Innovative approaches for deformation monitoring

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The potential of tiltmeters as a low-cost technology in baseline ground movement monitoring

Geothermal energy has received increasing attention in recent decades due to the net-zero emission targets. However, the impact of energy technologies that utilise the subsurface, lacks systematic understanding still. Such an impact is potential ground motion at the surface due to changes (thermal, chemical, pressure) induced at depth. Precise monitoring data and appropriate analysis methods could help on this. This study is part of a wider project on the use of abandoned underground coal mines for energy storage. Here, we test the potential of tiltmeters as a low-cost monitoring system, in providing information on tiny movements of the ground surface that could be used as baseline ground movement for areas that are relatively flat and without any known ground instabilities. We discuss our observations after a full year of measurements, the challenges faced in the analysis of data, mainly due to the effect of temperature on the measurements, and provide considerations on aspects of the monitoring design for similar applications.

Keywords: Ground movement, Tiltmeters, Temperature drift, Time-lag

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Determination of the coordinates of a circle using distributed fibre-optic length changes

Distributed fiber optic sensors (DFOS) are used to determine the deformation of engineering structures (objects). This measurement method analyzes changes in the backscatter signal along a fiber in order to determine changes in length and/or temperature. Various analytical and setup procedures make it possible to separate thermal and mechanical influences affecting the fiber. The geometric object changes can be directly derived as strain. The information of strain is not sufficient for a number of object state descriptions, so that further variables, such as inclinations, curvatures and coordinates, must be derived. In order to determine these variables, several fibers are often installed in a suitable geometric arrangement along the

deformation directions. For example, a curvature can be determined from two fibers running parallel at a known distance. Deriving coordinates from curvatures or other intermediate values is much more complex and uncertain. This work focuses on the derivation of coordinates and coordinate changes for circular or elliptical objects (e.g. boreholes, tunnels or shafts) by means of length change measurements. Two approaches are evaluated in which some of the geometric constraints can be controlled. On the one hand, a popular approach using an adjustment of local circles is evaluated. On the other hand, an approach based on divided lines and a line network adjustment is developed. A highly precise test data set is created for the development and evaluation of the methods. The test dataset consists of DFOS, laser tracker and photogrammetric measurements of a test object in different deformation states.

Keywords: Distributed fiber optic sensors, Deformation monitoring, Adjustment calculation

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F.-B. Cartiaux, J. Semiao, A. Mege-Ythier

Deformation monitoring and model updating: three case studies on the Paris Metro

The Paris Metro is among the densest and most extensive public transportation networks in the world. It comprises several kilometers of viaducts, with some of them dating back to the very beginning of the 20th century. These exceptional assets combine the problematics of highly strategical infrastructure, very frequently loaded civil works, and heritage buildings all together. Thus, their management involves innovative assessment methods. Structural Health Monitoring (SHM) by means of deformation measurements contributes to this management and has been frequently applied to the viaducts in the last years, in combination with advanced modeling of the structures. Three practical case studies are presented. The relative displacement of a bearing device, because of the temperature variations on one viaduct, has been monitored for one year, and the measurements have been used to quantify precisely the frictional behavior of the device, through optimization methods applied to a strongly non-linear model. To assess the effect of an upgrade of the rolling stock, a one-kilometer portion of viaduct comprising 42 spans has been monitored with continuous strain measurements. The model updating, based on the results of load testing, enabled

the precise determination of the real effect of the trains braking. The Austerlitz Viaduct over the river Seine is one of the most iconic civil works of the network. It has been continuously monitored since 2010 with a set of optical strand strain sensors. Massive data analysis tools have been developed to process the measurements.

Keywords: Structural Health Monitoring, Model updating, Data analysis, Asset management, Civil infrastructure

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P. Krnjak, A. Kosor, H. Tomić, A. Marendić, R. Paar

Comparative Analysis of Achieved Accuracy Using Low-Cost Mobile Phone LiDAR and Remote Sensing Techniques

The technological development of measurement technologies and associated sensors has transformed geodetic surveying methods. Contemporary geodetic techniques are efficient and reliable, employing a variety of passive and active sensors. This frequently results in the creation of new products, such as point clouds, meshes, textured meshes, digital surface models, and orthophotos, whose application sometimes necessitates adapting existing data formats or developing new ones and/or standards. In engineering geodesy, it is essential to evaluate whether a specific measurement technology meets the required precision and accuracy standards. Unmanned Aerial Vehicles (UAVs) equipped with imaging sensors are now frequently used for a wide range of surveying tasks, using a digital photogrammetric method. With recent advancements in sensor technology, systems with LiDAR 3D laser scanners are now available on smaller and relatively affordable UAVs. Recently, mobile phones have also been equipped with LiDAR sensors which are cost-effective solutions for various groundbased geodetic measurements and tasks. Terrestrial Laser Scanners (TLS) are a type of 3D scanning technology that provides exceptional precision and efficiency, widely utilized to capture large-scale environments in 3D. This paper explores the application possibilities of various methods for surveying, detecting geometric changes of measured objects from the point clouds in different epochs and calculating the volume of embankments, excavations, and other similar projects. The survey of the embankment dam will be performed using a low-cost mobile device equipped with a LiDAR sensor. Also, the same embankment dam will be measured by remote sensing techniques using a laser scanner and UAV. This way the analysis of achievable accuracy using

all mentioned methods will be done. This paper analyses the advantages and disadvantages of the applied survey methods and evaluates their suitability based on achievable accuracy for various surveying tasks.

Keywords: Low-Cost LiDAR, Mobile Phone, Quality Analysis, TLS, UAV
