Construction and Building Materials 110 (2016) 189–200

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Quality monitoring of metro grouting behind segment using ground penetrating radar

Qi-ming Yu, Hui-lin Zhou *, Yu-hao Wang, Rong-xing Duan

Department of Electronic Information & Engineering, Nanchang University, Nanchang 330031, China

HIGHLIGHTS

- Field measurement of the dielectric constant of the concrete segment.
- Laboratory monitoring for dielectric constant of grouting mixture.
- Grouting layer thickness and defects nondestructive testing.

ARTICLE INFO

Article history:
Received 28 August 2015
Received in revised form 10 December 2015
Accepted 16 December 2015
Available online 17 February 2016

Keywords:
Ground-penetrating radar (GPR)
Metro tunnel
Non-destructive testing
Wave velocity inversion
Thickness estimation
Structural damage

ABSTRACT

In this paper, a survey of the Nanchang Metro Line 1 is completed to determine the effectiveness of a grout assessment method combines GPR and image processing. Two aspects are used as a basis: one is to estimate the thickness of the grouting layer, and the other is to determine the presence and distribution of any damage. Finite-difference time-domain simulation is used to assist the interpretation of measured data. The results show most grouting layer is approximately 30 cm thick (i.e., the standard 30 cm). Several defects in the grouting layer were also found, primarily voids, crack or fissure.

1. Introduction

The rapid increase of urban passenger transport demand coupled with the lag of transportation infrastructure caused by urban traffic and the decrease in traffic management quality significantly limits the development of urban regions. One of the effective ways to solve urban traffic problems is to develop metro systems due to their high passenger capacities, speed, convenience, comfort, and relatively low energy consumption. The construction of the Nanchang metro can help mitigate traffic problems, alleviate the described issue of supply and demand in traffic, and ultimately promote the rapid development of urban economy.

The shield construction method was applied to the Nanchang metro during construction; this method is the mainstream of underground structures currently and is widely used to construct transportation systems [1]. It can be economical and rapidly executed without affecting the daily life of a city. However, after shield excavation, two problems typically result: significant movement of surface soils, and increased flows of sand, water seepage, and spewing in water-rich areas, rivers or lakes [2]. At present, both problems can be mitigated by installing an effective grouting layer. It is also necessary to test and maintain the grouting layer using such technologies as GPR during its service life.

GPR is a high-frequency electromagnetic technique used in geophysical explorations. Using the characteristics of electromagnetic waves through non-continuous media, this technology produces reflections and scattering to form a continuous image [3]. The travel time, frequencies, amplitude and phase are recorded by the radar system. This method detection is non-destructive, the detection is rapid, and the test results are intuitive with a high resolution [4].

GPR has been widely used in different fields and has been successfully solved complex engineering and science problems, such as pavement analysis, bridge monitoring[5–8], railway monitoring, the assessment of tunnels, the location of reinforcing bars [9] and metal elements in concrete bases [10], and assessing damage to reinforced concrete [11–12]. Currently, the most common applications of GPR in metro surveys include: (1) grouting layer

* Corresponding author.
E-mail address: gprzhou@hotmail.com (H.-l. Zhou).

http://dx.doi.org/10.1016/j.conbuildmat.2015.12.109
0950-0618/

thickness estimation [13–14]; and (2) potential damage detection and localization [15]. The method of shield tunnel grouting detection by GPR is consistently being developed [16–17]. Some authors applying ground penetrating radar method in Shanghai shield tunnel grouting detection have reported that this method can effectively detect grouting distribution, which provides a basis for longitudinal dynamics control tunnel deformation behavior [18].

Using the solid segment grouting distribution simulation test, some authors have also summarize the imaging regularity of different grouting morphologies using GPR and its data processing method [19].

In this paper, there are two goals in assessing the effectiveness of the grout treatment: one is to estimate the thickness of the grouting layer [20], and the other is to determine the presence and distribution of any damage in the grouting layer. The mechanical effects of the grouting in the soil include filling gaps, squeezing soil and splitting spread. Due to grouting pressure, filling grout gaps, infiltration and compaction of soil, and condensation reinforcement are used to improve the mechanical properties and water permeability of the soil to achieve settlement control and water plugging.

Due to the presence of groundwater, its permeability and irrigation, grouting is not necessarily uniform and may be not denser behind a segment. Grouting liquid may also be lost along certain grout paths, leading to large amounts of grout in certain areas and weak grouting pressure. Grouting is may take a long time to cure and cause large changes in the soil, resulting in uneven grouting layers. Grouting liquid may also condense at different rates, leading to voids and low density grouting layers. These situations may influence structural safety or cause accidents.

The velocity in the concrete and grout must be known to estimate the grout's thickness. Contrary to intrusive coring or semi-intrusive methods used in engineering applications, this paper uses electromagnetic wave travel time in the segment and grouting blocks to calculate wave velocities to avoid harm to the concrete while effectively calculating the thickness of the grout.

After field detection, the image established by GPR is analyzed; however, it typically contains many clutter signals and unwanted noise, which is the primary factor that affects the captured reflections, obscuring the target information in the image. To mitigate this issue, data processing is used to ultimately achieve internal defect detection and classification [21].

The finite-difference time domain (FDTD) technique has evolved into one of the most popular advanced modeling tools for interpretation of GPR data in tunnel inspection. In this paper, the metro tunnel is evaluated by combining GPR and FDTD techniques to estimate lining thickness and determine damage based on prior tunnel structural design information.

The following image interpretation must extract the stability characteristics of the target information, including parameters such as amplitude, phase and frequency of the echo signal. Different lining defects and medium interfaces relative to the electromagnetic waves with different reflection characteristics. Their typical waveform characteristics have been defined for comparison [22].

After evaluation, grouting repairs ensure the quality of metro tunnels and mitigate any hidden operational dangers.

2. Describe of metro

Survey was performed on the Nanchang Metro, Line One, a length of 2.3 km, between the Ai Xi Lake East Station to Ai Xi Lake West Station. A brief geographical position is presents in Fig. 1a.

Six segments (Fig. 1d) assembly into a ring as the tunnel first lining, and then grouting through grouting hole (Fig. 1e) to form second lining (grouting layer) behind the segment (Fig. 1c), The thickness of segment and grouting layer have both been designed for 30 cm. The grouting layer was constructed more than 6 months prior to testing.

Grouting can be considered to be a mixture of water, air and sand. The relative permittivity of water is near 81[23]; the relative permittivity of the air can be considered to be that of a vacuum and thus equals 1. The quantity of above three components (water, air

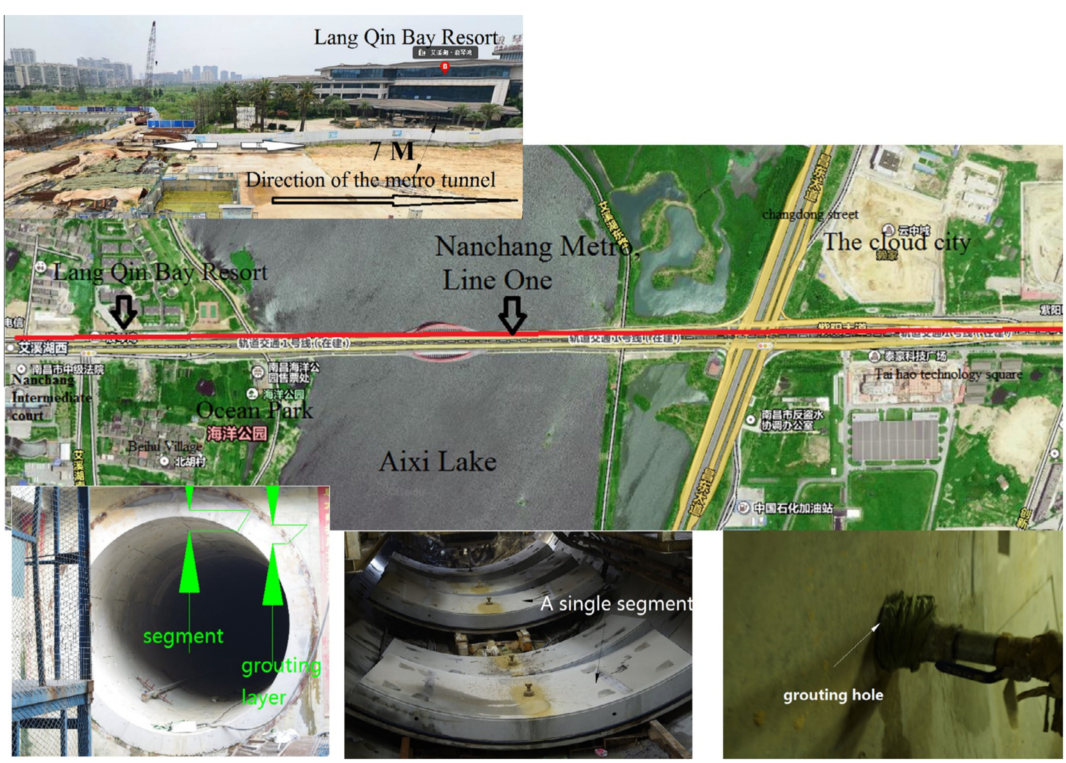

Fig. 1. A brief geographical position of Nanchang Metro, Line One.