EXPERIMENTAL DESIGN FOR APPLYING GEOPHYSICAL METHODS IN INVESTIGATING THE SPATIAL DISTRIBUTION OF HARD FORMATIONS IN THE EXCAVATION FACE OF BUCKET WHEEL EXCAVATORS

EKSPERYMENTALNY PROJEKT ZASTOSOWANIA METOD GEOFIZYCZNYCH W BADANIU PRZESTRZENNEGO ROZKŁADU TWARDYCH FORMACJI W CZOLE ZABIERKI URABIANEJ WIELONACZYNIOWĄ KOPARKĄ KOŁOWĄ

Miltiades Triantafyllou, S. Pirtses, L. Myronidis, Christos Roumpos, Fragkiskos Pavloudakis - Public Power Corporation of Greece, General Division of Mines
Theodore Michalakopoulos, George Apostolopoulos - National Technical University of Athens, School of Mining and Metallurgical Engineering
Michael Galetakis, Antonios Vafidis - Technical University of Crete, School of Mineral Resources Engineering

The estimation of hard formations spatial distribution is critical for the planning of the Bucket Wheel Excavator's (BWE) operation. It can be made by the application of geophysical methods in correlation to drilling data and other geological criteria.

The main objective of this work was to design an expert monitoring measurement system, intended to inform in advance the BWE operators for the occurrence of hard rock inclusions or difficult or even non-diggable geological formations. In this framework, numerous technical limitations were taken into consideration, regarding mainly the interference of the measuring device with the metal structure of the bucket wheel and its boom.

Moreover, field tests were carried out regarding the operation of the hard rocks detection system, which was installed on a BWE that operated in several locations within the overburden strata of South Field Mine, Ptolemais, Greece. The selection of the measuring excavation face positions was based on specific criteria. Field tests were performed in excavation faces where the hard rock inclusions had been mapped in detail, as well as in others where the locations of the hard formations were unknown.

According to the results of these tests, the response of the detection system to the variations of hard rock layers thickness is satisfactory. However, further work is required for improving the rigidity of the detection system, as well as the accuracy of the GPS device that monitors the position of the bucket-wheel in real time.

Keywords: *bucket wheel excavator, unmineable inclusions detection, electromagnetic geophysical methods*

Oszacowanie rozkładu przestrzennego twardych formacji skalnych ma kluczowe znaczenie dla planowania pracy wielonaczyniowej koparki kołowej (BWE). Można to osiągnąć, stosując metody geofizyczne w zestawieniu z danymi wiertniczymi i innymi kryteriami geologicznymi.

Głównym celem tej pracy było zaprojektowanie eksperckiego systemu monitorowania, mającego na celu wcześniejsze informowanie operatorów koparki wielonaczyniowej BWE o występowaniu wtrąceń twardych skał lub trudnych, a nawet nieurabialnych formacji geologicznych. W tym kontekście brano pod uwagę liczne ograniczenia techniczne, dotyczące głównie interferencji urządzenia pomiarowego z metalową konstrukcją koła czerpakowego i jego wysięgnika.

Ponadto przeprowadzono testy terenowe dotyczące działania systemu wykrywania twardych skał, który został zainstalowany na koparce BWE i działał w kilku miejscach w obrębie pięter nadkładowych w kopalni South Field Mine, Ptolemais w Grecji. Wybór zabierek wybranych do badań terenowych oparto na określonych kryteriach. Testy polowe przeprowadzono na skarpach czołowych wybieranych zabierek, w których wgłębienia z twardego kamienia zostały wcześniej szczegółowo odwzorowane, a także w innych, gdzie umiejscowienia twardych formacji były przed badaniem nieznane.

Zgodnie z otrzymanymi wynikami można stwierdzić, że zastosowanie układu detekcyjnego dla wykrywania zmian grubości twardych warstw skał jest zadowalające. Konieczne są jednak dalsze prace nad poprawą konstrukcji mocowania systemu detekcji, a także nad dokładnością urządzenia GPS, które monitoruje pozycję koła czerpakowego w czasie rzeczywistym.

Słowa kluczowe: *koparka wielonaczyniowa kołowa, detekcja wtrąceń nieurabialnych, elektromagnetyczne metody geofizyczne*

INTRODUCTION

Lignite is an abundant domestic fossil fuel source in Greece. With a total lignite production of 37 Mt in 2017, lignite-fired power plants accounts for 33% of the electricity generation and still plays o key-role in the country's energy production sector.

The most important lignite deposit of Greece is located in Ptolemais basin. Since 1958, $1.68.10^9$ t of lignite have been produced and supplied, almost exclusively, to mine-mouth located thermal power plants, which have today a total installed capacity of 3.725 MW. During the last decade old, low- efficiency thermal power units with a total installed capacity of 663 MW have been decommissioned and another 1.800 MW will be decommissioned by 2025.

On the other hand, a new, high efficiency unit of 660 MW, equipped with desulphurisation system, is under construction and it is expected to be ready for commercial utilisation by 2022. Taking into account that the remaining exploitable lignite reserves in mines that are currently in operation are estimated to be 740 Mt, it is concluded that lignite exploitation should maintain a critical share in the energy market of Greece at least for the next 30 years (Roumpos et al. 2018:1).

For the exploitation of the lignite of Ptolemais deposit large scale open pit mines have been developed, incorporating continuous surface mining systems consisting from bucket wheel excavators, spreaders/stackers and belt conveyors. This type of equipment has been proved efficient to numerous open pit mines all over the World, which exhibit similar geometric characteristics and aim at production rates as high as the mines of Ptolemais area.

Nevertheless, in the case of Ptolemais lignite deposit exploitation continuous mining systems have to deal with the following site-specific features that complicate the mine planning and operating conditions:

- The poor energy content of the lignite produced (Net calorific value of 5.4 MJ/kg).
- The so-called zebra type structure of the lignite bearing strata (i.e. lignite is divided in numerous seams with thickness varying from 20 centimeters to a few meters, which are separated by intercalated seams of marl).
- The occurrence of hard rocks in the overburden strata especially in South Field Mine.

In this framework, facing the challenges of the competitive electricity market and trying to reduce the cost of lignite production through the increase of equipment's operating efficiency, South Field Mine (SF Mine) investigates the possibility to develop an automated monitoring system, intended to inform in advance the BWE operators for the occurrence of hard rocks. This system is expected to lead to an increase of the Load Factor of BWE, which is already low due to the selective excavation of lignite seams with relatively small thickness compared to the dimensions of the bucket wheel. In Table 1, the different Load Factors of BWE operating in benches with (SE1) and without (SE6) hard rocks are presented (Roumpos et al. 2018:2).

CHARACTERISTICS OF HARD ROCK FORMATIONS

SF Mine can be considered unique regarding the mining conditions and technologies used to exploit the lignite deposit. Approximately 13-16 Mt of lignite are extracted annually from this mine by moving some 65-70 Mm³ of earth material. Annual overburden removal totals about 45 Mm³, while ca.40% of the overburden consists of hard and semi-hard formations, which are removed using a combination of continuous and non-continuous mining methods (Figure 1).

Overburden strata in South Field lignite deposit consist of fine and coarse clastic sediments such as clays, marls, gravel, conglomerates with embedded hard layers of sandstones, cemented conglomerates and mudstones (Anastopoulos & Koukouzas, 1972). The spatial alternation of these sediments is irregular (Figure 2).

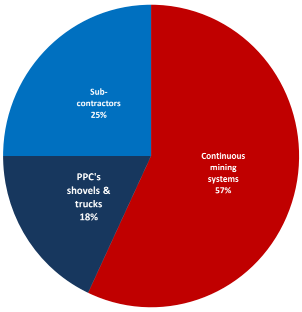


Fig. 1. Contribution of different mining systems to the total annual excavations of SF Mine in year 2017

Rys. 1. Udział poszczególnych systemów eksploatacyjnych w całkowitym wydobyciu kopalni South Field w 2017 roku

Tab. 1. Comparison of the operating efficiency of BWE operating in benches with (SE1) and without (SE6) hard rocks

Tab. 1. Porównanie efektywności pracy koparek pracujących w piętrach z utworami trudno urabialnymi (SE1) i bez (SE6)

Bucket wheel excavator		SE1		SE6
Materials excavated		overburned		ignite strata
Soft/hard & semi- hard rocks ratio (2017)		31/69		94/6
Theoretical capacity		Fm³/h	**4.170**	3.972
Annual production	**theoretical**	10^6Fm³	**36.53**	34.79
	achieved (2017)	10^6Fm³	**2.82**	4.53
Annual Time of Operation		h	2.818	2.526
Time Operating Factor (n_t)		%	32	29
Avarage production rate		Fm³/h	1,001	1.792
Load Factor (n_l)		%	0.24	0.45
Utilisation Factor($n_u = n_t \cdot n_l$)		%	7.72	13.01

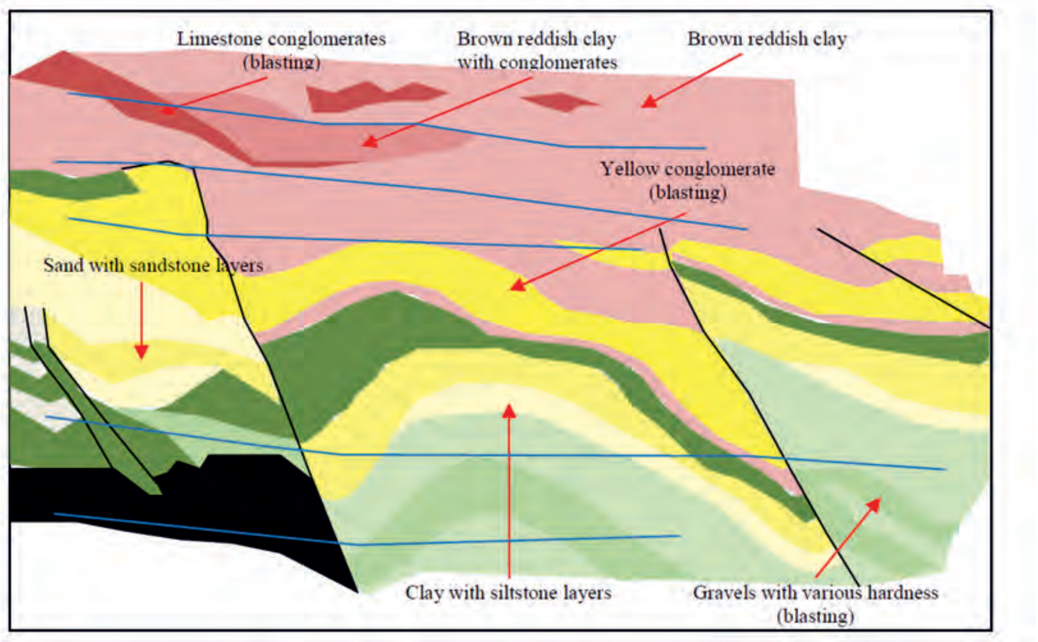


Fig. 2. Typical geological section of overburden strata of SF Mine
Rys. 2 Typowy przekrój geologiczny warstw nadkładowych w kopalni South Field

The average in-situ specific weight of the overburden is 2.0 ton/m^3, the average bulking factor ranges from 1.4 to 1.5 and the thickness ranges from 55 to 75 meters. Table 1 shows the range of the mechanical and physical properties of the hard rock formations (Agioutantis et al. 2001).

From the initial stage of SF Mine opening, it was realized that bucket wheel excavators are not able to dig the above-described hard rock formations. Therefore, the modification of the existing mining systems was necessary. After a short period of field tests using mobile crushers for size reducing of the hard rocks before loading on belt conveyors, as early as 1981, it was decided to use both large scale explosives to loosen the hard rock formations and conventional load and haul equipment to move it (Bozinis et al. 2006). Nowadays, about 4.000 tons of explosives are consumed annually by detonating more than 1.200 shots.

SELECTION OF SENSOR TECHNOLOGY FOR THE HARD ROCKS DETECTION SYSTEM

Field tests for assessing the possibility of identifying the material type and detecting the interfaces of rocks with a sensors system operating in parallel with the bucket wheel are reported by Overmeyer et al. (2007). According to these tests, the sensors system is possible to be installed either next to the bucket wheel or in the bucket wheel itself. Taking into consideration physical, technical and economic aspects, a combination of ground penetrating radar and geo-electric technologies were proved to be the most promising for identifying different rock types. Mathiak et al. (2011) implemented ground penetration radar and geoelectric sensor technology by endowing with them a bucket of a bucket wheel excavator. The sensor bucket was tested in Inden Mine, Germany. The detailed information gathered by this measuring setup gives an opportunity for applying efficient selective mining processes, provided that effective processing and interpretation algorithms have been developed.

Based on the information presented above, the following geophysical methods were selected to be tested in SF Mine in order to choose the most affective one to incorporate in an automated hard rocks detection system:

- Geoelectric tomography (measurement of the electrical resistivity of rocks and soils).
- Ground Penetration Radar (GPR) with shielded antennas of 100 MHz and 250 MHz central frequency and 6 m and 3 m detection depth, respectively (reflection of high frequency electromagnetic waves at interfaces that separate media of different dielectric constant and conductivity).
- Electromagnetic conductivity (EMC).

According to the tests that were carried out in April 2016, the geoelectric tomography and EMC methods are able to outline lateral inhomogeneity, while GPR method can do so if the

Tab. 2. Physical and mechanical properties for the hard rock formations
Tab. 2 Fizyczne i mechaniczne właściwości twardych utworów skalnych

Parameter	Range
Uniaxial compressive strength (MPa)	15-143
Tensile strength (Mpa)	2.4-11.2
Density (t/m^3)	2.4-2.7

signal can pass through the conductive clayey materials before facing the hard formations. Also, the later method cannot identify layers or bodies in respect of their lithological features, unless advanced signal processing algorithms are integrated in the measuring system. Finally, the method that was chosen to be used in the next stage of tests was EMC. The most important advantage of EMC method is the fast, contactless measuring of apparent conductivity. On the contrary, goelectric tomography requires the placement of a series of electrodes in contact with the ground and in certain geometrical patterns.

EMC instruments measure the conductivity of the subsurface which includes soil, groundwater, rock, and objects buried in the ground. Geologic variations, groundwater contaminants, or any subsurface feature associated with changes in ground conductivity can be investigated using EMC. Sand, granite and dry soils all have a relatively low conductivity. Clay, shale and high water content soils all have a relatively high conductivity (GF Instruments, 2018).

The EMC method using two coils is based on a primary electromagnetic field from the source coil (Transmitter) that is spreads out above and below the ground. In the presence of a conductive body the primary field produces eddy currents in the conductive body. These eddy currents produce a secondary field which is added to the primary one. The resultant field produces a current in the Receiver coil which is the measured response (Figure 3a).

The EMC instruments measure: (i) the out-of-phase parameter, which is the apparent conductivity of the whole hemispheric space with radius the effective exploration depth, and (ii) the in-phase parameter, which is connected with the magnetic susceptibility of the space. A typical effective exploration depth is about 3 m. This means that EMC instruments must be kept as closer as possible to the ground in order to detect early a hard rock formation that is at a distance of 2 m from the mining face. Figure 3(b) presents a graphical representation of EMC instrument response for four different cases regarding the relevant position of hard rock and EMC field. Furthermore, EMC instruments must be at a distance from any steel structure at least two times the detection depth (i.e. with the detection depth of 3 m, the EMC measuring device has to be approximately 6 m far from the steel structure of the bucket wheel boom). Also, the mock-up that supports the EMC instrument must be made of a material other than steel (e.g. wood, plastic).

HARDWARE DESIGN PARAMETERS

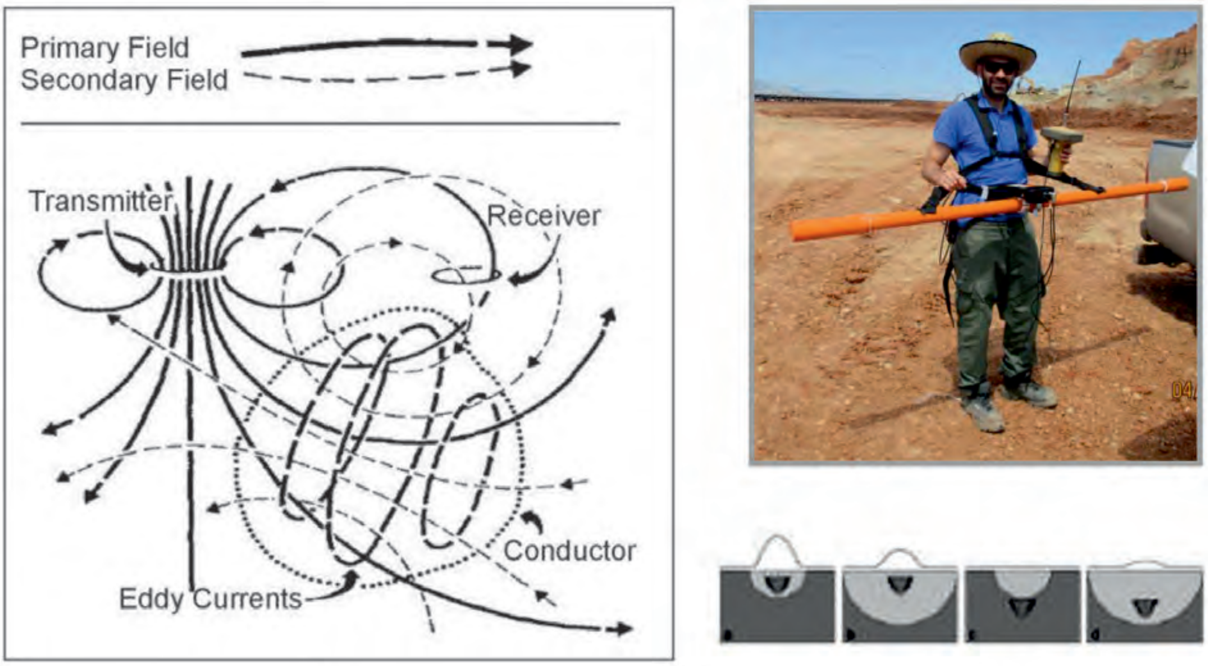
In order to develop a hard rocks detection system based on the above resented EMC instrument, the construction of a mounting mock-up is necessary. This mock-up was installed in the slewing boom of the bucket wheel.

The initial designs of the mounting mock-up are presented in Figure 4. According to these designs, which were prepared by the Mining Engineering Department of The National Technical University of Athens, the mounting mock-up should allow the measuring device to move front-back and up-down in order to keep always the appropriate distance from the mining face (i.e. to allow to the produced electromagnetic field to entry the rock mass and, at the same time, to avoid collision of the measuring device on the surface of the excavated rock).

Moreover, special attention was paid for keeping a clearance of 5-6 m from the steel structure of the BWE, which may interfere in the measurements. For this reason, the parts of the mounting mock-up that were close to the measuring device, were finally decided to be constructed by wood beams.

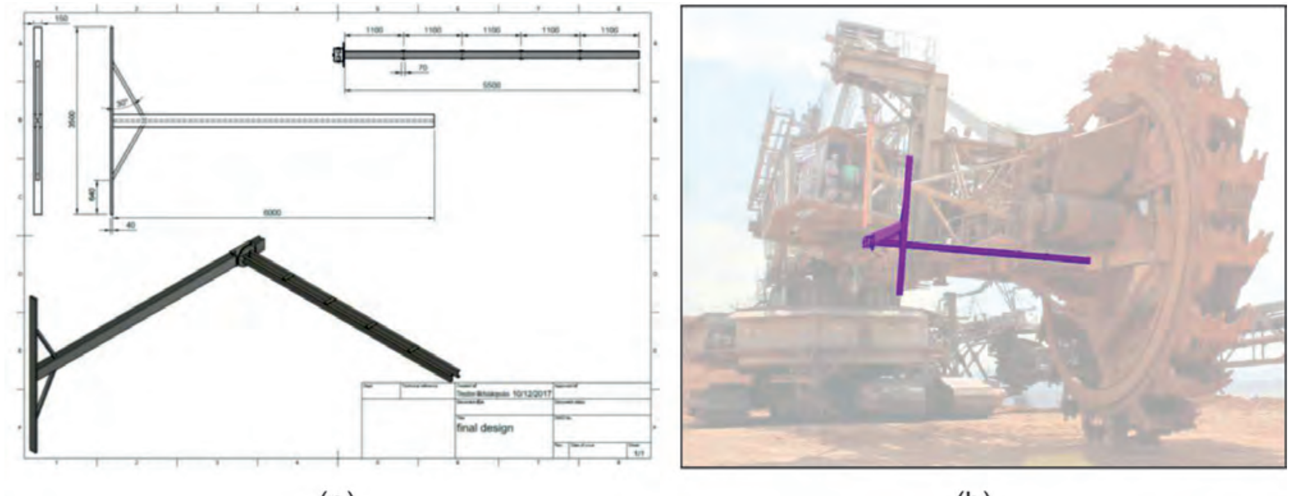
HARDWARE CONSTRUCTION

The construction of the mounting mock-up and its wooden beam was performed by the staff of PPC S.A. in the facilities



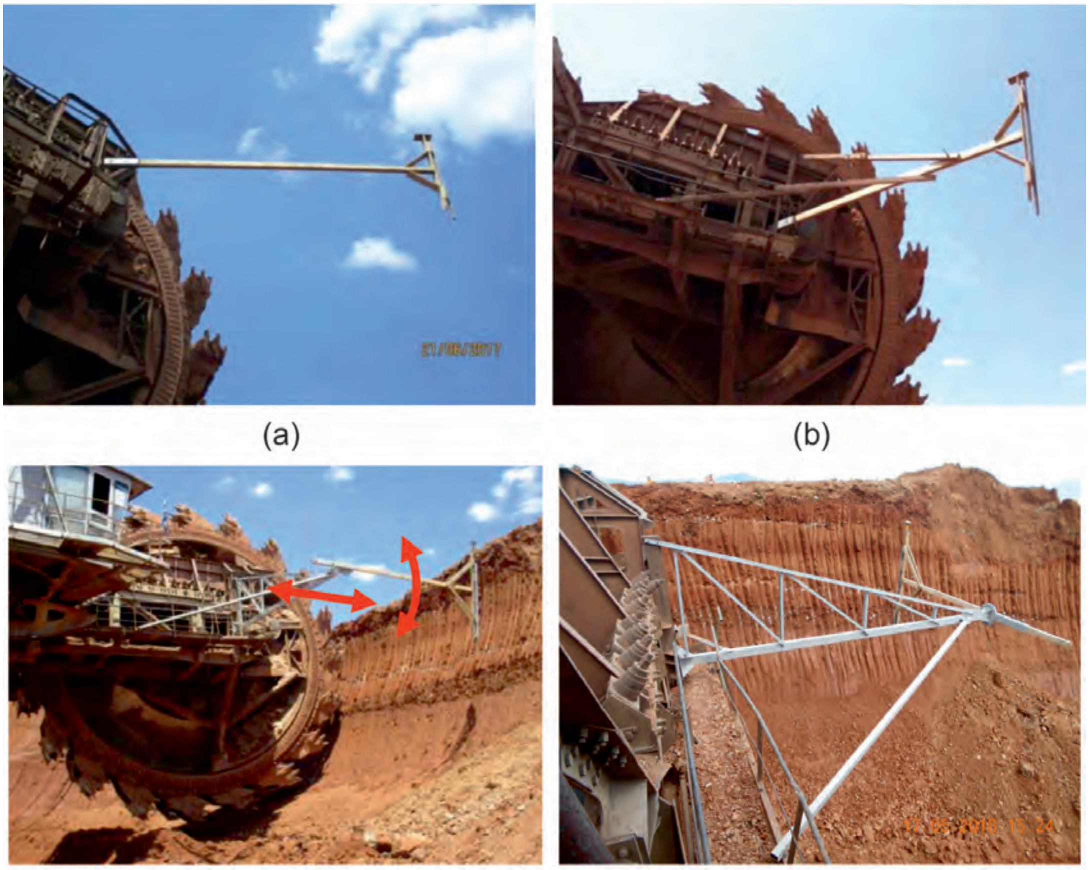
(a) (b)

Fig. 3. Schematic representation of electromagnetic phenomenon, EPA, 2018 (a) depth of detection and signals received for various cases of targets (b)
Rys. 3. Schemat działania zjawiska elektromagnetycznego, EPA, 2018 (a) głębokość wykrywania i sygnały otrzymane dla różnych wtrąceń (b)



(a) (b)

Fig. 4. Initial designs of the mounting mock-up (a) and installation system on BWE (b)
Rys. 4. Wstępny projekt konstrukcji wysięgnika (a) i miejsca jego instalacji na koparce wielonaczyniowej (b)



(a) (b) (c) (d)

Fig. 5: Evolution of mounting mock-up during the realization of the project: (a) fixed wooden beam, Apr-16, (b) wooden frame, Jun-16, (c) and (d) steel frame supporting a rotating wooden beam of adjustable length, Mar-18
Rys. 5. Ewolucja konstrukcji wysięgnika mocującego podczas realizacji projektu: (a) sztywna drewniana belka, kwiecień 2016; (b) drewniana rama, czerwiec 2016; (c) i (d) stalowa rama podtrzymująca obracającą się drewnianą belkę o regulowanej długości, marzec 2018

of the SF Mine. After a series of in-field tests, the Mechanical Maintenance Sector of SF Mine decided to modify the initial designs of the mounting mock-up in order to keep all the operational characteristics but doing it more rigid.

The construction stages of the mounting mock-up are presented in Figures 5. The initial designs set-up that allows the wooden beam to move front-back and up-down remained the same (Figure 5 c).

The modified designs of the mounting mock-up are presented in Figure 6. The steel parts of mounting mock-up form finally a 3-D frame, which has proven rigid enough for the realisation of the tests in SF Mine, which lasted a few hours. However, vibrations during normal operation of BWE still exist and may cause collapse of the wooden beam within a couple of days. Therefore, additional effort is required in order to improve further the mechanical strength of the mock-up.

It worth noticing that, at the end of the project period, the installation of the mounting mock-up in the slewing boom of the bucket wheel lasted less than an 8-hours shift. This fact is crucial for the mine operation because of the reduction of the duration of stoppages and non-productive operation of the BWE.

FIELD TESTS - INITIAL RESULTS

The field tests were carried out in the upper bench of overburden (S1) in the sector 6 of SF Mine (Figure 7). In this bench there are areas with hard rock inclusions that had been mapped in detail, as well as areas where the exact location of the hard formations is unknown. Tests were carried out in areas of both types. The EMC instrument and its mounting mock-up were installed in a TAKRAF SRs 2000.32/5.0 bucket wheel excavator.

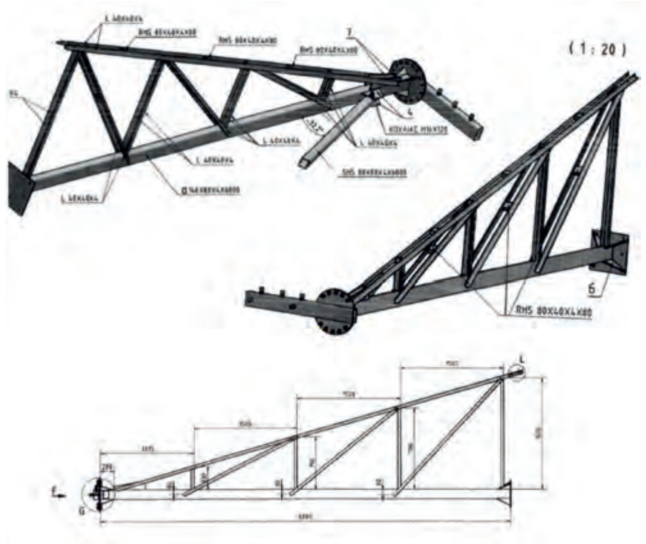


Fig. 6. Design of mounting mock-up as modified by the SF Mine
Rys. 6. Projekt wysięgnika mocującego opracowany przez kopalnię South Field

During the first stage of the field tests, the rigidity of the structure was examined. The tests included operation of the BWE with the mounting mock-up only and with the mounting mock-up and the hard rocks' detection system in operation. Also, the appropriate position of the wooden beam for the realization of the measurements was determined.

During the second stage of the field tests, the performance of the detection system was tested in excavation faces where hard rock seams of limited horizontal expansion occur. This rock pattern is ideal for the tests because it allows transition of the detection system from areas of soft rocks to areas of hard ones during the horizontal movement of the slewing boom of the bucket wheel.

Finally, the last stage of the field tests included the position of a hard rock volume of known dimensions at a certain distance from the excavation face and the measurement of the gradual increase of the resistivity values as excavation proceeds and the EMC instrument approaches the hard rock mass.

Table 3 presents a typical data set collected during the various stages of tests carried out in SF Mine. Apart from the data related to the time and coordinates, the EMC instrument measures the apparent conductivity and inphase. The later parameter is defined as the relative quantity (in part per thousand) of primary magnetic field and is closely related to magnetic susceptibility of measured material. The inphase is an indication of artificial metal objects like cables, pipes, reinforced concrete, tanks etc. Thus the inphase measurements can help to distinguish artificial structures from natural geology seen in apparent conductivity map (GF Instruments, 2018).

In Figure 8 is shown an indicative diagram of the conductivity (vs. time) measured during a test that lasted approx. 10 min. The starting point of the measurement was selected to be an area of the excavation face without hard rock formations. After calibration, the detection system was moved for 3 minutes along the excavation face approaching rock surfaces with gradually higher hard rocks percentage. Then, the detection system returned to the starting point and, finally, it completed another move from softer to harder rock formations.

In Figure 9 is shown a form of the visual representation of spatial (linear) variation of conductivity (resistivity), which is considered appropriate for the BWE operator, in order to keep him informed about the occurrence of hard rocks in front of the bucket wheel. It is obvious that the hard rock mass existing in the middle of the bench (upper part of Figure 9) is responsible for a significant increase of the resistivity measured during the horizontal movement of the bucket wheel boom along the excavation face. The resistivity values are becoming higher as the successive cuts of BWE move the EMC instrument closer to the hard rock.

Future work

The hard rocks detection system can be developed to commercial scale by improving the manoeuvrability of the wooden beam that supports the EMC instrument and controls its relevant position in front of the excavation face. At the moment, every movement of the wooden beam (front-back or up-down) is executed with the BWE out of operation. A small crane and at least two technicians are needed to loose numerous screws, adjust the position of the wooden beam and tight again the screws to stabilise the beam. This is a time-consuming procedure that must be replaced by an automated system, which will adjust the position of the wooden beam within a few seconds. It is estimated that the rotating angle of a wooden beam installed on a bucket wheel slewing boom of 50m that operates in a bench of 20m height is about 24 degrees (Figure 10).

Tab. 3. Part of original data, collected from EMC meter during the tests carried out in SF Mine
Tab. 3. Fragment oryginalnych danych zebranych z miernika EMC podczas badań prowadzonych w kopalni SF

Latitude	Longitude	Altitude	Time	Conductivity [mS/m]	Inphase [ppt]
40.4372058667	21.8386390967	696.801	09:10:01.97	28.50	5.90
40.4372058633	21.8386390867	696.794	09:10:02.87	28.54	5.91
40.4372057417	21.8386390167	696.816	09:10:03.92	28.65	5.90
40.4372057583	21.8386390233	696.793	09:10:04.97	28.91	5.90
40.4372058933	21.8386391583	696.670	09:10:06.92	29.19	5.87

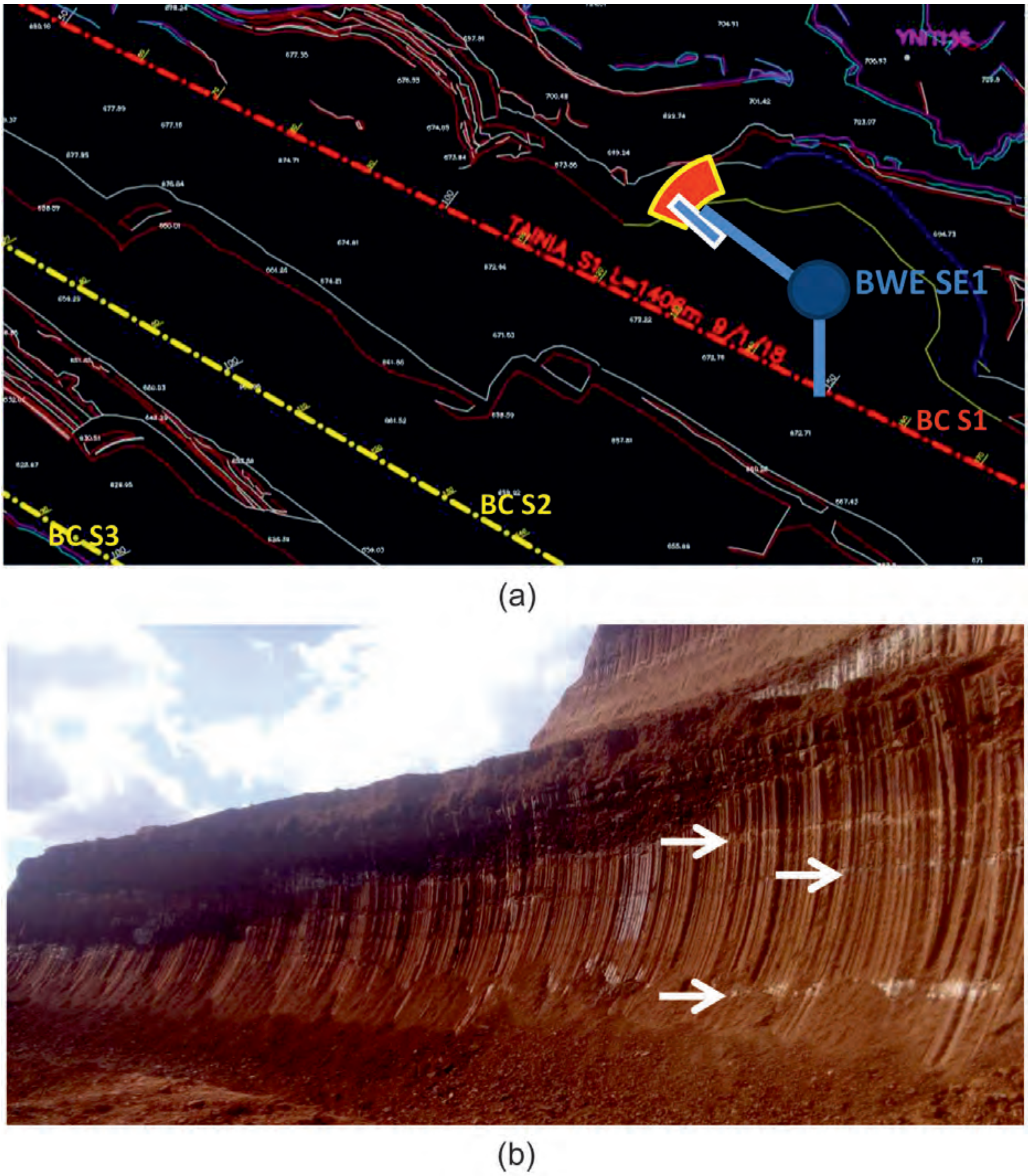


Fig. 7. Measuring location of field tests (a), Hard rock formations (white colored rocks) in the face where the final stage of the field tests was carried out (b)
Rys. 7. Lokalizacja badań terenowych (a), odsłonięte twarde formacje skalne (kolor biały) w skarpie czołowej, gdzie przeprowadzono końcowy etap badań polowych (b)

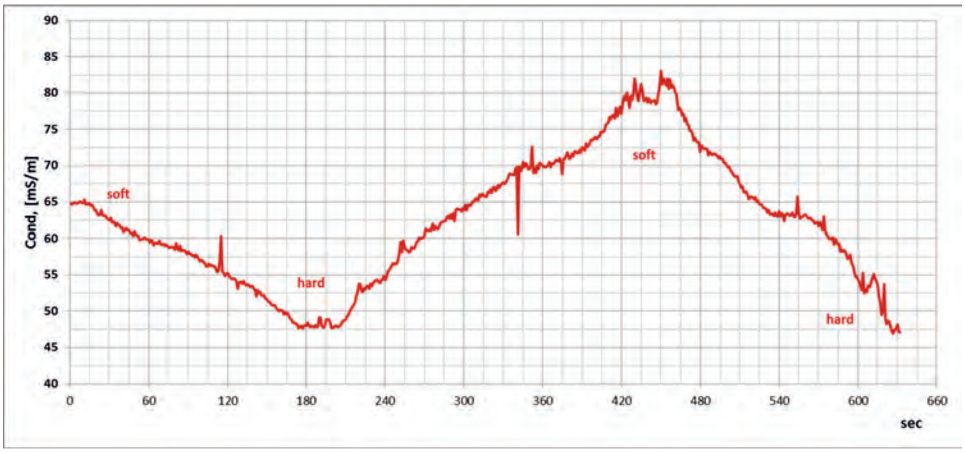


Fig. 8. Indicative diagram of the field tests
Rys. 8. Wykres przewodności zmierzonej podczas badan terenowych

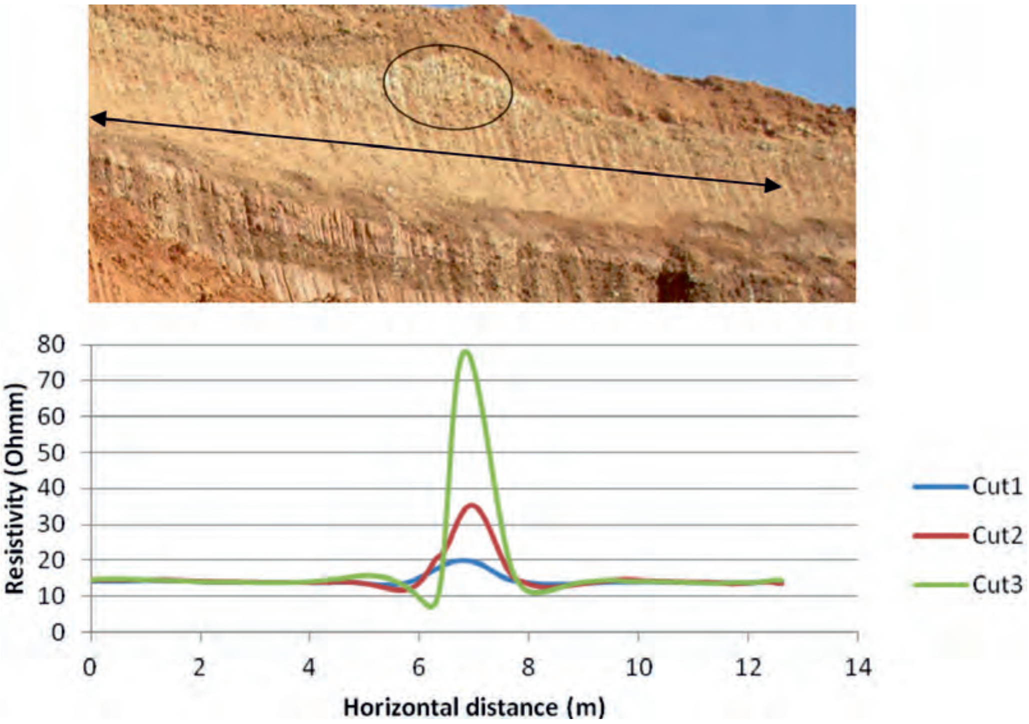


Fig. 9. Visual representation of linear variation of resistivity measured during the horizontal movement of the bucket wheel slewing boom along the excavation face
Rys. 9. Wizualna reprezentacja liniowych odchyleń rezystywności mierzona podczas poziomego ruchu wysięgnika z kołem czerpakowym wzdłuż urabianego stopnia zabierki

CONCLUSIONS

The spatial distribution of hard rocks appearances in the excavation face of BWE is possible to be determined fast and without contact to the excavated rocks using a high resolution EMC meter. In order to achieve this, a sophisticated system of measuring (EMC sensor, mounting mock-up, DGPS, CCD camera), data collection, storage, transmission and processing is necessary to be installed on the slewing boom and in the control room of BWE operator.

In addition, special attention must be paid to the development of an automated mechanism for controlling the relevant position of the EMC instrument to the excavation face. This is critical for increasing the penetration depth of the electromagnetic field in the rock mass, taking into consideration its limited expansion around the EMC instrument (ca. 3 m). The design and construction of such a mechanism is complicated further due to limitation regarding the materials that can be used (metal parts interfere with the EMC instrument) and the vibrations occurring during normal operation of a BWE.

The field tests that were carried out in the overburden strata of SF Mine, West Macedonia Lignite Centre, Greece during the last two years gave promising results in terms of reliability of measurements and possibility of providing the BWE operator with an easily interpreted visual signal related to the occurrence of hard rocks.

ACKNOWLEDGEMENTS

This research project has received funding from the European Commission - Research Fund for Coal and Steel under grant agreement No RFCR-CT-2015-00003. The presented results reflect only the authors' view and the European Commission is not liable for any use that may be made of the information contained therein.

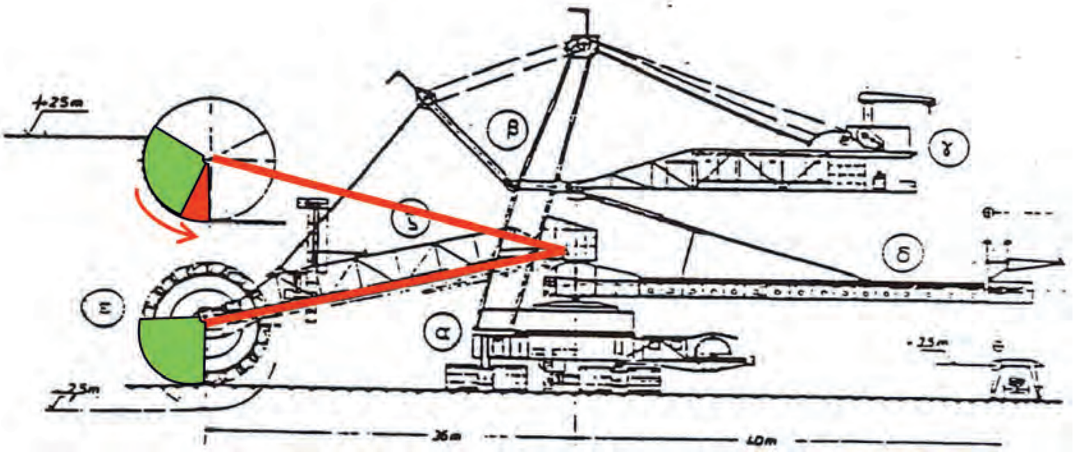


Fig. 10. Estimation of the rotation angle of the wooden beam that supports the EMC meter
Rys. 10. Obliczanie kąta obrotu drewnianej belki wspomagającej instrument pomiarowy EMC

Literature

[1] Agioutantis Z., S. Bozinis, G. Panagiotou and K. Kavouridis, (2001). *Evaluation and Analysis of Blasting Procedures for Removing Hard Formations at the South Field Lignite Mine, Ptolemais, Greece.* 17th Intl. Mining Congress of Turkey, Ankara, June 19-22. pp. 305-313

[2] Anastopoulos J. and C. Koukouzas, (1972). *The lignites of the southern part of the lignite-bearing basin of Ptolemais. Institute of Geological & Minerals Exploration,* Athens, pp. 201 (in Greek)

[3] Bozinis, S., F. Pavloudakis, M. Triantafyllou and Z. Agioutantis, (2006). *Design considerations when blasting in the proximity of inhabited areas.* 2nd Intl. Conf. on Advances in Mineral Resources Management and Environmental Geotechnology, Hania, Greece, 25-27 Sept. 2006, pp.681-686

[4] EPA (2018). *Frequency Domain Electromagnetic Methods,* Environmental Geophysics, https://archive.epa.gov/esd/archive-geophysics/web/html/frequency_domain_electromagnetic_methods.html (site visited at 10-07-2018)

[5] GF Instruments (2018). *Short guide for electromagnetic conductivity mapping,* https://whitefordgeoservices.com/media/1195/cmd_short_guide_en.pdf (site visited at 10-07-2018)

[6] Mathiak T., M. Kesting, L. Overmeyer and V. Gau, (2011). *Automatic material and boundary layer detection during the process of mining on a bucket wheel excavator*. In Proceedings of the 35th APCOM Symposium (eds. EY Baffi, I Porter and RJ Kininmonth). Australasian Institute of Mining and Metallurgy, Carlton South, VIC, p. 735-741

[7] Overmeyer L., M. Kesting and K. Jansen, (2007). *SIMT technology: sensory identification of the material type and direction of the interfaces*. Bulk Solis Handling, Vol. 27, No. 2, p. 92-98

[8] Roumpos, C., F. Pavloudakis, A. Liakoura, D. Nalmpanti, K. Arampatzis (2018 :1). *Utilisation of Lignite Resources within the Context of a Changing Electricity Generation Mix*. 10th Jubilee Intl. Brown Coal Mining Congress: "Brown Coal Today and in the Future". Bełchatów, 16-18 April 2018

[9] Roumpos C., D. Sideri, F. Pavloudakis, N. Kolovos, T. Michalakopoulos, G. Apostolopoulos, M. Galetakis and A. Vafidis, (2018 :2). *Possibilities for improving work efficiency of continuous surface mining systems operating in rocks with excessive digging resistance.* Conf. "BEWEXMIN-Bucket wheel excavators operating under difficult mining conditions including unmineable inclusions and geological structures with excessive mining resistance - Project RFCR-CT-2015--00003'', Wroclaw, 13-14 June 2018

fot. RS-K

Architectural details of Wrocław