Accounting for the Steel Lining Influence on the Results of Solid Rock Resistivity Probe from Development Working Boundary

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Abstract. When solving problems of predicting the hazards of solid rock bump and outburst in development and stope workings, the resistivity probe methods are often used, in particular, the four-probe method, in which electrodes are placed on the roof or the sill of the mine. The presence of steel lining in the mine significantly affects the measurement results until the complete collapse of electric field, so the electrodes are embedded into the rock. To obtain the true value of rock resistivity, it is necessary to make corrections due to the metal lining influence. This paper is devoted to the determination of these correction factors.

1 Introduction

Currently, the development of mining is associated not only with the improvement of mining equipment [1-3] and geotechnology [4-9], including mineral enrichment [10-12], but also with the introduction of information technologies [13-17]. This includes complex modeling of sustainability of rock arrays.

2 Materials and Methods

Consider a three-layer environment (Fig. 1), in which the layers are numerated as 1, 2, 3. The layer 3 is the rock layer enclosing the coal seam, the h-thickness layer 2 is a steel lining, the layer 1 is the roadway and the host rocks.

Let the current sources A and B, as well as the receiving electrodes M and N be located on the same line and be separated from the boundary of the layer 2 at a distance of z_1 (see Fig. 1). The probe arrangement is symmetric (see Fig. 1). Select the beginning of the cylindrical coordinate system in the current source A and direct the z axis in the direction of the layer 1. As is known [18], the solution of the Laplace equation in cylindrical coordinate system is expressed as follows

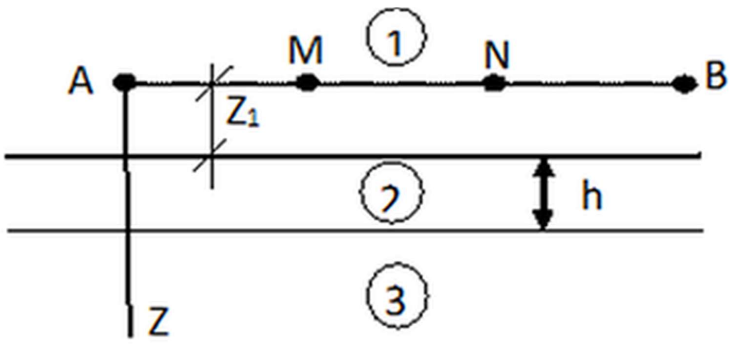

Fig. 1. Scheme of the calculation of the correction factor to the apparent specific resistivity when probing a solid rock from a steel-lined development working.

$$u_1^{(3)} = \frac{\rho_1 I}{4\pi}\int_0^\infty A_1 \exp(-\mathrm{m}\cdot \mathrm{z}) \mathrm{J}_0(\mathrm{m}\cdot \mathrm{r}) \mathrm{dm};$$
$$\mathrm{u}_2^{(3)} = \frac{\rho_2 I}{4\pi}\left[\int_0^\infty A_2 \exp(-\mathrm{m}\cdot \mathrm{z}) \mathrm{J}_0(\mathrm{m}\cdot \mathrm{r}) \mathrm{dm} + \int_0^\infty B_2 \exp(\mathrm{m}\cdot \mathrm{z}) \mathrm{J}_0(\mathrm{m}\cdot \mathrm{r}) \mathrm{dm}\right]; \tag{1}$$
$$u_3^{(3)} = \frac{\rho_3 I}{4\pi}\left[\int_0^\infty \exp(-\mathrm{m}\cdot |z|) \mathrm{J}_0(\mathrm{m}\cdot \mathrm{r}) \mathrm{dm} + \int_0^\infty B_3 \exp(\mathrm{m}\cdot \mathrm{z}) \mathrm{J}_0(\mathrm{m}\cdot \mathrm{r}) \mathrm{dm}\right],$$

where number 3 in the potential's superscripts means the layer's number, in which the current source A is located, the subscripts correspond to the potentials of the corresponding layers, $\rho_{1,2,3}$ – specific resistivity of the layers; I – the source current; $\mathrm{J}_0(\mathrm{m}\cdot \mathrm{r})$ - the zero-order Bessel function; $A_{1,2}$, $B_{2,3}$ - constant coefficients to be determined from the boundary conditions of the problem.

$$u_3^{(3)}\Big|_{r\to 0, z\to 0} = \frac{\rho_3 I}{4\pi\sqrt{r^2+z^2}}; \quad u_3^{(3)}\Big|_{z\to+\infty} = 0; u_1^{(3)}\Big|_{z\to\infty} = 0; \tag{2}$$

$$u_3^{(3)}\Big|_{z=z_1} = u_2^{(3)}\Big|_{z=z_1}; u_1^{(3)}\Big|_{z=z_1+h} = u_2^{(3)}\Big|_{z=z_1+h};$$

$$\frac{1}{\rho_3}\frac{\partial u_3^{(3)}}{\partial z}\Big|_{z=z_1} = \frac{1}{\rho_2}\frac{\partial u_2^{(3)}}{\partial z}\Big|_{z=z_1}; \frac{1}{\rho_2}\frac{\partial u_2^{(3)}}{\partial z}\Big|_{z=z_1+h} = \frac{1}{\rho_1}\frac{\partial u_1^{(3)}}{\partial z}\Big|_{z=z_1+h}. \tag{3}$$

3 Results and Discussion

The first three boundary conditions automatically hold by virtue of writing the solution in the form (1). Substituting equations (1) into the remaining boundary conditions (2.3), we obtain a system of equations for arbitrary constants $A_{1,2}$, $B_{2,3}$:

$$\begin{aligned} & 1+B_3\exp(2\,\mathrm{mz}_1)=\frac{\rho_2}{\rho_3}\left[A_2+B_2\exp(2\,\mathrm{mz}_1)\right]; \\ & A_1=\frac{\rho_2}{\rho_1}\left[A_2+B_2\exp(2\,\mathrm{m}(\mathrm{z}_1+\mathrm{h}))\right]; \\ & A_1=A_2-B_2\exp(2\,\mathrm{m}(\mathrm{z}_1+\mathrm{h})); \\ & \mathrm{B}_2\exp(2\,\mathrm{mz}_1)-\mathrm{A}_2=B_3\exp(2\,\mathrm{mz}_1)-1. \end{aligned} \tag{4}$$

Introduce the layers' reflection coefficients by the formulas

$$k_1=\frac{\rho_2-\rho_1}{\rho_2+\rho_1},k_3=\frac{\rho_3-\rho_2}{\rho_3+\rho_2}. \tag{5}$$

Then the solution of the system of equations (4) is given by

$$\begin{aligned} & A_2=\frac{2\exp(2\,\mathrm{mh})}{k_1k_3+\exp(2\,\mathrm{mh})};B_2=-\frac{2k_1\exp(-2\,\mathrm{mz}_1)}{k_1k_3+\exp(2\,\mathrm{mh})}; \\ & B_3=\frac{(\mathrm{k}_1\mathrm{k}_3-2\,\mathrm{k}_1)\exp(-2\,\mathrm{mz}_1)-\exp(2\,\mathrm{m}(\mathrm{h}-\mathrm{z}_1))}{k_1k_3+\exp(2\,\mathrm{mh})}; \\ & A_1=\frac{2(1+\mathrm{k}_1)\exp(2\,\mathrm{mh})}{k_1k_3+\exp(2\,\mathrm{mh})}. \end{aligned} \tag{6}$$

Since the specific resistivity of the layer 2 (steel lining) is zero, then

$k_1=-1; k_3=1.$

It follows that $B_3=-\exp(-2\,\mathrm{mz}_1)$.

Substituting this coefficient into the solution for the potential of the third layer gives

$$u_3^{(3)}=\frac{\rho_3 I}{4\pi}\left[\int_0^\infty \exp(-\mathrm{m}|z|)\mathrm{J}_0(\mathrm{m}\,\mathrm{r})\mathrm{dm}-\int_0^\infty \exp(-\mathrm{m}\,\mathrm{z}_1)\mathrm{J}_0(\mathrm{m}\,\mathrm{r})\mathrm{dm}\right], \tag{7}$$

From where it is obvious that the potential of the third layer does not depend on the thickness of the second layer, i.e. does not depend on the thickness of steel lining

Both integrals in equation (7) are Weber integrals and are easily evaluated. Suppose that the solid rock (layer 3) is probed practically from the border of layers 2 and 3, the depth of the electrodes (Fig. 1) in layer 3 is equal to z_1, the distance from current sources A, B to measurement points M , N is much larger than the coordinate Z , that is $r = z$. Then the solution (7) can be written as follows

$$u_3^{(3)} = \frac{\rho_3 I}{4\pi r}\left[1 - 1/\sqrt{1 + (2z_1/r)^2}\right]. \tag{8}$$

This solution shows that when the depth of the electrodes is equal to zero, i.e. $z_1 = 0$, the field completely collapses; therefore, to eliminate the effect of metal lining, it is necessary to embed the electrodes in the roof (sill) of the roadway.

Let's now calculate the apparent resistivity of the layer 3 when it is probed by the symmetric four-electrode arrangement shown in Fig. 1, we obtain the potential difference between the electrodes M , N

$$\Delta u_3^{(3)} = u_{3M}^{(3)} - u_{3N}^{(3)} = \frac{\rho_3 I}{4\pi}\begin{bmatrix} 1/AM - 1/BM - 1/AN + 1/BN - 1/\sqrt{AM^2 + 4z_1^2} + \\ 1/\sqrt{BM^2 + 4z_1^2} + 1/\sqrt{AN^2 + 4z_1^2} - 1/\sqrt{BN^2 + 4z_1^2} \end{bmatrix}. \tag{9}$$

Taking into account that

$AM = BN, AN = BM, AN - AM = BM - BN = MN,$ will get

$$\Delta u_3^{(3)} = \frac{\rho_3 I}{2\pi}\left[1/AM - 1/AN - 1/\sqrt{AM^2 + 4z_1^2} + 1/\sqrt{AN^2 + 4z_1^2}\right]. \tag{10}$$

According to the well-known resistivity prospecting formula [1], we consider the apparent specific resistivity of the layer 3

$$\rho_k = \frac{2\pi\Delta u_3^{(3)}}{I(1/AM - 1/AN)} = \rho_3\left[1 - AN/MN\sqrt{1 + (2z_1AM)^2} + AM/MN\sqrt{1 + (2z_1AN)^2}\right] = C_n\rho_3.$$

4 Conclusion

Thus, in order to obtain the true value of the specific resistivity of the host rocks, it is necessary to divide the resulting apparent specific resistivity by the correction factor C_n

$$C_n = \left[1 - AN/MN\sqrt{1 + (2z_1AM)^2} + AM/MN\sqrt{1 + (2z_1AN)^2}\right]. \tag{11}$$

The last formula includes the distances between the electrodes of a four-probe symmetric arrangement and the depth magnitude of the electrodes (see Fig. 1).

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