Stability of the Åknes rock slope and the influence of water

-A summary of results from two PhD and one MSc studies

Guro Grøneng, Norwegian Geotechnical Institute

Rock slope stability 2004-2009 + 2014

Vidar Kveldsvik

Static and dynamic stability analyses of the 800m high Åknes rock slope, western Norway

Thesis for the degree philosophiae doctor

Trondheim, July 2008

Norwegian University of Science and Technology
Faculty of Engineering Science and Technology
Department of Geology and Mineral Resources Engineering

NTNU

Doctoral Thesis

Doctoral theses at NTNU, 2010:30

Guro Grøneng

Stability Analyses of the Åknes Rock Slope, Western Norway

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Department of Geology and Mineral Resources Engineering

NTNU
Norwegian University of Science and Technology

Masteroppgåve

Henrik Andreas Langeland

Utvikling av revidert geologisk modell og stabilitetsanalyser for øvre deler av ustabil fjellside på Åknes

Trondheim, mai 2014

NTNU
Det skapande universitetet

International Journal of Rock Mechanics & Mining Sciences 46 (2009) 479–488
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ELSEVIER

Shear strength estimation for Åknes sliding area in western Norway

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Dynamic distinct-element analysis of the 800 m high Åknes rock slope

Vidar Kveldsvik [a,b,*], Amir M. Kaynia [a], Farrokh Nadim [a], Rajinder Bhasin [a], Bjørn Nilsen [b], Herbert H. Einstein [c]
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Rock Mech Rock Eng (2009) 42:689–728
DOI 10.1007/s00603-008-0005-1

ORIGINAL PAPER

Numerical Analysis of the 650,000 m^2 Åknes Rock Slope based on Measured Displacements and Geotechnical Data

Vidar Kveldsvik · Herbert H. Einstein · Bjørn Nilsen · Lars Harald Blikra

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Bull Eng Geol Environ
DOI 10.1007/s10064-009-0198-x

ORIGINAL PAPER

Geovisualization, geometric modelling and volume estimation of the Åknes rockslide, Western Norway

Trond Nordvik · Guro Grøneng · Guri Venvik Ganerød · Bjørn Nilsen · Chris Harding · Lars Harald Blikra

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Engineering Geology 102 (2008) 1–18
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ELSEVIER

Geological model of the Åknes rockslide, western Norway

Guri Venvik Ganerød [a,b,*], Guro Grøneng [c,d], Jan Steinar Rønning [a,c], Einar Dalsegg [a], Harald Elvebakk [a], Jan Fredrik Tønnesen [a], Vidar Kveldsvik [c,d,e], Trond Eiken [f], Lars Harald Blikra [d,g], Alvar Braathen [h]

Original Article

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Vidar Kveldsvik · Bjørn Nilsen · Herbert H. Einstein · Farrokh Nadim

Alternative approaches for analyses of a 100,000 m^3 rock slide based on Barton–Bandis shear strength criterion

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Original Paper

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Guro Grøneng · Hanne H. Christiansen · Bjørn Nilsen · Lars Harald Blikra

Meteorological effects on seasonal displacements of the Åknes rockslide, western Norway

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ELSEVIER

Modelling of time-dependent behavior of the basal sliding surface of the Åknes rockslide area in western Norway

Guro Grøneng [a,*], Ming Lu [b], Bjørn Nilsen [a], Arne K. Jenssen [c]

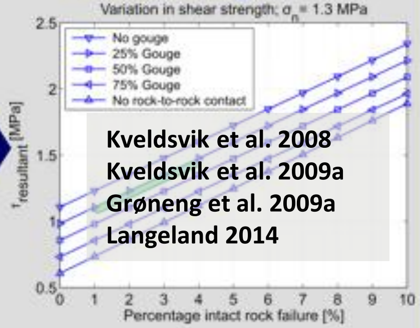
Analysis of rock slope stability typically follows a procedure:

Rockslide

Geometry

Ganerød et al. 2008
Nordvik et al. 2009

Shear strength

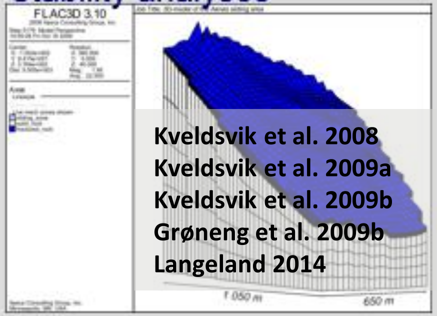


Kveldsvik et al. 2008
Kveldsvik et al. 2009a
Grøneng et al. 2009a
Langeland 2014

Groundwater

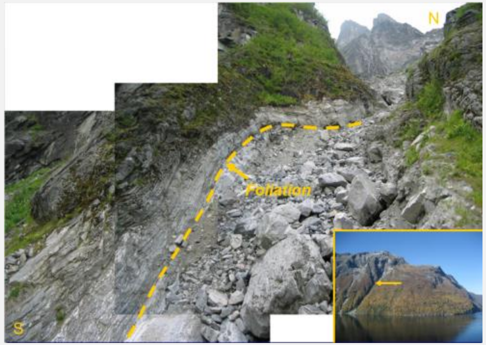
Grøneng et al. 2009b

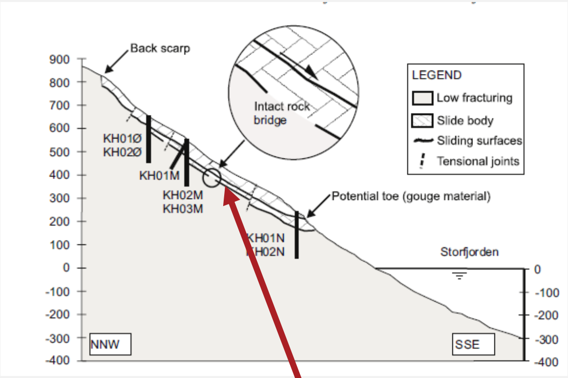
Stability analyses



Kveldsvik et al. 2008
Kveldsvik et al. 2009a
Kveldsvik et al. 2009b
Grøneng et al. 2009b
Langeland 2014

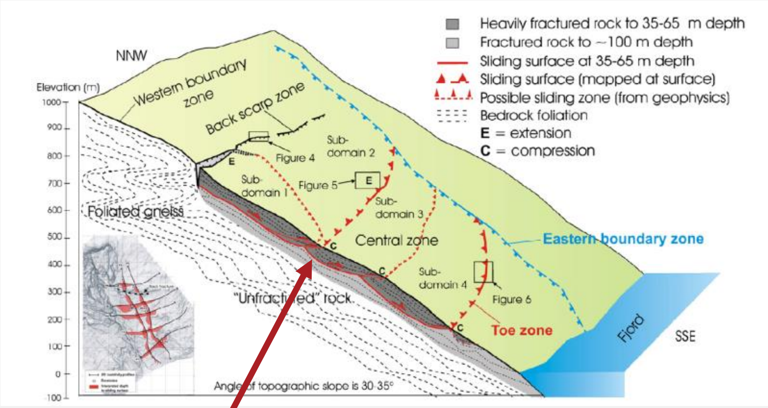
Geological models



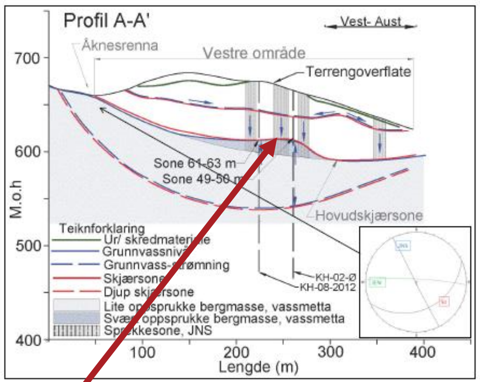


Complex sliding plane (Grøneng et al. 2009)

The sliding body has a complex geometry with several sliding planes at different levels 25-60 m below the surface, involving unfilled joints, gouge material/brecciated material as well as bridges of intact rock.



Geological model with undulating sliding surface at 35-65 m depth (Ganerød et al. 2008)



Single sliding plane (Langeland 2014)

Single sliding plane, geological model updated with data from KH-08-2012, sliding planes at 49-56 m and 61-63 m depth.

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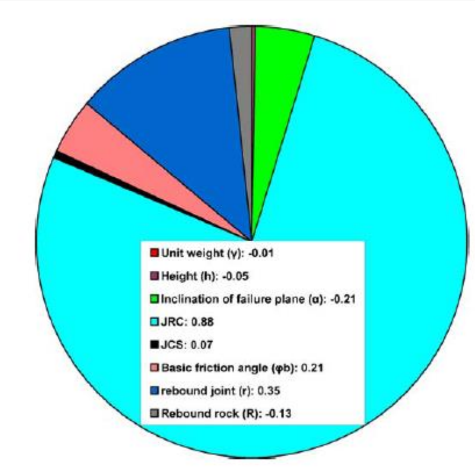
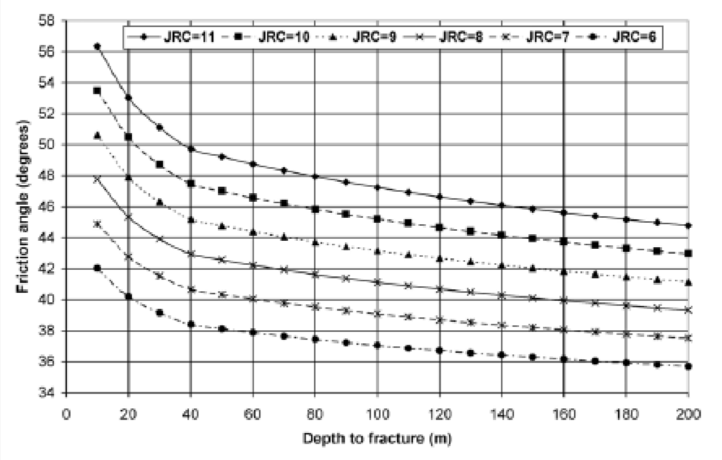
Analysis of shear strength at Åknes 1 (of 3)

- Barton-Bandis shear strength criterion has been used for assessment of shear strength along joints (Kveldsvik et al. 2008, Kveldsvik et al. 2009a, Grøneng et al. 2009a and Langeland 2014), including probabilistic analysis of the parameters and sensitivity analysis (Kveldsvik et al. 2008)

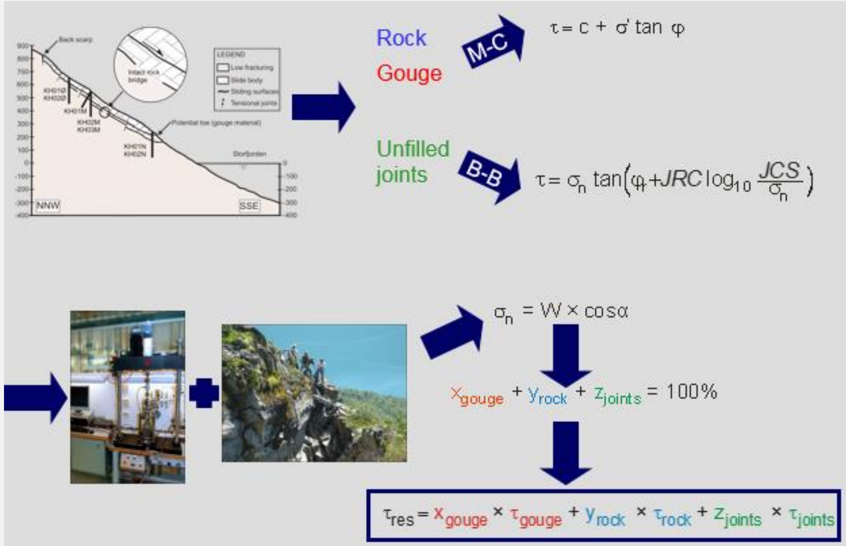
$$\tau = \sigma_n \times \tan\left[JRC \log_{10}\left(\frac{JCS}{\sigma_n}\right) + \varphi_r\right]$$

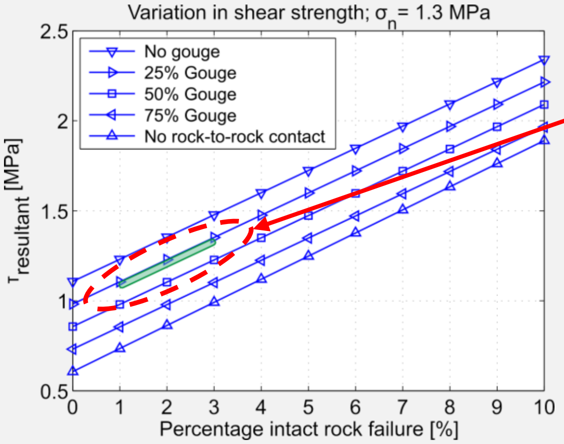




Analysis of shear strength at Åknes 2 (of 2)

- A new methodology for estimating the shear strength of a complex sliding plane consisting of gouge material, bridges of intact rock and joints (Grøneng et al. 2009)





1-3% rock

25-35% gouge filled joints

62-74% unfilled joints

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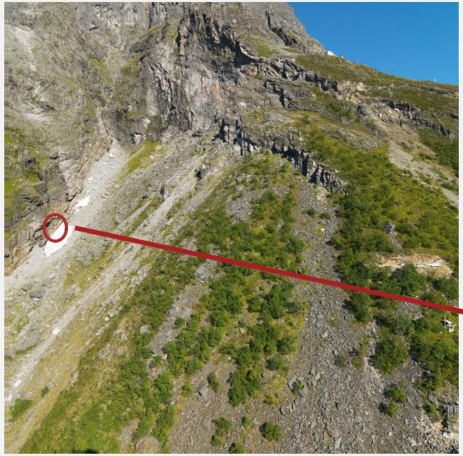
Analysis of shear strength at Åknes 3 (of 3)

- Direct shear test of material from “Åknesrenna”. Mineral composition similar to mineral composition of gouge material from core at depth of 61-63 m in KH-08-2012 (Langeland 2014)



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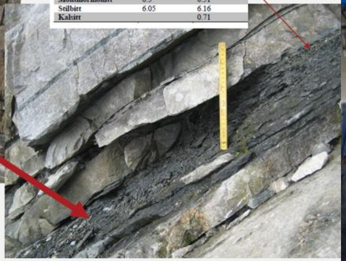
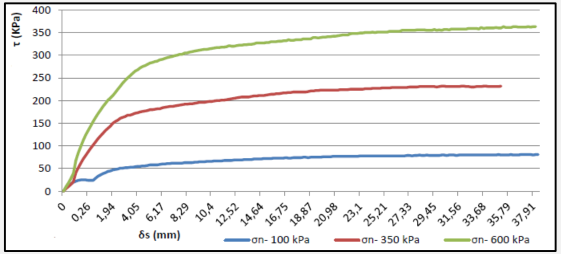
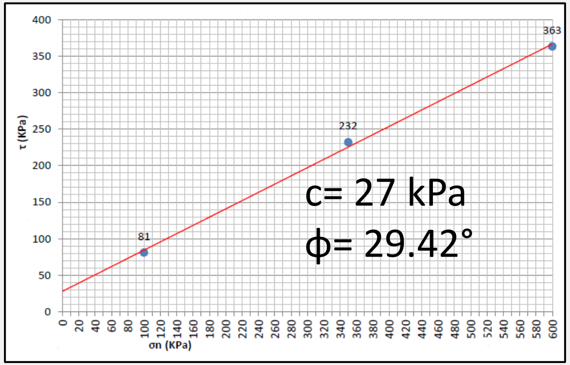


Mineral (%)	Prove 1(084)	Prove 2(085)
Kvarts	18.25	16.66
Albitt	24.91	18.96
Sideritt	0.12	0.22
Biotitt	17.5	20.47
Magnesiohornblende	8.83	4.31
Mikroklin	8.22	9.97
Kloritt	13.24	18.71
Diopsid	2.38	3.34
Montmorillonitt	0.5	0.51
Stilbitt	6.05	6.16
Kalsitt		0.71





τ at σ_n=0.5 MPa	τ at σ_n=1.3 MPa	
0.23	0.61	Grøneng et al. 2009
0.31	0.76	Shearbox test 2013

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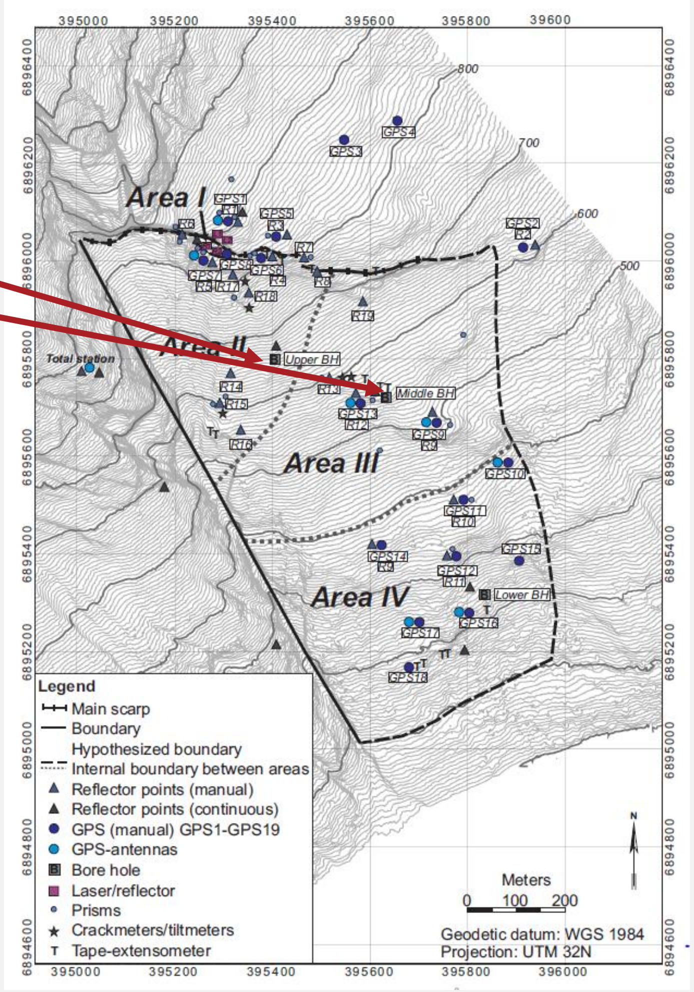
Groundwater and slope stability

Groundwater may affect the stability of a slope in several ways:

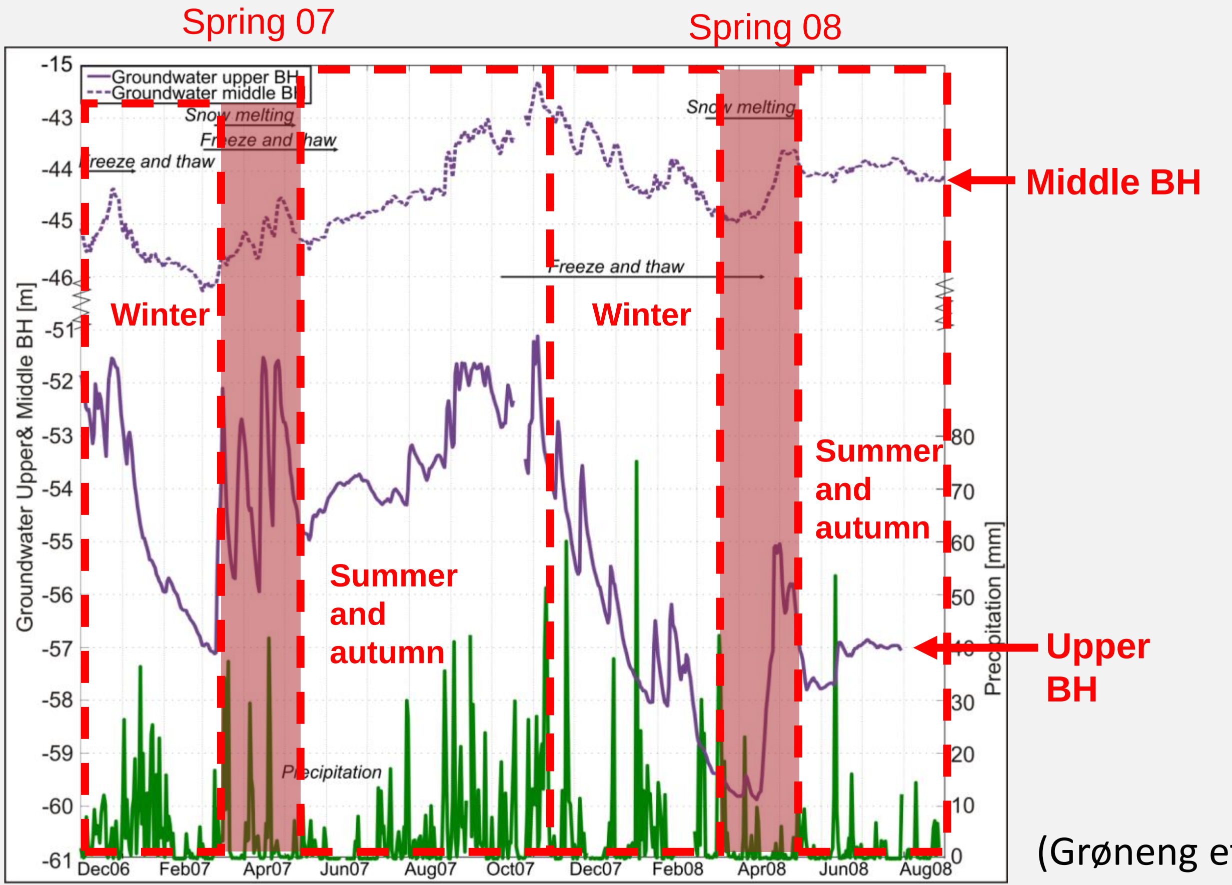
- ***By reducing the normal stress; groundwater pressure will reduce the normal stress acting on the sliding plane(s) and by this reduce the friction along the sliding plane(s).***
- ***By acting as a driving force; the groundwater may act directly as a driving force in tension joints.***
- ***By reducing the internal friction; the groundwater may reduce the internal friction, i.e. the strength of joint filling material and possibly also cause swelling of gouge material.***
- Due to expansion by freezing; water expands by approximately 10% when freezing, which may cause considerably displacements and forces reducing the stability.
- By causing erosion; in weak rock, flowing water may cause washout and erosion reducing the stability.

Hydrogeological input data

- Groundwater levels at upper and middle borehole in the period November 2006-August 2008
- Measurements of water inflow in new borehole KH-08-2012 in 2013 carried out by NGU



Groundwater in upper and middle borehole is strongly affected by snowmelt 2007-2008



(Grøneng et al. 2009)

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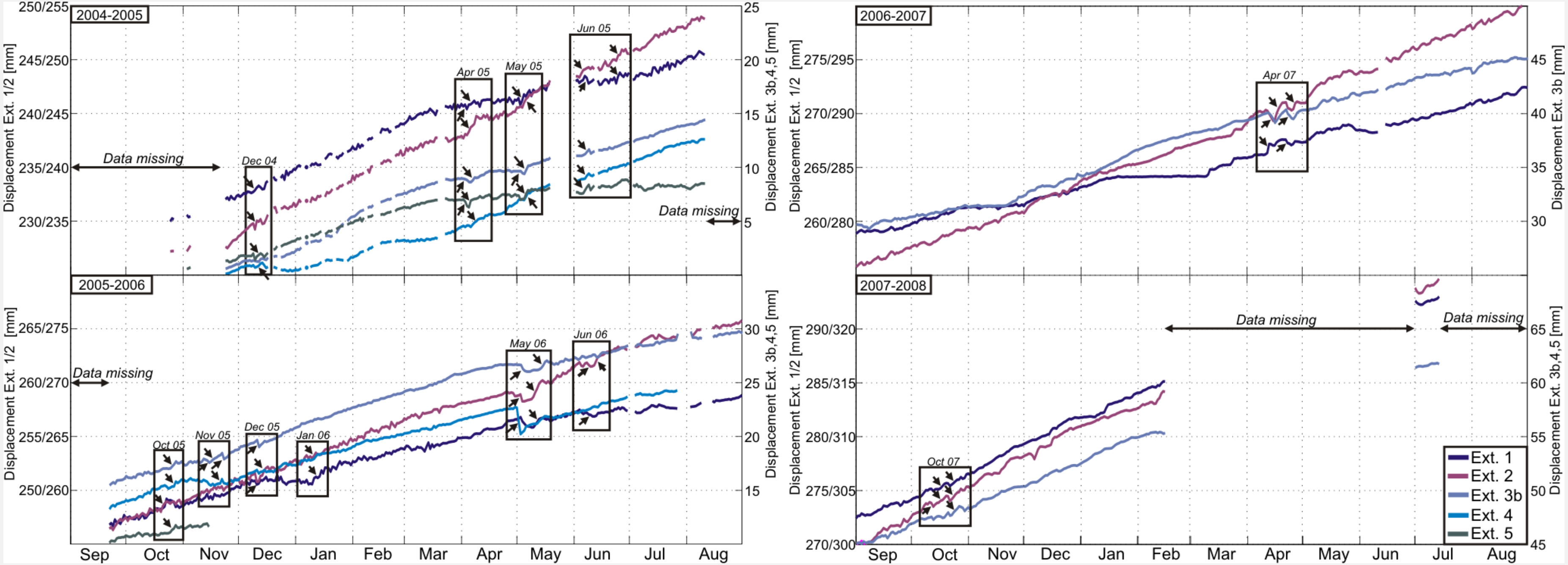
Meteorological effects on recorded extensometer displacements



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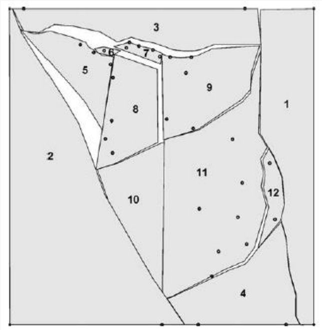
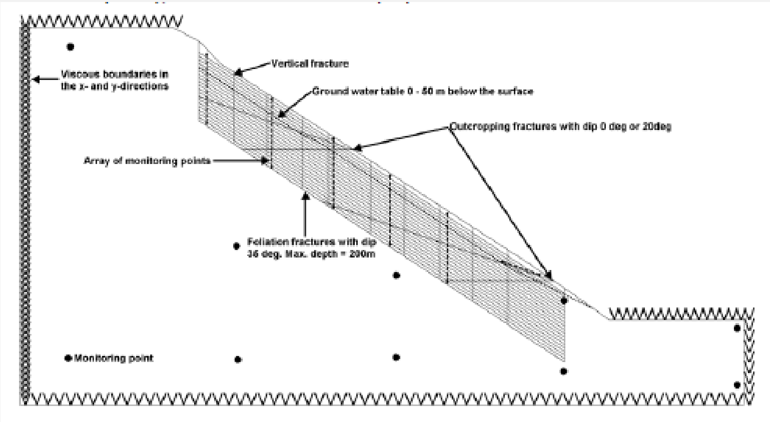
Stability analysis and results 1 (of 3)



Block model by DDA based on displacement measurements at the slope surface 2004-2006 (Kveldsvik et al. 2009a)



Stability analysis by the use of UDEC. also including dynamic input based on earthquakes with return periods of 100 and 1000 years by UDEC (Kveldsvik et al. 2009a & 2009b)

- By varying fracture geometry, fracture friction, and groundwater conditions (based on site-specific data), stability of a number of possible models were compared.

Main conclusions related to stability and groundwater:

- The analyses indicate that an earthquake with a return period of 1000 years is likely to trigger sliding to great depth in the slope at the present ground water conditions and that the slope will remain stable if draining is implemented. The analyses also indicate that sliding is not likely to be triggered by an earthquake with a return period of 100 years at the present ground water conditions.
- Measuring water pressure at different depths in the boreholes should be carried out as the groundwater conditions may play an important role in defining sliding surfaces deeper than about 40 m.

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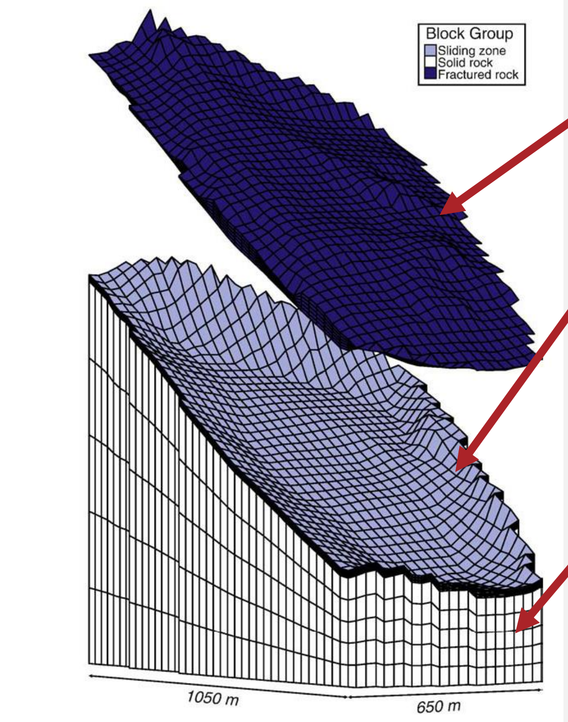
Stability analysis and results 2 (of 3)



Time dependant stability analysis by creep model (Burger's model) in FLAC3D for 100 years (Grøneng et al. 2010).

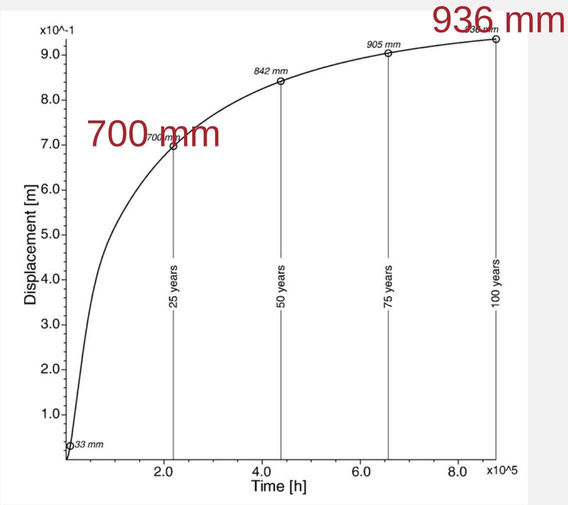
Mohr-Coulomb material model

K, G, c, φ

Burger-Creep Viscoplastic material model

G_k, η_k, G_m, η_m, c_{res}, φ_{res}, K

Elastic material model K, G



Main conclusions related to stability and groundwater:

- At the groundwater level representing measurements between Aug. 2007 and Aug. 2008, modelling indicates failure of the toe at 100 yrs. when the shear strength parameters are reduced to parameters corresponding to 1% intact rock in the sliding plane.
- Sensitivity analysis for the variation of the groundwaterlevel should be carried out when more data is available.

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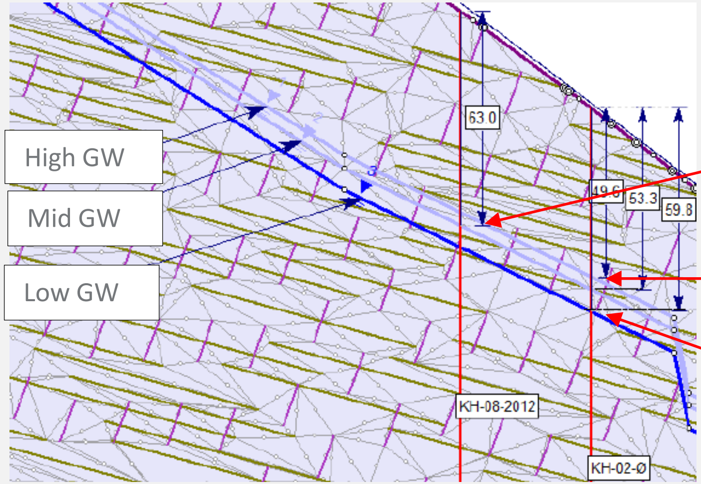
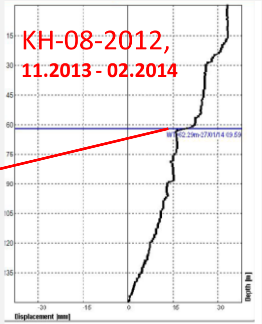
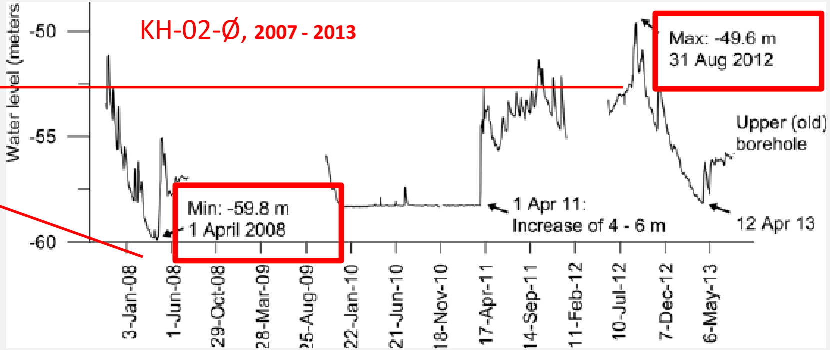
Stability analysis and results 3 (of 3)



Stability analysis by Phase2 (Langeland 2014)





- Groundwater: Modelling was carried out at «high», «middle» and «low» groundwater levels according to the highest measured waterlevel in KH-02-Ø (610 mASL (2012-08-31)) and lowest measured waterlevel in KH-02-Ø (600 mASL (2008-04-01)).

Main conclusion related to stability and groundwater:

- There is clearly a big FoS reduction when GW-level changes from middle to high. Reduction in shear strength also clearly affect FoS.

Conclusions

- Work from two PhD and one Master thesis has concluded that more information about geometry, sliding plane/zone, shear strength parameters, and hydrogeological conditions is crucial for improved stability analyses.

- Of alle the factors metioned above; the groundwater and hydrogeological conditions is the factor which has been least investigated.

- Stability calculations from Åknes all indicate that the groundwater table(s)/water pressure at different levels play an important role. It is believed that the groundwater both reduces the normal stress, acts as a driving force and reduce the internal friction at Åknes, additional data about hydrogeology will make it possible to:

-Develop a hydrogeological model at Åknes

-Use numerical codes combining groundwaterflow and stability analysis

-More relevant analysis of the potential effect of drainage, including probabilistic approaches for stability analyses and risk analyses related to potential drainage mitigation.

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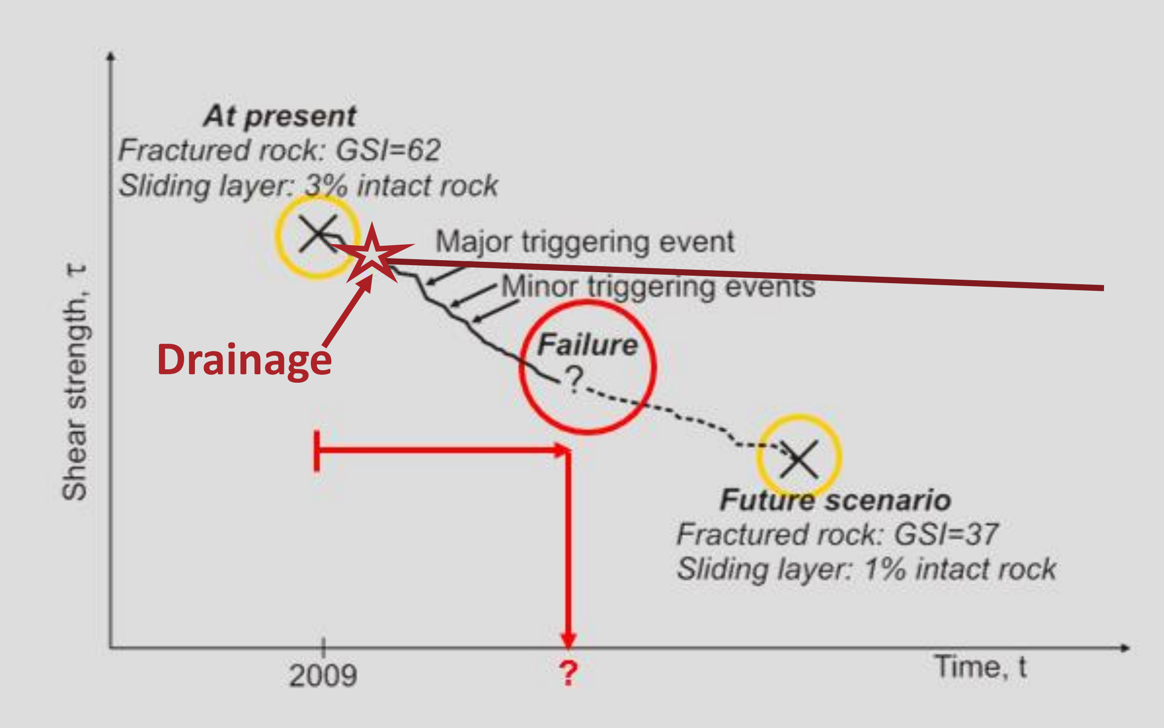
Conclusions



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