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Diversity of Electrical Conductivity in a Water-Bearing Rock Material

M.K.Gökay & İ. Özkan
Department of Mining Engineering, Selçuk University, Konya, Turkey

ABSTRACT: The electrical conductivity of rock materials was analysed in order to develop practical laboratory-based measurement equipment. In order to proceed with the selected aim, artificial rock materials were prepared by using plaster of Paris. Test samples were prepared in two categories: the first was the original material; the second group of samples contained glass pieces. Glass pieces were located in the test samples in a certain pattern to simulate random joint orientation in natural rock masses. The tests showed that, electrical fields around the joints are higher due to their high water-bearing characteristics. This property was used in the tests to determine hidden joint locations in the selected rock masses and model samples provided. Underground gas, water or petroleum storage excavations or excavations opened for waste dumping are all sensitive to seepage of the gases or liquids both into them and out of them. Evaluation of these rock masses for joint occurrence requires at least seismic and electrical conductivity measurements. In this research study, alternative measuring techniques were investigated for laboratory and field test procedures. The resulting graphics obtained in the laboratory tests illustrate how the joints in the rock masses were detected in the samples.

1 INTRODUCTION

Electrical conductivity depends on free electrons or ions in a material, which increase the conductivity. Metallic substances are conductive due to their free orbital electrons. Rocks, on the other hand, are known as isolating materials due to their very high resistance to electron passage. If electricity is supplied to such a rock, it can not pass through easily. This can be occur only at very high voltages, such as 25-50 kV. At normal voltages, 110-220V, electricity constitutes electrical potential differences in water-bearing rock materials. There can be sectional differences in rock material where resistivity varies according to property and water content differences in those sections. Water, as a supplier of free ions, is particularly important. The differences in water concentration in a rock denote irregular free ion distribution in the rock material. Therefore, electrical conductivity in different sections of,the same rock mass can be different. The water content of the rock material depends on the material characteristics, such as porosity, permeability, and mineralogical and structural properties. Since there İs no existing rock mass without weakness zones or discontinuities, capillary action takes water from any part of the rock section to the other side. In particular, discontinuities behave like water passageways in the rock mass and they contain more water than the massive parts of rocks. This also means that there are more free ions in/around discontinuities, so electrical resistance values at these sections are expected to be tow.

Electrical conductivity measurements have been used in mineral exploration, cavity localisation, exploration of water-bearing formations and many other engineering applications. This technique was recently used in Konya, Turkey by MTA, a state-owned organisation, for the evaluation of natural hot water reserve extensions in a host rock mass, providing very important information used to establish a thermal health centre. In the present study, however, laboratory investigations were carried out using similar techniques for laboratory-size samples. The aims of this research are the determination of the water content of the rock samples and location of the sectional variation of water concentration in the same specimens by using electrical conductivity measurements. In order to achieve this, special laboratory apparatus was designed and prepared.

Electrical resistance is a material property which is dependent on the type of material tested. If the material allows electric current to pass through, its resistance (ohm) to electric current passage can be calculated by dividing the electrical potential differences (volt) between the material ends by the electric current flow rate (amper). If the test material is resistive to the passage of electrical current, when the current is applied to this material, there might be very low (or no) current passing through. However, if the required electrical potential differences are applied to these types of material, like rocks, electrical potential fields are created inside them. There are several measurement techniques that have been introduced to determine potential difference levels in the field. These are the gradient, dipole-dipole, pole-dipole, Wenner, and Schlumberger techniques (Long, etal., 1996).

The electrical potential field created by the given input voltage was then measured for different points. The electrical resistance of the tested sample was then calculated by following Ohm's law. The electrical resistance over a certain distance in sample *R* (Ohm.cm) is then equal to R=(Vp/I).(A/L). In this equation, Vp is the measured potential voltage (volt) between two selected points on the surface of the sample. The distance between the selected points is *L* (cm) and the current on the main input line is / (amper), which is very low in value. The label *A* stands for the-cross-section area (cm^2) in this equation.

The specific electrical resistivity of certain minerals has been determined using similar testing equipment (Figure 1). As can be seen in this figure, metallic material and minerals have relatively low resistivity values with respect to magmatic and silicified rocks.

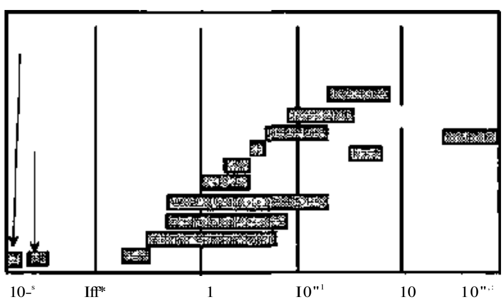

Figure 1. Specific electrical resistivity (Ωm) of certain rocks (Ergin, I973).

In fact, Ward (1990) listed the major effects of various geological processes on electrical resistivity. According to his study; clay alteration, dissolution, faulting, salt water intrusion, shearing and weathering decrease the specific electrical resistivity of the rock mass. He also listed the processes which increase electrical resistivity: induration, carbonate precipitation and sİlİcification. Metamorphism can result in either decreasing or increasing resistivity.

2 ELECTRICAL RESISTANCE MEASUREMENTS IN ROCK MATERIAL

During the preparation of the test instrument in this study, Wenner's four-point measurement technique was put into practice. As can be seen in Figure 2, the input DC voltage, which can be adjusted according to the rate required, was obtained by converting normal 220 ACV mains voltage in Turkey, This input voltage was applied to the selected samples as illustrated in Figure 2. The samples for this test were prepared so that they were cylindrical İn shape and the standard followed was similar to that for uniaxial compressive test sample preparation advised by the ISRM.

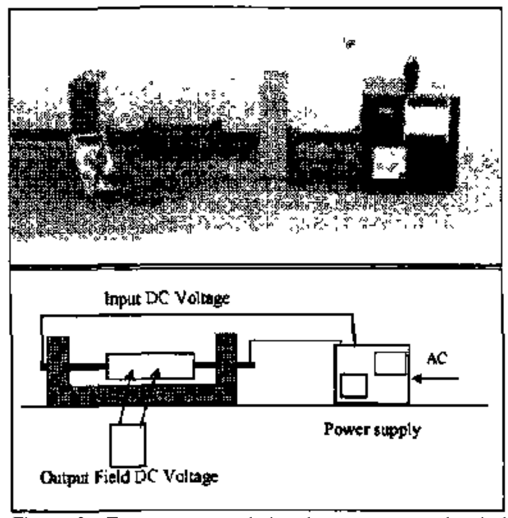

Figure 2. Test apparatus designed to measure electrical conductivity of the samples.

Since the resistance of dry rock İs so high, it was not possible to create an electrical field using normal input voltage (max. 350 DCV). In order to understand the conductivity of the dry rock, a 20cm-long cylindrical dacite sample (die diameter of the sample was 54mm) was tested for resistance to high AC voltages in the special test room of MED AS, the state-owned electricity distribution company for the Konya region. It was observed mat the test sample would resist 25-40kV AC. In order to facilitate electrical conductivity and enable the test to be conducted in normal laboratory conditions, the electrical conductivity measurements were performed with water-saturated samples. The electrical conductivity measured on die sample surface is then dependent on the water content of the samples. Water ions in the sample aid the formation of electrical potential fields in the rocks. Research on water has demonstrated that saline water (sea water) increases the electrical conductivity of the medium. Schlumberger (1989) gave the results of a research showing a decrease in the electrical resistance of a medium when the temperature and NaCl solution are increased in that medium. Rock mass absorbs water and the water content depends on porosity characteristics.

Electrical conductivity tests were also performed previously in the Mining Engineering Laboratory of Selçuk University with actual rock samples, using the prepared test apparatus. The results obtained from these tests (Figure 3,4) have proved that discontinuities and water content in rock material cause differences in electrical resistivity (Gökay & Özkan, 2000).

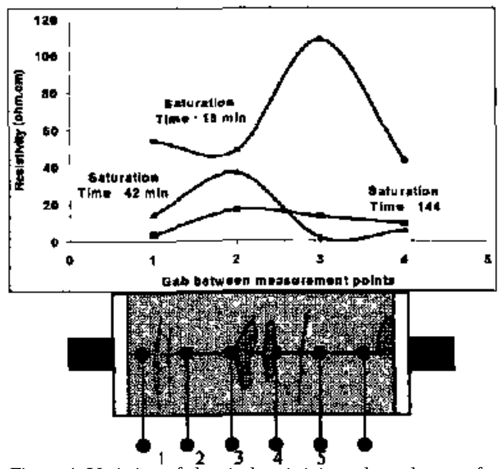

Figure 4 Variation of electrical resistivity values along surface of the limestone sample, discontinuities in the sample cause sudden increase or decrease at the resistivity, m between coincided measuring points (Gökay & Özkan, 2000).

3 ELECTRICAL RESISTANCE MEASUREMENTS IN MODEL MATERIAL

Since the actual rock mass consists of many irregulanties in the mineralogical and structural basis, it was decided that the same test procedures would be used with artificially prepared samples as well. In the research study presented here, the test samples were prepared artificially from plaster of Paris in order to control their structural homogeneity.

3.1 *Test sample preparation*

The test samples were prepared at the Rock Mechanics Laboratory of Selçuk University, Mining Engineering Department. In order to ensure the homogeneity of the prepared test sample, the following sample preparation steps were followed. First, moulds were prepared. Hard plastic pipe pieces

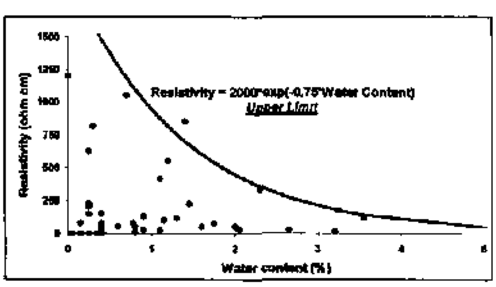

Figure 3. Relation between water content and electrical resistivity in a limestone sample (Konya region).

Second, special oily substances (wax)were used to grease the mould. This was to lessen the friction between the sample and the mould's inner surface. Thus, the samples would be removed from the moulds more easily. The main step in sample preparation was the mixing of homogeneous plaster of Paris powder with water so that liquefied plaster was obtained. This material was then poured into a specially prepared plastic mould and, once full, the mould was vibrated so that the material settled completely. The vibration and shaking actions forced any air bubbles present out of the mould. Then the mould and the material inside were allowed to dry for a short time (about two minutes). After this, the sample was forced out of the mould and put on a shelf in the laboratory. All the samples were then allowed to dry out completely on the laboratory shelves for as along as two weeks.

In order to create discontinuity surfaces in the prepared samples, glass pieces were used. They were selected because they can not absorb water. However, water fills the microvoids surrounding the glass plates when the samples are saturated. The glass pieces used for this purpose were 3mm thick with different dimensions according to the sample size. In general, they were rectangular and circular in shape. During preparation of the sample, the glass pieces were located horizontally or vertically in the sample. When the samples were removed from the mould for the final drying period, there was no sign of glass on the sample surface. They were totally hidden and buried in the samples.

After the samples had dried out, they were cut to required test size in the laboratory. All the samples, both with or without glass plates, were cut to 3 different sample sizes. These sizes were 46-127mm, 57-157mm and 71-196mm in diameter-length format. The samples were also labelled so that mey could be differentiated, label A was used for the samples without glass plates and labels B and C were used for the samples with glass plates.

3.2 *Mechanical characteristics behaviour of the model samples*

When all the samples were ready for electrical conductivity tests, some were separated for mechanical tests, while the others were tested for conductivity. During the test procedure, some of the test samples were destroyed" and it was not possible to obtain any measured values for them. However, most of the samples were tested as intended and the results were analysed for further engineering purposes. Therefore, the test samples prepared without glass plates were tested for their porosity, density and water absorption rate (Table 1,2). Since plaster of Paris is very sensitive to water, the test samples absorbed water very quickly as can be seen in Figure 5. Selected samples were also tested for their uniaxial compression and indirect tensile strength values, which were found to be in the ranges 0.54-3.79±1.10MPa and 0.10-0.33MPa respectively. The calculated average point load index, ïs{50), was 0.52 MPa and the anisotropy index was found to be 2.68.

3.3 *Electrical characteristic behaviour of the model samples*

After these mechanical characteristics had been determined, it was concluded that the prepared test samples were porous and their strength values were very low. Electrical conductivity tests were tien

Table 1 Density test results of model samples.

Sample #	Volume (cm^3)	Dry weight (Br)	Saturated weight (gr)	Dry density (gr/cm^3)
1	36.56	36 56	58 48	1.01
2	38 22	30.02	53.44	0.79
3	38.22	29.39	51.37	0.77
4	38.22	30.43	53 61	0.80
5	40.72	32.38	56 52	0.80
6	39.06	30.86	53 40	0.79
Average	38.50	3161	54 47	0.83

Table 2 Porosity test results of model samples.

Sample #	Sat. Density (gr/cm^3)	Σ (pore volume) (cm^3)	Water Saturation, (%)
1	160	21.40	58 52
2	1.40	23.42	61.26
3	1.44	21.98	57.50
4	1.40	23.18	60.63
5	139	24 14	59 29
6	137	22 54	57 72
Average	143	22 78	59 16

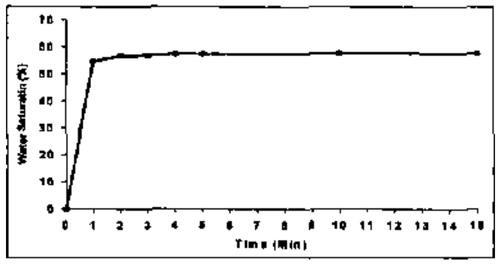

Figure 5 Water saturation characteristics of model samples

performed on test samples whose main strength characteristics had already been determined. Firstly, samples without glass plates (A group) were tested. A total of 12 samples were tested for electrical conductivity with 10 different levels of water content. Therefore, in these test a total of 1780 output voltage readings were measured and loaded into a data base using MS-Excel software. In the second group of tests, samples (total 11 samples) with horizontal glass plates (B group) were tested for electrical conductivity. Similarly, they were also tested with 10 different water contents, so a total of 1580 readings were taken for the purpose of characterising the second group of samples.

The result of the test readings were used to obtain characteristic features of electrical conductivity that could be used for further engineering purposes. Since the samples were specially prepared model material, the resulting electrical conductivity changes were determined exactly as the theoretical studies described. The samples without glass plates showed increased electrical conductivity only with increasing water content. The samples with glass plates, on the other hand, demonstrated valuable behaviour as previously obtained with limestone samples (Figure 4). Figure 6 shows one of the graphs obtaining from the test results of the B group samples, and it illustrates the relation between electrical conductivity and the saturation time of the sample. In this graph, it can be seem that there are two groups of curves. The curves situated in the upper part of the graph correspond to the measurements obtained from gaps which contain glass plates.

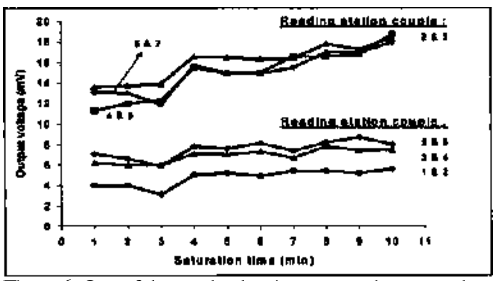

Figure 6. One of the graphs showing measured output voltage on B group samples with respect to saturation time

Thus, it was determined that the electrical conductivity was high compared to other gaps without glass plates. With regard to the curves in Figure 6, the reading points and input DC voltage were kept constant, while the water content of the tested models was increased. Then, as illustrated here, the measured output DC voltages increased as the water content increased.

If the same test data are plotted on a graph showing the changes in electrical conductivity along the surface of the test sample as output DC voltages between reading station points, it İs easy to evaluate the locations of discontinuities as seen in Figure 7. In this figure, modelled discontinuities (with glass pieces) corresponded to sudden conductivity increases between the readings of output potential field voltage. As shown in Figure 7, the glass piece locations in the sample appear with high peak voltage values. In addition, it was also determined that the water content increase in the test sample made the glass location on the resulting graphics more obvious. At the beginning of each conductivity test with samples (B group) of low water content, the resulting conductivity curves were smoother than those for values obtained from samples with high water content. These curves were rougher and conductivity values measured were high because water ions aid the formation of a high intensive electrical potential field.

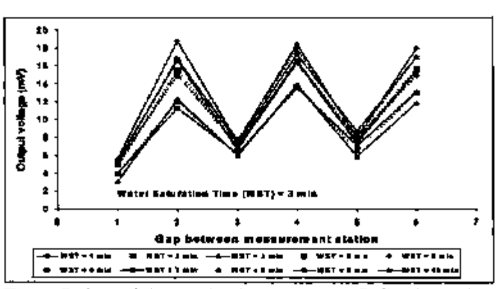

Figure 7. One of the graphs showing output DC voltage change in between the reading stations.

4 ENGINEERING USE OF ELECTRICAL CONDUCTIVITY

Electrical conductivity measurements in actual field work can be used in monitoring tasks. For example, country rocks surrounding galleries or 'equired excavations can be checked continuously by electrical conductivity props. After the idendification of problematic positions, these locations can be equipped with testing apparatus, as in the laboratory,

as shown in Figure 8. If readjusted measuring points on selected sample are connected to a computer base monitoring system which reads the output voltage between the station points and saves these data in a special database, the changes in output voltages in time can be obtained for any location whenever required. This helps engineers in field to visualise crack initiation and propagation through regular time base conductivity curves.

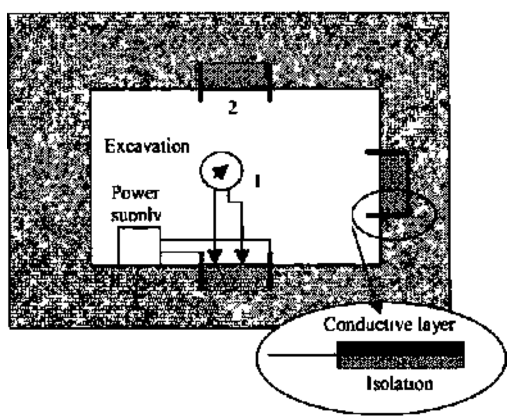

Figure 8 Momtonng task planned for excavation Any form of cracks initiated on excavation wall is detected through the output voltage (I), measured in continuous manner at problematic locations (2).

Cracks in any concrete blocks are also determined and monitored by designing special electrical conductivity measurement equipment. For this purposes, cracks in a concrete block which had been created through axial and lateral stresses in the Civil Engineering Laboratory of Selçuk University were analysed. It could also be supposed that these cracks are the result of a destructive earthquake. Electrical conductivity measurements were begun after permitting water absorption by the concrete block. Input DC voltages were supplied through metallic plates and the output voltages were obtained through points arranged as a net {Figure 9). When the resulting output voltages were plotted, it was found that higher voltage outputs corresponded to visible and invisible joints on/in the concrete block. This means that joints which could not be located with the human eye were also determined and positioned. This is valuable information for mining and civil engineers as part of their repair programs.

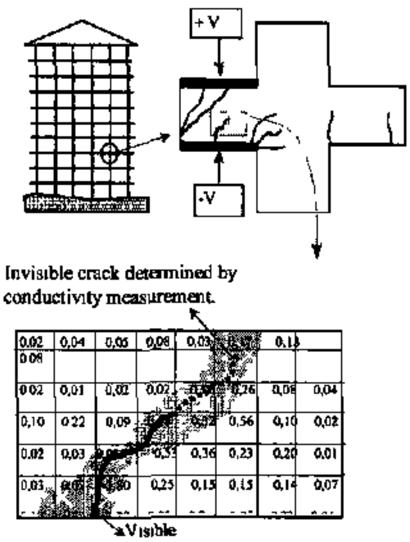

Figure 9. Monitoring of the cracks on concrete blocks.

5 CONCLUSIONS

In this research study, 81 test samples prepared from plaster of Paris were tested for electrical conductivity. Some structural and mechanical strength properties were also obtained for comparison with the test results. Since electrical conductivity measurements are not destructive in respect of test samples, this procedure has been used in many mining and civil engineering projects. Some research institutes have been using these measurement techniques for the localisation of the water-bearing strata or discontinuities. The measurement technique employed were implemented so as to develop laboratory-size apparatus for the localisation of inner joints in test samples. The aim was to apply the test procedure outcome during these works on artificial rock samples.

Since the original material (plaster of Paris, gypsum) in the sample İs sensitive to water, all the model samples reached maximum water content in a 4-5-minute time period. Strength test on the prepared model samples produced very low strength values, which is understandable if the porosity of the samples had been checked. The values were very high and influenced strength in a negative manner. The conductivity test results showed that when the water content in the model samples (A group) increased, electrical conductivity also increased. The relation between these two parameters depends on the porosity of the samples. The simulated discontinuity test samples (B and C groups) were also tested and the simulated discontinuity locations were estimated without mismatches. The graphics resulting from these tests indicated the location of the glass plates in the model samples. The test which were performed on concrete blocks were also found to be positive for determination of joint positioning. In addition, invisible joint surfaces were also determined from the electrical conductivity measurements. By applying electrical conductivity measurement techniques to mining and civil engineering projects more practically, engineers wilJ feel more confident in making engineering decisions.

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