Integration of thermal digital 3D model and a MASW (Multichannel Analysis of Surface Wave) as a means of improving monitoring of spoil tip stability

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Abstract. Spoil tips are anthropogenic terrain structures built of leftover (coal) mining materials. They consist mostly of slate and sandstone or mudstone but also include coal and highly explosive coal dust. Coal soil tip fires cause an irreversible degradation to the environment. Government organizations notice the potential problem of spoil tip hazard and are looking for ways of fast monitoring of their temperature and inside structure. In order to test new monitoring methods an experimental was performed in the area of spoil tip of Lubelski Węgiel „Bogdanka" S.A. A survey consisted of creating a 3D discreet thermal model. This was done in order to look for potential fire areas. MASW (Multichannel analysis of surface wave) was done in order to find potential voids within the body of a tip. Existing data was digitalized and a 3D model of object's outside and inside was produced. This article provides results of this survey and informs about advantages of such an approach.

1 Introduction

Spoil tips are anthropogenic terrain structures built of unusable rock material excavated during underground or open pit mining. Usually the term spoil tips refer to coal spoil tip. As such they consist mostly of slate and various types of sandstone or mudstone, also include coal and coal dust. Depending on the percentage amount of mentioned elements spoil tips can are susceptible to fires [5], [7].

Coal tips fires could be caused externally or internally. External cause is relatively easy to eliminate – usually during construction and revegetation those structures are closed for public access or open only to some extent. However there are still a few that belonged to closed mines and could be viewed as a constant treat. Most tip fires begin inside the structure. If a stack effect is introduced within the body of the tip air movement can induce coal dust to explode. If enough coal is located in the vicinity of the explosion it can caught on fire. Stack effect occurs when there are holes in the tip, usually vertical, chimney-like, that allowed for air to move from the outside thru spoil tip with large speed. This also provides oxygen for the fire that started inside. Depending on the size of the tip, amount and kind (age, fraction, placement etc.) of flammable material and amount of oxygen being transferred inside the speed in with the fire grows varies. It can take up to few years before signs of fires become visible as flames or smoke. In a meantime tip's stability degradation, contamination of the water etc. can occur. Stability can be so demolished that fire brigades are unable to enter the structures safely while trying to extinguish the source. Since there are usually a few sources of fire hidden inside and access to them limited stopping the fire may take years rather than weeks or days. Thus prolonging the degradation of the environment [4].

Spoil tips build currently are constructed in a way that should mitigate or a least minimalize possibility of fires. It is worth to mention that during past few years coal excavation in Poland has changed, becoming more and more effective. Nowadays lower coal seams are being excavated and there is much less leftover material containing coal. Also more emphasis is put on localisation of spoil tips. They are being constructed, if possible, further from human habitats and lakes, rivers, springs etc. The latter being important due to the fact that internal fires ware often fumed with oxygen coming from vaporising water. Rain water is being transported from the tip. Also way of stacking is planned and monitored. Machines compress the material so to avoid creating voids and waste material is mixed to minimise coal concentration.

Currently some spoil tips are undergoing monitoring process. However this is usually done in a traditional way. Responsible personnel walks the area and looks for fire, land slide or holes in the structure. In winter this survey also includes looking for places with vast vegetation or lack of snow cover. This may be unsafe for person responsible since spoil tips burn from the inside usually seem normal on the outside. Stepping on a fine cover may cause the hole to appear or poisonous gas to emerge [7,15,17].

In the view of recent spoil tips fires and landslides of tips within open pit mines some government organizations

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and mines see the potential in creating systems for constant or periodic monitoring of their geometric and thermal stability. This article provides a combined survey, thermal and geophysics method of monitoring the tip that could be implemented within mine's environmental hazards monitoring system.

2 Spoil tip of LW Bogdanka coal mine

In order to test new ways of observing coal spoil tips an experimental monitoring technique was performed in the area of spoil tip of Lubelski Węgiel „Bogdanka" S.A. hard coal mine in December of 2015. LW "Bogdanka" hard coal mine is located in the east part of Poland. Its coal deposit stretches alongside polish border and crosses to Ukraine. Bogdanka is one of the youngest polish coal mines, only underground hard coal mine and only mine excavating this deposit on polish side of the border.

Spoil tip of "Bogdanka" coal mine is supplied with two kinds of waste material. One comes from excavation process (waste rock longwall excavation method) and drilling new corridors, other from coal handling and preparation plant. In order to facilitate multiple local law regulations (national park, local govern plans etc.) during recent years a lot of work has been put into using as much waste material as possible in eco-friendly methods (landfill material, clinker brick factory etc.). This is why while an increase in waste material production has been noticed the spoil tip growth was within plans. Stored material can be devised as fallows 35 % of claystone of non or minimum cleavage with little organic matter, 20 % of dark grey shale and claystone with clear cleavage with higher content of organic matter, 20 % of grey mudstone with no cleavage, 10 % of siderite 15 % of mudstone and sandstone. Average grainsize: 40–50 % of coarse gravel (200÷20 mm), 30–40 % of sand (20–0.5 mm) and slit (less than 0.5 mm) [10].

The object covers the area of 88.56 ha, however only 76 ha is the actual tip. The rest is being used as emergency roads, drainage dich etc. The current height is between 16 and 29 metres. Planed height could be up to 90 metres. Currently most of the bulking is being performed in the east part of the tip. For the past 12 do 20 years South-West slopes have been planted with various threes in order to ensure stability [10].

3 3D and thermal survey of Bogdanka spoil tip

In order to perform a proper diagnostic of a coal spoil tip four factors need to be taken in to account: slope angle and stability, temperature on the surface of the tip (possible anomalies), interior structures (existence/lack of voids a holes). Obtaining necessary information and taking in to account tips geological structure, water conditions and its history allows for not only establishing the current state of the structure but also predicting possible dangerous changes in its stability.

During this study three surveys were performed simultaneously.

3.1 3D discreet model – Digital Terrain Model

First step of the project was to create a base – a model of the structure – that all other (thermal, geometry, geophysics) data could be tied or implemented into. In this case it was necessary to create a Digital Terrain Model (DTM) – 3D representation of a terrain's surface defined as a discreet representation of terrains height and includes and interpolation algorithm that would allow to recreate its shape [2]. In this case survey had to be done during bulking process and in the way least disturbing for maintains crew.

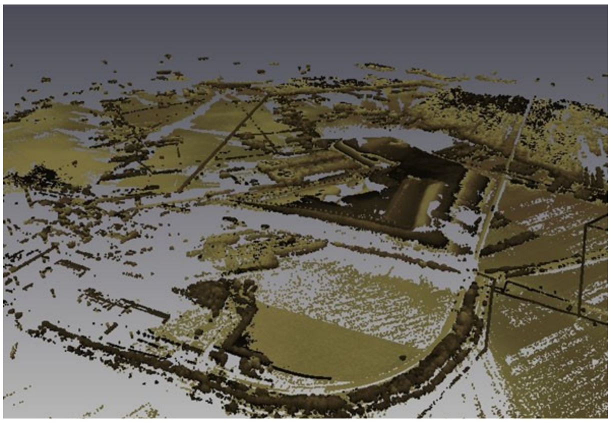

Fig. 1. Point cloud of "Bogdanka" spoil tip done with RIEGL laser scanner [10].

It was decided that the fastest way of generating a discreet model of such an object would be to use laser scanner [8]. Laser scanners are devices that allow for measuring distance and angle to numerous points of an object and estimating there placement in the local coordinates (registered) system. Later, laser scans done from separate scan station could be connected with the use of targets – natural or pre-prepared elements of known geometry. If coordinates of those elements are measured (with GPS etc.) point cloud could be transformed into global coordinates system [11].

In this case it was decided that a long range scanner should be tested [10]. This allowed the survey crew to enter the measured, potentially dangerous object only in a limited way. Five scans were performed with the use of RIEGL laser scanner (range up to 10 km). Scans were registered automatically with the use of natural elements. This also allowed for limiting access of the crew to the object (Fig. 1).

Those scans have become the base for all further survey and can be viewed as discreet Digital Terrain Model. They covered the general shape of the structure but did not give detail information on every slope. Spoil tips structure is complicated with multiple higher and lower points and various drainage diches. Also some of the transporting machines provided an obstacle for the scanner. Nevertheless this scan season provided an excellent reference model for further analysis.

3.2 Temperature of a spoil tip – Thermal Digital Terrain Model

Thermal Digital Terrain Model is a type of DTM with added information on surface temperature. In case of discreet DTM it simply means that an extra column, representing temperature is added.

There are multiple ways of obtaining value of temperature of an object. In this case a remote method had to be used due to the size of the object, time management and minimising crew presence on the tip. Remote ways include infrared cameras that detect and register the radiation in the long-infrared range of the electromagnetic spectrum. Then Stefan-Boltzmann or Planks laws that bound the heat emitted from the object with object's temperature are being used. Cameras used in thermography measure strength of emission of electromagnetic waves (that come from a certain direction). The value of temperature depends on the strength of received signal. This is called radiation flux. All objects emit a certain electromagnetic strength of long-infrared wave [16,18].

It is possible to create a Thermal DTM with the use of pictures an scans done from a plane, using standard photogrammetric method [1], [2], [3]. However the aim of this study was to create a system that could be used in all conditions and did not require any outside help. This is why a new Z+F IMAGER 5010 laser scanner equipped with T-Cam Rev 1.0 thermal camera was used. This camera is calibrated with laser scanner and provides the same geometric results as internal camera. It is possible to cover the point cloud with colours from thermal images automatically provided the usage of appropriate Z+F software. This point cloud can be later exported in to other formats and edited [9], [10].

This laser scan was performed on two, potentially most susceptible to fires and lads slides parts of the slopes. The result was 26 laser scans registered manual with the use of natural elements. Later on those scans were registered again and connected to the point cloud from RIEGL laser scanner so to create a proper 3D thermal model of the structure.

Results of such an experiment were satisfactory to some extent. There was little problem with registering the long range scans, they connected not only with the use of the elements of the spoil tip but also nearby buildings and mines chimneys were used. However registering Z+F scans has proven to be difficult due to the lack of easily identifiable elements in the vicinity. Also the range of the T-Cam Rev 1.0 camera was not satisfactory at all times. Scan stations in some cases had to be place in 10 to 20 metre distance from the edge of the spoil tip. Distance from the scanner to the top was more than 50 metres which was apparently to fair for cameras software. In most scans some thermal data was cut off thus living top parts of the tip without thermal information (point cloud existed) (Fig. 2). It is recommended to place scanner stations closer to an object in order to get more reliable thermal information. Also, in case of such object, scanner travers with stabilised scan stations of known coordinates would prove to be more effective. They would be more accurate and faster in post-processing and time of field survey would not increase significantly**.**

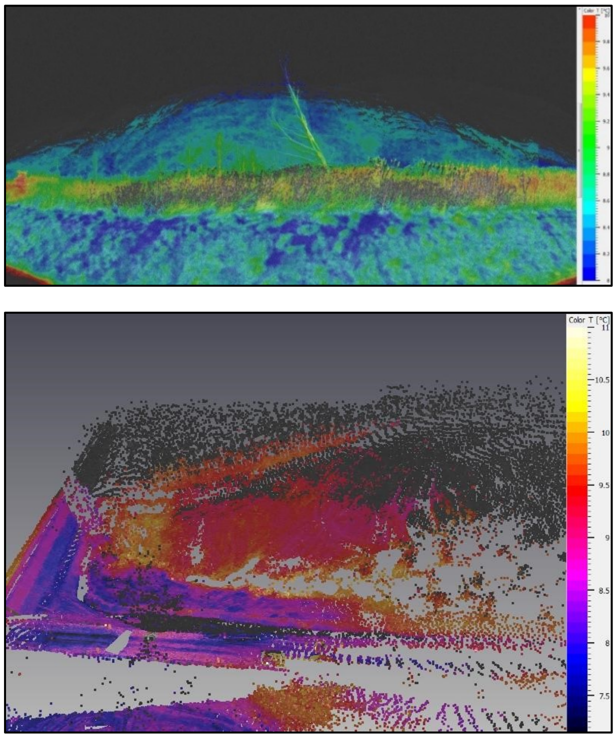

Fig. 2. Top: panorama from Z+F laser scanner with T-Cam Rev 1.0 extension. Bottom: point cloud coloured to some extend with temperature [10].

What is worth to mention that this method is relatively fast during the survey what is extremely important in thermal imaging. Changes in light, temperature of the atmosphere and even amount of water vapour can make images incomparable (if not done in the same conditions an over a short period of time). This is why such survey should take as little time as possible and presented system allows for that.

4 3D inventory of possible voids within spoil tips

None of previously presented survey methods give information on inside structure of the spoil tip. In order to fill this data gap a seismic method was used to monitor the vicinity of the object [6].

Multichannel analysis of surface waves is one of the most popular seismic method for obtaining information on the properties of the subsurface. The method requires a controlled seismic source of energy, such as hammer etc. that induces a surface wave. A properly placed set of geophones, receives generated seismic waves and measures time that waves take to travel from the source (each geophone detects them separately). If the dispersion curve of surface wave is known it is possible to set a process of seismic inversion to build up subsurface model [12], [13], [14].

The acquisition was completed with the use of ABEM seismic system with the use of 24 - 4.5 and 10 Hz geophones placed alternately. Distance between geophones was at 1 m what relates to 24 internal that correspond with 24 metre seismic deployment. At each of them a series of signals in 2 metre intervals was inducted. 7 geophone spreads and 4 response profiles were created. Seismic monitoring was done in three regions, two being flat areas on the top of the object and one on the west slope. On this area thermal monitoring was performed and no fire source or other thermal anomalies were detected. This area was treated as a base of ideally maintained area. It was used as reference area during post processing since there were no potential fire voids detected.

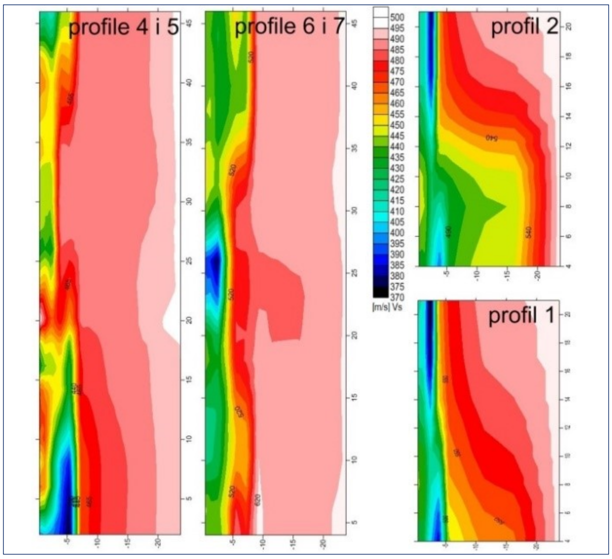

Fig. 3. Multichannel analysis of surface waves – obtained profiles.

Other spreads were placed on the top part of the spoil tip. This area was choose because it was undergoing stabilisation after few years of bulking. The profiles were placed in east-west and north-south direction. The transverse wave speed does indicate that there is a high consolidation of the stored material. During post processing inducted and passive (indicted by passing cargo trains) waves were taken in to account in order to deepen the obtained profile. Results show that material on the top of the spoil tip is less compressed than in lover regions. This is not surprising since bulking process was just finished at the time of the survey. No noticeable voids or significant differences in the kind of stored material were detected. Figure 3 shows the profiles obtained.

Profiles were then connected and a 3D internal structure model interpolated. During acquisition a GPS measurement of geophone placement was performed [11]. It allowed for implementing 3D inside model into Digital Terrain Model thus creating a full 3D model of the structure.

5 Conclusions

The aim of this project was to combine new survey and geophysics technology into one fast method of inside and outside monitoring of coal spoil tips. A monitoring method should be fast, as much work as possible should be done remotely. The final results should be given in a 3D digital forma but also 2D plans and drawings should be given.

The realisation of this project took 5 days of on side work, including gaining access, preliminary walk on the object and gathering existing data from the mine. The field personnel varied but never was more than three people. Only in two instance (2 scan stations of RIEGL scanner and geophysics acquisition) required presence of one or two people on side of the tip. Post processing took about 3 days however it was partly done simultaneously (when geophysics acquisition was being performed scans were registered and processed). The project ended with giving a detail rapport to LW "Bogdanka" environmental division. Personnel was satisfied with quality and quantity of the results.

This project shows that it is possible to combine data obtained by multiple specialists into one 3D model and that with proper planning results could be generate fast. This being important in the view of ensuring public safety and environmental control.

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