitational mass movements on slopes in steep terrain (Masi et al., 2021). These types of landslides usually interest the uppermost layer of soil or weathered rock (Phillips et al., 2021), posing a serious threat to people, infrastructure as well as agroforestry production in mountain areas. Lately, the

use of vegetation as a Nature-based Solution (NbS) as a mitigation measure for shallow landslides is receiving increased attention in the scientific community (Capobianco et al., 2022). Vegetation can contribute to slope stability through both hydrological and mechanical processes. Plants can provide mechanical reinforcement through the tensile strength of the root network and the interaction between the roots and the soil and/or bedrock (Bischetti et al., 2005). The hydrological reinforcement effects of plants consist of reducing the amount of water in the soil, i.e., reducing the driving forces in the slope caused by pore water pressures. The water content is reduced through plants' ability to intercept water on their canopies and by root water uptake through transpiration (Chirico et al., 2013). Furthermore, vegetation can affect the stability of a slope by surcharge due to self-weight (Gray & Megahan, 1981) and by being subjected to wind (Kim et al., 2020). Soil permeability is also affected by the presence of roots in the vadose zone, resulting in a change in the infiltration and drainage capabilities of the slope (Vergani & Graf, 2016).

Site specificities, such as climate seasonality, environmental conditions and soil conditions can play a role in how vegetation affects the soil hydro-mechanical properties (Boldrin et al., 2021). Until now, no studies on the effects of vegetation on slope stability has been conducted for Nordic conditions. Additionally, direct comparison between the hydrological conditions in a forest and a neighbouring open field has never previously been carried out in this region. To contribute to filling this knowledge gap, a monitoring program is installed and field investigations are conducted in a natural slope in the Flåm valley, located in western Norway. The case study site is situated on a slope partially used as hayfield, and partially covered by deciduous forest. Both the hayfield and the forest site are assessed to compare the effects of the presence of vegetation on slope stability. This paper provides an overview of the case study site, a description of the monitoring program, field and laboratory campaign and some preliminary results. Finally, the plans for further data analysis and research are presented.

2 MATERIALS AND METHODS

2.1 Case study site

The case study site, the farm Ryo, is situated on the hillslopes of the Flåm valley in western Norway (Figure 1). The area is composed of fjords and mountains with small, populated areas concentrated in the lower river valleys. This unique setting is recognized by UNESCO as a world heritage site, and the cultural landscape is maintained by the local inhabitants through traditional farming methods. The mountainsides are steep causing frequent shallow landslides, rock falls and avalanches. Ryo is located about 600 m.a.s.l., and the land is partially used as hayfield, and partially covered by a naturally growing deciduous forest composed by alder (*Alnus incana*), birch (*Betula pubescens*), aspen (*Populus tremula*), and willow (*Salix caprea*) trees (Figure 2, Figure 3). The slope angle of the hillslope is approx. 30° around the farm. The soil in the area consists generally of landslide debris of phyllite rock, which over the years has decomposed into well-graded material.

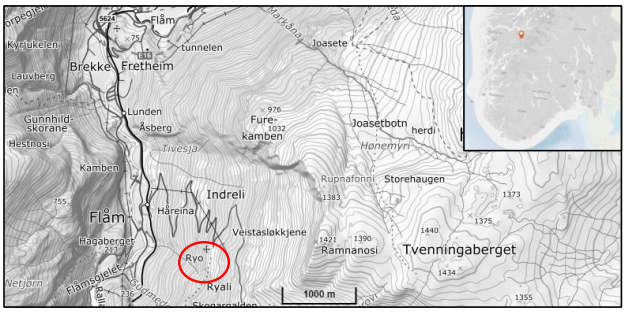

Figure 1. Location of the study site, Ryo. Source: www.norgeskart.no.

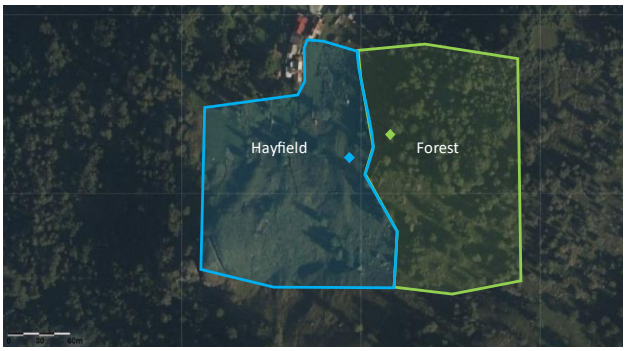

Figure 2. Satellite image of the case study site with approximate locations of the monitoring stations. Source: www.norgeibilder.no.

Figure 3. Photos from Ryo. Left: hayfield. Right: forested area before the growing season.

2.2 Monitoring setup

The locations of the two monitoring stations, one in the forest and one in the hayfield, are shown in Figure 2. In each location, a monitoring program was installed in May 2023, including two precision field tensiometers (Teros32), and four volumetric water content (VWC) sensors (Teros10, Teros 11) (Table 1). In addition to the measurement of VWC and soil suction, temperature is measured at all depths. The sensors are connected to data loggers, which log the measured variables every 15 minutes, and the data is wirelessly uploaded to the cloud through the cellular network. All the sensors and the data loggers were provided by the METER Company.

Table 1. Overview of monitoring equipment. T=Temp., c_ψ=matric potential and VWC=volumetric water content.

Depth [cm]	Variable	Sensor
10	VWC, T	Teros11
40	VWC, T, c_ψ	Teros10, Teros32
80	VWC, T, c_ψ	Teros10, Teros32
110	VWC, T	Teros11

In 2015, a weather station including, a Geonor T-200B series all weather precipitation gauge and a Lufft WS500 weather sensor measuring wind speed, direction, air temperature, relative humidity and air pressure, was installed at Ryo. Data from this weather station was intended to supplement the data collected by the monitoring equipment at the site. However, a site visit to the area showed that a component of the precipitation gauge had broken. Local, climatological data is therefore lacking from the start of our monitoring period (May 2023). To ensure a robust system for data collection of climate variables, a new weather station, of the model ATMOS 41W provided by the Meter Group, was installed in November 2023.

2.3 Field and laboratory investigations

Field investigations were conducted in September 2023. Soil profiles were excavated to a depth of approx. 60 cm respectively at 1.0 m and 2.5 m distance from the trunks of one young birch and one young alder, and at 1.0 m distance from an older birch in the forested area (Figure 4, left). The root distributions in the soil profiles were mapped in a grid of width 50 cm and depth 50 cm, with cell size of 10 cm x 10 cm (Figure 4, right). In each grid cell the root diameters were measured and the number of roots of different diameter classes (1-2 mm, 2-3 mm, …) was recorded. Roots with a diameter smaller than 1 mm were not counted.

Roots of different sizes were collected from each soil profile and brought to laboratory to test their tensional strength using a Quasar 250 Material Testing machine, developed by Galdabini SPA. To ensure proper preservation of the roots from collection to tensile testing, the roots were sprayed with a 20% alcohol solution and stored in the fridge before the tensile tests were performed (10 days from collection date). A total of 46 roots were tested. Thicker roots were debarked at their extremities and clamped directly, whilst the thinner roots were coiled around a rounded metal structure to distribute the stress and prevent breakage at the extremities. The results of the tensile tests have not yet been analysed and is therefore not presented herein.

Disturbed soil samples were collected from each sensor depth at the two monitoring locations (10, 40, 80 and 110 cm), and a total of eight undisturbed soil samples from depth 10-60 cm were collected from the soil profiles close to the three selected trees for soil characterisation in the laboratory. The undisturbed samples were collected using cylinders of Ø72 mm and length 20 cm.

The laboratory analysis of the collected soil samples is yet to be conducted. The laboratory campaign will include measurement of grain size distribution for all the samples, and soil density, organic content and field, residual, and saturated VWC for the undisturbed samples.

Figure 4. Left: Soil pits at dist. 1.0 and 2.5 m from a young birch. Right: Root distribution mapping grid. Cell size 10 x 10 cm.

3 PRELIMINARY RESULTS

3.1 Hydrological conditions

VWC and suction measured between May and October 2023 at 40 cm and 80 cm depth are presented in Figure 5. Air entry in the hayfield tensiometers around the beginning of June caused the sensors to malfunction until they were refilled the 12th of September. Suction data in this period are therefore not reliable. The forested area shows both higher suction and VWC values than measured for the hayfield. For both areas,

the deepest sensors shows both lower suction and VWC values than the shallowest sensors.

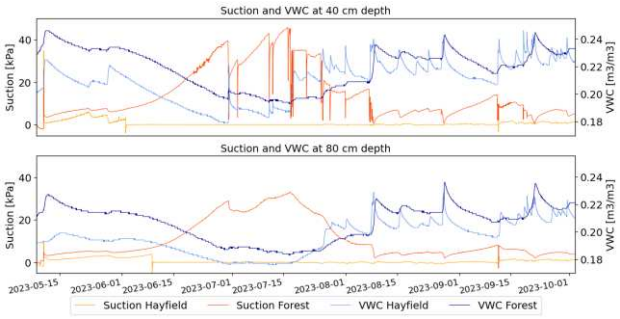

Figure 5. VWC and suction May-October 2023 at Ryo.

3.2 Root distribution

All trees have the highest number of roots in the smallest considered diameter class (1-2 mm). The younger trees do not have roots that are thicker than 15 mm, whilst it was recorded roots with diameters up to 27 mm for the older birch. The Root Area Ratio (RAR), i.e., the ratio between the rooted area and the total area of the soil profile, is calculated for each of the investigated trees (Figure 6). For the alnus, there is no clear difference in RAR from the soil profile at 1.0 m and 2.5 m distance from the stem. On the contrary, for the young birch, there seems to be a decrease in RAR with distance from the stem. The older birch has a peak in RAR at 20-30 cm depth, corresponding to the depth of its largest root (27 mm), whilst showing similar values as the younger trees otherwise. The obtained RAR values are of the same magnitude as found by Bischetti et al. (2005).

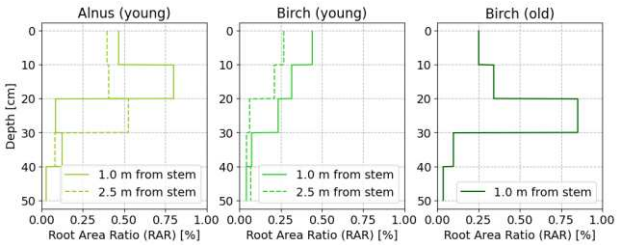

Figure 6. Root Area Ratio (RAR) with depth for the three investigated trees at Ryo.

4 FUTURE RESEARCH

The data gathered in this study will be analysed and used as input data for slope stability modelling, with the aim to assess the effectiveness of the existing forest at Ryo as a shallow landslide mitigation measure. Moreover, the effect of different forest management strategies for the area will be explored.

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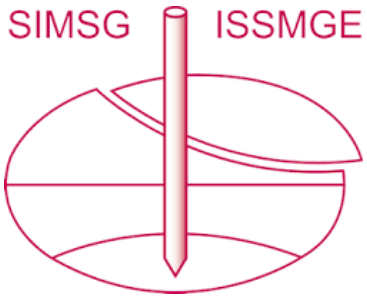

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