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Application of Ground Penetrating Radar Numerical Simulation Technology in Quality Inspection of Reclamation Embankment

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Abstract: Ground detection radar detection technology is an effective and feasible non-destructive testing technology for the quality inspection of reclamation embankment engineering. It has the advantages of high detection precision, high speed and continuous detection, but it is restricted by environmental conditions, which reduces the detection efficiency. Based on the FDTD algorithm, the forward modeling of overhead hidden danger in the reclamation embankment is carried out, and the typical radar image is obtained. The radar image characteristics of the reclamation embankment are summarized, which provides a theoretical basis for the application of ground penetrating radar to identify abnormal bodies in engineering practice.

1. Introduction

The hard target proposed in the Outline of the Eleventh Five-Year Plan for National Economic and Social Development to ensure the area of 1.8 billion mu of arable land has accelerated the pace of reclamation in coastal areas of China. Since the "Ninth Five-Year Plan", coastal areas have organized a plan to implement a million-mu tidal flat reclamation. Taking Jiangsu Province as an example, as of 2004, only Jiangsu Province has accumulated more than 170 times of tidal flat reclamation with a total area of 3.46 million mu. In the face of such a huge reclamation project, the seawall is an important part of the reclamation project. In order to ensure its safe operation, it is necessary not only to carry out high standards and strict requirements on construction quality, but also to regularly monitor and inspect the reclamation seawall. At present, compared with several other conventional detection methods, ground penetrating radar technology has significant advantages such as high resolution, high efficiency and non-destructiveness [1].

At present, there are few studies on the application of ground penetrating radar (GPR) in the safety detection of reclamation embankment, especially the study on the shape and range of hidden dangers of reclamation embankment by combining the detection image of GPR. Forward modeling facilitates the research of ground penetrating radar technology. Effective information can be obtained through simple computer simulation, and cost and time can be saved greatly compared with field acquisition. The structure of reclamation embankment is complex. Through forward modeling of overhead hidden danger of reclamation embankment, abundant radar images are obtained, which has guiding significance for

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practical engineering and plays an important role in the application of ground penetrating radar in the safety inspection of reclamation embankment.

2. Numerical simulation method and theory of ground penetrating radar

2.1. Development and application of FDTD

In 1966, K. S. Yee proposed the finite difference time domain method (FDTD) for numerical calculation of electromagnetic field [2]. The two components of electromagnetic field are separated by alternating sampling in time and space. Each component of electric field (magnetic field) is surrounded by four components of magnetic field (electric field). The Maxwell equation with time variable is transformed into a set of difference equations by using this discretization method, and the spatial electromagnetic field[3] is solved step by step on the time axis.

By arranging Maxwell's equations, the relationship between electromagnetic field components can be obtained:

$$\frac{\partial H_z}{\partial y}-\frac{\partial H_y}{\partial z}=\varepsilon\frac{\partial E_x}{\partial t}+\sigma E_x \tag{1a}$$

$$\frac{\partial H_x}{\partial z}-\frac{\partial H_z}{\partial x}=\varepsilon\frac{\partial E_y}{\partial t}+\sigma E_y \tag{1b}$$

$$\frac{\partial H_y}{\partial x}-\frac{\partial H_z}{\partial y}=\varepsilon\frac{\partial E_z}{\partial t}+\sigma E_z \tag{1c}$$

and:

$$\frac{\partial E_z}{\partial y}-\frac{\partial E_y}{\partial z}=-\mu\frac{\partial H_x}{\partial t}-\sigma_m H_x \tag{2a}$$

$$\frac{\partial E_x}{\partial z}-\frac{\partial E_z}{\partial x}=-\mu\frac{\partial H_y}{\partial t}-\sigma_m H_y \tag{2b}$$

$$\frac{\partial E_y}{\partial x}-\frac{\partial E_x}{\partial y}=-\mu\frac{\partial H_z}{\partial t}-\sigma_m H_z \tag{2c}$$

Where, $\boldsymbol{E_x}, \boldsymbol{E_y}, \boldsymbol{E_z}, \boldsymbol{H_x}, \boldsymbol{H_y}$ and $\boldsymbol{H_z}$ are the components of electric field and magnetic field in x, y and z direction, respectively, at the moment t. FDTD algorithm is based on the six partial differential equations in equations (1) and (2).

FDTD has many outstanding characteristics such as direct time-domain computing, wide applicability, saving storage space and computing time, being suitable for parallel computing and the universality of computing programs, etc., so it has been widely used.

2.2. Absorbing bound condition

Finite-difference time-domain method (FDTD) can simulate electromagnetic wave continuously in computer, so it will occupy infinite space, while the storage space of computer is limited. In order to make the simulation process work properly, it is necessary to set the absorbing conditions at the boundary of the simulation space so that the electromagnetic waves transmitted to the boundary of the space can be absorbed and no longer propagate outward. Absorbing Bound Condition (ABC) evolves from interpolating boundary - Mur absorbing boundary - perfectly matched layer (PML) absorbing boundary to generalized perfectly matched layer (GPML), which is widely used up to now. GPML is suitable for simulation of lossless media as well as lossy media .The principle of parameter selection in GPML calculation is given in literature.

3. Forward modeling of overhead panel model

Aimed at the common overhead hidden dangers in reclamation embankment, numerical simulation is carried out to analyze the influence of overhead range and shape on radar wave, and the method of identification of overhead detection map is summarized. Under the repeated action of tides, the sand filling of the levee body is carried away by sea water and the levee body sinks, forming an overhead under the face plate of the levee body. According to the requirement of detection depth and accuracy, calculation parameters are set: the calculation domain is 2.5m×0.6m; the offsets of X and Y axis are both 0.0025m; the discrete scales of X and Y direction are both 0.02m; the absorbing bound condition is GPML; and excitation source parameters are set: the frequency is 900MHz; the waveform is first derivative Gaussian wave (ricker); the amplitude is 1. By simulating the overhead range and different overhead shape data, the characteristics of overhead radar images are studied to provide theoretical basis for engineering practice.

3.1Overhead range simulation

In order to study the characteristics of radar images corresponding to different overhead ranges of the reclamation embankment, the rectangles with overhead depths of 20cm and horizontal dimensions of 20cm and 40cm are simulated, respectively. The structural parameters of each layer are shown in Table 1. The simulated structure is shown in Figure 1, where the oblique line filling portion in the figure is an overhead area.

Table 1 Dielectric parameters of each layer within 0.6m of the embankment

	thick (m)	Dielectric constant ε	Electrostatic conductivity
The first layer (concrte)	0.25	6	0.005
The second floor (gravel)	0.35	5	0.01

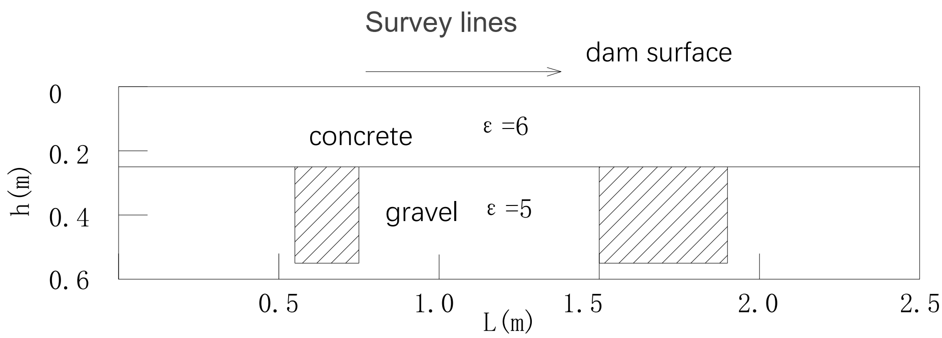
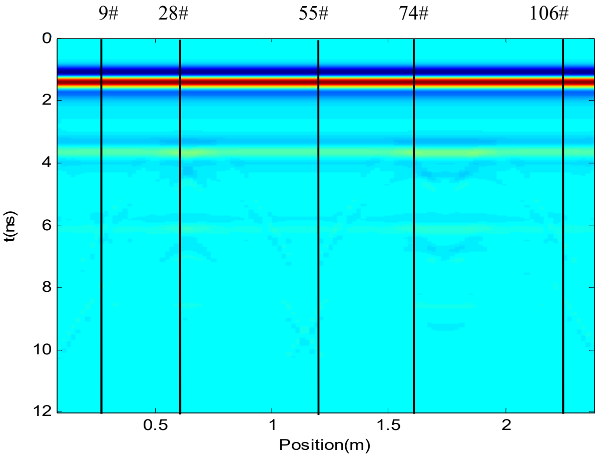


Figure 1 Overhead scope diagram

The gravel layer is simplified as a uniform medium with a dielectric constant and electrostatic conductivity between the granite and the air. The simulated radar profile of the overhead range is shown in Figure 2, and the typical waveform is shown in Figure 3.



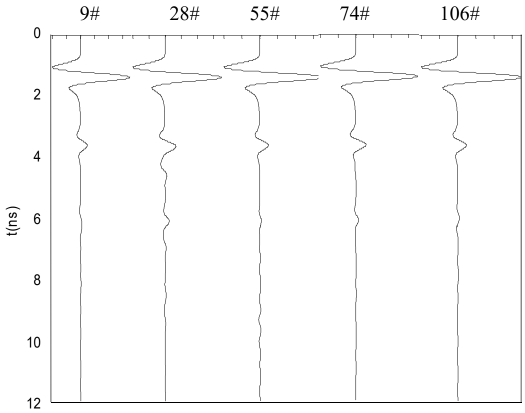


Figure 2 Sectional view of overhead area   Figure 3 Typical waveform of overhead range

According to the overhead position, five channels of typical waveforms (Fig.3) are selected for analysis. The specific sampling method is shown in Figure 2. The five channels of waveforms show reflected waves in phase with the electromagnetic waves excited by the antenna at around 3.8 ns.

The reflection waves in the 28-channel and 74-channel waveforms are stronger than the other channels. This is because the 28 and 74 channels waveforms at 3.8ns are the interface between concrete and air, while the reflection waves in other channels are the interface between concrete and gravel. he 28-channel wave shows obvious reflection wave around 6ns and is inversely correlated with the electromagnetic wave excited by the antenna. This is the interface between air and gravel layer.

3.2Overhead shape simulation

In order to study the radar image features corresponding to different overhead shapes of the reclamation embankment, semicircle, triangle and rectangle with a simulated overhead depth of 20cm are simulated. The simulation structure diagram is shown in Figure 4 and 7, and the oblique line filling part is the overhead area; the radar profile is shown in Figures 5 and 8; the typical radar waveform is shown in Figures 6 and 9.

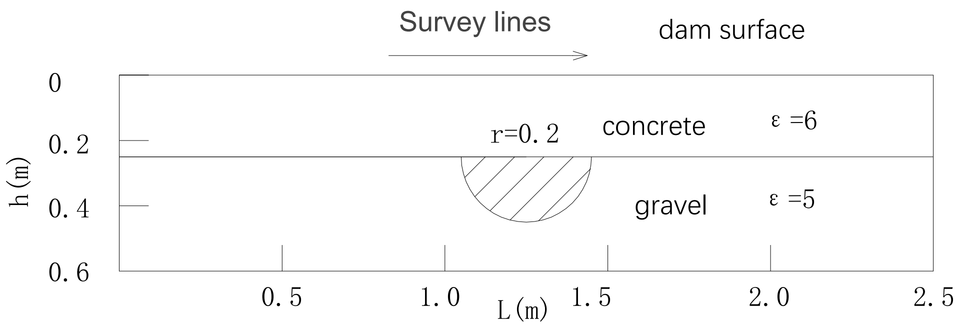
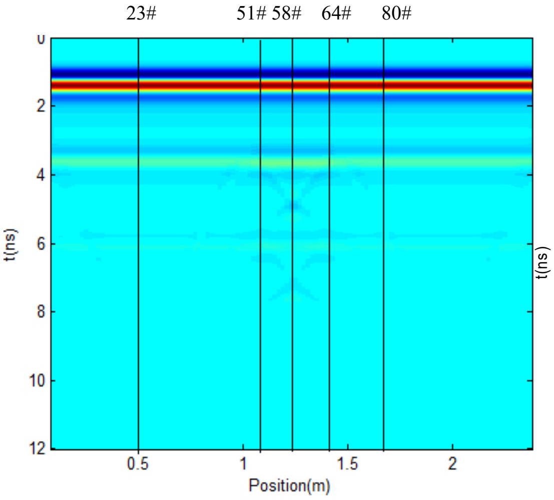


Figure 4 Diagram of semi - circular overhead structure



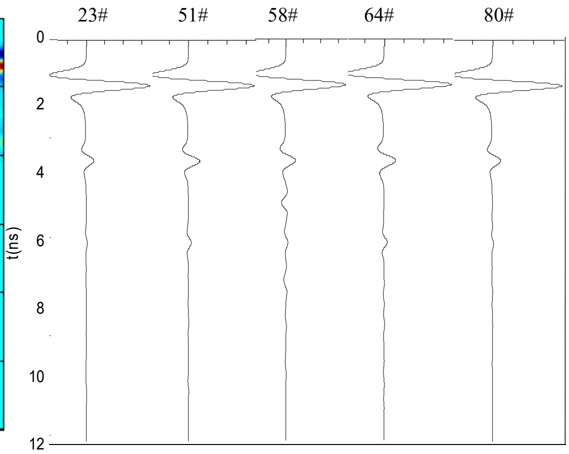


Figure 5 A semicircular aerial section Figure 6 Typical waveform of semicircle overhead

It is known from Fig. 5 that the two-dimensional radar profile of the semicircular target body is an inverted triangle, and there are curved in-phase axes on both sides of the target area, which is caused by the diffraction phenomenon of electromagnetic waves at the end angle. It can also be seen from the figure that there are multiple waveforms below the target area, which is caused by multiple reflections. The semi-circular target has multiple reflection waves in a hyperbola.

According to the overhead position, five channels of typical waveforms (Fig. 6) are selected for analysis. The specific sampling method is shown in Figure 5. The five channels of typical waveforms show reflected waves in phase with the electromagnetic wave excited by the antenna at about 3.8 ns. The reflected waves in 58-channel are stronger than the other ones. This is because the 58-channel reflected wave at the interface of concrete and air at 3.8 ns. The reflections of the other channels are reflected at the interface between concrete and gravel; the 58-channel waves show obvious reflected waves around 5 ns, and are inversely correlated with the electromagnetic wave excited by the antenna. This is the interface between air and gravel layer. 51-channel and 64-channel have weak reflections at 6 ns due to multiple reflections of reflected waves at the interface between air and concrete.

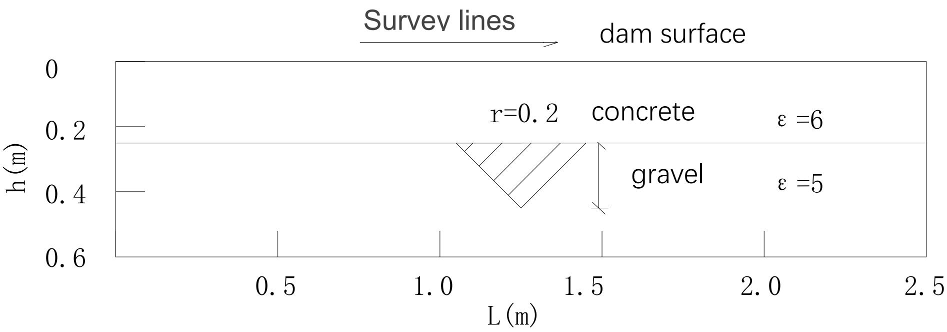
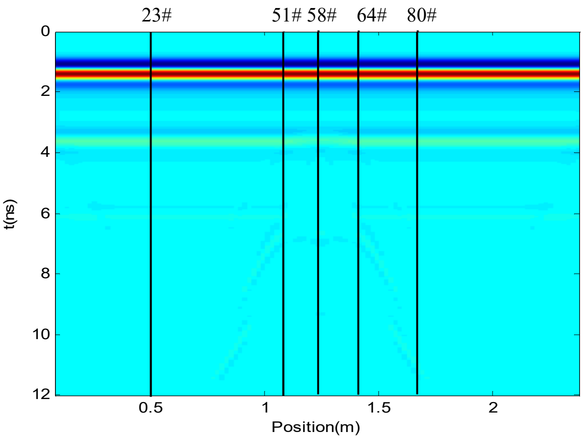


Figure 7 Inverted triangle overhead structure drawing



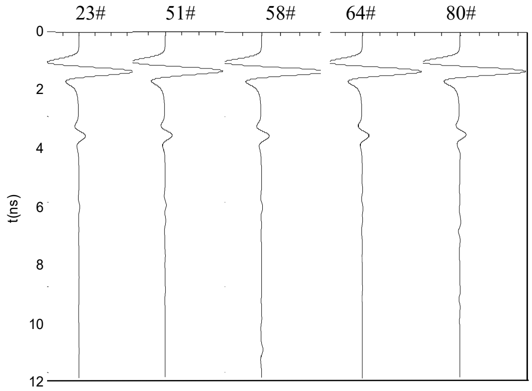


Figure 8 Inverted triangle aerial section Figure9 Inverted triangle overhead typical waveform

It is known from Fig. 8 that the two-dimensional radar profile of the inverted triangle has no characteristic shape, and there are curved in-phase axes on both sides of the target area, which is caused by the diffraction phenomenon of electromagnetic waves at the end angle.

According to the overhead position, five channels of typical waveforms (Fig. 9) are selected for analysis. The specific sampling method is shown in Figure 8. The five channels of typical waveforms show a reflected wave in phase with the electromagnetic wave excited by the antenna at about 3.8 ns. The reflected waves in 58-channel are slightly stronger than the other ones. This is because the 58-channel reflected wave at the interface of concrete and air at 3.8 ns. The waveform of the inverted triangle overhead area has no obvious reflected wave at the bottom of the overhead area, because the vertical resolution of the 400MHz antenna to the air layer is only about 10cm.

4. Engineering case analysis

The 400,000-mu reclamation area of the "first reclamation" along the coast of Jiangsu Province has a high proportion of low beaches and a large length of embankments. However, on-site inspection is affected and limited by conditions such as site conditions and climate. Especially in the side slopes of seawalls with poor environmental conditions, the inspection work should be carried out at low tide levels. According to the detection results, representative radar images are selected for analysis: Figure 10 shows the overhead radar image of the reclamation pavement panel.

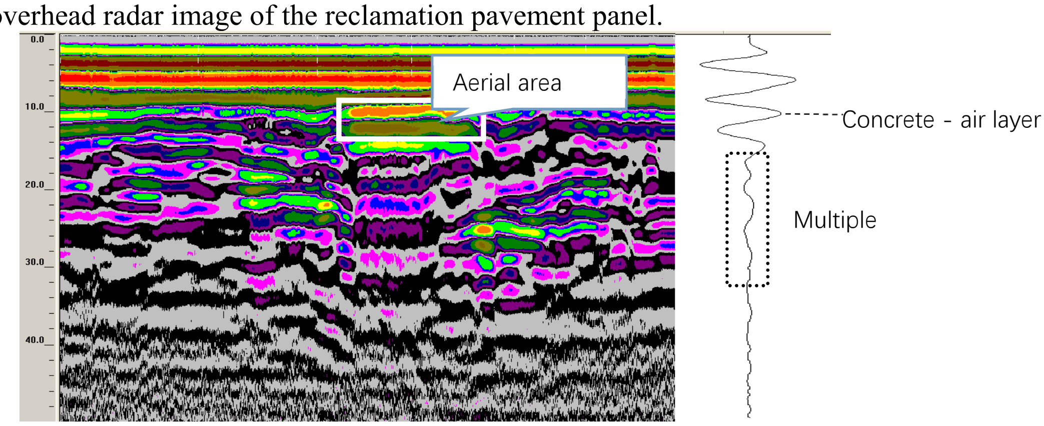


Figure 10 Aerial radar image of road surface panel of reclamation dike

In the radar profile view in Figure 10, a band-shaped strong reflection region can be seen, and a significant reflection wave appears at 10 ns. According to the forward modeling results and geological data, the reflected wave is the interface reflection wave of the concrete shield and the embankment overhead area.

5. Conclusion

As a new type of embankment structure, the reclamation embankment has less research on its safety detection. Its structural characteristics and internal medium characteristics meet the requirements of ground penetrating radar detection. In order to study the feasibility and accuracy of ground penetrating radar for safety detection of reclamation embankment, this paper introduces FDTD algorithm to carry out forward modeling of ground penetrating radar for reclamation embankment detection, obtains abundant radar images, and verifies the correctness of the simulation result combined with field test data, which has important guiding significance for engineering practice and provides a theoretical basis for the application of ground penetrating radar in reclamation embankment detection.

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