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Observation Method in the Control of Stacker Capacity Under Landslide Hazard – A Case Study

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Abstract: The article presents both an application and the purpose of the observation method in the control of stacker capacity. It lists the types of the measured (observed) quantities, which serve as a basis for the observation method. It also describes the procedure of the method and discusses its individual steps. It further provides examples of applying the method in defining the capacity levels of a stacking machine ZGOT-11500, based on the recorded surface and subsurface soil displacement values. The article also offers the increment values and speeds for the individual parameters, which serve as a warning against deterioration of the geotechnical condition of the soil. Knowledge of the relationships between the parameters that describe soil deformation and the required defined stacker capacity may serve as a basis for further research and experiments on the observation method, which may increase the safety of stacking operations. The analysis was based on the results of geotechnical and geodetic measurements, as well as on the operating parameters of the stacker, acquired over a period of 5 months.

Keywords: open-cast mine; mine spoils; observation method; geotechnical hazard.

1 Introduction

The observation method that is used in the control of stacker capacity under landslide hazards is a method of early warning against geotechnical threats. The method consists in the regulation of stacker capacity on the basis of the analyzed measurement data obtained from the elements of the geotechnical monitoring system and from *in situ* observations which provide information on the behavior of the soil. The method is applied to use this information on the behavior of the soil medium in a decision-making process aimed at an efficient and safe stacker operation.

For the observation method to be used effectively, the mining and geological conditions in the mining facility must be well known and the methods and criteria for the evaluation of the current geotechnical situation must be defined. For this reason, the method can be modified depending on the geology of the soil, on the applied control and measurement elements, and on prior experiences. Investigations of natural phenomena with the use of geotechnical monitoring systems are an important element of risk management (Borecka et al., 2017; Gorska et al., 2013; Mazzanti, 2014; Severin et al., 2014; Carri et al., 2021). An early detection of slope deformations which may lead to slope failure is thus an important issue in the fields of geomechanics and geoengineering (Carla et al., 2017a, b; Minardo et al., 2021).

A hazard related to the loss of slope stability in lignite mines is a significant problem considered in the context of the majority of mining works (Masoudian et al., 2019). As a consequence, most of the large surface mining operations around the world are integrating various instruments in extensive slope monitoring programs undertaken as part of their mine performance monitoring systems (Carla et al., 2019b). In Poland, geotechnical monitoring based on the measurement and analyses of individual parameters is the most common method for evaluating current geotechnical conditions. Despite long and extensive experience, it is difficult to unequivocally indicate the values of both surface and subsurface displacements which cause the slope to be subjected to significant stability loss resulting in hazard to both people and machinery. In the majority of cases, such a deterministically assumed value cannot be globally identified, and therefore, each significant displacement increment recorded by the measuring apparatus is analyzed and evaluated individually.

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The literature typically mentions various values describing the behavior of a soil mass during slope movement (Bednarczyk, 2015, 2019). The geotechnical monitoring devices and the applied measurement methods provide results which are ambiguous and difficult to interpret, and nevertheless used as a basis to raise alarms about the condition of the slope. Therefore, the warning values and the critical values describing the behavior of the soil medium are typically determined and assumed individually and later implemented into the alarm system.

The case analyzed in this article is a complete cycle of an observation method used in a situation of an actual alarm. The analyzed decision-making procedure, which depends on sensor readings illustrating the behavior of the soil medium in time, may serve as a basis for further research into the application of the observation method in other cases and in other geotechnical objects. It provides practical information regarding preventive means implemented against landslides occurring in the vicinity of the stacker.

2 Description of the observational method

The observation method is one of the most popular research and design techniques applied in geotechnical engineering and is used, inter alia, to stabilize the Leaning Tower of Pisa (Burland et al., 2009), to control the influence of the Beauregard landslide on the concrete dam in the Aosta Valley (Barla et al., 2010), to monitor changes in the angle of inclination of the roof strata in the Polkowice-Sieroszowice underground copper mine (Stolecki & Szczerbiński, 2022), as well as to monitor the Zelazny Most tailings pond (Jamiolkowski, 2014). It is based on three important principles: observation, gathering information, and analysis and interpretation of the gathered information (Peck, 1969). The method is most effective in the case when a wide range of uncertainty exists in relation, inter alia, to the geological and hydrogeological conditions or to the drainage of individual soil layers (Patel, 2012). Geotechnical observations rapidly developed in the 1990s and in the early 2000s as a result of a technological evolution in the field of geotechnical monitoring (Spross & Johansson, 2017).

An adjusted observation method is frequently used in surface mining for controlling the overburden dumping process and as an aid in the decision-making processes regarding the operation of stacking machines. It is based on the data provided by geotechnical monitoring systems and the information obtained from *in situ* observations. It consists in observing the measurement results of individual values characterizing the behavior of a soil medium and in evaluating the current geotechnical condition. The conclusions allow appropriate decisions to be made in order to ensure the safe operation of mining machinery. In surface mines, unlike in the classical observation method described by Peck (1969), observations lead to preventive actions taken to protect the stacking machine.

Currently, it is an accepted method for the verification of limit states (Mazzanti, 2012), and therefore, it can be successfully employed in preventing landslide hazards or in minimizing the losses due to a geodynamic event.

The observation method comprises six stages, which are the following:

2.0.1 Evaluation of mining and geological conditions

At this stage, the analysis covers conditions that affect the geotechnical situation in an investigated area. The aim of this analysis is to identify the geotechnical parameters and the soil properties, as well as to gather additional information about the area. Soil analysis should provide information required to describe the conditions in the deposit soil, which have an impact on the mining works and can be used as a basis to estimate the geotechnical parameters (PN-EN 1997-2:2009). This stage must include the definition of geological factors such as the presence of faults and hydrogeological conditions, for example, water content in the soil, which may significantly influence slope stability. The main tools used at this stage are laboratory analyses of undisturbed soil samples collected from the subsoil of the overburden heap. Other data used at this stage include information from geological and engineering maps, from static and dynamic probing, as well as from geophysical tests.

2.0.2 Identification of the measurement methods

In situ instruments are of key importance in geotechnical measurements (Dunnicliff, 1993). In this case, the selection of research methods depends not only on the measurement infrastructure deployed in the area, but also on the experience gained when using individual types of instruments in a particular object. The scope of the planned activities should allow for local conditions (Bednarczyk, 2012). A rational application of the observation method relies on a detailed identification of the relationships between the readings from a particular sensor and the behavior of the soil medium. In regions most prone to deformations, both surface and subsurface monitoring networks need to be developed and combined with systematic *in situ* observations (Kurpiewska et al., 2013).

The measurement methods most frequently employed in geotechnical monitoring include the following:

- subsurface displacement monitoring – measurements of displacements with the use of inclinometers or extensometers, performed manually or automatically;
- surface displacement monitoring – performed with the use of the Global Positioning System, electronic total stations, theodolites, precise leveling instruments, stadia, surface extensometers, and subsidence indicators;
- pore-water pressure monitoring – measurements of water pressure in soil pores;
- soil subsidence monitoring – terrain surface subsidence measurements on small depths, for example, at shear surface depth (Bednarczyk, 2012);
- groundwater level monitoring – groundwater table depth measurements performed with piezometers;
- aerial or terrestrial laser scanning – quick and high-resolution geodetic measurements, which allow detection of early landslide indicators by comparing sequential scans (Abellan et al., 2009);
- radar interferometry – remote sensing method for determining large-scale ground movements by comparing radar images covering the same area at different times (John, 2021);
- *in situ* observations – searching for symptoms of dangerous geodynamic phenomena, such as cracks or rockfalls, and visual inspection of changes in the terrain surface, for exmaple, crack propagation; and
- geophysical monitoring – used to control seasonal changes of ground moisture in railway embankments, based, inter alia, on electrical resistance probe (Chambers et al., 2014; Gunn et al., 2015) and Rayleigh surface seismic waves (Bergamo et al., 2016).

Also, this stage must involve the identification of such measurement locations that will be most affected by the operating stacker. In the majority of cases, a proper interpretation of the geotechnical situation requires more than one parameter to be analyzed (Mazzanti, 2017). The selected monitoring elements should be located in the area directly affected by the dumping process and in its close vicinity, so that the spatial reach of the phenomenon could be identified. Data from the locations selected on the basis of the above principle are assumed to provide, in the fastest and most accurate manner, information on the effects due to the operating stacker. This information can serve as a basis for further interpretations of the geotechnical conditions. The technological evolution in the recent years has provided several systems for the monitoring of selected geotechnical parameters, as well as for facilitating management and decision-making processes (Mazzanti, 2017). A currently used common monitoring system is based on manual measurements (Zhang and Cai, 2011), but this method may cause problems in the conditions of a surface mine, as the measurement locations are situated at great distances from each other and frequently also in places which cannot be easily reached. However, innovative automatic monitoring systems are becoming increasingly popular, and these allow improved identification of the cause-and-effect relationships, as a greater number of parameters are recorded and at a higher frequency (Segalini et al., 2019; Carri et al., 2021).

2.0.3 Identification of the warning and critical values

The alarm values are such readings from the measuring apparatus that trigger appropriate actions. Due to the diversity of geological and engineering conditions in different objects, no standard measurement values exist which would function as a criterion for a decision to reduce the capacity of the stacker. For this reason, the warning and the critical values are defined individually for each measurement location, depending on the actual situation. These values are identified empirically and are based on observations of the measurement data provided for a number of years by the *in situ* instruments. A warning value may be illustrated on an example of a 1 mm/day subsurface displacement, but the final decision will be influenced by criteria such as the depth of displacement and the character of the deformation.

2.0.4 Identification of the measurement frequency

The measurement frequency in individual measurement locations depends on a number of factors such as the size and type of an object, the number and type of the measurement locations, the measurement time for an individual element of the monitoring system, the number of measurement sets, etc.

One of the methods allowing increased measurement frequencies is to modernize the measurement locations by installing modern automatic sensors which send the results remotely, in a near real-time manner (Allasia et al., 2011). At present, automatic measuring instruments show increased reliability and have become a standard solution. Innovative automatic measuring instruments have enabled full and instantaneous verification of the results provided by the monitoring systems (Segalini et al., 2012; Minardo et al., 2021).

2.0.5 Measurement analysis

Although during the analysis of the measurement data, note is made primarily of the characteristic values recorded by the measurement apparatus, other factors are also included depending on the applied measurement method. Table 1 presents examples of characteristic data indicating a change in geotechnical conditions.

2.0.6 Making decisions regarding the operation of the stacking machine

Based on the performed analysis and the assumed evaluation criteria, appropriate measures can be taken to ensure adequate safety and optimize mining processes (Jiang & Feng, 2011; Silva et al., 2021). In order to enable appropriate actions aimed at an optimal operation of the stacking machine without deteriorating the geotechnical conditions, the readings from the measuring instruments must be compared with the critical and the warning values defined in the previous step.

In the case when the recorded measurement data exceed the critical values, the stacking operation should be immediately stopped and the machine should be evacuated to a safe location away from the region prone to the landslide. The stacker may resume its work in the area only after the geotechnical conditions stabilize and the stacking technology is modified in order to ensure greater slope stability.

In the case when the data from the monitoring system do not reach the critical values, but exceed the defined warning values, a hazard to the stability of the slope or its part occurs. In such a situation, decisions should be made to limit the stacker capacity to a certain level, depending on the degree of the hazard and the technological potential. The measurement frequency should also be increased, and the impact of the stacker on the geotechnical situation should be further observed.

If the readings from the geotechnical monitoring systems do not exceed the warning values, the operation of the stacker may be assumed not to have a significant influence on the geotechnical conditions. In such case, the stacker capacity does not need to be limited (Rybicki et al., 2019a). However, observations of the measurement data should be continued in accordance with the defined frequency.

Table 1: Examples of factors indicating the geotechnical conditions.

Type of monitoring	Geotechnical condition indicators
Subsurface displacement monitoring	Displacement value (mm)
	Displacement increment speed (mm/day)
	Deformation depth (m)
	Deformation character
Pore-water pressure monitoring	Pore-water pressure value (bar)
	Pressure increment speed (bar/day)
	Sensor installation depth (m b.g.l.)
	Temperature (°C)
Surface displacement monitoring	Horizontal displacement value (mm)
	Benchmark subsidence value (mm)
	Displacement increment speed (mm/day)
	Displacement azimuth (°)
Soil subsidence monitoring	Subsidence value (mm)
	Deformation increment speed (mm/day)
Groundwater table monitoring	Groundwater table depth (cm)
	Groundwater table depth differences in successive measurements (cm)
In situ observations	Visual changes on slope surfaces
	Rate of changes

The procedure in the observation method for the control of stacker capacity is shown schematically in Figure 1.

A similar schematic representation of the procedures involved in geotechnical monitoring, collecting large arrays of data and using them to make decisions aimed at ensuring the safety of structures was offered by Alekseev et al. (2021) in a research paper on the automatization of geotechnical monitoring in cryolithozone.

3 Application of the observation method in the Turów Lignite Mine – A case study

This section provides an example of using the observation method to control the capacity of a stacker operated at the Turów Lignite Mine. An analysis of the relationship between the operation of the stacker and the geotechnical situation in its operating area was performed in the eastern and northeastern part of the inner overburden heap, in

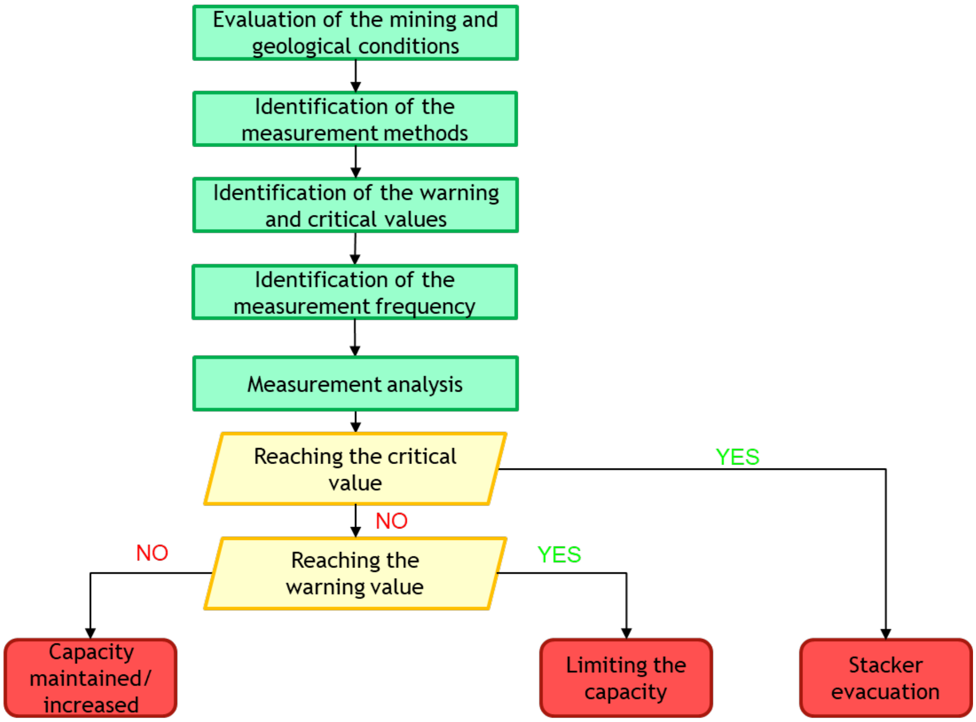

Figure 1: The procedure of the observation method for the control of stacker capacity.

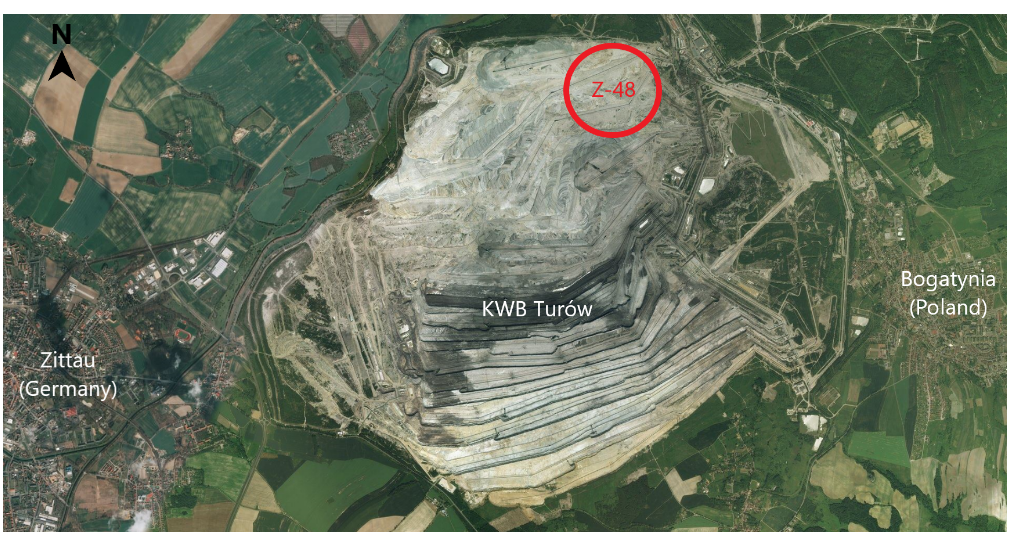

Figure 2: Operating area of stacker Z-48 in 2019 (Bing Maps).

which the stacker type ZGOT-11500, further referred to as Z-48, operated between January and August 2019.

3.1 Identification of the mining and geological conditions

The Turów Lignite Mine is a lignite surface mine in Poland having a specific geological structure and geotechnical conditions, in particular, within the inner heap. Figure 2 shows the location of the analyzed area with respect to the entire mine. The subsoil of the heap in the operating area of stacker Z-48 has a complicated geological structure and difficult geoengineering conditions. The subsoil of the heap in the analyzed region is formed of sub-lignite and inter-lignite series, mostly of clays and clay gravels. Clay soils typically have a plastic consistency and less frequently have a solid consistency.

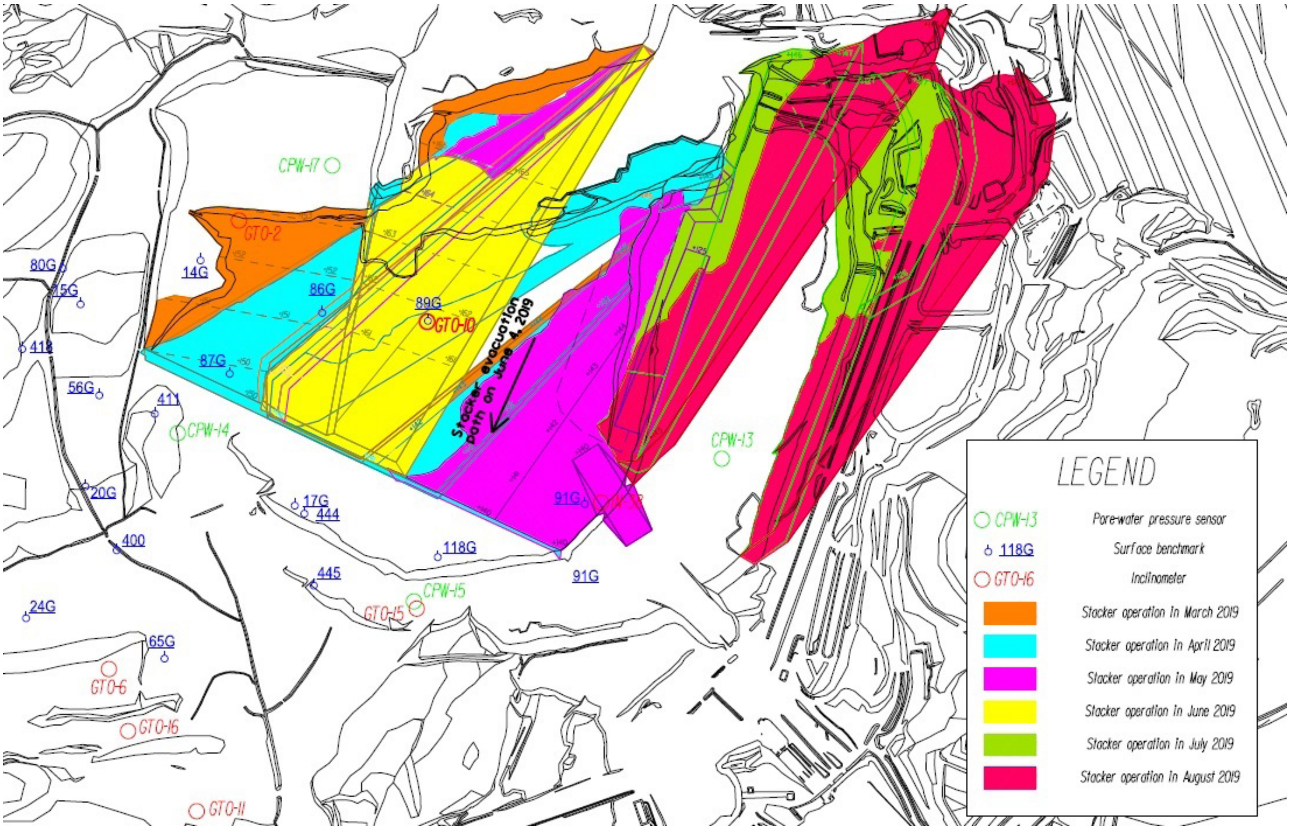

Figure 3: Operating area of stacker Z-48 with inclinometer locations.

In April 2019, laboratory examinations of undisturbed drillhole cores collected from the forefield of undisturbed soil in front of the overburden heap, in the area where the stacker operated, revealed local water-rich zones with weak water-containing clays having a consistency from plastic to liquid. Cracks and voids were also observed in the drillhole profiles, mainly near the basalt dome. Based on the laboratory examinations, the subsoil of the inner overburden heap formed in the analyzed region was identified to be weak. The stacking operations in the analyzed area are facilitated by the fact that the heap rests, on its eastern and southeastern side, against slopes made in the undisturbed body of soil. The stability of the heap is also positively influenced by the edge of the main fault, which retains the lower parts of the heap (Rybicki et al., 2019b, c).

3.2 Identification of the measurement methods

During the analyzed period, the area in question was monitored by a geotechnical and geodetic system based on the following:

- Inclinometer measurements – The subsurface displacement monitoring was performed mainly with the use of inclinometer GTO-10 located within the range of the operating stacker and also with the use of benchmarks: GTO-15 located in the southern forefield and IN-38 located in the east. The subsurface deformations were, to a lesser extent, controlled with the use of inclinometers GTO-2, GTO-6, GTO-11, and GTO-16.
- Geodetic measurements – Surface displacement monitoring was performed with automatic benchmarks (8G, 11G, 13G, 14G, 15G, 18G, 55G, 56G, and 59G) and manual benchmarks (434, 435, 437, 438, 439, 440, 444, and 445).
- Pore-water pressure measurements – Pore-water pressure was monitored with the sensors CPW-13, CPW-14, CPW-15, and CPW-17.

A decision was made that the observations would be based mainly on the results from the inclinometers. In the mining and geological conditions characteristic of the object, they offered the best representation of the relationship between the operation of the stacking

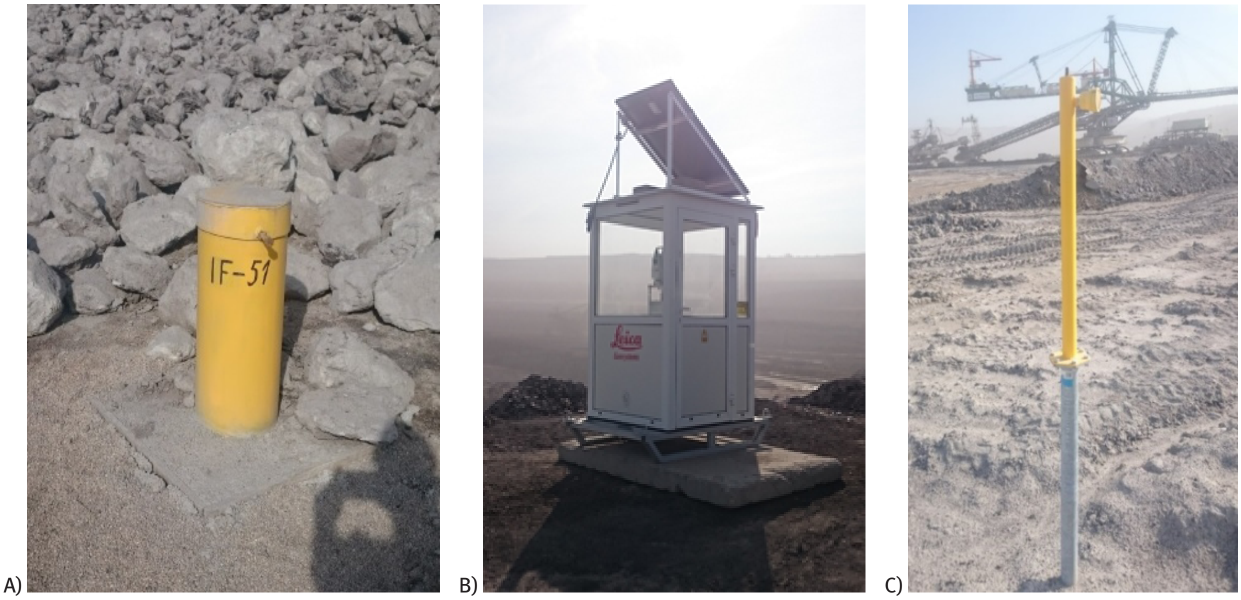

Figure 4: (A) Inclinometer, (B) box of the GeoMoS system, (C) the GeoMoS benchmark.

machine and the deformations of the soil medium. Observation of subsurface displacements is one of the basic methods used in geoengineering for identifying landslide movements and allows early detection of landslide indicators (Stiros et al., 2004). The nature of the data obtained from the inclinometers causes them to be very important for understanding both the nature of and the reasons for the behavior of the overburden heap, as well as for proposing possible preventive measures (Stark & Choi, 2008). The remaining elements of the monitoring system provided supplementary data which supported the measurements of subsurface displacements. Figure 3 shows the locations of the measurement instruments in the area of the operating stacker over successive months, and Figure 4 presents photographs of representative monitoring elements: the inclinometer, the monitoring box, and the GeoMoS benchmark.

3.3 Identification of the warning and critical values

Due to the significant role of the inclinometers in controlling the operating area of the stacker, the alarm values were set only for subsurface displacements, and they were

- warning value – 1 mm/day and
- critical value – 2 mm/day.

3.4 Identification of the measurement frequency

The original measurement frequency was defined on the basis of the Geotechnical Service Plan and was as follows:

- subsurface displacements – once per week;
- surface displacements (manual measurements) – once per 2 weeks;
- surface displacements (automatic measurements) – once per day; and
- pore-water pressure (automatic measurements) – once per day.

In further stages of the observation method, the frequency was defined individually and adjusted to current conditions.

3.5 Measurement analysis

The analysis of the measurement data for the investigated 5-month duration of the stacker operation can be divided into seven periods as follows:

Feb 26–Mar 24, 2019

Stacker Z-48 started to operate in the analyzed region in 2018 and continued with its capacity not limited. The observation method was initiated in February 2019 due to a significant increment of subsurface displacements recorded on inclinometer GTO-10 at a depth of 60 m b.g.l. –

the displacement was 4 mm over 3 days, following the 190° azimuth toward the south. The significantly increasing deformation trend observed on this inclinometer resulted in a decision to limit the capacity of stacker Z-48 to 50,000 m^3/day. The frequency of displacement monitoring on inclinometer GTO-10 was also increased.

Mar 25–May 6, 2019

On March 25, 2019, the displacement velocity observed on inclinometer GTO-10 was reduced. No other symptoms of hazardous deformations were observed in the remaining elements of the monitoring system. Therefore, a decision was made to increase the capacity of stacker Z-48 to 70,000 m^3/day and to continue the monitoring activities at an increased frequency of one observation per 2–3 days.

May 7–21, 2019

On May 7, another measurement analysis confirmed that no significant displacements occurred on all the inclinometers in the area. Observations suggested an additional small decrease of pore-water pressure and a reduced surface displacement speed. Therefore, the sub-level operation of the stacker was found not to affect the stability of the eastern part of the inner heap, and a decision was made to remove the stacker capacity limit.

May 22–June 3, 2019

Both the surface and subsurface monitoring systems did not indicate any significant deformations which could be viewed as hazardous to the stacker operation. However, on May 27, after the displacement vectors were combined for a longer period, the creep was observed to continue along the shear surfaces identified in February.

Pore-water pressure, monitored by sensors CPW-14 and CPW-17, also remained at a high level, but with a slightly decreasing tendency. Although the geotechnical situation was stabilized, the stacker capacity was set at 70,000 m^3/day due to the fact that the machine operated in a new region.

June 4–10, 2019

The analysis of the results provided by inclinometer GTO-10 on June 4 indicated significant displacements, which occurred over a period of 6 days and reached 20 mm at the +79 m level and 30 mm in the near-surface part of the column. Due to very large deformations exceeding the critical values, an immediate decision was made to withdraw the stacker to a safe location near the conveyor drive station in the southeast. The frequency of both surface and subsurface monitoring was maximized, and surveying of the region at risk was scheduled to at least twice per working shift. Further measurements on inclinometers GTO-10, GTO-15, and IN-38 were performed on a daily basis, and the results indicated displacements of as much as 20 mm/day. Readings from inclinometer GTO-10 also showed that the azimuth of the displacement direction changed from 190° to 170°, while the displacement graph from IN-38 showed creep of a 25-m-deep block layer of soil. An increase in the displacement speed observed on the benchmarks of the surface systems was also significant, albeit not as high as the one indicated on the inclinometer columns. This fact demonstrates a delayed reaction of the upper part of the soil to the load. Further analyses of the actions aimed at the observations of both surface and subsurface displacements confirmed that the decision to stop the stacking operation was correct (Rybicki et al., 2019b).

June 11–16, 2019

After a week since the increased geodynamic movements had exceeded the critical values and the stacker had been evacuated, the displacement speed decreased significantly and the reach of the phenomenon was limited only to the overburden heap formed by the stacker from June 4. Evaluations of the current geotechnical situation allowed a decision to resume the stacking operation at a capacity of 30,000 m^3/day. In order to limit the risk of damage to the machine and of landslides on multiple slopes, the stacker started the formation of the lowest level of the heap, with the aim of increasing the stability of the entire slope. This region was monitored mainly by the benchmarks GTO-15 and IN-38.

June 17–July 28, 2019

On June 17, as the dynamics of the subsurface displacements recorded on the inclinometers decreased, and as the stacker operated at the lowest heap level, the capacity limit of stacker Z-48 was removed, while still maintaining increased frequency of subsurface displacement measurements. In the case of benchmark GTO-10, displacements only occurred in its near-surface part, while GTO-15 only showed limited displacements, up to 0.5 mm/day at a depth of 50 m b.g.l, and inclinometer IN-38 did not show any deformations. Further displacements were recorded on small depths and were of a block character, which poses a lesser hazard to the general slope stability. Without further increases of the deformation trend, the regular monitoring frequency was restored after a month.

Figures 5–7 are graphs of subsurface displacements recorded over the analyzed period on inclinometers GTO-10, IN-38, and GTO-15.

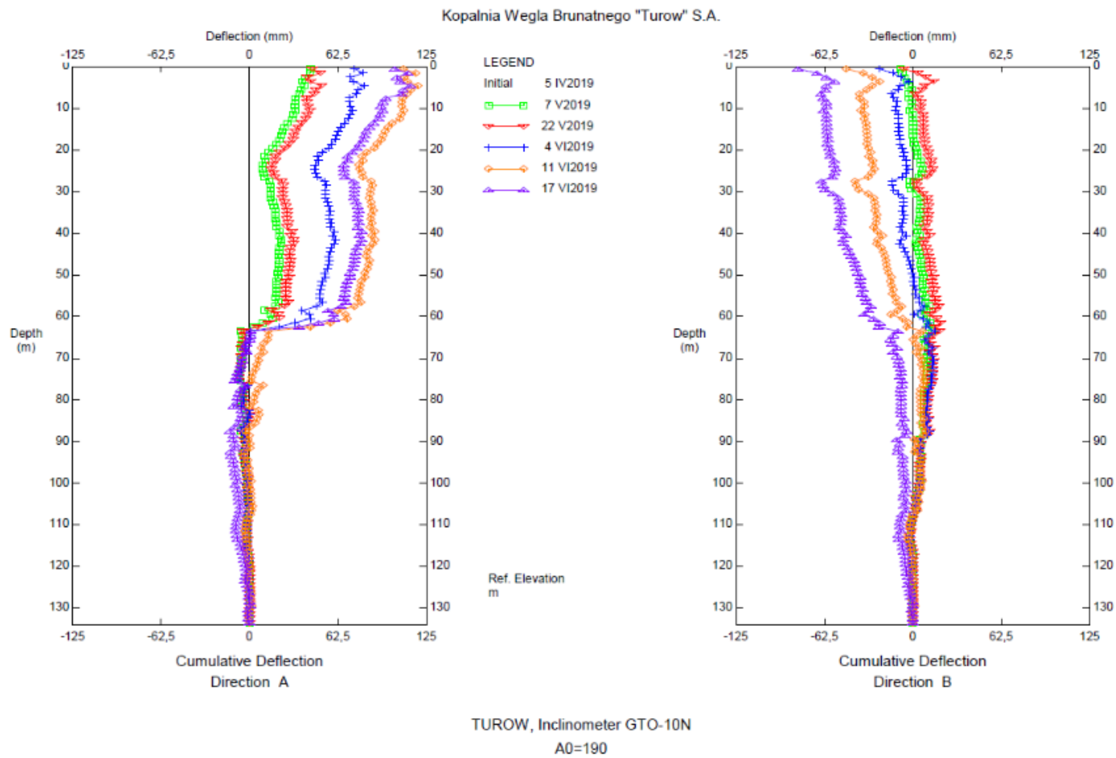

Figure 5: Subsurface displacements on inclinometer GTO-10.

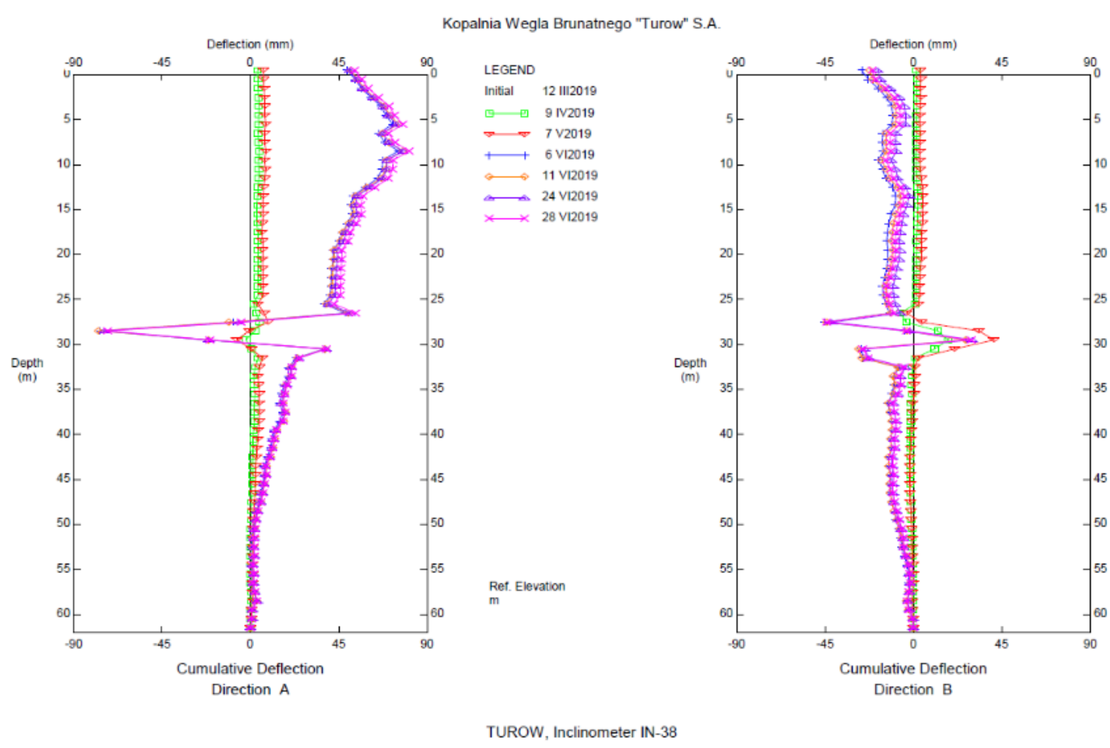

Figure 6: Subsurface displacements on inclinometer IN-38.

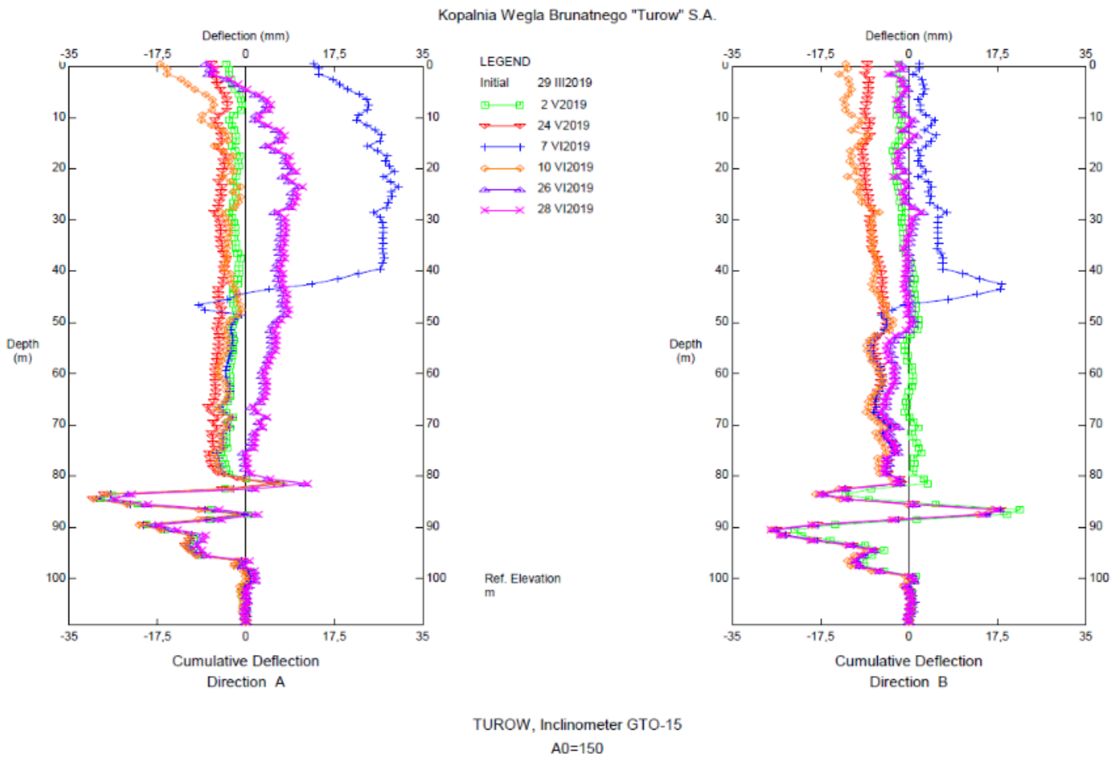

Figure 7: Subsurface displacements on inclinometer GTO-15.

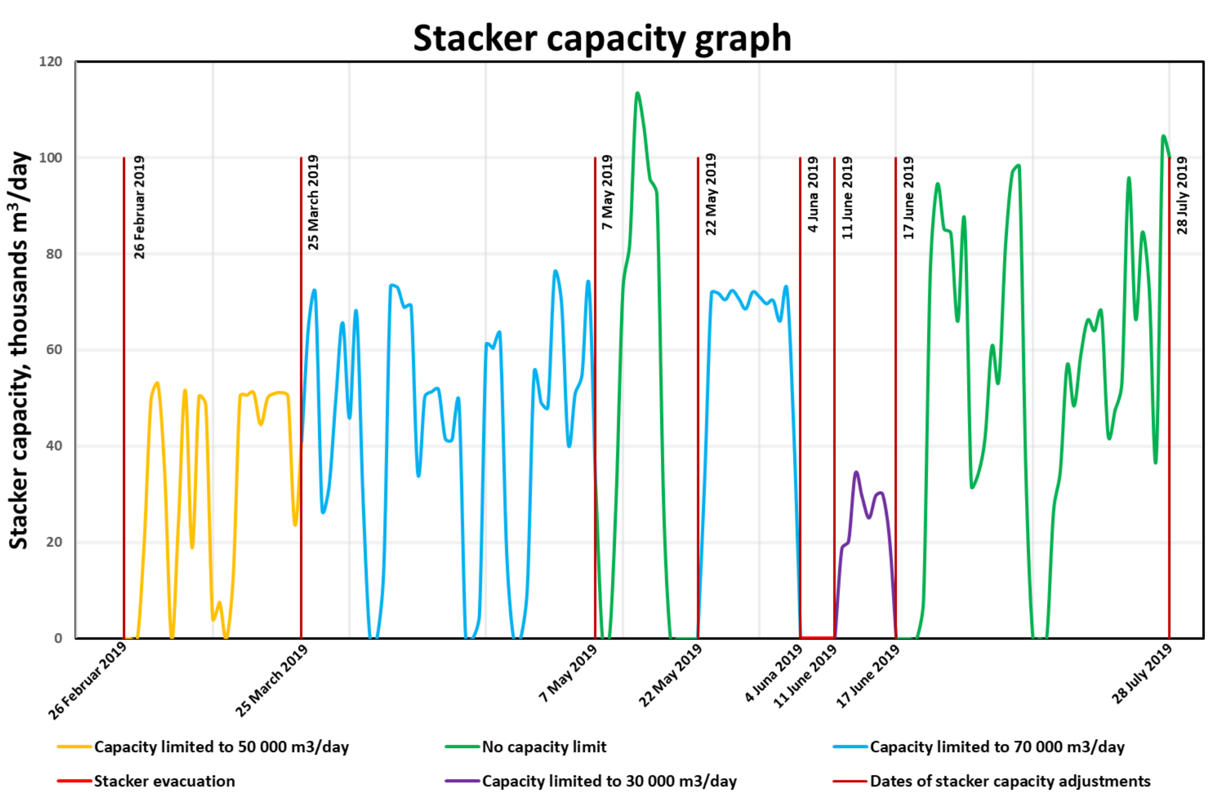

Figure 8: Capacity of stacker Z-48 over the analyzed 5-month period.

4 Effectiveness analysis of the observation method

Figure 8 shows the summarized capacities of stacker Z-48 over the analyzed implementation period of the observation method, along with the maximum capacity levels defined for this stacker.

Various monitoring techniques implemented in the mine together form a measurement database, which can be analyzed to indicate warning and critical values for alarm thresholds and, as a result, to allow systematic decisions on the technologies implemented in mineral extraction and stacking operations. Figure 8 shows that in the analyzed case, the capacity levels of the stacker changed immediately in accordance with the results provided by the analyses of the inclinometer readings (Figures 6, 7). When the displacements reached the alarm values, the capacity of the stacker was limited, for example, on June 4, 2019. A comparison of the graphs representing the subsurface displacements in Figures 6 and 7 with the graph representing the stacker capacity (Figure 8) indicates that the decisions to stop the stacker or to limit its capacity each time resulted in a decrease of the adverse deformation trend or even in the return of the inclinometer to its previous displacement rate. This fact may serve as a confirmation that the presented alarm thresholds based on the relationship between the stacker capacity and the monitored subsurface displacements were defined correctly. The implemented actions effectively prevented further propagation of the displacements, which may have caused a landslide, while ensuring that the stacker operated at the highest possible capacity.

5 Summary and conclusions

The article discusses the observation method applied to stacker capacity control, demonstrates its procedure, and describes the types of the decisions made. It also presents examples of monitoring systems, which may be used in the observations, as well as the types of the recorded values required in the evaluation of the geotechnical hazards. It offers a case study of the application of the observation method, which effectively prevented a landslide in an area prone to it.

In surface mines, analyses of the results of geotechnical measurements represent one of the methods for the continuous monitoring of the safety of mining operations. Observations of the factors which may contribute to slope failure, for example, surface and subsurface displacements, or changes in the pore-water pressure and groundwater level, allow the behavior of earth masses during stacking operations to be predicted and controlled on an ongoing basis (Silva et al., 2021).

It should be noted here that the observtion method based on measurement data analysis is prone to measurement errors and failures of the measurement apparatus, which may lead to false alarms. An unnecessary limitation or interruption of the stacker operation may delay the overburden deposition process, and thus lower the lignite output level. This, in turn, may cause significant financial losses for the mining company. These losses, however, are incomparable to the losses generated due to a landslide, which can be catastrophic in both economic and environmental terms or can even cause a threat to the health and lives of the workers.

Experiences gained when using the observation method allow the formulation of the following conclusions:

- In surface mining, one of the methods to prevent the propagation of slides on the slopes of overburden heaps is by controlling the capacity of the stacking machine. An adequate control of the stacking operations allows the displacement speed to be reduced and landslides to be prevented.
- The observation method is one of the landslide prediction methods (Bonazzo et al., 2017) and is based on readings from selected elements of the geotechnical and geodesic monitoring system. In a surface mine, it allows extraction to be performed in optimal conditions, while minimizing the hazard of slope failure in an overburden heap.
- Constant observations allow an evaluation of how the limitations imposed on stacker capacity influence the behavior of the soil medium, and as a result, they also allow further decisions and process optimizations.
- Evaluations of geotechnical conditions using the observation method are fast and of low cost, but have some limitations due to the large amount of the analyzed information. For this reason, the method should not be implemented solely with automatic tools. The entire process should be supervised by a team of experienced professionals capable of making appropriate decisions.
- Excessively low warning values may lead to false alarms and result in economic losses, whereas excessively high critical values can cause a threat to the workers and machines if an alarm situation is overlooked (Intrieri et al., 2013). For this reason, these thresholds should be estimated very carefully.
- Continuous slope-monitoring procedures employ increasingly advanced tools, for example, automatic

pore-water pressure sensors, optical fiber sensors, synthetic aperture radar interferometry (InSAR), electromagnetic induction-based deep displacement sensor, global navigation satellite systems (GNSS), and other instruments, which contribute to the constant development of geotechnical observations (Shentu et al., 2011, 2012; Silva et al., 2021; Minardo et al., 2021).

– In a surface mine, the observation method is also developed in relation to advancements in the automation of the measurement stations, which gradually replace manual monitoring systems. This process significantly improves the documentation of the observations and the analyses of changes in time (Fernandez-Steeger et al., 2015; Maddison & Smith, 2014; Ramesh, 2014; Alekseev et al., 2021). In addition, the use of automated monitoring systems allows measurements to be performed without the need to operate the measuring units in risk-prone areas (Stacey et al., 2018; Carla et al., 2018). However, it should be emphasized that such techniques cannot be used as a substitute to man-made decisions and should be used only as a supporting tool (Carri et al., 2021).

In conclusion, the analysis of data gathered from geotechnical monitoring systems may be used as a tool for adjusting the stacker capacity to current geotechnical conditions. Experiences from the application of geotechnical observation techniques in the evaluation of the behavior of earth masses indicate that the method has a significant potential for ensuring the safety of workers and machines in surface mines by limiting the risk of catastrophic failures or by limiting their results. The tests performed so far have proved the usefulness of the developed method in the process of predicting landslides.

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