Airborne EM mapping of rock slides and tunneling hazards

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Weakness zones in hard rock

• Location & Hazards

• Survey concept

• AEM results
Location & geo-hazards

- ~ 500,000 tourist p.a.
- > 100 cruise ships
- E16 Oslo-Bergen
Sliding past

Historic slide plane

Shallow fjord (10-20m)
Sliding present

~ 1 cm/year from GPS

Sporadic movements up to meter scale

Flåm

Aurland
Tension cracks
Sliding mass 200,000 – 40,000,000 m$^3$

-> Tsunami ~20 m high (up to 40 m/s)
Solution: drainage?
Weakness zones in hard rock

- Location & Hazards
- Survey concept
- AEM results
Targets

- Sliding planes and sliding mechanism
- Weakness zones along tunnel corridor
Phyllite – Gneiss - Clay

- Tension cracks
- Surface water
- Phyllite gets crushed to clay
- $\rightarrow$ Conductor!
Weakness zones in hard rock

- Location & Hazards
- Survey concept
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AEM survey

Courtesy CRC LEME
SkyTEM Survey

3 flight days
250 line km
125 m line spacing

Dual moment 60% duty cycle
2.5 kAm² @ 200 Hz &
63 kAm² @ 100 Hz

Time gates 8.4 µs to 2.5 ms
HGG processing & SCI
AEM survey

Courtesy CRC LEME
Depth slice interval resistivity 40-50 m and 100-110 m below ground.
AEM challenges: Topography !!
Area A: Phylite / Gneiss contact

Interval $\rho$ 30-40 m draped over topography
Complex anomalies connected to rock slide?

Interval $\rho$ 70-80 m draped over topography
Very preliminary interpretation

A: Bathymetry 40-60m AEM vs. 43-59m charts

B: Crushed phyllite or phyllite / gneiss interface ???

C: Contact zone phyllite (W) / gneiss (E)

D: Potentially indications of sliding planes connected to Stampa river

E: Indications of creeping horizons in Flåmsdalen and along the fjord
Road ahead

- ERT/IP follow up
- 3D AEM interpretation
- Instrumented drill holes
- Reassessment of stability
ERT results Viddal T60
ERT data acquired Joasete map view

Line 235: 700 m profile WNW – ESE
Line T20a: 400 m cross-profile NNE – SSW
ERT results Joasetter lines T20a and 235.
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Airborne EM mapping of rockslides and tunneling hazards

We have investigated potential rockslides in Western Norway using a time- and cost-efficient airborne electromagnetic (AEM) survey approach. The study area comprises phyllite, a low-grade metamorphic rock type that tends to be reworked to clay in disturbed zones. Mapping these electrically conductive clay zones was the aim of the AEM survey. Based on indications that precipitation drives the reported rockslide movements, the local municipality and regional hydropower company are evaluating the option of draining the unstable area to a nearby hydropower reservoir using a drainage tunnel of more than 10 km. We conducted the AEM mapping survey to locate the sliding planes and to investigate the tunnel corridor for areas with potential tunneling hazards. Spatially constrained inversion of the data set reveals extended conductive zones interpreted as sliding planes and/or faults/phylite interface. Detailed follow-up of these initial results is planned with targeted percussion drilling and ground resistivity surveys.

Introduction

The inner Aurland Fjord with the adjacent Flåm Valley (western Norway) are among Norway’s most famous tourist destinations with up to 450,000 visitors and more than 100 cruise ships a year visiting the area. The main road between Oslo and Bergen (E16) passes through Flåm, by-passes the fjord, and enters the 24.5 km Landalsstunnelen in Aurlandsdalen. Evidence of large rockslides in the geological past has been documented in the area with ground movements evident to the present day. The area is subject to potential rockslides composed of creeping rock and debris masses (Figure 1). The intent of our study was to provide geophysical input to the ongoing natural hazard assessment programs in Aurland municipality.

Based on repeat GPS measurements and anecdotal observations in the area, rock and debris movements are influenced by precipitation and snow melt. Based on this empirical evidence, the local municipality and regional hydropower company ECO Vannkraft are evaluating the potential of draining the unstable area to a nearby hydropower reservoir (Viddalalmagensen) with the aid of a 10 km tunnel. Initial interpretations of an airborne electromagnetic (AEM) mapping survey conducted in June 2009 reveal indications of the sliding planes and assess the tunnel corridor for potential tunneling hazard areas.

The investigated area consists of a basement of high-grade Precambrian metamorphic gneisses overlain by a nappe (sheet) of phyllite with another layer of high-grade metamorphic gneisses with minor layers of quartzite and other rock types resting on the phyllite layer. During the formation of the nappe, the weaker phyllite acted as lubrication in the thrust zone between the basement of the Precambrian gneisses and the overlying gneisses. Normally the thrust zone recrystallizes to a schistose layer, during postmovement low-grade metamorphism.

AEM survey

Unstable rock in the study area, some 1000 m above sea level, has been mapped as massive phyllite broken by numerous tension cracks with openings up to several meters. Field observations also document significant amounts of surface water in streams on the mountain plateaus around Flåm.