The Schlucher Landslide: An Unusual Earthflow Located near Malbun, Liechtenstein

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ABSTRACT

Predicting the triggering and propagation of rapid, flowlike landslides is a crucial but challenging task for landslide risk assessment. This work summarizes the preliminary results of such an assessment of a landslide located near Malbun, Liechtenstein. This landslide has accelerated dramatically in recent years, accumulating over 10 meters of displacement. A surface and subsurface investigation has been undertaken to understand driving mechanisms, and to qualitatively assess catastrophic failure potential. We model snowmelt depth through time, and correlate it with measured pore pressures and displacements during a displacement phase that lasted from March to May, 2018. This analysis shows that snowmelt infiltration is a likely trigger for landslide movement. Additionally, preliminary analyses show that three brittle failure mechanisms could potentially result in catastrophic failure. One of these, macroscopic brittleness, is poorly understood at present but must be considered at similar sites.

1 INTRODUCTION

Extremely-rapid, flowlike landslides can impact people and property far from their source. Predicting the initiation and runout of these events remains a challenging task. A landslide risk analysis is often initiated when a known landslide is observed to accelerate, which can be a precursor to catastrophic long runout failure. Hungr (2016) suggests the following four steps to assess failure potential: 1) Identification of activity signs, 2) quantitative observations of displacement, strain and groundwater characteristics, 3) recognition of failure mechanism(s), and 4) identification of driving processes.

This abstract presents preliminary results regarding an ongoing study of the Schlucher landslide, an unstable colluvial soil mass located near Malbun, Liechtenstein. An overview of this landslide is shown in Figure 1. Displacement rates of 10-20 cm/year have been measured for the last 30 years (1984-2015). In 2016 and 2017, the landslide accelerated, and displacements on the order of 10 meters were measured. To assess the current driving mechanisms and potential future behaviour, a detailed surface and subsurface investigation program of the landslide was conducted. This investigation included four boreholes, laboratory and in-situ testing, and in situ monitoring including high-resolution GPS measurements of surface displacements. The borehole and GPS locations are shown on Figure 1B. Additionally, a timelapse camera was installed to monitor snowmelt in the catchment where the landslide is located (hereafter referred to as the ‘Schlucher Catchment’).

We interpret this data within the Hungr (2016) framework, briefly described above. To understand failure mechanisms and driving processes, measured pore-pressures and displacements are correlated with snowmelt, the latter of which was assessed using the degree-day method. Based on this understanding, we present a preliminary assessment of the possibility that the Schlucher Landslide will transition into an extremely-rapid, flowlike landslide. The forecast of potential future behavior presented here is the subject of ongoing work, and may be revised in the future as further information is integrated into the assessment.
2 Background

The Schlucher landslide was documented for the first time on an aerial image in 1974. In the same catchment, relatively frequent debris flows have been documented since 1944, as well as at least one small debris slide in 1981. Mitigation work to control the surface drainage of the landslide was undertaken from 1983 to 1985. The Schlucher Landslide is composed of a heterogenous transported soil, and the lithology of the landslide alternates between material derived from clay schist, sandy siltstone and Hauptdolomite. A thin, organic layer observed in one borehole suggests that the landslide material may be composed of the deposits of multiple mass movements, although there is only limited evidence to support this interpretation. The material sampled from the boreholes ranged from clayey sand to clayey gravel. The percentage of fines ranged from 17.1% to 46.7%, and, based on Atterberg limit tests and the USCS classification system, is classified as low plastic silt or low plastic clay. The volume of the landslide is approximately 200,000 m³.

2 Methods

To better understand failure mechanisms and driving processes, we simulate the snowmelt depth (in centimeters) in the catchment during an observed acceleration period that occurred from March to May, 2018. During this period, the measured cumulative displacements at the GPS stations was 2 m. Snowmelt depth was estimated using the degree-day method, which relates temperature to melt depth using a degree-day factor and the percentage of the total area covered by snow (Rango & Martinec, 1995). The degree-day factor is known to be subject to seasonal variability (Rango & Martinec, 1995), so a time-varying degree-day factor was input in to the analysis. A time-lapse camera, which photographed the catchment every 4 hours, was used to estimate snow cover in the catchment, and temperatures were interpolated from nearby weather stations. Snowmelt depth was estimated in three different zones, delineated based on elevation. Pore pressure sensors were installed in 3 of the 4 boreholes shown on Figure 1B. Additionally, repeat inclinometer and time domain reflectometry surveys were conducted in all 4 boreholes, which revealed two rupture surfaces at 7 and 15 m below ground surface.

To give a preliminary assessment of the potential for catastrophic failure, the likelihood of various strength loss mechanisms were assessed. As described in Hungr (2007) and Hungr (2017), extremely-rapid landslides occur when there is a large deficit of available shear strength as compared to the driving shear stress. Based on the site investigation data and interpretation, we qualitatively assess the potential for the following strength loss mechanisms: 1) static liquefaction, assessed based on SPT N values, and grain size distributions (McRoberts & Sladen, 1992; Fell et al., 2007), 2) sliding surface liquefaction, assessed based on the mineralogy of the deposit (Sassa & Wang, 2005; Hungr, 2017), 3) macroscopic brittleness and 4) loss of cohesion, both assessed based on previous displacement history (Fletcher et al., 2002; Hungr, 2007), and 5) shearing of clay from peak to residual strength, assessed based on grain size distribution and Atterberg tests (Hungr, 2007).
3 Results

Figure 2 shows the hourly 3D GPS velocities correlated with estimated snowmelt, which has been offset by 25 days. The 3D velocities have been smoothed using a lowpass Butterworth filter. Figure 2 shows snowmelt depth and water level as a function of time. In Table 1, potential for an extremely-rapid, flowlike landslide to occur was assessed based on three categories: likely, possible and unlikely. Three mechanisms that could result in catastrophic failure at site were assessed as possible. These include static liquefaction of the debris, sliding surface liquefaction and macroscopic brittleness. Static liquefaction of the fine grained portion of the debris could occur if the natural water content of this component is increased to within approximately 85% of the liquid limit, or if loose layers were missed during the site investigation. Sliding surface liquefaction could occur if the grains can be crushed at the stress levels present in the Schlumber landslide. This depends strongly on mineralogy, which at present is poorly constrained. Macroscopic brittleness could occur if future displacements dilate the debris, increasing the density to a value loose of the critical state density.

Figure 2: Estimated snowmelt (offset by 25 days) and cumulative 3D landslide displacements since March 28/2018. The offset snowmelt values show a non-linear relation with the first velocity peak, however there is a linear relation with the second velocity peak.

Figure 3: Estimated snowmelt depth plotted with pore pressure. The high value for KB2 could be a result of changing the depth level of the pore-pressure monitor. In KB3, the water level did not reach that of the screened interval until approximately April 23rd.

4 Discussion and Conclusions

The output of the degree-day method was correlated with measured displacements and pore-pressures. The results suggest that the acceleration period of the landslide noted between April 13 and June 03 was the result of snowmelt infiltration raising pore-water pressures within the landslide. By comparing Figure 2 and Figure 3, it can be seen that landslide displacements initiated while measured water levels were below the level of the sliding plane(s). When considering a time lag of 25 days, the first acceleration period does not match the recharge function but the second acceleration period coincides well with the simulated recharge from snowmelt (Figure 2). This indicates that during the first recharge period the heterogeneous landslide body re-
saturates and during the second recharge period the landslide velocity increases linearly with the amount of recharge.

Key uncertainties of the present analysis include the spacing and accuracy of the SPT tests in the boreholes (which may have missed loose layers), the mineralogy of the material located in shear zones, as well as the geometry of the rupture surface. Additionally, significant epistemic uncertainty exists in the assessment of macroscopic brittleness potential. This mechanism has been hypothesized for a number of cases that accumulated significant, ductile displacements before failing catastrophically (Fletcher et al., 2002; Jibson, 2006; Nicol et al., 2013; Aaron et al., 2017). More in depth research is required to better understand this mechanism.

Table 1: Potential for the reviewed source zone strength loss mechanisms to occur at the Schlucher Landslide. Potential is assessed based on relative likelihood.

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Likely</th>
<th>Possible</th>
<th>Unlikely</th>
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<tbody>
<tr>
<td>Static liquefaction of the debris</td>
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<tr>
<td>Liquefaction of quick clay</td>
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<td>Sliding surface liquefaction</td>
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<td>Macroscopic brittleness</td>
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<tr>
<td>Loss of cohesion</td>
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<td></td>
<td>x</td>
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<tr>
<td>Peak to residual strength drop</td>
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</tbody>
</table>

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REFERENCES


