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Role of Dams and Reservoirs in a Successful Energy Transition

Edited by

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Role of Dams and Reservoirs in a Successful Energy Transition – Boes, Droz & Leroy (Eds)

GRIMONIT (GroundRiskMonitor) – an early warning system for difficult measurement conditions

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ABSTRACT: In the context of hazard prevention, it is of central importance to continuously monitor deformations on bridges, dams, buildings or in underground mining. Equally challenging is the permanent monitoring of forested landslide areas that pose a risk to railroad tracks or roads. "GRIMONIT" (Ground Risk Monitor) is a fully automated hydrostatic measurement system, which is a further development of the LAS-Meter, developed in cooperation with the ETH. In this paper a measurement with the LAS-Meter is compared with GRIMONIT-measurements. The time span between the two measurements is 11 years. The task was to document the subsidence at the landfill site "Zingel".

RESUMEN: En el contexto de la prevencion de riesgos es de suma importancia la monitorización continuada de deformaciones en puentes, presas, edificios o mineria subterranea. Igualmente desafiante es el monitoreo permanente de zonas de deslizamientos boscosas que suponen un riesgo para lineas de ferrocaril o carreteras. GRIMONIT es un sistema de medición hidrostático completamente automatizado, resultante del perfeccionamiento del LAS-Meter y desarrollado en cooperación con la ETH. En este artículo se compara una medición llevada a cabo con el LAS-Meter con otra usando el GRIMONIT, realizada en el mismo lugar 11 años depués. El objetivo era documentar una posible subsidencia en la base del vertedero "Zingel".

1 INTRODUCTION

The development of the GRIMONIT-System has a long history. The idea for the development of GRIMONIT was born at the SNGT Dam Conference in St.Gallen in 2008. The topic at that time was the great danger posed by ageing earth dams at sawmill ponds etc., where, as is well known, no monitoring wells can be drilled and a measuring layout can only be oriented horizontally and not vertically.

The precedent version of GRIMONIT was the LAS-Meter. With this multiple measurement line instrument high resolutions are achieved, e.g., at the base of the Albigna power dam.

The basic physical principles and the implications of possible errors of the LAS-measurement method (Thierbach, 1979; Emter et al, 1989) are described in detail in the article "XII Ingenieurvermessung" in Graz 1996. Since these early days, a lot of experience has been gained in the use of the LAS-Meter (Meier et al, 2010, pp. 97-102). An internal calibration function allowed compensation of the sensor drift, but the maintenance effort was still very high. The reason was the slow response time, which is characteristic for such a system with long extensions. In addition, the impacts caused by fluid losses had to be corrected by means of precise refilling of the system. Long access routes account for a large part of the required service time. Another disadvantage of the LAS-Meter was the small measuring range of only a few centimeters.

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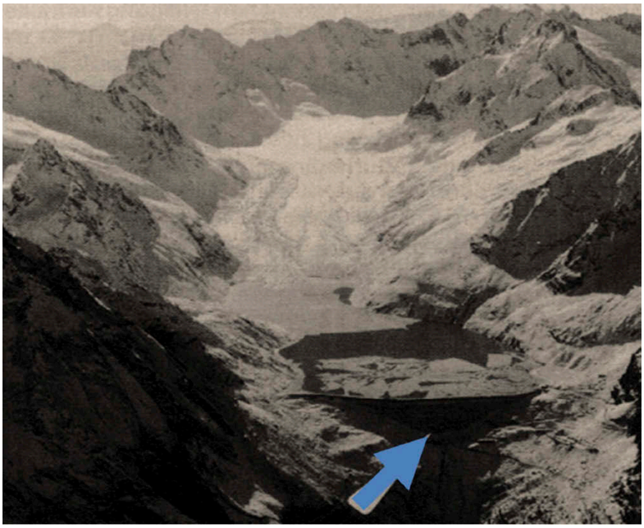

Figure 1. Powerdam Albigna, Graubünden, Schweiz (Meier et al, 1996, S. A 8/7).

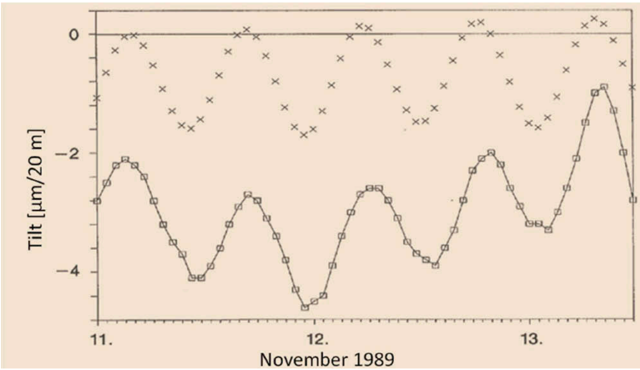

Figure 2. Earthtide record 1989 with LAS-Meter at Albigna power dam (Meier et al, 1996, S. A 8/9).

In contrast to the LAS-Meter, the focus of the current design of GRIMONIT is not on the highest possible resolution, but on the simplest possible handling of the instrument and on a large measuring range.

2 GRIMONIT

The heart of the GRIMONIT-System is composed of one differential and two relative pressure sensors. The measuring probes are connected to this central unit. The measuring probes and tubes are filled with a liquid, making the tubes hydraulically connected.

A differential pressure sensor registers pressure differences, which are converted into height differences. GRIMONIT is able to carry out the necessary filling, rinsing and calibration processes fully automatically, since all venting components are installed in the central unit.

2.1 *Measuring method*

As with the LAS-Meter, the differential pressure between two measuring probes is determined. Additionally, the relative pressures of these probes are also measured (Figure 4), which significantly increases the measuring range. The accuracy of the relative pressure measurement is lower than that of the differential measurement, but this also has an advantage as the

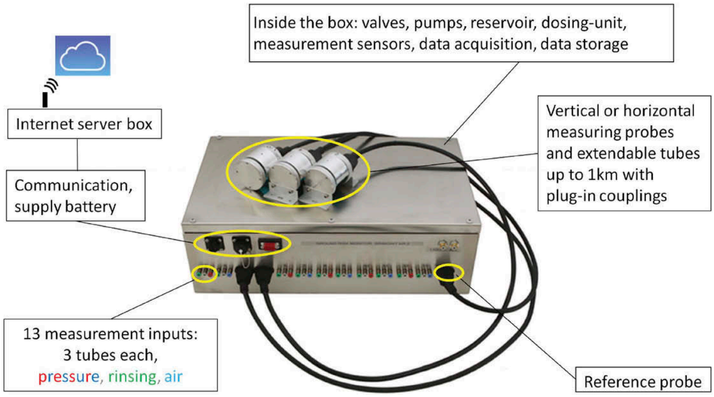

Figure 3. GRIMONIT central unit with two measuring probes and the reference sample connected.

differential pressure signal exceeds the measuring range and thus the progress of the deformation can be recorded for a long time without interruption.

In the current configuration of GRIMONIT, up to 13 measuring probes are set up and are switched sequentially to the pressure sensors. One of these is the reference probe, whose pressure is switched to both sides of the differential pressure diaphragm simultaneously for "zeroing". The diaphragm prevents the fluid from equalizing, as is the case with a hose scale. The deflection of the diaphragm is converted into an electrical signal, which is a measure for the difference in height between the probes. All measuring probes are switched to the same sensor combination. A measuring cycle, including the zero probe, can be executed in any time interval. In this way, a possible offset drift of the membrane is detected and a possible deviation is corrected with each pass of all measuring positions.

The measuring liquid is pumped from an internal reservoir to the measuring probes (Figure 5). Another tube is used to flush the measuring tube to remove possible air pockets from the liquid. With the LAS-Meter, it has been shown that air bubbles in the tubes of hydrostatic measuring systems are often the cause of incorrect measurements.

Nevertheless, air bubbles can also form inside the GRIMONIT tubes with time. GRIMONIT is therefore equipped with a venting routine that regularly - or manually triggered - vents the measuring tube. The third tube "air" (see Figure 5) connects all measuring probes so that all measuring probes are exposed to the same air pressure. To precisely control how much liquid is transported to the probes, the instrument is equipped with a dosing unit.

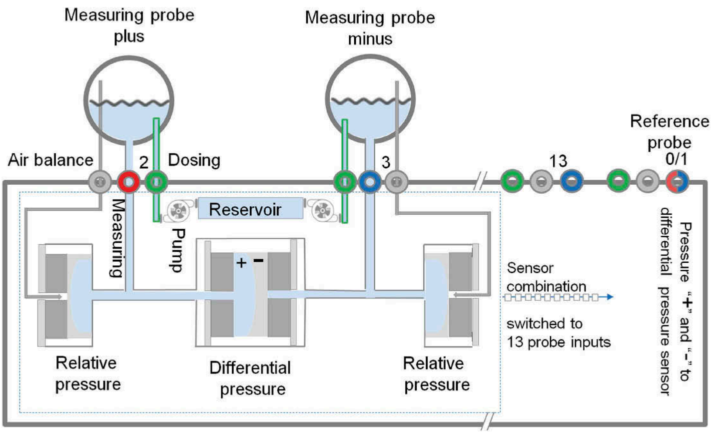

Figure 4. Measuring principle of GRIMONIT: The differential pressure of 2 measuring probes and the relative pressures of each probe are continuously recorded. This combination is switched sequentially to the other measuring inputs with valves. The liquid level in the measuring probes is controlled via the dosing line.

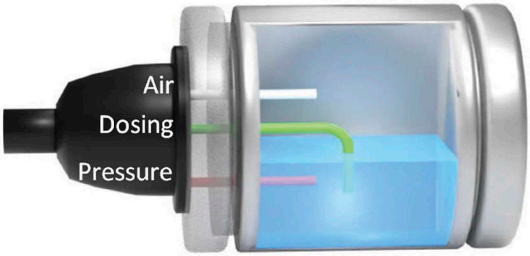

Figure 5. Measuring probe with symbolically drawn connections for pressure, dosing and air compensation. The probe does not contain any electronics and is therefore insensitive to overvoltage.

3 CALIBRATION AND ACCURACY

The most accurate hydrostatic measurements are obtained when an open continuous water surface is available and the distance to the water surface can be measured. This is proven by the results of 192 sensors we installed on a circumference of 300 m in the "Swisslight Source" accelerator at PSI (Paul Scherrer Institute) and that have been operating continuously since 2001. All these so-called HLS sensors register the movement of the base of the accelerator within earth tide resolution, comparable to the record in Figuire 2. Optimal measurement conditions were present at the Albigna dam as well as at the accelerator at PSI. For both measurements only a very small measuring range needs to be covered.

While the evaporation of liquid in the HLS measurement at the PSI accelerator has not caused any measurement errors, the loss of liquid in the Albigna measurement with the LAS-Meter caused a significant measurement error over the years.

Basically, GRIMONIT is equipped with the same measuring elements as the LAS-Meter. We can therefore assume that equal results will be achieved under comparable measuring conditions. However, in contrast to the LAS-Meter, the error due to loss of liquid is solved by the recalibration feature of GRIMONIT.

The volume of the measuring liquid increases at high temperatures and causes the level in the measuring probes to rise. The larger the liquid surface area of the measuring probe compared to the cross-section of the measuring tube, the less significant is the temperature-related expansion of the measuring liquid. In the relative pressure range, the expansion of the measuring liquid leads to a measurement error, since this increases the liquid level. However, this can easily be corrected with an additional temperature measurement and a calibration function. In the differential pressure range of the instrument, on the other hand, a change in temperature has no effect, since the liquid surface levels of both measuring probes change by the same amount. In general, the effect of the temperature is minimal for all hydrostatic measuring systems if the measuring probes and the tube delivery are at the same height at the beginning of the measurements.

Other error sources are air bubbles in the liquid. The tube in Figure 6 was filled without bubbles and was immediately connected to the probe. After two days, many air bubbles appeared.

Errors caused by growing air bubbles cannot be easily distinguished from real elevation changes. To eliminate such errors, GRIMONIT flushes the measuring tube before each calibration.

With a test setup in the laboratory, see Figure 7, the possible error influences were investigated. Probe samples of vertical and horizontal layout and different sizes were fixed in pairs on platforms between the floor and the ceiling. The paired probes on each platform could be measured within the range of the differential pressure sensor; the probes between the platforms could only be measured with the relative pressure sensors.

For testing the reaction at distant measuring points, probe 6 was connected to a 100 m tube with a diameter of 2.7 mm. The longer the measuring tube and the smaller the diameter, the slower is the reaction time. The time constant is a measure for defining the reaction time of

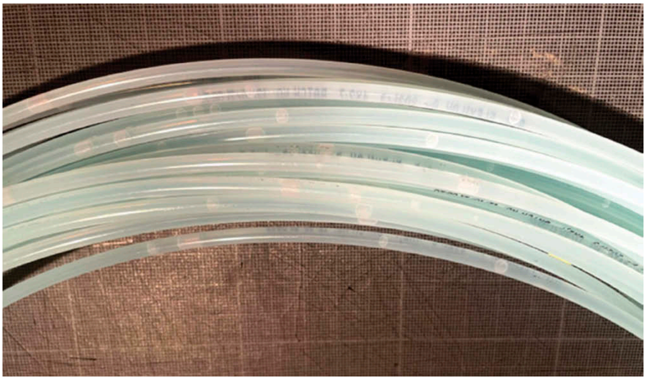

Figure 6. Liquid tube 2 days after first filling. Many bubbles were formed in the liquid during 2 days.

a measurement. It is defined as the elapsed time to reach 1/e = 36.8% of the final value of the step. For the 100 m tube, the measured time constant was 3.8 seconds.

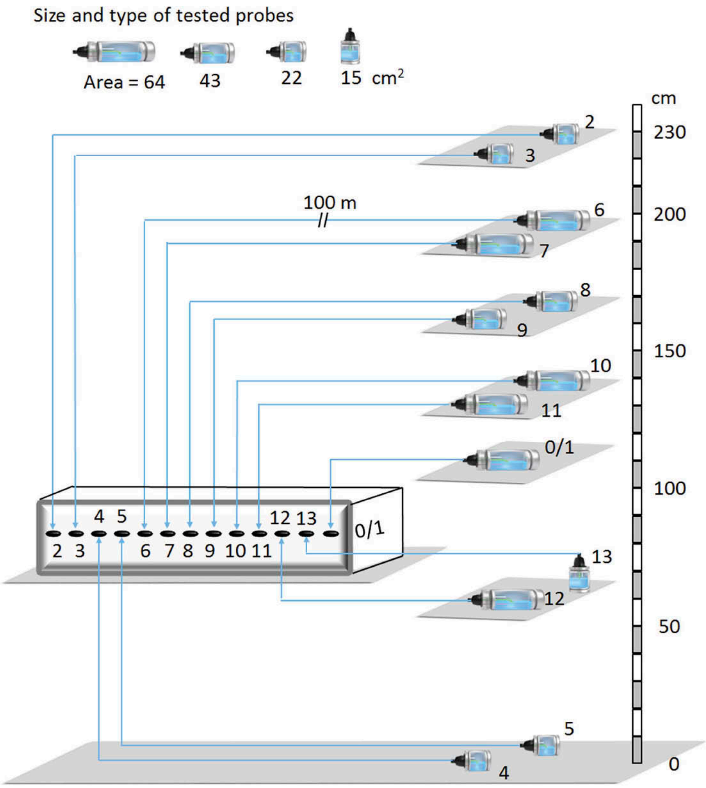

Figure 7. Test setup in the laboratory with probe levels from 0 cm to plus 230 cm.

4 APPLICATIONS

Siliceous limestone is mined in the Zingel quarry, near the town of Schwyz (central Switzerland). As part of the early excavations, a large hole was created that seemed ideally suited as a landfill (Figure 8). In 1997, a project plan for the storage of refuse slag was elaborated. In the rear area of the quarry siliceous limestone would still be mined and the material would be transported through the landfill body via a tunnel on a conveyor belt. The project was approved.

Figure 8. The Zingel quarry. The marked part of the early excavation was to be filled with waste slag, while siliceous limestone is still being mined in the rear part (Lumpert ZKRI, 2000).

As the nature reserve of Lake Lauerz is located in the immediate vicinity, eight inclinometer monitoring tubes were installed to monitor settlements below the landfill sealing. The tubes are accessible from the conveyor tunnel for the measurements. The objective was to record any subsidence of the landfill base due to further replenishment. The aim was to estimate the risk of cracking and leakage of the base barrier.

Since the zero measurements from the year 1996, the landfill has been monitored for over a period of 10 years using commercially available hydrostatic measuring systems and horizontal inclinometers. Due to the contradictory measurement results of the two systems, the person responsible for the landfill started looking for an alternative. He found the solution at the ETH. He decided to use the LAS-Meter.

The first measurements with the LAS-Meter were successfully carried out in 2010. In 2021, another measurement was carried out using GRIMONIT. The measurements with GRIMONIT were significantly less time-consuming as described in chapter three, because the filling and calibration were carried out automatically. GRIMONIT eliminates the maintenance work required with the LAS-Meter and the time-consuming troubleshooting in the event of air inclusions in the system. The control unit, all pumps, valves, and the reservoir are compactly housed in a central unit (chrome steel box Figure 9).

Figure 9. Deformation measurement of the landfill base in the Zingel landfill with GRIMONIT. A sliding rod is used to place the probe into the inclinometer tubes in meter increments. The pressure signal is transmitted via the 50 m long pipe drum. The differential pressure between the probe in the inclinometer tube and the moving reference probe is used to calculate the course of the inclinometer tube.

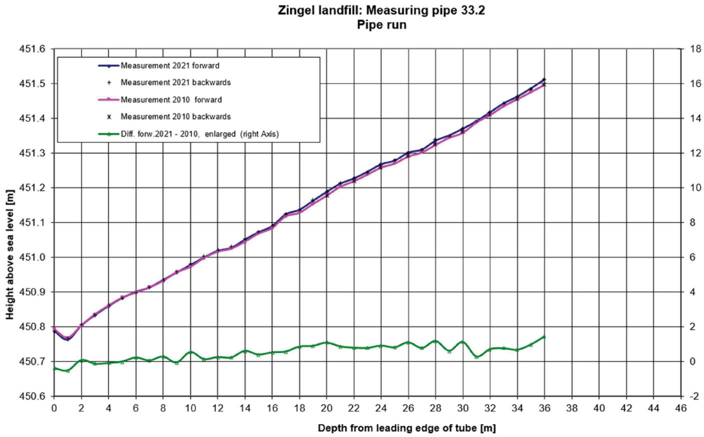

Figure 10. Measurement results from inclinometer tube 33.2, red line: forward and backward measurement 2010, blue line 2021, green line: difference of the two measurements, right scale.

5 CONCLUSION AND OUTLOOK

The 2021 measurement performed with GRIMONIT required a small fraction of the in-situ maintenance time needed in 2010 with the LAS-Meter. With the LAS-Metersystem, all pumps and valves had to be operated manually and it was necessary to wait a long time in the underground until the tubes were clear of air bubbles. However, in 2021, with GRIMONIT the work effort at the quarry was limited to the on-site setup of the system. Time-consuming venting could be conveniently triggered via a remote connection (Internet) at the push of a button.

Similarly, the time required in other fields of applications is shortened. In landslide areas, for example, with several measuring points, only the setting of the measuring probes and the installation of the supply lines are required. All other work steps, such as filling, venting, and calibrating, are performed by GRIMONIT. Once installed, all functions can be controlled and monitored in real time, from the office, via the Internet.

Another advantage of GRIMONIT is the flexibility to use the central measuring unit both continuously and periodically. For an initial hazard assessment, it is usually recommended to leave the GRIMONIT on site and measure continuously. Later on, it can be sufficient to measure after longer time periods as at the Zingel quarry. But inclinometer tubes are not available at every location. It is also possible to install the measuring probes and tubes and leave them permanently at the measuring points, while the GRIMONIT-System is connected later and removed again after performing the measurements.

GRIMONIT succeeds in recording deformations independent of weather conditions; it can also be used in underground mining or in agriculture for estimating soil resilience to compaction due to trafficking with heavy machines. This results in numerous new application possibilities that are waiting to be exploited.

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), and our five industrial partners, GRIMONIT is now available as a versatile and flexible early warning measurement system for vertical movements.

What we are looking to now, is to extend the long-term field experience. The measuring probes tested so far are constructed with Plexiglass, so that the liquid level can be visually checked at any time. In a final, robust version, the probes will be made of metal and the tubes will be appropriately protected to suit the environmental conditions. For this purpose, it makes sense to cooperate with high-voltage cable builders who already have a lot of experience in underground cable installation. In addition, the components installed in GRIMONIT and the control system software can be optimized to reduce energy consumption.

Therefore, interested collaboration partners who are willing to help with practical application and further development are welcome.

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