The Application of Three-Dimensional High-Density Electrical Method in Detecting Vertical HDPE Membranes at Landfill Sites

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Abstract. Landfilling is one of the important methods in hazardous waste treatment. In order to prevent the landfill leachate from connecting with external groundwater and prevent leachate from flowing into external polluted water bodies and soil, vertical anti-seepage membranes will be installed along the perimeter of the reservoir area. Given the structural characteristics of vertical HDPE membranes and site conditions, this study proposes the application of three-dimensional high-density electrical resistivity (3D-HDER) tomography for the detection of these membranes. Compared with the traditional resistivity method, the high-density resistivity method can realize automatic switching of electrode device type, electrode spacing and measuring points during the measurement process, thereby improving detection accuracy and work efficiency. By employing 3D-HDER for data collection on vertical HDPE membranes and inverting the subsurface resistivity distribution, the presence of leaks can be inferred based on the distribution of low-resistivity anomalies in the target underground area, thereby facilitating the integrity assessment of the vertical HDPE membranes. This research was applied in a practical investigation at a municipal landfill site in Hunan Province, where field tests were conducted, and the effectiveness of 3D-HDER in detecting vertical HDPE membranes was validated through excavation. The experimental results indicate that: (1) 3D-HDER is capable of effectively and accurately locating shallow leaks, and (2) low resistivity anomalies were observed in the vicinity of the leaks.

1. Introduction

Vertical anti-seepage in landfills mainly uses plastic concrete continuous walls, grouting methods, cement-soil mixing piles, and vertical slotted HDPE membranes. Flexible vertical anti-seepage curtains represented by HDPE membranes have gradually replaced traditional concrete walls and been widely used in landfill projects due to their low permeability, chemical resistance, durability and strong deformation resistance[1-2]. Despite their advantages, HDPE liners face vulnerabilities to defects from manufacturing and installation, risking leachate leaks and environmental contamination. The urgency for effective HDPE liner monitoring underscores the need for innovative, non-destructive detection techniques. This study explores the use of three-dimensional high-density electrical resistivity imaging to evaluate HDPE liner integrity, employing validation models and field tests. This method promises improved environmental safety through precise pollution source assessments, contributing significantly to pollution prevention efforts.

The utility of three-dimensional high-density resistivity imaging technology has been increasingly recognized for its capacity in the identification and assessment of pollution sources[2]. Esteemed for its rapid, non-destructive examination capabilities, high-resolution imaging, and negligible environmental disruption, this technology represents a significant stride forward in environmental assessment methodologies[3-4]. The present study elucidates the application of the three-dimensional high-density electrical technique in the integrity analysis of vertical HDPE anti-seepage membranes. This includes the development of theoretical validation models and the execution of empirical engineering evaluations. These initiatives have substantially enhanced the detection of integrity breaches in vertical impermeable membranes, thus facilitating more effective environmental protection measures and the prevention of pollution.

2. Theoretical foundation

2.1. The Demand and Challenges in Detecting Vertical HDPE Membranes

Within the domain of environmental engineering, especially in the contexts of landfill management and hazardous waste mitigation, the introduction of vertical high-density polyethylene (HDPE) membranes signifies a notable advancement in technology. Chosen for their exceptional characteristics, including low permeability,
chemical resilience, enduring durability, and considerable resistance to deformation, HDPE membranes have demonstrated superiority over traditional containment strategies, such as plastic concrete barriers and grouting techniques, in mitigating the infiltration of leachate into terrestrial and aquatic ecosystems[5]. The operational success of these membranes, however, is critically dependent on their structural integrity. Deficiencies arising during the manufacturing and installation phases have the potential to precipitate environmental hazards. Consequently, the formulation of non-intrusive, efficacious technologies for the evaluation of membrane conditions emerges as a pivotal necessity. This endeavor is essential for navigating the challenges presented by subterranean complexity and the extensive scope of membrane deployment, thus ensuring the longevity of landfill operations and the preservation of environmental sanctity.

2.2. The Principle of Three-Dimensional High-Density Electrical Method

The core advantage of the high-density electrical resistivity method lies in its ability to rapidly collect resistivity data and improve the traditional workflow of electrical exploration through efficient on-site data processing techniques, significantly enhancing work efficiency. Moreover, the high-density electrical resistivity method employs a composite arrangement of measurement devices, primarily exemplified by the Wenner array, as shown in Figure 1. Through the configuration of power electrodes (A, B) and sampling electrodes (M, N), it can accurately capture the real situation of potential changes between sampling points M and N, i.e., the potential difference directly beneath M and N under the influence of the power electrodes, thereby achieving higher measurement accuracy[6-7].

3. Methods and Model Design

3.1. Style and spacing

Utilizing the high resistive characteristic of HDPE membranes, and supplying power to one side of the impermeable membrane, the electric field is theoretically distributed only on one side of the HDPE membrane. However, given the limited depth of the vertical (HDPE) membrane which does not extend infinitely downwards, a small portion of the current may bypass the bottom of the membrane, resulting in a weak electric field distribution on the opposite side; if A supplies power, the potential value at A1 is almost 0, as shown in the simplified geoelectric model in Figure 1 and Figure 2. Should there be a leak in the impermeable membrane, a leakage electric field would occur, causing the potential difference between M1 and M2 on both sides of the impermeable membrane to decrease. Therefore, the position of leaks in the impermeable membrane can be determined through changes in the electric field[8].

3.2. Leak Model

The model is established under ideal three-dimensional conditions, measuring 12 meters by 60 meters by 13.5 meters. The surface is flat without any topographical variations, and the subsurface medium is uniform with a background resistivity of 500 ohm-meters. The vertical HDPE membrane measures 12 meters by 60 meters with a resistivity of 1x10^4 ohm-meters, and the leak within the vertical HDPE membrane profile is modeled as a rectangular prism measuring 0.3 meters by 0.3 meters. There are 64 electrodes, with a spacing of 4 meters, symmetrically distributed on both sides of the vertical HDPE membrane, with each side having two columns of 16x2 electrodes. When a leak occurs in the vertical HDPE membrane, the geoelectric properties at the site of the leak exhibit a significant difference compared to the rest of the vertical HDPE membrane. This difference provides the premise for detection by the high-density electrical method apparatus. The resistivity values are used to simulate two leaks in the HDPE membrane, placed at different locations[9-10], with their positions and sizes illustrated in Figure 3.
3.3. Result Analysis

After conducting numerical simulations, we obtained the apparent resistivity inversion results for leaks at two different locations, as shown in Figure 4. From the apparent resistivity spectrogram, we can observe that: (1) when leaks are present, their apparent resistivity values are lower than when there are no leaks, displaying low resistivity characteristics. (3) The anomalous area where the leak occurs is larger than the size of the leak itself, and the shape that is reflected undergoes a change. The anomaly in the apparent resistivity values at the edges is due to the finite size of the membrane, which is affected by current circumvention.

4. Engineering Case Study

4.1. Overview of the Landfill Site

The vertical impermeable barrier project employs a flexible vertical impermeable barrier system, inserting High-Density Polyethylene (HDPE) geomembranes vertically[11]. The sides of the geomembrane are equipped with unique locking fasteners, and sealing materials are poured at the bottom, together forming a vertical impermeable barrier system.

Detection targets: The first level vertical barrier wall, with a length of 146m, vertical impermeable membrane area of 1691.33m², and an average depth of 11m; the second level vertical barrier wall, with a length of 42m, vertical impermeable membrane area of 506.67m², and an average depth of 12m. The scene is shown in Figure 5.

4.2. Data Interpretation

The potential data collected from the field were preprocessed, and a three-dimensional apparent resistivity inversion was obtained using the high-density electrical method apparatus, as shown in Figure 6. There are noticeable anomaly areas, forming low-resistivity channels on both sides of the vertical HDPE membrane[12-13]. The precipitation-induced active flow field indicated the presence of a leakage conduit. Subsequent excavation at the engineering site corroborated the detection outcomes, affirming their accuracy.
5. Conclusions

This study confirms the effectiveness of three-dimensional high-density electrical resistivity imaging technology in detecting the integrity of vertical HDPE impermeable membranes. Through detailed model construction and real-case analysis, this technology can accurately identify and locate leaks, providing a reliable method for assessing the integrity of vertical impermeable membranes.

The study further demonstrates the wide application potential of three-dimensional high-density electrical resistivity imaging technology in environmental protection and pollution prevention efforts. Especially in the context of increasingly strict environmental protection standards, this technology offers significant technical support for enhancing the monitoring capabilities of impermeable systems and optimizing site remediation plans.

For simplification and effectiveness, the resistivity values of vertical HDPE membranes were set particularly high, and inversion was conducted with the incorporation of a priori information models without considering boundary issues. Further research should continue to explore the impact of boundary problems on the accuracy of numerical simulations.

References