Workshop
Drainage of large rockslides

Experience with DMS® subsurface instrumentation at Åknes rockslide and new developments

Oslo, 30-31th of January 2017

Mario Lovisolo
CSG Srl - Italy
OVERVIEW

DMS® Differential Monitoring of Stability

DMS® subsurface instrumentation at Åknes

New developments
DMS® DIFFERENTIAL MONITORING OF STABILITY

DMS® is a in place geotechnical monitoring system, multi-parametric, automated for continuous monitoring in real time of stability of slopes and engineering works. The DMS® columns are constituted by a sequence of instrumented rigid modules, connected by flexible joints, robust with high resistance that also allow extraction and reuse.

What can be measured in continuous:
• Displacement x, y and z along the entire column
• Piezometric level of 1 or more hydraulically separated levels
• Temperature (log T)
• Vibrations along the entire column.

DMS® is an instrument fully engineered, designed and produced by CSG since 2000. The system and the cases of application have been presented for the first time to FMGM conference (Field Measurements in Geomechanics) held in Oslo, in 2003.
DMS®: HOW DOES IT WORK?

The column allows to “copy” the deformations of the borehole and, more generally, of the object to be monitored, constituting a sort of "backbone" of the same, strictly maintaining the mechanical orientation of the axes of each module.

The rigid elements are provided in the basic version by:
- Biaxial inclinometer
- Temperature sensor

On demand:
- Pressure sensor
- Accelerometer
- Magnetometer
- Extensometer and others.

MULTIPARAMETRIC MONITORING USING DMS COLUMNS
MULTIPARAMETRIC COLUMNS DMS® 2D

Designed to monitor the stability of slopes, excavation fronts, geotechnical engineering structures, facilities and in general all sites in which the kinematics in addition to monitor the xy displacements, require also the groundwater level/s, temperature and acceleration along the entire vertical.

DMS® 2D columns elements:
1) rigid tubular modules, stainless steel AISI 304 or 316L internally and externally machined for M/F connections related to alignment axis inclinometer; modules contain sensors, electronics and cable for power and signal.
2) 2D flexible joints (RT = 10 to 50 kN) with special M/F connections related to alignment axis inclinometer
3) Polyurethane HD centralizers.
MULTIPARAMETRIC COLUMNS DMS® 3D

DMS® 3D column elements:
• Rigid modules containing measuring and control electronic
• Triaxial joint
• Injections packers

The DMS 3D column “copy” the horizontal and vertical displacements, thanks to the constraint generated with the expansion of the packers against the uncased borehole.

1. Installation in place
2. Packer expansion
3. Monitoring active
DMS® MONITORING SYSTEM

Multi-parametric columns
DMS® 2D
DMS® 3D

Remote units for control and data transmission

Software suite for acquisition and real-time data management
Early Warning

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**DMS® COLUMNS: APPLICATIONS**

**LINE DMS® 2D**

**Active slides**

- **DMS® 2D Slide**
  - Column length max: 30 m
  - I: range ±20°/±45°; repeatability ±0.05°, U: range 30/100 psi

**Slow slides**

- **DMS® 2D Slope**
  - Column length max = 100 m
  - I: range ±20°/±45°, repeatability ±0.02°, U: range 30/100 psi

**Deep seated rockslides**

- **DMS® 2D LST**
  - Column length max = 250 m
  - I: range ±10°/±30°; repeatability ±0.01°
  - U: range 100/250 psi
  - Digital compass: repeatability ±1° azimuth

**Engineering works**

- **DMS® 2D GV**
  - Column length max = 100 m
  - I: range ±20°/±45°; repeatability ±0.02°
  - U: range 30 psi

**LINE DMS® 3D**

**Geotechnical engineering works**

- **DMS® 3D MP-LST**
  - Module length = 1 – 1,25 – 1,5 m
  - I: range ±10°/±30°; repeatability ±0.01
  - U: range 30/100/250 psi
  - E: range ±35 mm; resolution 0.01 mm
  - Digital compass: repeatability±1° azimuth

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# DMS® Subsurface Instrumentation at Åknes

## Table of Instrumentation Details

<table>
<thead>
<tr>
<th>COLUMN ID</th>
<th>SITE</th>
<th>ELEV. (m asl)</th>
<th>DMS LENGTH (m)</th>
<th>JOINT TYPE</th>
<th>TRACTION (KN)</th>
<th>BOREHOLE DEPTH</th>
<th>LAST INSTALLATION DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AKU005-150</td>
<td>NEW UPPER</td>
<td>710</td>
<td>150</td>
<td>4SH</td>
<td>50</td>
<td>200</td>
<td>22/08/2013</td>
</tr>
<tr>
<td>AKM006-120</td>
<td>MIDDLE</td>
<td>565</td>
<td>120</td>
<td>4SH</td>
<td>50</td>
<td>202</td>
<td>22/05/2014</td>
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<tr>
<td>AKL004-120</td>
<td>LOWER</td>
<td>236</td>
<td>120</td>
<td>R2AT</td>
<td>20</td>
<td>197,30</td>
<td>04/08/2015</td>
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<tr>
<td>AKU007-060</td>
<td>OLD UPPER</td>
<td>658</td>
<td>7 + 53 ext</td>
<td>R1S / 4SH</td>
<td>10/50</td>
<td>200</td>
<td>05/08/2015</td>
</tr>
</tbody>
</table>

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[Map of Åknes area with monitoring stations indicated]  

[Image of DMS instrument at Åknes]  

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**DMS® SUBSURFACE INSTRUMENTATION ÅKNES OLD UPPER SITE**

**14 September 2006 - First installation -**

**2009 Active**

**2013 August - Final extraction -**

*DMS IUT L=50m (position –83 / -133m)*

*DMS IUT L=127m Temporal extraction (2dd) to allow hydrogeological tests*

*DMS IUT L=127m Max Traction 22 kN (with tackle, recovery of the entire column saving also the borehole)*
26 June 2008 - **Installation**

**DMS® SUBSURFACE INSTRUMENTATION AT ÅKNES LOWER SITE**

DMS 2D IUT, Length = 100m
Monitoring interval: –21/-121m bgl

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**DMS® Real time / Early warning system**

### READING SENSORS OUTPUTS

The **remote unit scan in continuous all the modules** of the column and provides by default 1 record/1h per each sensor.

### DATA TRANSMISSION AND PROCESSING

Data transmission is carried out trough GSM/GPRS modems and managed inside Monitoring Centre using the dedicated software suite.

### WARNING MANAGEMENT

The RU CU 200 can manage 4 warning levels (incremental order) for Pitch/Roll axis and water table, velocity/h, velocity/d. SMS messages/direct call are sent to the staff on duty.

### DATA ANALYSIS

Available personnel can check data inside and outside the monitoring centre using DMS Ew Full and Client.

**RU settings for Åknes sites**

<table>
<thead>
<tr>
<th>Reading</th>
<th>Continuous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value recorded/sensor</td>
<td>1 hour</td>
</tr>
<tr>
<td>Active continuous alarms (SMS):</td>
<td></td>
</tr>
<tr>
<td>Pitch, Roll</td>
<td>0.1°</td>
</tr>
<tr>
<td>Water Pressure</td>
<td>1/3 m</td>
</tr>
<tr>
<td>Power off/on</td>
<td>Yes</td>
</tr>
<tr>
<td>Column/cable disconnected</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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**DMS EW [Set warning thresholds]**

<table>
<thead>
<tr>
<th>Level</th>
<th>Threshold</th>
<th>mm/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>10.00</td>
<td></td>
</tr>
</tbody>
</table>

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DMS ÅKNES OLD UPPER SITE

Date: 18/04/2013

Wt: 56,5 mbgl

Main sliding zone: 49-51 m bgl
Water table – velocity along slide zone

Period 1y  June 2012 – May 2013

Δw = 8.5 m
Date: 25/01/2017

Wt: 62,1 mbgl

Main sliding zone: 62-63 m bgl
Water table – velocity along slide zone

Period 1y January 2016 – December 2016

Δw = 1.6m

WT scaled same 2012-2013 AK old upper diagram for comparison
DMS ÅKNES MIDDLE SITE

Date: 25/01/2017

Wt: 44,6 mbgl

Main sliding zone: 33-34 m bgl
Water table – velocity along slide zone

Period 1y January 2016 – December 2016

Δw = 1.3m
Date: 25/01/2017

Wt: 41,8 mbgl
Water table
Period 1y  January 2016 – December 2016

\[ \Delta w = 3.3 \text{m} \]
Rain event
start: 27/09/2016 6pm
end: 01/10/2016 1am
Cumulative rain = 50mm

DMS ÅKNES ROCKSLIDE
SNOW MELTING EVENT
Start: 14/04/13 8pm

DMS ÅKNES ROCKSLIDE

Δw = 0.55m

Δw = 0.20m

Δw = 1.2m
**SNOW MELTING EVENT**
Start: 14/04/13 8pm

**Temperature LOG record:**
15/04/2013 time 12.28
Aligned to 12/04/2013 time 00.00
(Before the increase in air temperature)

Delta T= -0.2°C centered at 29m bgl
Delta T= -0.3°C centered at 41m bgl
Injection of water more fresh (tracer)
DMS ÅKNES ROCKSLIDE

- DMS monitoring data in Åknes shows a link between displacement and water table (quite complex, more evident in the upper side, less in the lower)

- To better describe variation and complexity in water level a larger network is important

- Other types of borehole design and instrumentation are available such as **DMS Plus** (inside casing) or **DMS MP** (2D or 3D multi-packer inside uncased borehole).
New modular element **DMS® Plus** developed specially for deep-seated gravitational deformations to monitor \( z \) component and more generally usable for settlement monitoring of geotechnical engineering works.

This new modular element could be joined to other modular elements types of the DMS 2D series to monitor locally the \( z \) component together with \( x-y \) displacements, piezometric variations, temperature variations and vibrations.
DMS® PLUS

- **THIN LAYERS PACKER**
- **RIGID MODULE** (containing measuring and control electronic)
- **EXTENDIBLE CASE**
- **PIEZOMETRIC SENSOR**
- **BIAXIAL JOINT**
DMS® 2D MP

RIGID MODULE IN INJECTION PACKER (containing measuring and control electronic)

PIEZOMETRIC SENSOR

BIAXIAL JOINT

\[ i(t) \]

\[ w(t) \]

\[ T(t) \]
DMS® 3D MP

- RIGID MODULE IN INJECTION PACKER (containing measuring and control electronic)
- PIEZOMETRIC SENSOR
- TRIAXIAL JOINT

$i(t)$, $w_i(t)$, $T_i(t)$, $s_i(t)$, $e_i(t)$
TRANSMISSION: **SAT** (stand alone ultra low power / back up)
GSM, GPRS,
RS485, RS232
option **optical fiber**, ethernet, wireless

MODULES: up to 250

DATA MEMORY: circular buffer/ SD (extended T range)

POWER: 9-15V\(_{\text{DC}}\) solar cells, 24 V\(_{\text{DC}}\), 24 V\(_{\text{DC-AC}}\), 48 V\(_{\text{DC}}\), 220 V\(_{\text{AC}}\) with surge arresters

BOX: IP65-66

BATTERY BACK UP: 12 V

ALARMS: SMS/direct call GSM

Audio / visual devices for alert can be connected on request

**CONTROL AND TRANSMISSION RU**
FULLY PROGRAMMABLE EVEN REMOTELY

The frequency of reading, data acquisition intervals, the zero reading function, calibration, alarms set, the configuration of the mobile gsm numbers of the personnel on duty for alarms, etc can also be set with the remote control.
DMS® DEVELOPMENTS: DMS® CONTAINER

The container solution allows the complete autonomy of the DMS® management system, from the installation of the column to its extraction and subsequent repositioning, with the possibility to also include the direct data management.

✓ INSTALLATION SIMPLE AND RAPID
✓ START UP OF MONITORING IMMEDIATE
✓ SOLUTION COMPLETE FOR MONITORING IN EXTREME ENVIRONMENTS

CONTAINER 10’/13’ EQUIPPED WITH DMS REELER 4 SEGMENTS
Compact container, suitable for columns length up to 60m.

CONTAINER 15’ EQUIPPED WITH DMS REELER 6 SEGMENTS
For columns length up to 150m.

The standard container equipment includes:
• Tailgate ceiling connected to the actuating device
• Floor in marine plywood
• Circular hole in the floor for placement on top of borehole
• Hydraulic pump unit with electric motor for the installation
• of the column

The container configuration is designed and built by CSG engineers on specific customer requirements, to ensure maximum functionality and reliability of the instrumentation in the destination site.
CSG SRL

CSG since 1997 has been provider of geotechnical services, on a base of previous twenty years experience in the field of geo-engineering of its founders. The company is located in the Monferrato hills, on a area of 10.000 m², with a covered area of 1.500 m² which includes offices, monitoring room, conference hall, laboratories and warehouses, with a testing field and helipad for early warning applications.

The awareness of the needs and problems in the geological-geotechnical field and the passion for the instrumentation and the inventiveness of its engineers are the basis for a significant growth process of the company that has achieved a world leading position in the production of multiparametric columns for geotechnical monitoring on own patents.
The CSG testing field developed in Ricaldone since 2005 and 2009 has been extended in 2016. Now is equipped with a total of n.11 boreholes for testing for a total of more than 1000 m drillings:

- 1 borehole inclined i=10°, L=230 m
- 1 borehole vertical L=225 m
- 1 borehole vertical temperature controlled L=100 m
- 1 borehole inclined i=10° temperature controlled L=60 m
- 1 borehole inclined i=10° temperature controlled L=40 m
- 1 borehole vertical L=130 m
- 2 boreholes vertical L=100 m
- 3 boreholes vertical 20<L<40 m

In the testing field:

- Azimuth Calibration ARC Test
- Test LTS (Long Term Stability Test)
- Calibration on temperature (on specific range of the destination site)
ArcTest® recognizes and compensates phase shifts.

The column is inserted into an inclined borehole in the testing field having a known inclination (10°) requiring that the individual modules of the column measure the x and y components of the inclination.

The ArcTest® C.S.G. proprietary software provides to reconstruct the layout of the borehole measured by the column under test; this layout is automatically compared with the known profile to correct the residual disalignment in axes orientation.
DMS® DEVELOPMENTS: INSIDE ELECTRONIC LAB

- Stability test electronic (climate room)
- Stability Test inclinometric sensors (climate room)
- Automatic bench certificated for calibration and testing of the inclinometric axes Pitch, Roll, Yaw.

- Climate room for the temperature calibration with reference sensor certified Accredia
- Pressure chamber for calibration of piezometric sensors with reference Accredia

Automatic calibration bench – P, R, Y

Stability test inside climate room
✓ Joint traction test: ultimate traction

The system is designed to be robust:
All the electrical connection are protected **inside** the INOX structure.
More than 59 cm displacement on one module (deep 7m bgl)

The instrumentation was still working

The DMS column has been recovered and reused in the same site
The geotechnical continuous monitoring through new multi-parametric techniques can provide a valuable contribution in the resolution of stability problems, supporting not only monitoring and early warning but also the design, construction and testing of mitigation actions by providing reliable parameters and guidance to the project engineers.

Thanks for your attention!