GeoBeads, multi-parameter sensor network for soil stability monitoring

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Abstract

In 2008 Alert Solutions introduced its sensor network GeoBeads for levee and slope stability monitoring. GeoBeads was developed to provide all essential dynamic parameters for the determination of soil stability.

The fully digital network nodes with semiconductor technology sensor devices can scale to a wide area network of measurement locations. Installation methods have been developed complying to geotechnical standards which allow positioning in all relevant underground layers using minimally invasive techniques.

The GeoBeads sensor network has been installed in over 25 field projects for continuous monitoring of levees, embankments, slopes and excavation pits, thereby providing insight in their vulnerability to seasonal or extreme circumstances. Along the way much experience was gained in positioning of the measurement nodes in relation to local soil build-up and geotechnical risk profiles.

Data availability is immediate and is distributed via the internet. Providing live data of hydraulics and deformations in the underground enables real-time (re)calculation of soil stability under changing circumstances. GeoBeads data has been successfully interfaced to several industry-standard computational models, providing a powerful tool for safety monitoring and maintenance management of infrastructural works.

Using continuous data reduces uncertainty factors in stability assessments, supports safe execution of building activities, enables the setting of priorities in maintenance and optimizes constructional designs.

1 Introduction

In 2008 Alert Solutions introduced its sensor network GeoBeads for levee, infrastructure and slope monitoring. Each GeoBeads sensor module provides several essential parameters for the determination of soil stability (Peters & van der Vliet, 2009).

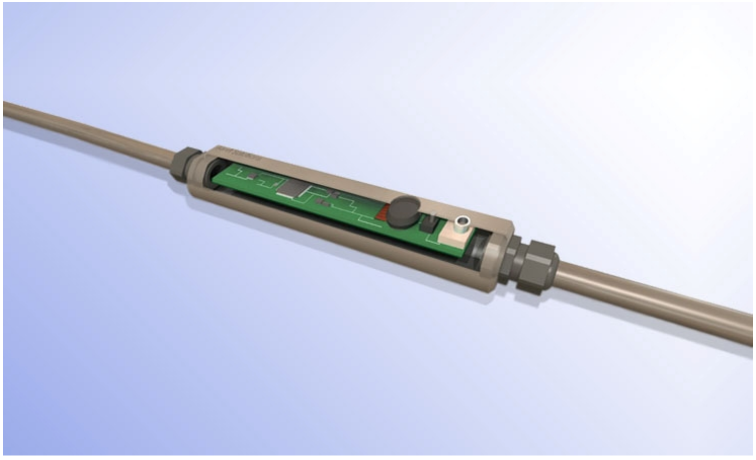

Figure 1: Cross section of a GeoBeads multi-sensor module containing a piezometer, an inclinometer and thermal sensors.

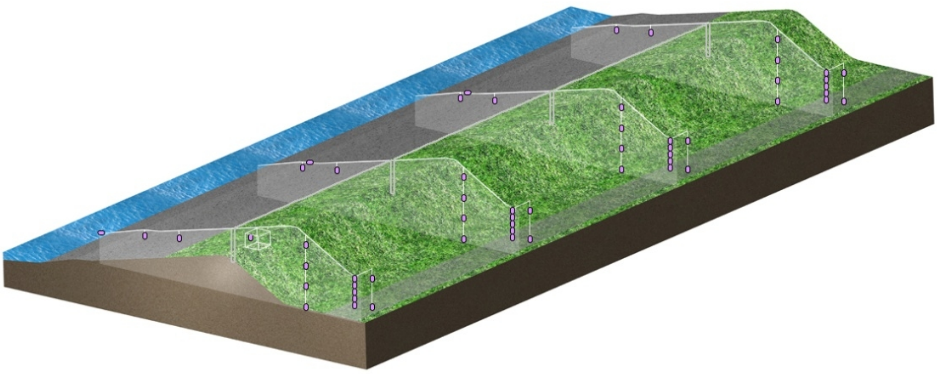

Figure 2: Overview of a GeoBeads sensor network consisting of more than 50 nodes installed in a coastal flood defense embankment in the north of The Netherlands. Measurement data is available for the client using an internet based platform.

The digital communication platform of the GeoBeads module allows the connection of many to form a sensor network. The network infrastructure also holds the possibility to integrate third party measurement devices. The network can relay its data in real-time to central servers and a web-based application for immediate data access from anywhere.

Figure 3: The Alert Solutions platform independent web app ‘Data Panel’ running on an iPad, enabling live access to sensor data of all projects.

The sensor system is designed to be deployed in remote locations. It offers high temporal resolutions of data acquisition and continuous monitoring over prolonged periods. Results can be relayed to centrally accessible databases in real-time.

GeoBeads is currently used in over twenty five sites, spreading from The Netherlands to the United Kingdom and France.

2 String of Sensors

GeoBeads consist of fully digital sensor modules (nodes) based on robust semiconductor technology that can scale to a wide area network of measurement locations. Each small sized node in the network can simultaneously house various measurement devices. The set per node commonly includes a piezometer, an inclinometer and thermal sensors. The modules are designed to capture the most relevant parameters needed for thorough insight into the risks at hand. Sensor elements for additional parameters can be integrated for specific project needs.

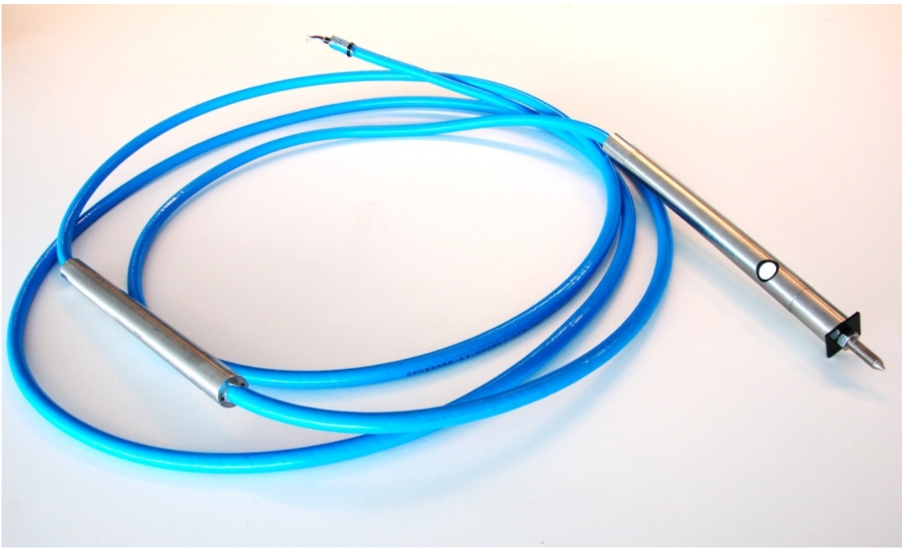

Figure 4: A GeoBeads string can contain from 1 to 100 sensor modules on a single cable.

Many modules can be connected to a single cable to form a sensor string. This is a convenient way to achieve a compact multi-level measurement system to monitor different depths in a single borehole or probing. Commonly used specific versions of this set-up are the Pore Pressure Array and the Inclinometer Array.

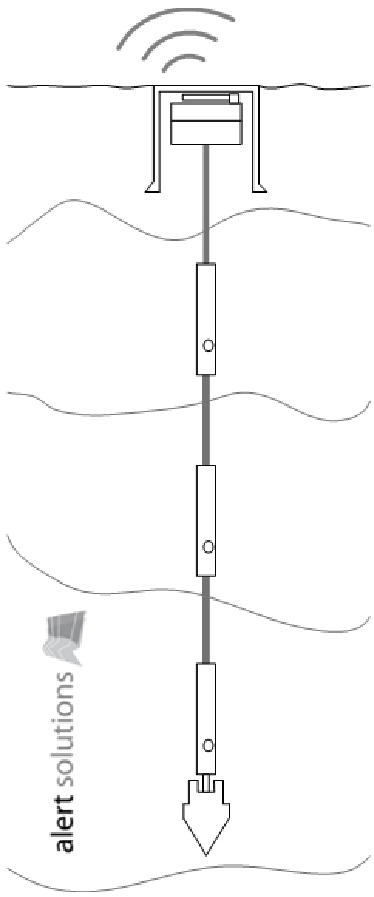

Figure 5: Schematic overview of a GeoBeads sensor string installed vertically for multi-level measurements as applied in levees, mountain slopes and construction activities. A specific example of this application is the Pore Pressure Array.

To withstand the harsh measurement conditions and support a long lifespan the nodes are housed in robust and waterproof enclosures. Due to the limited diameter of 22mm and the possibility to link multiple nodes to one signal cable (string of nodes), installation is time efficient and low-cost.

3 Installation

Local contractors execute the installation with regular drilling or push-rig equipment. For this purpose installation procedures have been developed that comply to geotechnical standards and allow positioning of the nodes at all relevant locations using minimally invasive techniques.

The GeoBeads sensor strings can be fitted with integrated bentonite shells to ensure hydraulic isolation between the sensor modules positioned in various soil layers at multiple depths. Shells made from Wyoming bentonite with a swelling capacity of over 400% have been developed for this purpose. Application in a multitude of field projects has shown effective multi-level pore water pressure measurements using this configuration. It has been applied in highly varying soil build-ups containing both permeable and non-permeable layers. Alternatively, depending on local circumstances one can use a fully grouted method for multi-level installation.

Figure 6: GeoBeads sensor string with integrated bentonite shells for hydraulic isolation between measurement depths.

Figure 7: Installation of a GeoBeads string using a light weight direct push-in rig with sonic drilling head.

4 Plug-and-Play Network

A typical GeoBeads system set-up consists of several strings of sensors linked to a single or several strategically positioned network controllers, which control measurement settings, collect the data and forward it to a remote database. This set-up allows for a high density measurement network without the need for many individual installations and thick cable bundles to be buried.

The network infrastructure has a modular nature, meaning that it the configuration can be expanded or altered at any time to support changing project needs. Also, any type of GeoBeads sensors (multi-parameter, piezometer only, inclinometer only, etc.) can be combined freely to collect the required data from the selected locations. Newly connected sensor nodes are detected and addressed automatically, becoming part of the monitoring system without the need for software re-configurations.

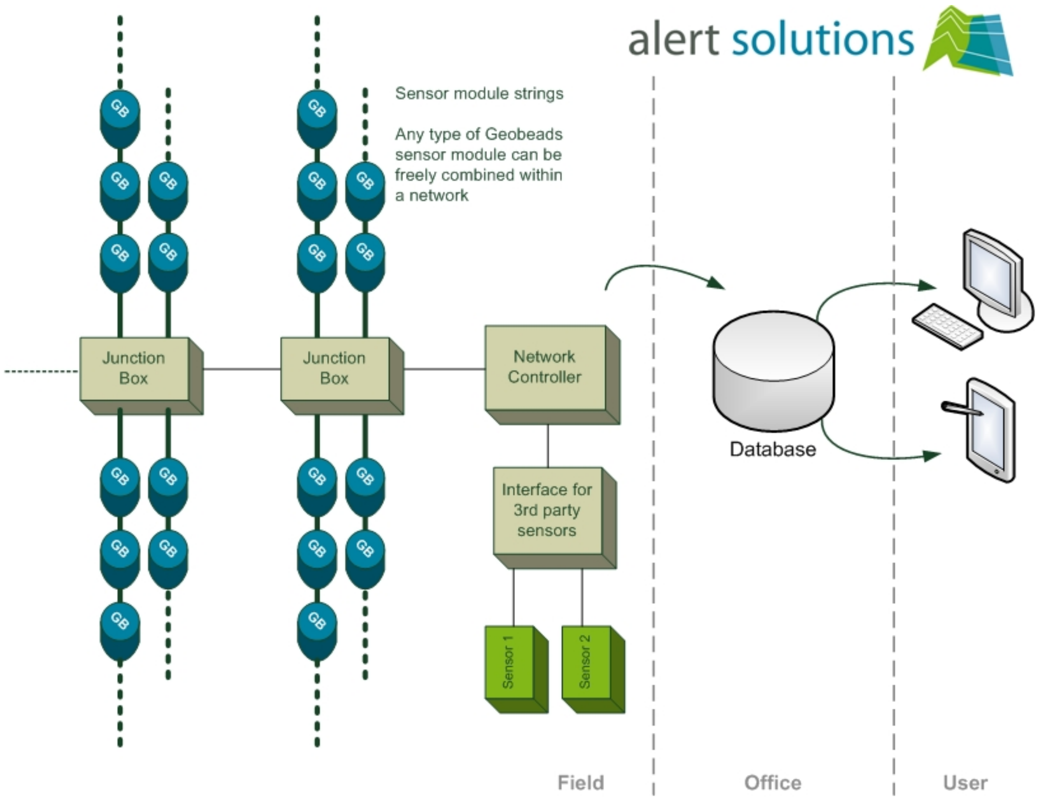

Figure 8: GeoBeads sensor network configuration depicting the modular and scalable set-up. Items involved are GeoBeads sensor strings, junction boxes, network controller, interface for connecting third party sensors, modem, central database and a web application for access by internet devices.

The open network infrastructure allows third party instruments and/or data streams to be connected. With available interface boxes these external sensors can be integrated seamlessly in the network and serviced over the same communication lines as the regular GeoBeads data. As such GeoBeads is a network infrastructure that can unlock all relevant monitoring instruments and/or external data for a total project site.

5 Web Apps

The system architecture of the GeoBeads sensor network is such that it can provide real-time availability of measurement data. The long range link from project site to the central database can consist of any common communication technology and is usually TCP/IP based, being the most prevalent internet protocol. It allows for two-way communication with the network controllers enabling remote management of sensor network settings such as sampling intervals. Keeping the communication pipe open continuously will make data availability virtually immediate. Activating this mode will depend on desired battery lifetime and urgency of monitoring a changing situation. Triggers can be build into the field system in order to go into live transmit mode based on pre-programmed alarm conditions.

Alert Solutions has developed online access to the database via a web application called the Data Panel, which visualizes time trends into graphs and allows data export for further offline analysis. The Data Panel can be reached via any internet connection. A personal log-in account secures safe access.

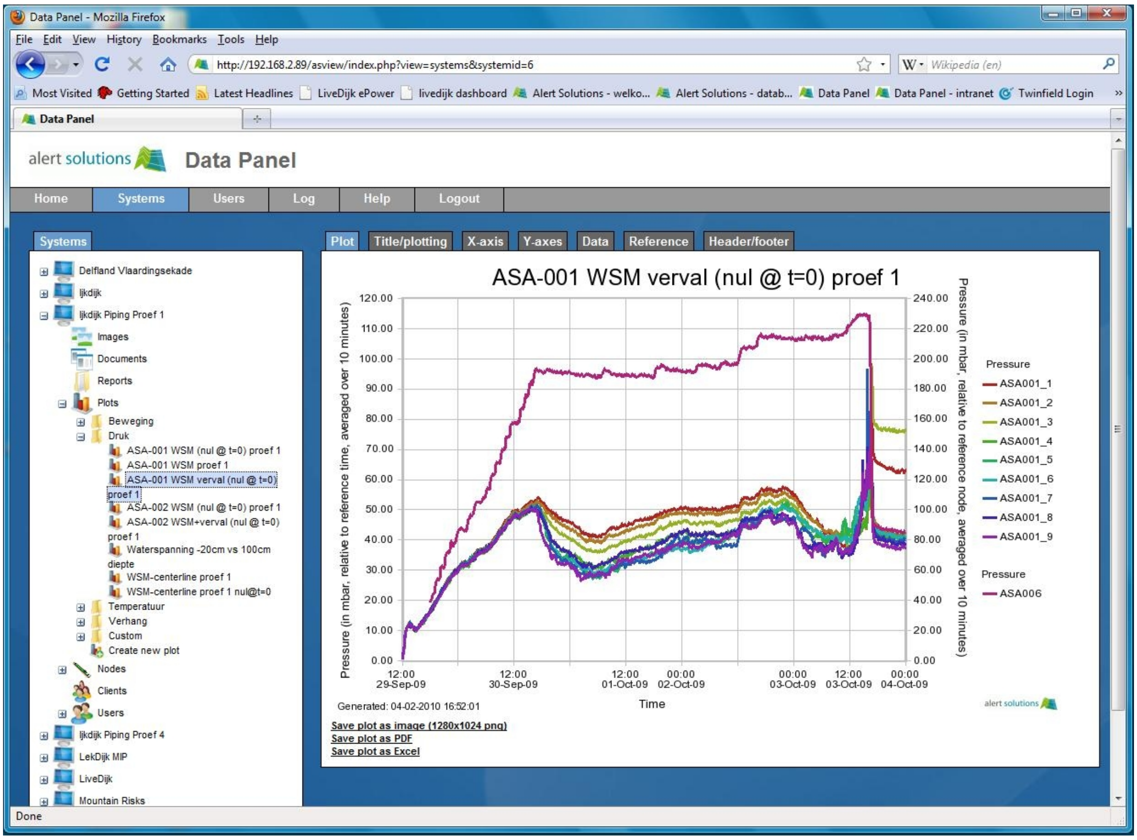

Figure 9: Screenshot of the “Data Panel’, a web application giving instant access to measurement data and analysis results from all monitored sites.

6 Stability assessment and early warning systems

GeoBeads creates the opportunity for continuous stability assessment. As the measurement data is real-time available the build-up of early warning systems is within reach. The continuous data sets of current GeoBeads projects enable this development.

GeoBeads data has already been successfully interfaced to several industry-standard geotechnical computational models. Automatically recalculating the models at each new sample interval results into a trend of the stability factors of a certain site. Remotely altering the sampling frequency in case of threatening situations provides a more or less live update of the stability analysis.

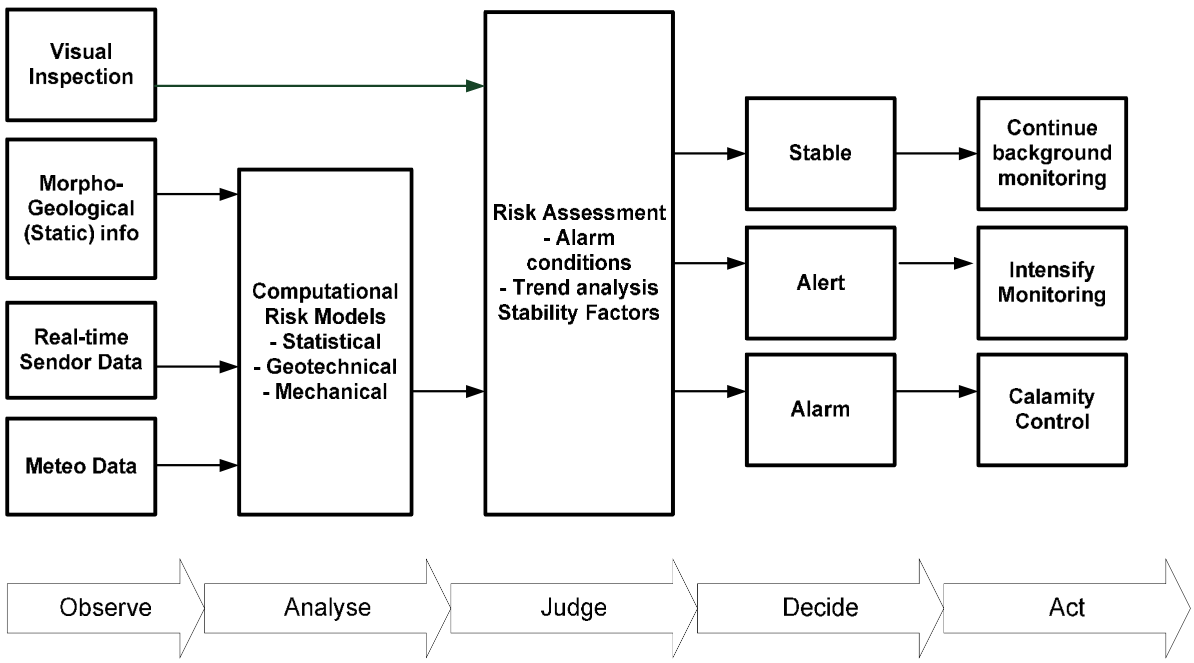

Figure 10. Flow diagram depicting elements of an early warning system applying real-time monitoring in order to continuously update stability calculations and assessment of alarm threshold conditions.

Adding sensor data to the observations of asset managers hands them a powerful tool to strengthen safety monitoring and enhance the maintenance management of infrastructural works.

6 GeoBeads Case studies

Since inception in 2008 the GeoBeads sensor network has been installed in over twenty five projects providing continuous monitoring of levee, slope and embankment stability and insight in their vulnerability to seasonal and/or extreme circumstances. Below two case studies are presented.

6.1 Monitoring of a primary levee in the centre of The Netherlands

Figure 11: Locations of GeoBeads monitoring locations in critical sections of the embankment along the Lek River east of the port of Rotterdam, The Netherlands.

In 2010 a part of the Lekdijk was equipped at three different locations with several strings of GeoBeads sensor modules. The Lekdijk is the levee on the south bank of the Lek, a major river in The Netherlands that drains Rhine water to the North Sea. Due to large changes in river throughputs and the influence of high and low tide, the levee is continuously confronted with varying water level heights.

The sensor strings were probed at the toe of the levee with regular CPT rigs. Each string consisted of multiple sensor nodes at different installation depths ranging between 2 and 16 meters below the surface.

Figure 12: Installation of GeoBeads sensor string just behind the levee on the south bank of the Lek River. The levee itself has become an urbanized area, which poses a challenge for any strengthening design.

The GeoBeads network is installed to measure pore pressures and inclination in different ground layers beneath the levee. The soil build-up with peat, clay and deep sand layers makes the levee vulnerable to potential heave of the inland due to increased water pressures following high river water levels. This would lead to a decrease in the levee stability (Peters 2009). To create a better understanding of the risk that this potential failure mechanism poses, the client requested installation at three different locations. The installed GeoBeads sensors monitor the pore water pressures in the various ground levels on a continuous basis (Figure 13; upper graph).

To translate the measurement data into valuable levee insight, these values are used as input for the Bishop ground mechanical model for a continuous levee stability calculation (Figure 13, lower graph). The use of GeoBeads shows the responsiveness of the levee to changing external conditions.

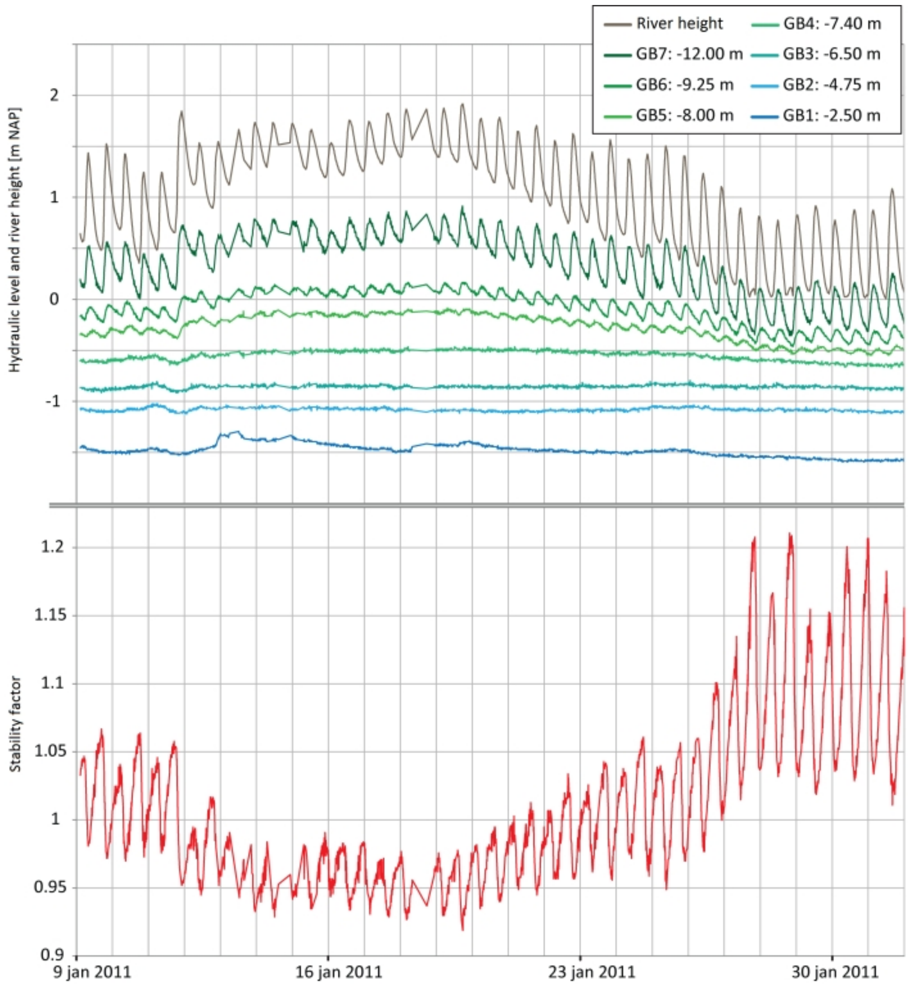

Figure 13. The levee along the Lek River is equipped with a GeoBeads network for continuous pore water pressure measurements (upper graph). The data is directly used as an input for the Bishop ground mechanical model for stability calculation with the Stability factor as an outcome (lower graph).

6.2 Monitoring of landslides in the French Alps

In July 2008 the landslide site at the Super-Sauze mudslide in the Alpes-de-Haute-Provence region, France (Malet, 2003) was equipped with several strings of GeoBeads sensor modules. The sensor strings were vertically lowered in boreholes at four different altitudes on the slope. Each string consisted of three sensor modules to monitor at different installation depths ranging between 0,5 and 2 meters below the surface.

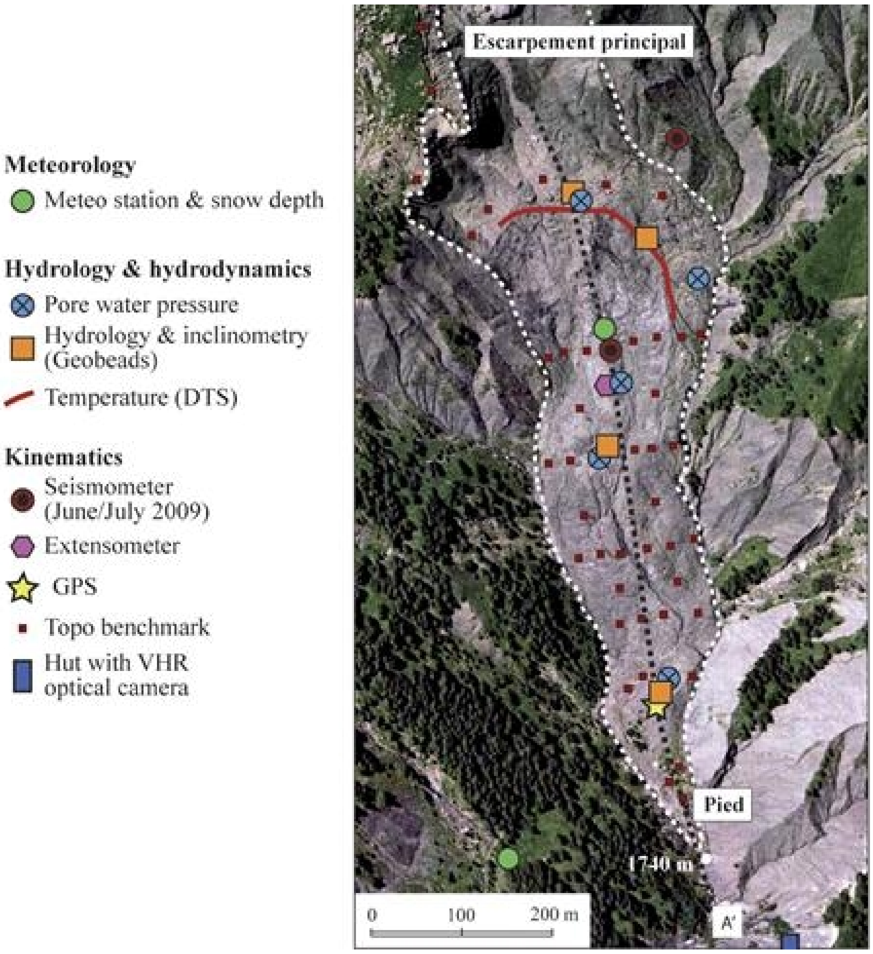

Figure 14: Top view of the Super-Sauze mudslide in the French Alps. GeoBeads sensor string locations are indicated by the orange squares.

Each of the GeoBeads modules at the landslide site registers three different parameters simultaneously. These parameters are pore water pressure in the soil layer, temperature and inclination of the sensor housing with respect to the gravitational field. This specific set of three parameters are relevant for ground stability in landslide monitoring. Pore water pressure is a measure for hydrological forces in soil layers that can trigger displacements. Furthermore pore water pressure contributes to assessing conditions for the formation of slip surfaces, lowering the shear resistance of soil layers on slopes (Lissak, et al 2009, Malet 2003). Temperature is used as a measure for soil moisture, groundwater flow and infiltration (Steele-Dunne et al 2009). Inclination, as measured by the integrated inclinometers, is the detection mechanism for the onset of movement in soil layers on the landslide. This technique is especially effective when there is a difference in displacement between shallow and deeper layers, leading to a rotation of the vertically installed sensor string.

Figure 15: A GeoBeads measurement system on the Super-Sauze mudslide powered by a solar panel and set-up to travel along downhill with the mudslide.

The trends of the different parameters through the spring period of 2010 show evidence of solid correlation between pore water pressure build-up, displacement events and temperature changes (figure 16).

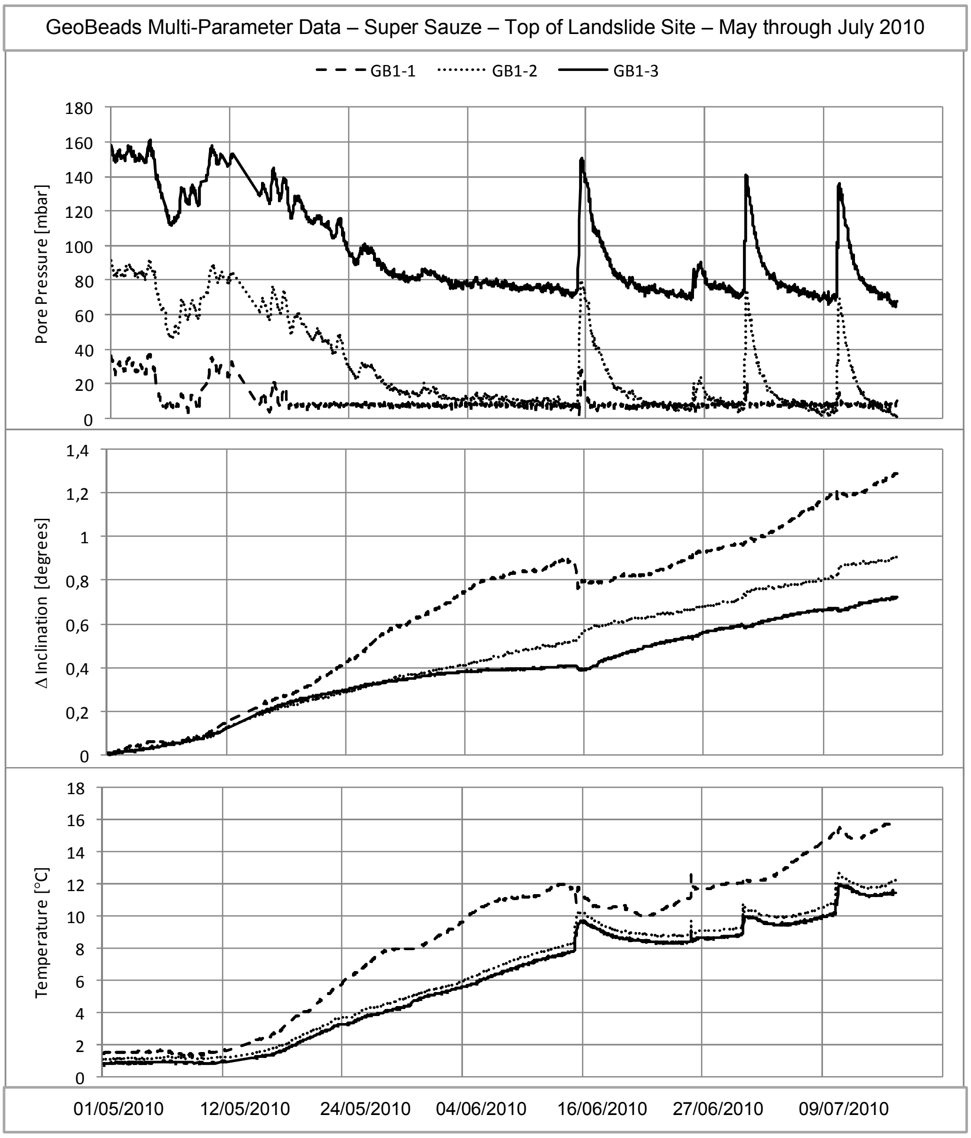

Figure 16. GeoBeads multi-parameter measurements from the installation at the top of the Super-Sauze mudslide over the period May to July 2010. From top to bottom graph, 1) pore water pressure [mbar], 2) delta inclination [degrees], and 3) temperature [°C]. Sharp pore water pressure peaks (top graph) coincide with observable inclination trend changes and temperature increases in the lower layers (Peters et al 2010).

7 Conclusion

GeoBeads is a monitoring solution with multi-parameter sensor nodes based on semiconductors technology, an open network architecture which also supports third party instruments and an internet platform for data distribution and analysis. Due to its scalability and its direct internet access, it is suitable for detailed real-time monitoring of ground and infrastructural stability over wide areas and in remote locations. GeoBeads networks run both on power lines or batteries and can transmit data from any project site by wire or wirelessly.

Field installations of the sensors have been put in operation at over twenty five sites on landslides, levees and near construction activities. Using GeoBeads for continuous monitoring enables its clients to reduce uncertainty factors in safety assessments supporting the setting of priorities in inspection and optimizing construction activities and designs.

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