GRIMONIT (GroundRiskMonitor) Fully automatic and remote-controllable deformation early warning system for difficult measurement conditions

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Key words: monitoring, deformation, settlement, hazard prevention, high-precision ground deformation, long-term stability, hydrostatic leveling system, vertical displacement, power dam, bridge control, Earth tide

SUMMARY

Hazard prevention is of crucial importance regarding monitoring settlements or deformations of bridges, dams, buildings as well as mines, caused by natural hazards or structural measures that have been taken. Apart from that, monitoring forested areas through which roads or train tracks lead is currently extremely challenging. Furthermore, it's equally difficult to monitor areas at risk using optical methods when meteorological conditions such as rain, snow or fog occur.

GRIMONIT (Ground Risk Monitor) is a hydrostatic measuring system, allowing for continuous monitoring, even if the conditions are unfavorable. Hydrostatic systems do not rely on a clear line of vision. Accordingly, weather conditions such as rain, snow or fog are not obstacles. Thus, measuring points can be covered or buried after installation; they do not have to be visible. Thanks to a comparably simple setup process, the device can be deployed within a short period of time and will then allow for continuous surveillance. The access via internet allows recalibration of the system remotely and data extraction from anywhere at any time.

SUMMARY (optional summary in one other language in addition to English, e.g. your own language)

La prevención de riesgos es de vital importancia en lo que respecta a la supervisión de las elevaciones/ asentamientos y/o deformaciones de puentes, presas, edificios y minas, causadas por riesgos naturales o por medidas estructurales que se hayan tomado. Además, la monitorización de zonas boscosas por las que pasan carreteras y/o vías de tren es actualmente compleja. Igualmente complicado es vigilar las zonas de riesgo con métodos ópticos cuando se dan condiciones meteorológicas como lluvia, nieve o niebla.

GRIMONIT (Ground Risk Monitor) es un sistema de medición hidrostática que permite una vigilancia continua, incluso si las condiciones son desfavorables. Los sistemas hidrostáticos

no dependen de una línea de visión clara. Por lo tanto, condiciones meteorológicas como lluvia, nieve o niebla no son un obstáculo. Así pues los puntos de medición pueden cubrirse o enterrarse después de la instalación; no es necesario que sean visibles. Gracias a un proceso de configuración relativamente sencillo, el dispositivo puede instalarse en un breve periodo de tiempo y permitir una vigilancia continua. El acceso a través de internet permite recalibrar el sistema a distancia y los datos pueden extraerse desde cualquier lugar y en cualquier momento.

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1. INTRODUCTION: The history of GRIMONIT's development

Since 1981, Edi Meier has been experimenting with hydrostatic measurement systems in the ETH Zurich. He completed his thesis after developing the "Long Baseline Tiltmeter", his first hydrostatic measurement system based on differential pressure systems.

After that, the LAS-Meter (Large-Area-Settlement-Meter) came: a hydrostatic deformation monitoring system for measuring large area deformations over baselines of 10 to several 100 m [1]. In 1989, the LAS-Meter was installed in the Albigna dam (Switzerland) and recorded the tilts resulting from the water load in the lake. Lunar tides could be resolved [3].

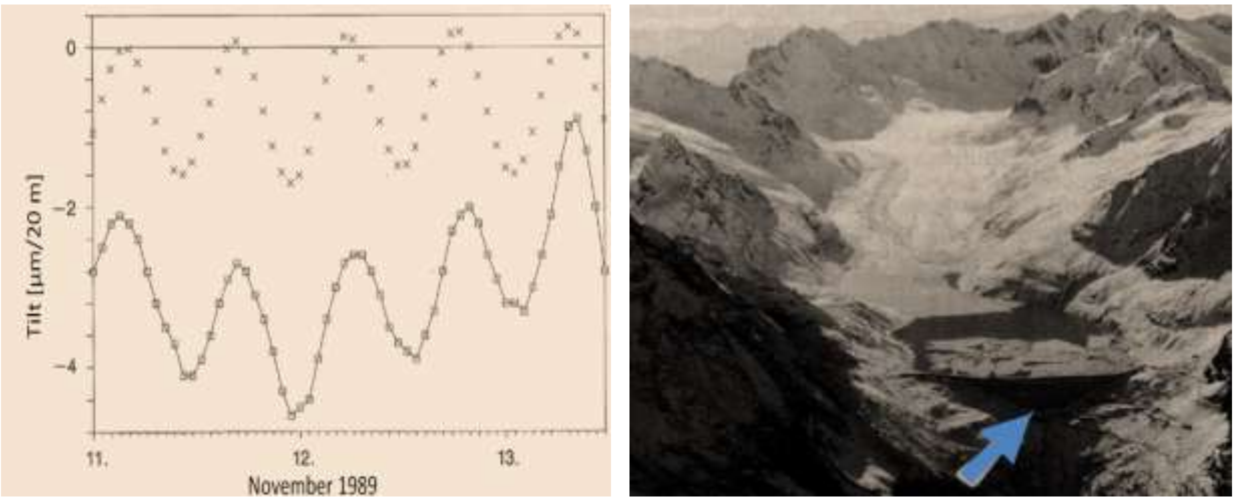

Fig. 1): Earth tides recording 1989 (left) in the Albigna dam (right), Switzerland.

However, it was found that the LAS-Meter was susceptible to leakage or entrapment of air in the measuring liquid leading to further development of the LAS-meter under the name "GRIMONIT" (Ground Risk Monitor). The aim was to develop a measuring device that automatically fills the measuring cells and periodically flushes the measuring lines. GRIMONIT is the successful result of these developments.

2. GRIMONIT

The heart of the GRIMONIT is composed one differential and two relative pressure sensors with measuring probes connected to this central unit. The measuring probes and tubes are filled with a liquid, making the tubes hydraulically connected. An intermediate precision diaphragm registers the pressure differences, which are converted into height differences. The GRIMONIT is able to carry out the necessary filling, rinsing and calibration processes fully automatically, as all venting components are installed in a central unit.

2.1 Measuring method

As well as the LAS-meter, in very general terms, the GRIMONIT is a differential pressure measuring device equipped with a differential pressure sensor and measuring probes connected to it [3]. In the current configuration, a maximum of 13 measuring probes can be connected, one of which is a fixed zero sample.

The differential pressure sensor itself has a diaphragm inserted which deforms according to the equalization of the liquid. As a result of pressure differences between the liquid columns, the diaphragm is deflected. The movement of this diaphragm is transformed to an electrical signal, which is a measure for the level difference between the 'chambers' at the end of the tube. GRIMONIT has several inputs, which are all sequentially switched to the same sensors. Sensor drifts are inconsequential as a result of the gradient calculation.

In addition, a relative pressure sensor is connected to each of the two supply lines to the differential pressure sensor, so that a larger measuring range can be covered. The relative pressure sensors are less accurate and are exposed to atmospheric air pressure fluctuations, but they are very useful for some applications, especially when the differential pressure runs out of range.

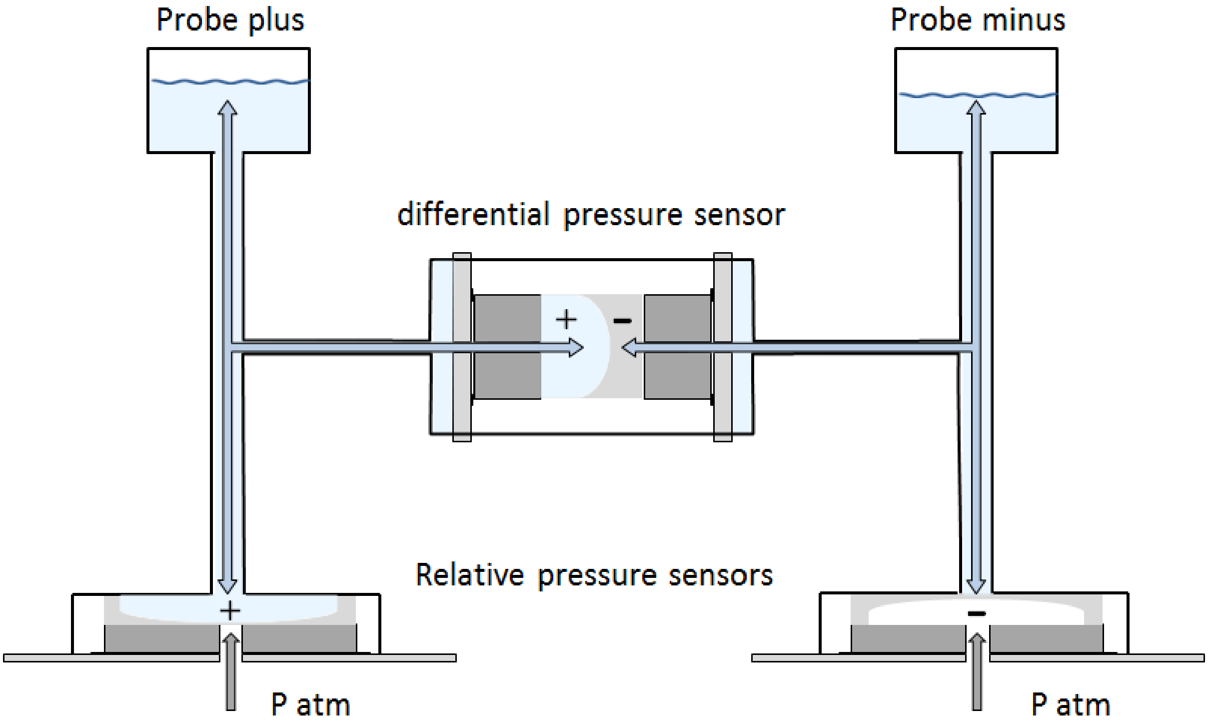

Fig. 2): Measuring principle of GRIMONIT.

The liquid is contained in an internal reservoir, and a pump transports it to the various probes. Using a series of valves, the desired probes are filled with the liquid. In order to precisely monitor how much liquid has been transported into the individual probes, the instrument is equipped with a precise dosing device.

Since air can build up in the lines as well as the measuring probes over time, the GRIMONIT was equipped with a venting routine. Automatically, at regular intervals - or also manually - the lines and the measuring probes are flushed for this purpose. To compensate for a possible loss of liquid over time, the device can refill from an internal reservoir. Should this not be enough, a larger, external reservoir may also be connected.

The individual components are coordinated by a program running on a Campbell scientific data logger. The program has various routines that automate the various processes. In addition to the recording of the measurement data, these also include the filling and calibration of the measuring probes. For remote control, the software Loggernet of Campbell scientific is used.

The GRIMONIT is composed of the same basic elements as the LAS-meter including improvements of its precision. Therefore, we can state that the measurements made with the GRIMONIT are as reliable as those made with the LAS-meter.

2.2 Parts of the system

The GRIMONIT is composed of a central unit where the electronic and hydraulic mechanisms of the system are integrated. Additionally, there are the probes and tubes, in charge of transmitting the movement of the ground in the form of pressure, which are connected to the central unit. Last but not least, the fluid.

2.2.1 Central unit

With a very compact layout, the measuring sensors, valves, pumps, reservoir and dosing unit that generate the data are housed in a well-structured stainless steel. Also the data acquisition and data storage are located in this box.

The box has connectors for the external reservoir, 13 measuring inputs for 3 tubes each: pressure, flushing, air. Furthermore the connections for communication and battery supply are there, together with the internet server box.

Presently, the average power consumption of the GRIMONIT is about 24 mA at 12 volts for measuring five probes hourly and two probes every half second. During internet access and pumping for calibration, the power consumption is about ten times larger.

2.2.2 Outside parts

Depending on the requirements of the application, measuring probes for vertical or horizontal configurations and tubes extendable up to 1 km with plug-in couplings are available.

2.2.3 The fluid

The fluid used to fill the tubes and deposits is currently a water-glycol solution. This allows a wider range of applications due to its low freezing point.

Fig. 3): GRIMONIT central unit with two measuring probes and the zero sample connected.

2.3 Applications

Extrapolating the experiences of the LAS-Meter to its successor GRIMONIT, we can guarantee that its applications cover a wider range, as the new device does not require direct access for recalibration or maintenance work like its predecessor [2].

GRIMONIT is a very versatile measuring device. In its original design it was intended for the monitoring of sloping terrain (such as wooded slopes) to detect slow displacements; hence its robustness among other features. However, both in the initial configuration and with minor adaptations, GRIMONIT is capable of detecting settlements and deformations in: bridges [4], dams and other structures including, fork buildings, forested areas, underground construction, etc. It can also register the quantity of soil compaction by heavy vehicles [5].

Another feature is its flexibility in choosing the frequency of use. It is possible to do continuous measurements for monitoring an area or just carry out individual measures at determined periods, e.g. annual single measurements. In this way, the tubes and probes remain on site and the GRIMONIT is connected and taken away after the measurement.

3. Example: Landfill in Zingel quarry near Schwyz

Siliceous limestone is mined in the Zingel quarry, near the town of Schwyz (central Switzerland). As part of the first stage of excavation, a large hole was created that seemed ideally suited as a landfill. In 1997, a project plan was submitted that provided for the storage of waste slag there. In the back zone, siliceous limestone would continue to be extracted and the material would be transported through the landfill body by means of a tunnel and conveyor belt. The project was approved.

Fig. 4): Zingel quarry. The marked part of the first excavation was to be backfilled with waste slag, while siliceous limestone is still being mined in the rear part.

Since the nature reserve of Lake Lauerz is located in the immediate vicinity, eight horizontal inclinometer tubes were laid underneath the landfill liner for monitoring purposes, capable of being surveyed from the conveyor belt tunnel. The objective was to record any deformations of the landfill base due to further backfilling. This allowed the risk of cracking and leakage at the base barrier to be estimated.

Since the zero measurements were carried out in 1996, the landfill has been monitored for a good 10 years using commercially available hydrostatic measuring systems and horizontal inclinometers. Due to contradictory measurement results, an alternative was pursued. Eventually, it was decided to use the LAS meter from the ETH.

First measurements with the LAS-Meter were successfully carried out in 2010. In 2021, another measurement took place, using the GRIMONIT, the further development of the LAS meter. Not only did the measurements prove to be reliable, but they were much faster to obtain, since the filling and regular calibration are carried out automatically. This eliminates the maintenance work necessary with the LAS meter and the time-consuming troubleshooting in case of air pockets in the system. There was also a decrease in the effort and time spent in the transportation of material and organization since the control unit, all pumps, valves and the reservoir are compactly housed in a central unit.

The result of the GRIMONIT-measurement of tube 33.2 is almost congruent with the values determined 11 years ago by the LAS-meter. This indicates that the measurements taken with both devices are reliable. Thus, hardly any settlement can be detected, which is good news for the landfill operator. The measurement performed in 2021 using GRIMONIT required a fraction of the time needed in 2010. In 2010, all pumps and valves had to be operated manually and maintained in the uncomfortably damp and cold underground. In 2021, the work was limited to on-site setup. Time-consuming venting could be conveniently triggered via a remote (Internet) connection at the push of a button.

The result of the measurement of the tube 36.1 in 2010 with the LAS-meter and the measurement in 2021 with the GRIMONIT show significant differences. A difference of up to 13 cm at a distance of 30 m in the tube was found. This indicates a settlement of the ground in that area of the indicated amount.

This is also an example of non-conventional use of GRIMONIT and shows how adaptable it can be.

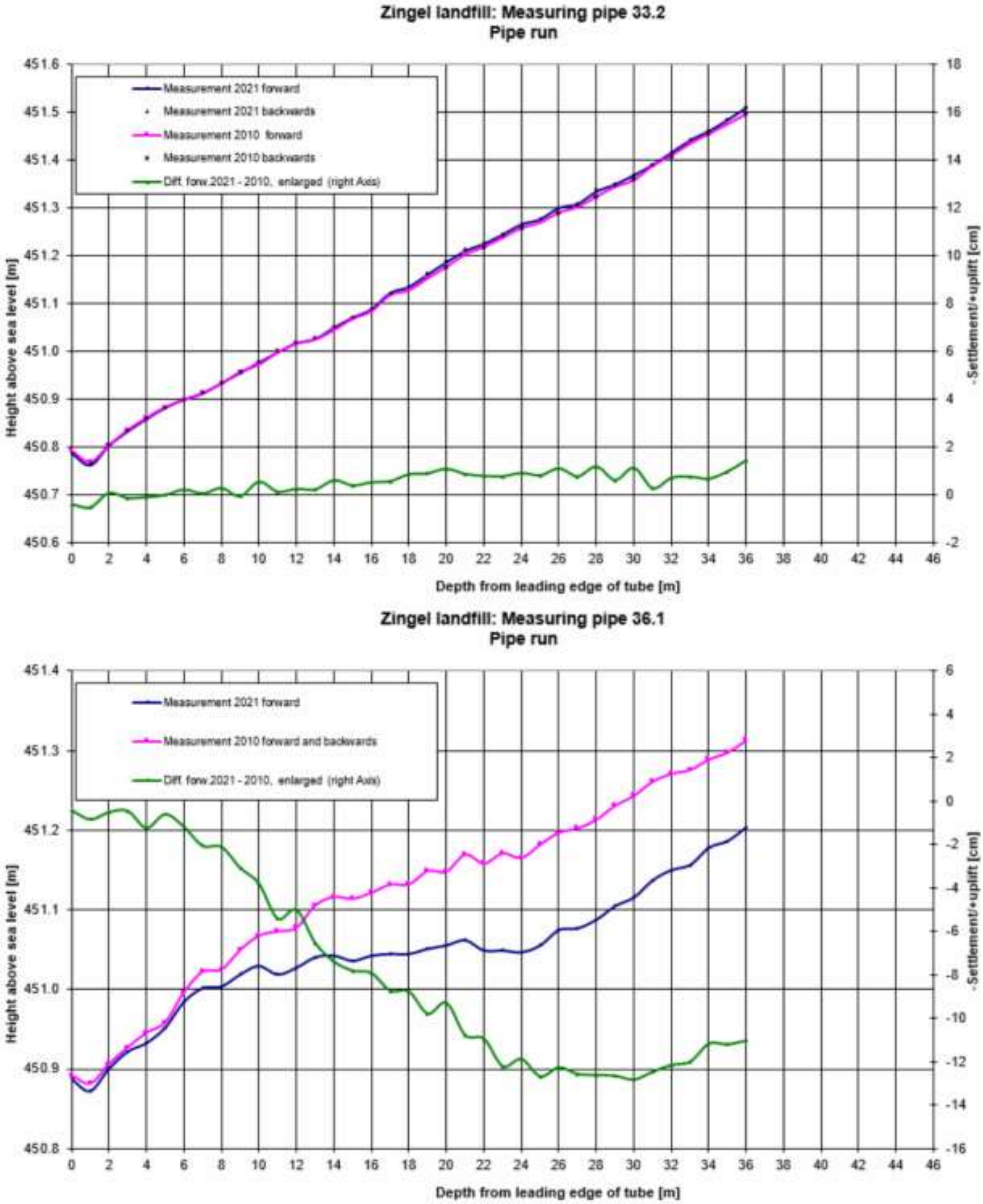

Fig. 5): Measurement results of the tubes 33.2 (above) and 36.1 (bottom). Red: forward and backward measurement 2010, blue: forward and backward measurement 2021, green: difference of the two measurements (right scale).

4. Conclusions and Outlook

The results of the GRIMONIT are very reliable because the basic measurement system is the same as the LAS meter, which has a long and successful measurement history. In addition, new functions and a significant reduction in application time have been added.

For example, in slide slopes with several measuring points, only the setting of the measuring probes and the laying of the supply lines is required. All other work steps such as filling, venting and calibrating are carried out by the GRIMONIT. Once installed, all functions can be controlled and monitored in real time, from the office, via the Internet.

Thanks to financial support from the Federal Office for the Environment (FOEN), cooperation with the University of Applied Sciences Rapperswil and the Swiss Federal Institute of Technology (ETH) as well as our five industrial partners, GRIMONIT is now available as a versatile and flexible early warning measurement system.

It is able to monitor and record deformations of land, bridges, dams and buildings independent of weather conditions. The GRIMONIT can also be used in underground mining. This opens up numerous new application possibilities in hazard prevention that are waiting to be exploited.

REFERENCES

[1] Meier, E., Geiger, A., Ingensand, H., Licht, H., Limpach, P., Steiger, A., Zwyssig, R. (2010): Hydrostatic levelling systems: Measuring at the system limits. Journal of Applied Geodesy 4 (2010), 91–102 6 de Gruyter 2010. DOI 10.1515/JAG.2010.009

[2] Meier, E., Huggenberger, P., Ingensand, H (1998): Precision monitoring of displacement over large areas, Hydropower & Dams, Commission 5, Issue Six, p. 77 – 88.

[3] Meier, E., Ingensand, H (1998): A multipoint hydrostatic system for permanent deformation monitoring, International Federation of Surveyors, XXI Congress Brighton, Commission 5, p. 369 –381, ISBN 0-85406-901-1.

[4] Steiger,A., Licht, H., Zwyssig, R. (2009): Nationalstrasse A2/3 – Lärmschutz und Instandstellung Riffig-Reussegg, Auswertung der Kontrollmessungen, Bericht Nr. 10.106-018, Ingenieurgemeinschaft Kompetenz Emmen.

[5] Tobias, S., Hennes, M., Meier, E., Schulin, R. [2001], Estimating soil resilience to compaction by measuring changes in surface and subsurface levels. Soil Use and Management, 17, 229- 234.

BIOGRAPHICAL NOTES

Inma Gutiérrez is a geologist and is currently working at the engineering company Edi Meier + Partner AG, Winterthur, Switzerland. She studied Geology at the University of Granada (Spain) and completed a complementary Master in "Integrated water management" at the University of Cádiz (Spain). After some experiences in the geotechnical and water management branches, she is working since 2017 in the geophysical branch, specializing in GPR.

Edi Meier is currently the managing director of the engineering company Edi Meier + Partner AG, Winterthur, Switzerland. He studied Geophysics at the Swiss Federal Institut of Technology, ETH Zurich. Subsequently he worked as a manufacturer of seismic instruments (Streckeisen Switzerland) for six years and founded his own engineering company in 1987. His company is specialized in development and construction of precision deformation measuring systems and in geophysical services using Geoelectric and Georadar (GPR) tools.

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