Earth Current Field Information Transmission Technology

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Starting from the need for emergency rescue information transmission in tunnel engineering accidents focuses on researching and solving the technical problems of information transmission between rescue personnel and trapped personnel after tunnel engineering collapse accidents, before and during the rescue process.

grounding electrode
current field
information transmission
channel characteristics
electrical performance

1. Introduction

Tunnel engineering has the characteristics of being "long, narrow, curved, and deep", and belongs to limited space; During the tunnel excavation process, especially before the completion of the inverted arch and secondary lining, collapse accidents often occur; After the accident, the thickness of the collapsed rock and soil between the tunnel entrance and the construction face is generally 30–80 m. This type of "closed-door" collapse will form an underground enclosed space between the tunnel construction face and the collapsed body, causing the construction personnel on the tunnel face to be trapped. Because their external information transmission link is completely "cut off" by the collapsed body, it poses great difficulties for the rapid rescue of tunnel engineering. As shown in **Figure 1**.

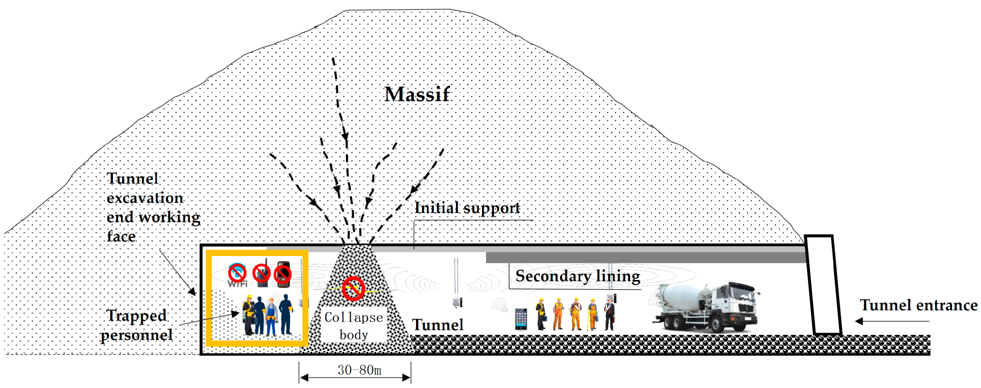

Figure 1. Schematic diagram of collapse accident status in tunnel engineering.

Through comparative analysis of theoretical and practical research results in relevant fields both domestically and internationally, the use of earth electrode current field information transmission technology is currently the only effective way and method to solve the problem of information transmission between rescue personnel and trapped personnel during tunnel engineering collapse, pre rescue, and rescue processes.

The current field information transmission method of the earth electrode is a method of using extremely low-frequency electrical signals to be applied to two electrodes inserted into the earth's soil layer, thereby forming a current field in the rock or soil layer. Wireless information transmission is achieved through signal detection at the receiving end. The essence of the earth electrode current field information transmission mode is to use the electric field current to carry information data. When the carrier frequency is low, the field current is mainly a conducted current, but when the carrier frequency is high, the field current is mainly a displacement current. At this time, the circuit formed by the wire, electrode, and earth is equivalent to a ring antenna, therefore the essence is also near-field electromagnetic wave information transmission.

The process of electromagnetic wave transmission in terrestrial channels is relatively complex, and it is influenced by non-uniform media. Electromagnetic waves interact with the media, producing various electromagnetic effects such as polarization, magnetization, and conduction. The impact of these electromagnetic effects on the transmission of electromagnetic waves is mainly evident in the reflection, refraction, and attenuation of electromagnetic wave signals. The inhomogeneity of the earth medium, the impact of geomorphic features, and multi-path transmission will cause signal distortion, attenuation, or changes in the direction of electromagnetic wave propagation. The strong penetration depth of the earth electrode current field information transmission method is related to factors such as the conductivity of the formation, signal frequency, current intensity injected into the earth, contact impedance between the electrode and the soil, and the material and shape of the electrode. The sensitivity of the receiving host is related to the distance between the receiving electrodes and the contact impedance between the electrode and the soil. The greater the distance between the two electrodes, the greater the detected voltage value; the smaller the contact impedance between the electrode and the soil, the higher the detected voltage value [1].

2. Earth Current Field Information Transmission Technology

In recent years, many experts, and scholars from around the world have conducted research on the transmission technology of geomagnetic field information and its applications in related fields.

From 2009 to 2016, V Bataller and A Munoz et al. investigated the issue of contact impedance in a strong penetration information transmission mode based on current field propagation and pointed out that the effective information transmission distance is related to factors such as the conductivity of the rock and soil layer, the input signal frequency, the current intensity injected into the earth, and the material and shape of the electrode. In 2015, Van L. and Sunderman C., et al. studied a channel attenuation model based on electrode strong penetration information transmission. Considering noise interference and signal attenuation characteristics, the receiver sensitivity and transmitter power required for information transmission were calculated, and the field distribution model of the earth electrode strong penetration information transmission system in a uniform half-space was derived. The configuration scheme of the receiver and transmitter was provided. In 2016, Yan L, Zhou C, Miguel R et al. established and simulated a signal attenuation model to investigate the significant impact of signal attenuation characteristics on receiver sensitivity, transmitter antenna length and direction, and operating frequency on Earth. At the same time, a prototype was used for testing, and the results of the simulation and testing were very similar. In 2017, Yan L., Zhou C., Reyes M., et al. proposed a fully executable solution for three electric field components for electrode-based TTE information transmission. In 2017, Damiano N., Yan L., Whisner B., et al. studied the current injection and contact impedance characteristics of very low frequencies by analyzing recent simulation and measurement results from the National Institute of Occupational Safety and Health (NIOSH) in the United States and discussed the main factors affecting electrode based low-frequency information transmission systems. In 2017, Maxim Ralchenko, Mike Roper, et al. of the University of Carlton in Canada discovered the presence of low-frequency signals on two slender conductors near the transmitter, which may greatly increase the signal transmission distance. To better explore this phenomenon, they conducted many experiments and simulations. Simulate slender conductors with thin wires or use railway tracks or elevator shafts. By measuring the three magnetic field components near the conductor, it was found that there is a coupling effect in the signal, which is caused by the current inside the slender conductor. This discovery can be used to predict the feasibility of strong penetration information transmission links in different settings and optimize the positions of the transmitting and receiving ends [2][3][4][5][6].

In 2010, Wu Zhiqiang et al. designed an underwater electric field communication system based on a digital signal processor (DSP) and conducted experimental verification. In 2010, Wang Dandan et al. proposed using a constant flow field model as a model for underwater current field communication, obtained the relationship between input and output, and analyzed the advantages of current field communication methods. In 2012, Zhang Xinguo et al. analyzed and studied the effect of electrode size on the electric field of ring electrodes. In 2014, Su Baoping established an underwater current field communication channel model and analyzed the relationship between received signals, transmission voltage, communication distance, and other parameters. In 2015, Li Panfeng applied current field communication technology in the Xiaolangdi hydrological operation of the Yellow River, verifying the reliability of the technology. In 2016, Geng Weizhi et al. studied the conduction current field theory of electromagnetic information transmission based on the conduction current field theory and established a simulation model. Based on this, they completed the design and implementation of the transmitting end of the current field mine’s strong penetration information transmission system. It is believed that wireless information transmission of conducted current field is a relatively reliable and effective method for emergency information transmission. In 2021, Liu Baoheng conducted mathematical modeling and analysis of the current field through the ground communication electric field, achieving information transmission distances of over 300 m. In 2021, Zhang Yixin et al. proposed an equivalent circuit for communication channels based on the characteristics of water bodies. Through finite element simulation, the transmission path and electric field distribution of electrical signals were analyzed, and the effects of practical factors such as communication distance, electrode plate depth, water width, electrode plate size, water conductivity, and dielectric constant on the equivalent circuit parameters were simulated and calculated. In 2022, Liu Zhimin and others conducted a forward simulation of the focusing and deflection effects of DC-focusing multi-point power supply detection. According to the mechanism of focused electrical detection, the finite element method is used to solve the potential of each node in the spatial multipoint power field, and the electric field line differential equation of the spatial field is derived. In 2022, Wang Feng et al. conducted research on AUV path planning for optimal energy velocity in current fields. In 2023, Zhao Jun and others used finite element methods to solve the normal and abnormal potentials of spatial fields. Based on COMSOL Multiphysics software, a uniform three-dimensional geoelectric detection model was constructed and segmented using a tetrahedral mesh adaptive algorithm. Researchers compared and analyzed the accuracy of numerical solutions, studied the distribution and changes of the focusing current field, and determined the range of influence of the focusing effect on the current ratio coefficient. In 2023, Xu Zhan et al. studied the transmission characteristics of wireless strong penetration information in the horizontal direction of the earth electrode current field based on an extremely low frequency horizontal dual electrode current field channel. Considering the effects of parameters such as electrode radius, electrode penetration depth, electrode spacing, transmission signal frequency, and signal transmission distance on the transmission performance of Through the Earth (TTE) communication, a TTE communication path loss model for the earth electrode current field was established, Analyzed the impact of various parameters on path loss and determined the optimal operating parameters for signal transmission. An extremely low-frequency current field TTE communication system was constructed based on selected parameters. The path loss of 3–10 Hz signals was tested at communication distances of 200 m and 400 m. The accuracy of the model was verified through comparative analysis of experimental data and simulation results [7][8][9][10][11][12][13][14][15][16][17].

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