A new in-situ monitoring system to determine stability of underground coal pillar subjected to dynamic loading: electrical resistance measurement system (ERMS)

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ABSTRACT: The electrical resistance measurement system (ERMS) was tried to be developed. The first in-situ applications were carried out in A6 panel in GLİ underground coal mine. As perpendicular to the pillar face, two parallel boreholes with 4 m long and interval 30 cm were drilled. The copper plates with a width of 200 mm and a thickness of 0.5 mm was wrapped on the measuring rod with 50 cm intervals and also soldered with copper wires. Then two rods were separately inserted into boreholes named as ERMS-#. In this way, 5 stations were installed with 5 m intervals. Measurements were carried out by ohmmeter using each electrical wire coming from the copper plates located at the same depth of boreholes. ERMS values measured on pillar subjected to dynamic loading due to longwall mining operations were shown that there were unstable in the first 2.5 m region of the pillar side.

Keywords: Longwall coal mining, Coal pillar, In-situ measurement, Electrical resistance behavior.

1 INTRODUCTION

The electrical permittivity depends on the degree of freedom of the electrons or ions of the materials. Metallic materials are conductive due to their free orbital electrons. On the other hand, it is known that rocks behave like insulator materials because they show very high resistance to electron transfer. If a rock material is electrified, electric current cannot flow easily. Electrical conductivity in water-free or dried rock materials can be achieved at very high voltages such as 25-50 kV. However, electrical potential differences in rock materials containing water can occur even at normal voltages (110-220V). Electrical resistance behaviors may differ depending on the rock material properties and water content differences. Water is an important parameter that allows free movement of ions. Differences in water concentration in the rock cause uneven distribution of free ions in the rock material. Therefore, different parts of the same rock mass may show differences in electrical conductivity. Consequently, electrical resistance is an important material property that depends on the type of material being tested.

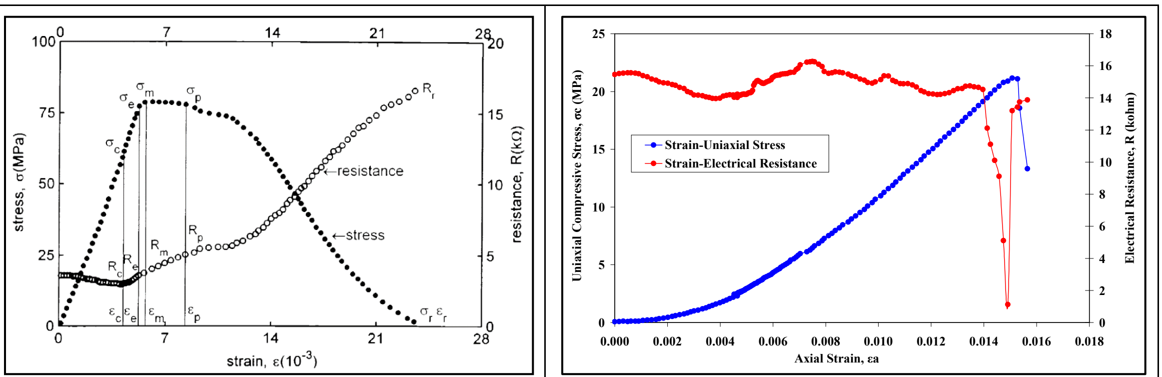
The water content of the rock material is respectively; it depends on material properties such as porosity, permeability, mineralogical and structural properties. In particular, discontinuities act as water passageways in the rock mass and contain more water than the bedrock blocks. This means that there are more free ions in and around the discontinuities, so low electrical resistance values in these sections are expected. Depending on this general structure, the explanations of which are given, the electrical conductivity measurement method today is respectively; It is used in mineral exploration, cavity localization, exploration of water-bearing formations and many other engineering applications. In a material that allows electric current to pass, the resistance (ohm) can be calculated by dividing the electric current flow rate (ampere) by the electric potential difference (volts) between the ends of the material.

With the new land stresses that develop during the use of rock engineering structures, new failure zones, namely cracks, occur in engineering structures such as mine heel and concrete fill. Rock engineers want to carry out additional fortification studies by following these failures in the rock structure. With the electrical method developed today, the locations of crack structures in rock materials can be determined.

The effect of electrical resistance on the physical properties of rock material and mass has been investigated by many researchers (Bahr 1997, Koelman & Kuijper 1997, Kamenetetsky & Novikov 1997, Roberts et al. 1999, Jiang et al. 1998, Jouniaux & Pozzi 1997, Gökay & Özkan 2001, Roberts & Tyburczy 1999, Shankland et al. 1997, Ravalec et al. 1996, Yoshida et al. 1997, Lorne et al. 1999, Jones 1999, Yardley & Valley 1997).

The relationship between stress and electrical resistance in rock materials was first investigated experimentally by Brace & Orange (1968). The under uniaxial pressure, stress (σ) - strain (ε) and also strain (ε) - electrical resistance (Ω) behaviors on 18 core samples prepared in three different rock units (diabase, limestone and marble) were examined by Chen & Lin (2004). It has been emphasized that failure can be explained by electrical resistance measurement (Figure 1a).

Stress (σ) - strain (ε) - electrical resistance (Ω) behaviors under uniaxial stress on different model rock units have been investigated in many studies (Özkan & Bilim 2007, Eser 2009, Özkan et al. 2018). In addition, electrical resistance behaviors under triaxial stress were investigated (Mesutoğlu & Özkan 2013). From the experimental results, it was determined that the electrical resistance (Ω) values on the material reached the lowest point when the rock material reached the failure strength (σ_c). It has been determined that while the stress (σ) values decrease rapidly after failure, the electrical resistance (Ω) values increase rapidly (Figure 1a, 1b).



a) Diabase behaviour (Chen & Lin 2004)	b) Yellow Tuff behaviour (Mesutoğlu & Özkan 2013)

Figure 1. Stress (σ) - strain (ε) - electrical resistance (Ω) behavior under uniaxial stress.

2 UNDERGROUND ÖMERLER COAL MINE

The study area is located in Tunçbilek town of Tavşanlı district of Kütahya province, Türkiye. In the basin, coal production is carried out by Turkish Coal Enterprises (TKİ)-Occidental Lignite Enterprise (GLİ). In the basin with 18 million tons of reserve, the thickness of the coal seam varies between 5-12 meters and has an average thickness of 8 meters. The coal seam contains intermediate with a thickness of about 15-30 cm at four different levels. The deepest part studied in the underground Ömerler mine is at +469 elevation and the cover layer thickness is approximately 330m.

In the underground coal mine, where a fully mechanized excavation system is used, coal production is carried out by the retreating longwall production method. The longwall panel widths are generally between 90-110 m, the length of the panel is between 500-1000 m, and the pillar width between the panels 20 m is selected by design engineers. In GLİ-Ömerler mechanized longwall panel gate roadways, the steel arches with profile type GI 140 are used. The width of these curved steel arches is 4600 mm and the height is 3500 mm. The gallery excavation area is 15.79 m^2. The uniaxial compressive strength, Brazilian tensile strength, modulus of elasticity, Poisson ratio values for coal material were detected as 8.84 MPa, 2.30 MPa, 2663 MPa, 0.18, respectively (Özkan et al. 2022).

3 ELECTRICAL RESISTANCE MEASUREMENT SYSTEM: ERMS

It was planned to carry out this study in TKİ-GLİ-Ömerler underground coal mine. First of all, the diagram shown below (Figure 2) was prepared for the design and manufacture of the Electrical Resistance Measurement System (ERMS). Manufacturing works were carried out in the Mechanical Workshop of TKİ-GLİ Ömerler underground mining operation. Then, the cables were soldered to the copper plates in the Electrical-Electronics Workshop.

In ERMS application region, there is a coal pillar between the A6 and A5 panels. A5 longwall panel was producted in 2015. However, A6 longwall panel is yet production stage. Application studies were carried out in the material gate roadway of the A6 panel. On the side wall of the coal pillar of the material gallery, two holes with a length of 4 meters were drilled at a distance of 30 cm, one above the other (Figure 2). The measuring rods shown in Figure 2 were inserted separately into both holes. Using this method, 5 measuring stations were set up at 5 m intervals in the region. They were named as ERMS-1, ERMS-2, ERMS-3, ERMS-4 and ERMS-5, respectively. The distance between the first measuring station ERMS-1 and the longwall excavation face was approximately 10 m. Consequently, intervals between ERMS measurement stations and longwall face, respectively, 10 m for ERMS-1, 14 m for ERMS-2, 19 m for ERMS-3, 24 m for ERMS-4 and 29 m for ERMS-5.

20 cm wide and 2 mm thick copper plates were wrapped the 0.5^{th}, 1^{th}, 1.5^{th}, 2^{th}, 2.5^{th}, 3^{th}, 3.5^{th}, 4^{th} meters of the measuring rods (Figure 2). In measurements, ohmmeter (Avometer) was used. Measurement was taken once daily from wires soldered to copper plates corresponding to the same meter of the upper (H1) and lower hole (H2) (Figure 2).

4 IN-SITU MEASUREMENT RESULTS

The electrical resistance behavior from in-situ measurement stations were monitored for approximately one month and also monitors currently. During the measurements, only 2 meters of advancing was made in the longwall excavation face. Apart from this, no coal was produced.

In measurement studies, the first measurement value was named as reference measurement (R_o). The measurements were symbolized by R_i. Electrical resistance measurements taken from 8 copper plates on each measuring rod were evaluated primarily based on time. In order to compare the measurements taken from each copper plate located in the H1 and H2 holes, the measurement results (R_i) has been divided into the reference measurement values (R_o). When this ratio (R_i/R_o) was less than 1, that was electrical resistance was decrease, it was considered that the rock material was compressed under dynamic load formed due to mining activities. However, if the electrical resistance was increase (Ri/Ro≥1), it was considered that the rock material fractured and loosens due to pressure.

Time versus electrical resistance ratio (R_i/R_o) behaviors for each measurement stations were given in Figure 3a, 3c, 3e, 3g, 3i, respectively. Where the R_i/R_o ratio equal to 1 in the graphs was indicated by a bold red color line. Where this ratio is less than 1, it was assumed that the pillar coal material is compression under pressure. Otherwise ($R_i/R_o \geq 1$), it was considered that the coal material fractured and loosens due to pressure. Measurement results obtained from ERMS-1 (10 m), ERMS-2 (14 m), ERMS-3 (19 m) were indicated that the coal material (L<2.5 m) closer the pillar edge was broken and loosened (Figure 3a, 3c, 3e). As can be seen from Figure 3g and 3i, it was understood that coal material continues to be compressed still under pressure at stations ERMS-4 (24 m) and ERMS-5 (29 m) installed further away from the longwall face.

The borehole depth (L) versus electrical resistance ratio (R_i/R_o) behaviors obtained ERMS stations by in-situ monitoring were given in Figure 3b, 3d, 3f, 3h, 3j, respectively. At the ERMS-4 (24 m) and ERMS-5 (29 m) stations (Figure 3h, 3j), it was immediately noticed that the coal material in the pillar was compressed under pressure along the entire measuring borehole (L=4 m). On the other hand, at the ERMS-1 station (Figure 3b) installed closer longwall face, it is observed that the coal material is more broken and loosened, especially in the 1.5m - 3m intervals of the measuring borehole (L). It was evaluated that the fragmentation and loosening formed due to existing stress on the pillar material were increased the electrical resistance (R) values. A similar situation can be noted in ERMS-2 and ERMS-3, although not as much as the ERMS-1 station (Figure 3d, 3f).

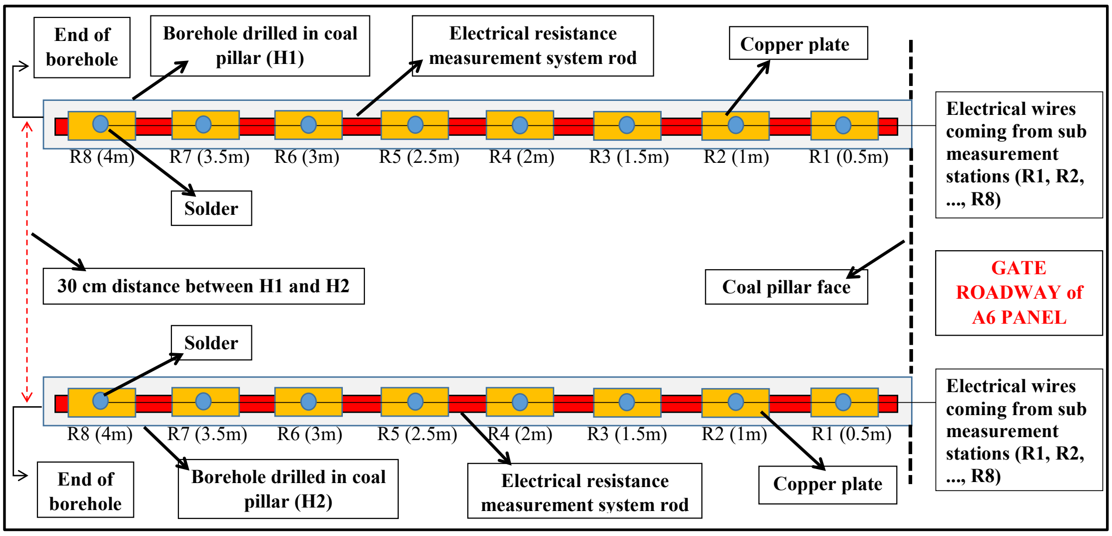
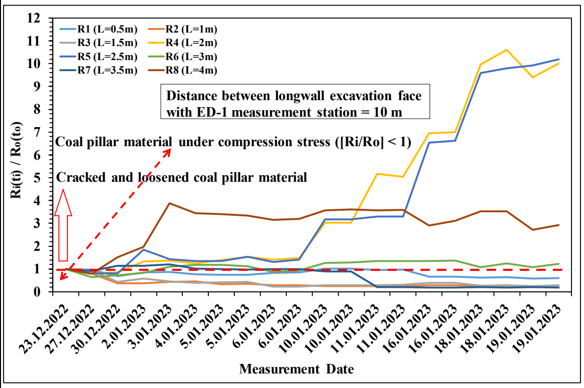
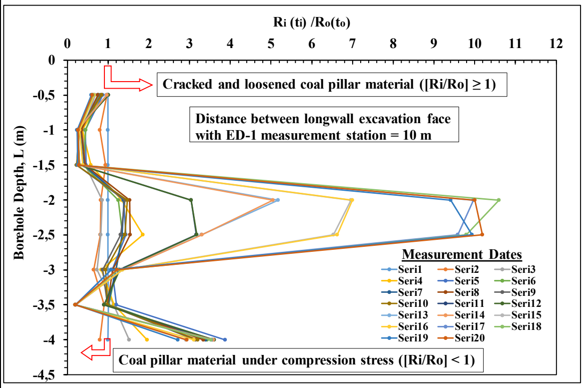


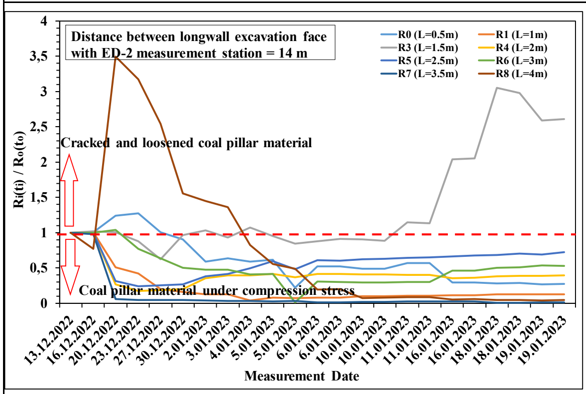
Figure 2. Schematic figure of the Electrical Resistance Measurement System (ERMS).



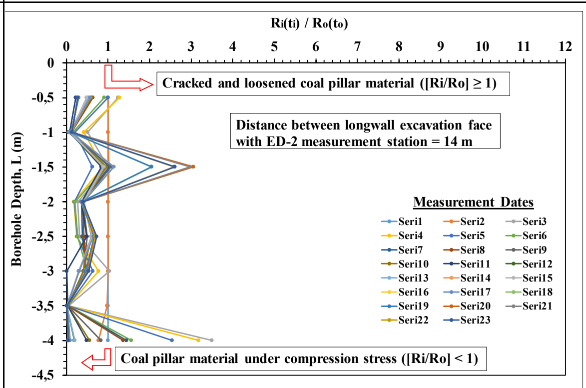
a) Time vs R_i/R_o ratio for ERMS-1 station.



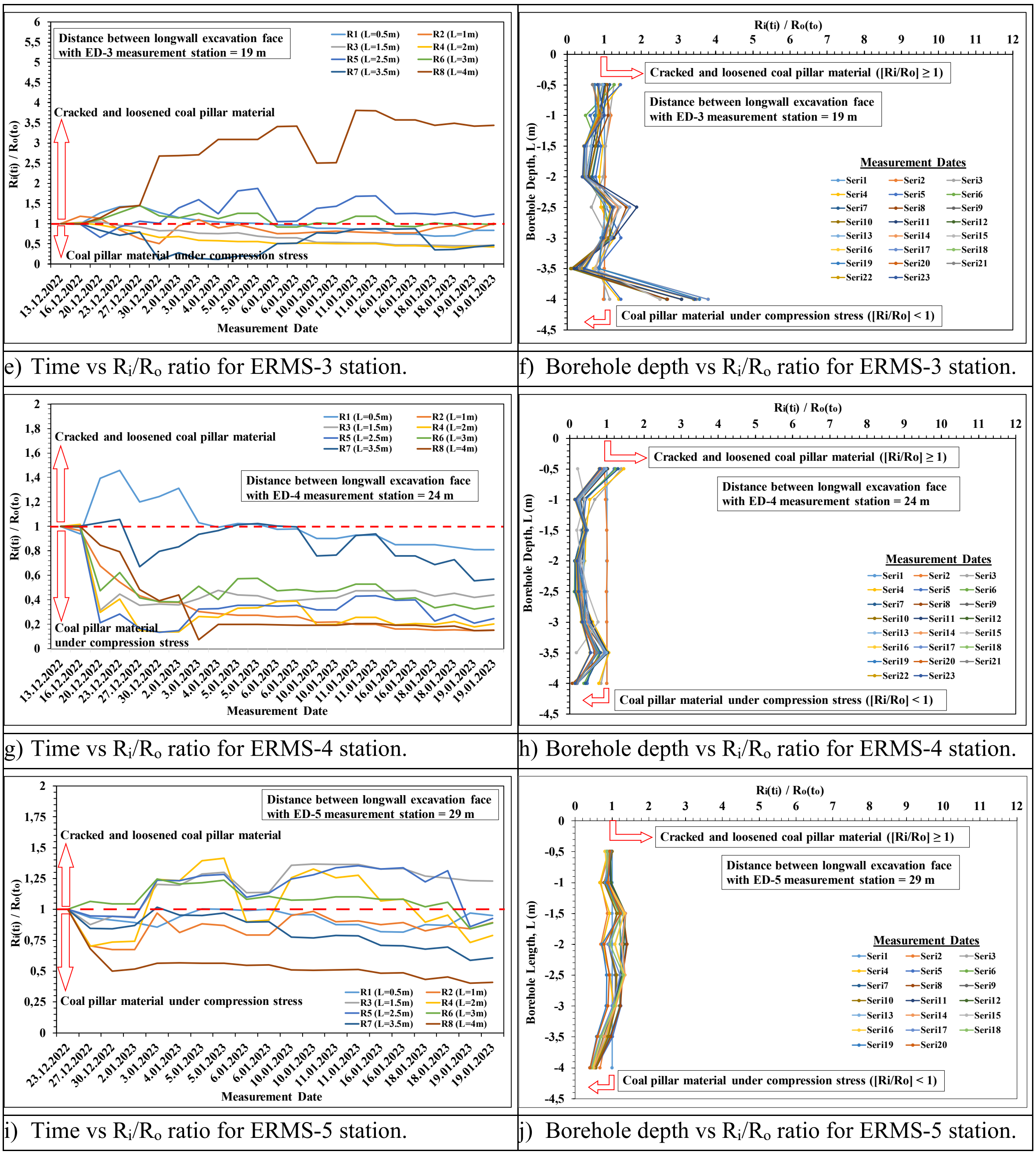
b) Borehole depth vs R_i/R_o ratio for ERMS-1 station.



c) Time vs R_i/R_o ratio for ERMS-2 station.



d) Borehole depth vs R_i/R_o ratio for ERMS-2 station.



e) Time vs R_i/R_o ratio for ERMS-3 station.

f) Borehole depth vs R_i/R_o ratio for ERMS-3 station.

g) Time vs R_i/R_o ratio for ERMS-4 station.

h) Borehole depth vs R_i/R_o ratio for ERMS-4 station.

i) Time vs R_i/R_o ratio for ERMS-5 station.

j) Borehole depth vs R_i/R_o ratio for ERMS-5 station.

Figure 3. Time vs electrical resistance ratio (R_i/R_o) behaviors and borehole depth vs electrical resistance ratio (R_i/R_o) behaviors obtained from ERMS measurement stations by in-situ monitoring.

5 CONCLUSIONS

This study includes the first results of the study carried out in a underground coal mine based on the laboratory test results performed previously. In the first stage of this study, a monitoring system named as ERMS was developed. In the second stage, five ERMS stations were installed on coal pillar in gate roadway of A6 panel.

In-situ measurement results showed that the electrical resistance values of the coal material under pressure decreased, in other words, the electrical conductivity increased. In addition, it has been understood that the electrical resistance values of the broken and loosened coal material increase. These results were obtained from the measurements at the measurement stations established at different distances to the longwall face. During monitoring period, longwall face was advanced only

2 m by drum shearer. It has been concluded that the first results based on in-situ ERMS monitoring are promising. By testing such measurements at different mine sites, the standard and limits of the ERMS measurement system can be determined.

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