First experience with the newly created monitoring system of dynamics of surface changes occurring during the transition into the post-mining stage

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ABSTRACT: The study of the manifestations of mining cannot be done without a technology that allows monitoring the dynamics of surface changes. The Automatic Geodetic Monitoring System was developed to obtain measurement data on surface movements at the CSM coal mine. This system will provide data of sufficient frequency and quality to evaluate the surface deformations caused by deep mining. Long-term monitoring will generate a dataset suitable for developing a method for assessing the consequences of mining after mine closure.

The monitoring system consists of two automatic total stations with an integrated 3D laser scanner, GNSS sensors and other accessories. The monitoring period was set to cover, at least in part, the main phase of surface movements caused by underground mining and their subsequent fading in time. However, it is important to note that measured data accuracy can be affected by various adverse factors, prompting ongoing enhancements to the monitoring system.

Keywords: subsidence, MultiStation, monitoring, hard coal, mining, post-mining.

1 INTRODUCTION

Mining activities have significant impacts on the surface, both during and after mining operations. To understand and assess these effects, it is crucial to have a key technology that enables monitoring of surface changes. In this regard, the Automatic Geodetic Monitoring System has been designed to gather precise periodical measurements of surface movements caused by deep underground mining.

This article presents the concept, technical implementation, and initial experiences with the newly created monitoring system at the CSM mine, which is the last active hard coal mine in the Czech Republic. The monitoring period was strategically determined to capture the main phase of surface movements during underground mining and the subsequent fading of these movements over an estimated period of approximately five years.

The implementation of the monitoring system involves various technical solutions, including the stabilization of monitoring system components, selection and placement of monitored elements, and data processing. The trial operation of the monitoring system commenced in July 2022. Based on the initial experience, additional measures are proposed to address influence by external factors such as environmental conditions, vibrations, and surface reflection, which can affect the quality of monitoring.

1.1 Purpose of Measurement

The purpose of long-term research on subsidence depressions is to understand the dynamics of surface changes within areas affected by underground mining activities. This research requires direct measurements of surface point displacements, which can be a time-consuming process. To effectively monitor these dynamics, frequent surface measurements are necessary.

Interestingly, during the formation of subsidence basins, anomalous phenomena such as short-term surface uplift can occur (Jiránková & Lazecký 2022). The occurrence of these phenomena depends on site-specific conditions and can reach even the first tens of centimeters. However, due to their short occurrence (weeks), they are often undetectable in the standard geodetic practice of semi-annual measurements.

To address the challenge of obtaining an adequate amount of data, we have explored innovative solutions to enhance the current practice of staged geodetic measurements for surface leveling. An ideal approach for automatic data collection is a measurement system that continuously tracks the position and altitude of surveyed surface points, commonly used in open pit mining. However, monitoring areas affected by deep mining present unique challenges. It is no longer possible to assume that any part of the surface remains stable, even in areas protected by shaft protection pillars. This makes the use of automatic geodetic monitoring in undermined areas unique. However, it is important to consider these limitations when processing the measurement data.

1.2 Description of the Site

The CSM mine, operated by company OKD, a. s., serves as the only suitable location for actively studying the dynamics of formed subsidence depressions. As the sole hard coal producer in the Czech Republic, OKD conducts mining operations in the southern part of the Upper Silesian coal basin, specifically in the eastern part of the Karvina coalfield. Situated in Stonava town, the CSM mine represents the last active mine in the Czech Republic. The mine site is divided into two sections, namely North and South, each equipped with intake and return-air ventilation shafts.

While the coal mining history in the Ostrava-Karvina region spans over 200 years, the CSM mine has a comparatively shorter history. In the 1950s, a borehole was drilled, confirming the presence of all coal bearing carboniferous strata. Subsequently, based on these findings, the decision was made to establish the mining area and construct the mine. However, due to complex hydrogeological and gas conditions, actual coal mining could only commence in 1968.

Coal extraction at the CSM mine employs a combination of shaft and horizontal roadways systems. Deep mining takes place under challenging geological conditions, traversing multiple strata that extend several hundred meters deep, reaching as far as -1103 meters (CSM South intake-air shaft). The coal deposits belong to the Paleozoic (Carboniferous) era and are mined within coal-bearing strata. The thickness of the seams within the CSM mine varies between 1 and 6.5 meters.

Due to the thickness of the coal seams and geological complexities, mechanized coal mining methods have been adopted. The primary technique employed is longwall mining, utilizing shearers and shield sets. Road-headers are predominantly used for corridor development, with less reliance on blasting and other methods.

The anticipated date for coal production termination at the CSM mine has undergone recent revisions. Presently, mining operations are scheduled to conclude in 2025. As the region enters its final stage of mining, this represents the last opportunity to monitor the actual effects of ongoing mining activities on the surface. The specification of the monitoring range was based on the mining plan, surface characteristics, and monitoring system parameters. It is expected that monitoring will continue throughout the subsequent phase of mining attenuation and the transition into the post-mining phase.

2 AUTOMATIC GEODETIC MONITORING SYSTEM

The accuracy of measured values serves as a crucial factor in selecting a surface measurement method. Surface movements during the primary phase of mining activities range from several centimeters to decimeters per month. As surface movements enter the phase of fading out of subsidence, the accuracy requirements for measured values increase significantly. The determination of stable areas relies on the precision of movement measurements derived from the collected variables. To meet these needs, the automatic monitoring concept employs high-precision instruments currently available in the market.

The newly designed Automatic Geodetic Monitoring System is installed atop the roofs of the CSM North and CSM South skip towers. These towers are slender reinforced concrete structures, standing several dozen meters high, and form the visible part of the mining shafts, safeguarded by protective pillars. The protective pillar defines a specific portion of the rock mass, protecting the mining shaft from the impacts of mining activities. The monitoring system's base on each skip tower comprises a MultiStation, a GNSS sensor, and additional instruments and accessories.

The MultiStations provide automatic geodetic monitoring of the undermined surface area of interest by targeting reflective system elements located within the surveyed area. Additionally, terrestrial 3D laser scanning of selected surface areas is performed (see Fig. 1). GNSS sensors ensure continuous position monitoring and are used to automatically correct the position of each MultiStation. This ensures that the position and elevation are known during each monitoring process. A stabilized network of points within the affected area forms a line observation station, enabling the analysis of monitored data based on independent geodetic measurements.

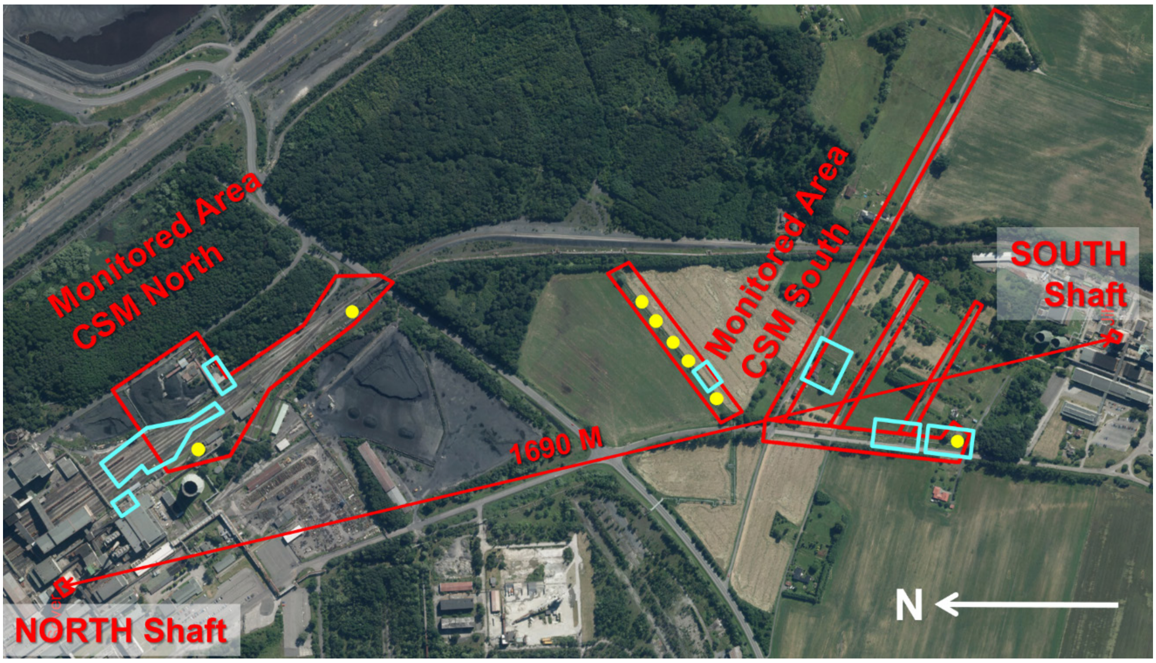

Figure 1. Summary view of the monitored area – reflecting system prisms (yellow), scanned areas (cyan).

2.1 Hardware Components

An identical monitoring set is deployed on both skip towers (see Fig. 2). The design of this set is well-suited for permanent outdoor installation.

The Automatic Geodetic Monitoring System consists of several key hardware components, which can be categorized as follows:

Figure 2. Monitoring set of Automatic Geodetic Monitoring System (CSM South).

Main active components

- **Leica Nova MS60 MultiStation**: This high-accuracy automatic total station enables various types of geodetic measurements. It performs point measurements of angles and distances using reflecting prisms and conducts terrestrial 3D laser scanning of specific objects and surface areas. The MS60 can operate manually (in the field) or in continuous automated mode. It excels in angle and length measurements, with a standard deviation of 1" (0.3 mgon) for angles, 1 mm + 1.5 ppm for length measurements with a prism, and 1.0 mm at 50 m for surface scans in 1000 Hz mode. Accuracy analysis determined a precision of 3.9 mm when targeting reflective prisms and 14 mm by surface scanning.
- **Leica GMX910**: This passive GNSS receiver tracks position changes of the MultiStation. It supports multi-frequency signals from GPS, GLONASS, Galileo, and BeiDou positioning systems. The chosen solution allows real-time position determination and periodic post-processing using corrections and data from the reference station network.

Passive components

- **Leica GPR1 Reflective Prisms**: These prisms are used to obtain current angles and distances between the permanent positions of monitoring sets on each skip tower.
- **Custom-Made Stainless Steel Support Structure**: This structure ensures the proper stabilization and alignment of the MS60, GPR1, and GMX910 on the roof of the skip tower and their alignment on a common vertical axis.

Control components

- **Server Computer**: A Windows Server 2022 Standard system hosts the service software of the monitoring system. Communication occurs through the mining company's intranet, with remote access available via Remote Desktop Connection. The server computer is located in the IT room of the CSM North office building.
- **Leica ComGate20**: A universal modem that facilitates communication with the active parts of the monitoring system and enables data transmission to the server computer.
- **External Power Sources**: 12V or 48V power sources supply electricity to all components requiring power in the Automatic Geodetic Monitoring System.

A universal control modem for communications and external power sources is housed in an enclosure (Rittal system) on the wall below the monitoring unit.

Additional components

- **TP-Meteosensors**: These sensors measure atmospheric temperature and pressure to make physical corrections for length measurements obtained by the MS60.
- **Hikvision Safety Cameras**: Cams are deployed in pairs on a support console on each skip tower. One is still watching the monitoring set, and the other, pointed at the landscape, allows to check weather conditions.
- **Reflective System Monitoring Prisms**: Large- and mini-diameter prisms are strategically placed at selected positions within the study area, easily acquirable from either MultiStation position.

2.2 Service Software

All utility software of active components of the monitoring system is installed on the aforementioned server computer and consists of the following applications:

- **GNSS Spider**: This software is responsible for controlling and communicating with the GNSS sensors. It also incorporates the implementation of corrections from the network of reference stations, in this instance from the JASZ reference station located in Poland.
- **Leica GeoMoS Monitor**: This application provides control, communication, configuration, and data collection from all the sensors involved in the monitoring process. It ensures seamless integration and management of the monitoring system.
- **Leica GeoMoS Now!**: This web service enables users to access the monitoring results. It serves as a platform for sharing and presenting the collected data in a user-friendly manner.
- **Leica Infinity**: This software is utilized for post-processing the outputs of laser scanning, specifically the point clouds generated by the system. It enables detailed analysis and manipulation of the laser scan data.

3 OPERATION OF THE MONITORING SYSTEM

3.1 Installation and Start-up Process

The installation and commissioning of the Automatic Geodetic Monitoring System took place between June and July 2022. During the installation, specific sub-areas of periodical scanning were defined to monitor the surface. These areas are regularly adjusted and expanded based on the knowledge gained from continuous monitoring. A measurement base of the reflective system elements was also established. The positions of all reflective prisms are measured periodically at hourly intervals.

The monitoring system is primarily managed remotely using the utility software installed on the server computer. However, occasional on-site visits are necessary for tasks such as equipment inspection, cleaning, and adjustments.

3.2 Influence of Specific Conditions

The application of automatic geodetic monitoring in the unique conditions of the undermined area requires careful consideration of data processing. It has been observed that the recorded movements of the monitoring locations on the skip towers, which reflect the surface movements in the monitored area, are not solely influenced by mining activities. The operation of the mine lift equipment itself also contributes to these movements, manifesting as vibrations in the direction of the lift traction rotation. The overlapping of these vibrations with the measurement time can introduce errors in the results. Filtering the measured data based on records of the mine lift equipment activity is one approach to address this issue.

Strong wind is another factor that can affect the movement of the upper parts of the skip towers. Filtering the data solely based on mine lift equipment records may not be sufficient in such cases. To enhance the monitoring capabilities, the Automatic Geodetic Monitoring System is being expanded with **Inclination Sensors** from Statotest company. These sensors enable continuous recording of oscillation velocity and inclination angles of the skip towers at the monitoring system positions.

Further steps involve the calibration of dynamometric measurements using the **Ground-Based Real Aperture Radar** method (GB-RAR) (Talich et al. 2021). It should provide with a detailed description of skip tower structure motions with an accuracy of one-hundredth of a millimeter. This calibration aims to establish an objective criterion for eliminating measurement results affected by errors caused by the aforementioned factors.

Additionally, plans are underway to stabilize a set of **passive corner reflectors** in the area of interest. These reflectors will be utilized in the processing of surface displacements using the **Satellite Radar Interferometry** method (InSAR), as described in the work by Lazecký et al. (2017). This method will provide valuable insights into surface movements and further enhance the monitoring capabilities of the system.

4 SUMMARY

The implementation of the Automatic Geodetic Monitoring System has provided valuable insights into the movement of monitored elements in the undermined area under study. Through continuous monitoring, we can compare theoretical assumptions about surface dynamics with real data. However, it is important to acknowledge that the measured data may be influenced by errors caused by various factors, such as vibrations from the operation of mine lift equipment, strong wind, etc. To address this, further enhancements to the monitoring system are necessary. Recent additions to the monitoring system include accelerometers placed on the roofs of the skip towers to monitor oscillation velocity. These variables will be correlated with skip tower movements determined by the ground radar interferometry method.

Our future focus will center around a comprehensive study of the dynamics of subsidence basins, with a particular emphasis on the phase of the gradual fading out of mining effects on the surface once mining operations have ceased. We also aim to develop a methodology for categorizing areas based on the extent of deep mining impacts during the post-mining period. Additionally, we plan to contribute to the advancement of the sensor system and the design of an expert system that incorporates data processing technologies, spatial analyses, and error detection. Last but not least, efforts will be made to develop a method for predicting surface displacements during mine flooding. Overall, our goal is to continually improve the monitoring system and its capabilities to enhance our understanding of the effects of mining activities on the surface.

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