APPLICATION OF SYNTHETIC MINE GEOPHYSICAL PROSPECTING TECHNIQUE IN DETECTING COLLAPSE COLUMNS

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ABSTRACT

A synthetic mine geophysical prospecting technique for detecting the collapse columns is put forward. It is well known that the radio wave penetration can ascertain the relative position of abnormal structures (such as collapse columns, faults, and the thinning area of a coal seam) within coal seams, while the mine transient electromagnetism (TEM) method can be used to make clear the water-rich situation of an abnormal structure based on the variation of resistivity. The application of both the radio wave penetration method and the TEM method in detecting the abnormal structure in 7218 working face is introduced. At the same time, that the electrical characteristics of water-bearing structures can be obviously reflected by radio wave penetration is expounded theoretically. In addition, the application of synthetic curve analysis and tomography in data interpretation is researched. Finally, the hydro-geological features reflected by the V-shaped and the half V-shaped curves are summarized.

Key words: synthetic mine geophysical prospecting technique; radio wave penetration; mine TEM; collapse column.

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INTRODUCTION

Hazardous geological abnormal bodies such as collapse column and its associated structures are often seen in coal mining. They affect the continuity of coal seams and often induce water disaster, resulting in accident of water burst. The collapse columns may not only cause accident, threatening miner's life, but also decrease the economic efficiency of a coal mine. Therefore, to summarize the development rule and find out a geophysical prospecting method suitable for mine geological conditions so as to quickly make clear the influence area of collapse columns is of vital importance. The formation of collapse columns in a coal mine is closely related to the development of Karst fractures of the Ordovician limestone. The development and enlargement of Karst fractures cause the surrounding strata to subside, which makes the filling materials within the collapse column be very complex in component and loose in structure; in addition, the normal formational sequence become disordered, leading to obvious difference in physical property such as density, velocity, radioactivity between collapse column and coal seam. These differences have provided a theoretical premise for using the mine geophysical technique to detect the geological abnormal bodies. At present, the main geophysical prospecting technique for detecting collapse columns includes the radio wave penetration method and the electric-resisrivity technique, and the latter includes the mine DC electric method and the mine TEM method.

PRINCIPLE OF RADIO WAVE PENETRATION METHOD

The radio wave penetration method is also called the tunnel perspective method. Different rocks and ores have different electrical properties such as resistivity ρ and dielectric constant ε and so they are different in absorbing the electromagnetic wave energy. Low resistivity rock has a good ability in absorbing electric wave. Meeting the interface of a fault structure, the electric wave will be reflected or refracted, leading to an energy loss. Under mine geological conditions, when the emitted EM wave reaches the faults, collapse columns, water-bearing fractures, the thinning area of coal seams as well as other structures, the wave energy will be absorbed or completely shielded, making the transmission signal very weak or even not able to be received by the receiver in receiving roadway, resulting in forming a perspective abnormal area which is the location and range of the geological abnormal body to be detected.

At present, available apparatus can only detect the amplitude component of the transmitting EM wave with a constant frequency. The change in electromagnetic property of medium and in wave impedance on the EM wave-path results in a change of electromagnetic field strength. Therefore, based on analyzing the change in electromagnetic field strength, we can know the change in physical properties of media in the detected area.

The electromagnetic field intensity of EM wave at any point of the coal seam can be expressed as:

$$E = E_0 \frac{e^{-\beta r}}{r} \sin\theta \qquad (1)$$

where E is the measured intensity at a certain point, μV; E_0 the initial radiation field intensity of the surrounding medium which determines the transmitting power, μV; r the distance between the transmitter and the receiver, m.; β the absorption coefficient of medium determined by working frequency, resistivity of medium, and dielectric constant, neper/m; and θ the angle formed by the transmitting antenna axis and the observing direction.

Obviously, E changes with r and β, of which the β on the ray path is the key factor for the abnormal change of E.

$$\beta = \omega\sqrt{\mu\varepsilon} \cdot \sqrt{1/2[(1+\sigma^2/\omega^2\varepsilon^2)^{1/2} - 1]} \qquad (2)$$

From formula (2) we can see that, when the frequency is a constant ($\omega = 2\pi f$), β is the function of dielectric constant ε of coal or rocks, magnetic inductivity μ, and conductivity σ. The difference in dielectric constant between roof and floor is very big while that of magnetic inductivity is very small. Therefore, when the EM wave passes through alternative coal seam and rock strata, β and E will have an obvious change. In addition, coal seam, as compared with its roof and floor, is a waveguide medium, which means that, when the thickness of coal seam changes (such as thinning), its wave impedance will also change, resulting in the change of β and E.

Being different in electrical parameters (ρ and ε, etc.), the collapse columns and other geological abnormal structures are also different in absorbing EM wave energy, with the low resistivity rocks being better in absorbing the EM wave energy as compared to the high resistivity rocks. In addition, the fault interfaces will refract or reflect the EM wave, leading to a loss of EM wave energy. Therefore, between the transmitter and the receiver, the EM wave energy will be absorbed or completely shielded by collapse columns, faults, igneous rocks, and thick horses. Then, by using the tomography method to process the collected data, we can have a visual distribution about the abnormal geological structures within the coal working face.

PRINCIPLE OF MINE TEM METHOD

For the TEM technique, the ungrounded loop-lines are used to transmit the primary field toward the surrounding rocks of a roadway. When the transmitting loop lines are power off, the electrical medium in surrounding rocks will form secondary field because of the abrupt disappear of the primary field. The magnitude and decay rate of the secondary field are related mainly to the electromagnetic property of the underground medium. Therefore, using the receiver coil to measure the change in induced electromotive force of the secondary field with time, we can make clear the change in magnetic property of the medium and, on the basis of this, make certain the abnormal structure including its size, occurrence, and distance to roadway. An rectangular transmitter coil with an area of *S*, a conductivity of σ and a magnetic conductivity of μ_0 was placed in an isotropic space (Figure 1.).

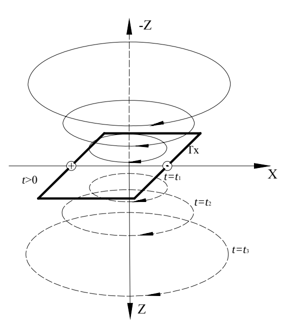


Figure 1.: Diagram of ring-like distribution of underground induction current.

As is seen in Figure 1., the transmitter coil is supplied with the step pulse current $I(t) = \begin{cases} I & t < 0 \\ 0 & t \geq 0 \end{cases}$. Before the current is turned off, the transmitted current forms a stable magnetic field surrounding the coil. At the moment of t=0, turning the current off abruptly will make the magnetic field disappear immediately. Such a rapid change will be transmitted back to the surround rocks, producing some induction current to temporarily maintain the magnetic field formed before, making the spatial magnetic field do not disappear immediately. Because of the ohmic loss of the medium, such induction current will be rapidly attenuated and this rapid attenuation will induce some new but much weaker eddy current. This process keeps going on till the energy becomes exhausted by the ohmic loss. This process is the so called transient electromagnetism process and the electromagnetic field accompanying this process is called the transient electromagnetic field.

The sedimentary sequence of coal measures is quite clear. Therefore, the conductivity of the original strata has a regular change vertically and is quite uniform horizontally. For the structurally fractured zone, if it does not contain any water, then it is poor in conductivity and its local resistivity will increase; if it is enriched with water, it is good in conductivity, which is equivalent to a local geological abnormal body with a low resistivity. To sum up the above arguments, if faults, fractures, and collapse columns exist within the roof and floor, no mater containing water or not, they will certainly break the variation rule of electric property in both vertical and horizontal directions. It is this breakage in variation rule of electric property that provides a good condition for using the TEM method to detect the abnormal geological bodies.

CASE STUDY

The collapse column is obviously different in electric property from the surrounding coal seams and rocks and the collapse column containing water is usually lower in resistivity than coal seams, which provides a physical basis for using the resistivity method. The formation of collapse column is usually accompanied by the change in occurrence of the adjacent coal seams, the development of fractures, and the water filling in large quantities within coal seams and fractures of roof and floor. Water-bearing structures can directly absorb the EM wave energy, which can be clearly reflected in radio wave penetration curves, providing the necessary physical conditions for using the radio wave penetration method to detect the concealed geological structures within the coal working face.

The 7218 working face in a certain coal mine of Wanbei Mining Area is 820 m in length and 150 m in width with a coal seam dip of 10°. The coal seam is stable in thickness, averaged by 4.8 m and is massive with fragments, interbeded by a layer of carbonaceous mudstone. After the driving task has been finished, no large water-bearing abnormal structure is seen in roadway and in the open-off cut. However, the water is found with small amount in the upper area of the coal seam, 80~100m far from the head of the conveyor roadway, and in a large area of the roadway the water flows out with a volume of 3~5m^3/h.

In order to detect the concealed abnormal geological structure, both of the two methods, the radio wave penetration and the mine TEM were immediately used (Figure 2. and Figure 5.).

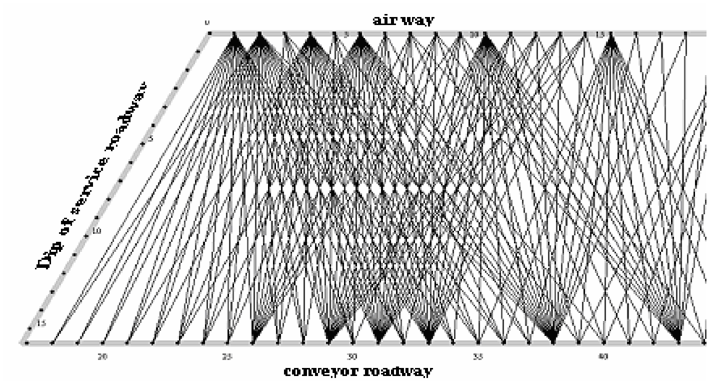


Figure 2.: Diagram of radio wave penetration rays for working face.

12~19 times of fixed point coverage detection was carried out using the radio wave penetration technique, and the interval of receiving points is 10 m, that of transmitting points is 20~50m, and the working frequency is 0.5 MHz. The received radio EM signal shows that there is an obvious abnormal zone in the upper of the conveyor roadway head, whose abnormal attenuation is (13~)38db. Figure 3. shows the fixed point observing curves (only the field intensity curve of the synthetic curves was analyzed) of which (a), (b), and (c) are the field intensity curves received in the conveyor roadway transmitted from points 1, 5, and 15 in the air way, while (d) is the field intensity curve received in the air way from the transmitted point 25 in the conveyor roadway. Curves of Figure 3a and Figure 3b are V-shaped or half V-shaped. The reason for forming the V shape is that the field intensity signal of the receiving points situated in the middle area is absorbed by the low resistivity abnormal body, while that for forming the half V shape is that such signal is affected on only one side. The field intensity curve in Fig. 3c is nearly the same as the theoretical one, showing that no low resistivity abnormal geological tructure exists between the area of the transmitting point and the receiving point. In Fig. 3d, the field intensity is small and we can also see the V-shaped curve, indicating that the whole area from the transmitting point to the receiving point is affected by a low resistivity abnormal body, which is different from that in Figure 3a and b. The above arguments indicate that the low resistivity geological abnormal structure is quite close to the conveyor roadway. By using the synthetic curve analysis and the tomography technique, we have obtained the interpretation result (Figure 4.). In Figure 4., there is a collapse column within the area of 70~110m from the roadway head and 20 m from the conveyor roadway, which has been well verified by the later mining practice.

From the radio wave penetration data of 7218 working face we can see that the attenuation value is -33 to -38db in the central area while the attenuation extent decreases toward the surrounding area and becomes -13~-33 db at last. The collapse column is located in central area of the working face, which is favorable for the detection in both of the two roadways. The synthetic field intensity curves (radio wave penetration) near the collapse column shows typical hydrological features such as half V shape, V shape, and funnel shape because the positions of transmitting points and receiving points relating to the collapse column changes dynamically, leading to the change in positions through which the EM wave penetrates. In the case that the transmitting point is near the collapse column, the received field intensity is far lower than the theoretical value, showing a low value response.

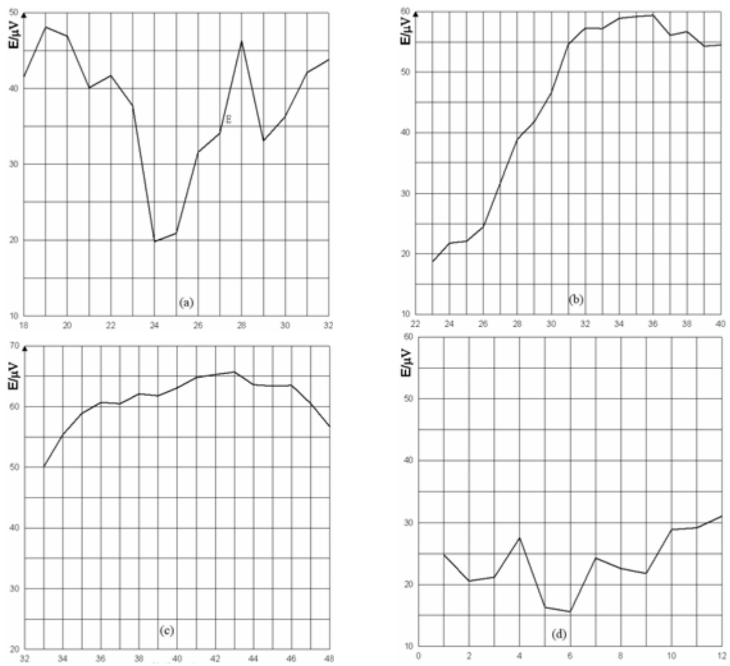


Figure 3.: Field intensity curves based on radio wave penetration technique.

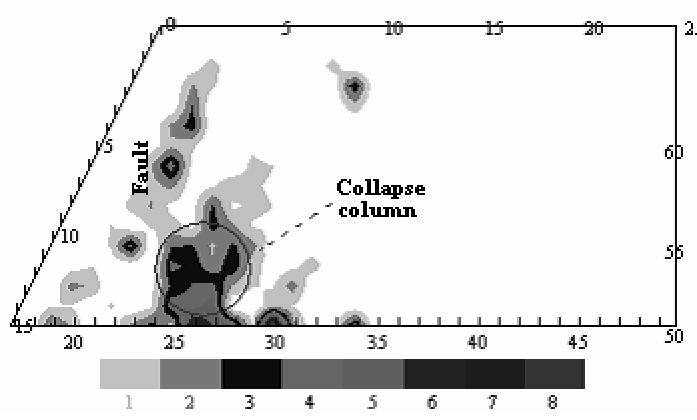
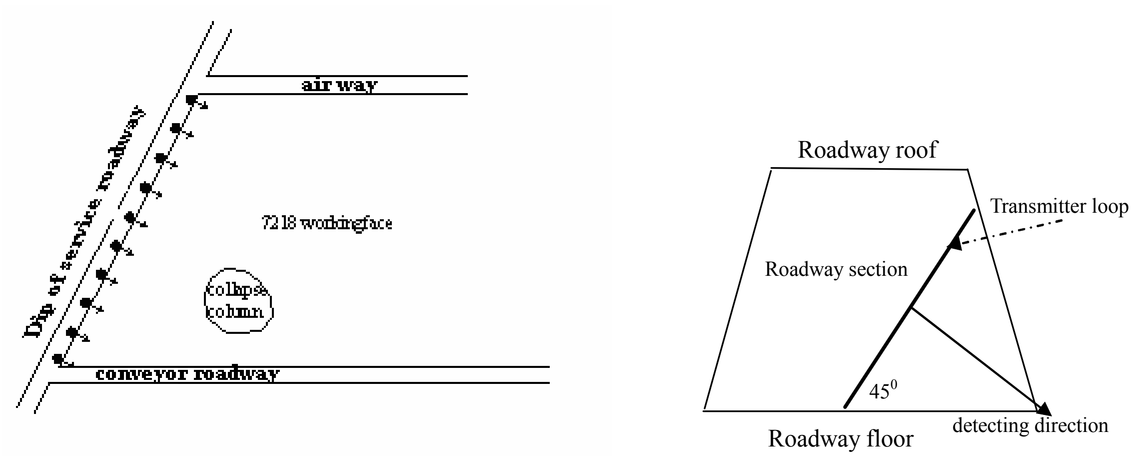


Figure 4.: The apparent tomography image of 7218 working face.

The water abundance and its position obtained by the radio wave penetration method were further confirmed by the mine TEM method. The detecting point of the mine TEM is in the service roadway between the airway and the conveyor roadway and a 2m×2m overlapping loop line combination was selected (Figure 5.).



(a) Sketch map of working face. (b) Detecting direction.

Figure 5.: Diagram of collapse-column and detecting direction.

Based on the theory of "smoke ring effect" of full space TEM transmission, the body detected by the TEM method is cone-shaped. In coal mine, the TEM method has a full space response, so the volume to be prospected is composed of two symmetric cone-shaped bodies with loop line being the symmetric axis. In the initial stage, it is mainly the short distance response because of shallow in detecting depth. So it is basically limited in coal seam or part of the roof and floor rocks, making the horizontal change be quite less and horizontal change be uniform in apparent resistivity isoline. With the time going on and the increase in prospecting volume and distance, the area dealt with coal seam and its roof and floor is enlarged and the electric property becomes complicated. In the pseudosection map of apparent resistivity isolines, there is a low resistivity abnormal zone with a width of 40 m (30~70m) located in the area about 50 m far away from the dip of service roadway, whose apparent resistivity isoline shows a semi-closed form. This low resistiivity zone is in good accordance with that reflected by radio wave penetration method, which is interpreted, based on some related geological data, as the collapse column. The apparent resistivity depth isolines calculated based on time is shown in Figure 6.

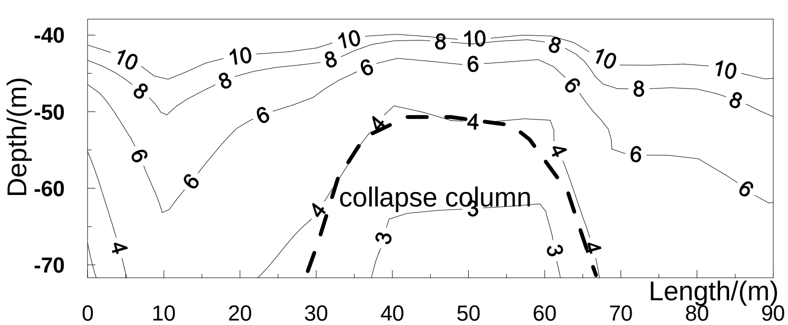


Figure 6.: Apparent resistivity section of collapse column.

In order to make certain the area and features of the collapse column, 5 boreholes were designed in different positions of roadway. The synthetic analysis based on core data and on water seeping position shows that the abnormal body is a collapse column with a radius of 40 m, 50 m far away from the dip of service roadway, and 20 m from the conveyor roadway. This is in good agreement with the result of using the mine TEM method and the radio wave penetration method.

CONCLUSION

Practice shows that the geophysical prospecting has advantages of high efficiency and low cost and so it is widely used in detecting collapse columns in coal mines. Based on the technical level, the use of several geophysical prospecting techniques is recommended. By doing so, the interpretation error resulted from using only one method can be avoided. However, we should keep accumulating experiences and exploring the correct interpretation method so as to improve the accuracy of data interpretation. In addition, the geophysical prospecting is closely related to geology, which means that, in detecting geological abnormal bodies, the data of geology, hydrology, and geological drilling should be taken into consideration to obtain good detecting result and to meet the needs of safety in coal mining.

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