1. Introduction

High-speed railway is an integral part of modern transportation mode. However, it has raised more complex engineering problems. The entire railway system must be in excellent condition to guarantee traveling safety and comforting. Ballastless slab track is an advanced structure form of non-ballast track. It is composed of rail, fastener, track slab, filling layer of cement emulsified asphalt mortar (CA mortar) and concrete base. The diseases existing in the underline structure of high-speed railway are complex and diverse. The track plate diseases are generally: track slab cracks, CA mortar layer segregation, permeation and support layer cracking \(^1\). Field investigation shows that the defects in the CA mortar layer will grow by long-term dynamic loading and bring potential risks to the operation safety \(^2\). The segregation of CA mortar layer almost appears in all
sorts of ballastless track structures, and it will not only cause violent vibration of the vehicular and track structure, but also will produce noise and affect the surrounding habitants. By long-term of operation, the track slab will be damaged and the maintenance work and cost are greatly increased.

Vibration monitoring and survey is of significant importance in structural dynamics and geotechnical engineering applications. Accurate measurement and monitoring of vibration is crucial for detection of the abnormal events and pre-warning of infrastructure defects \cite{3}. The Optical fibers can be used as fiber optic sensors utilizing the same physical principle to measure strain, temperature, acoustic field, pressure, vibration and other quantities by modifying the fiber so that the quantity to be measured modulates the intensity, phase, polarization, and wavelength or transit time of light in the fiber. If sensing is distributed along the length of the fiber, an optical time domain reflectometry (OTDR) is needed to locate the position of the intrusion or disturbance \cite{4}. In general, distributed optical vibration sensors have several advantages: distributed and multiplexed topologies, small size, large-scale monitoring, excellent flexibility, and compatibility with data transmission network.

Based on the OTDR technology, a trial was operated on a section of railway near Hongqiao high-speed railway station. The relationship between fiber vibration intensity and disengaging was discovered during the trial. The research result provides reliable basis for setting threshold value of slab disease early warning.

2. Working principle of vibration detection using distributed optical fiber sensors

Distributed vibration sensors operate a real-time detection, location and pre-warning of the surrounding vibration signals. It has broad application prospects in continuous distributed monitoring of track, airport runway and roadbed. Optical time domain reflectometry (OTDR) is the simplest distributed optical sensor and it is based on Rayleigh scattering. Rayleigh scattering is the most important factor for determining the transmission loss of an optical fiber\cite{5}.

The principle of phase-sensitive optical time domain reflect meter (OTDR) was initially introduced in the sensing application by Henry F. Taylor in early 1993.\cite{6} The overall structure of OTDR distributed optical fiber vibration sensing system is shown in Figure 1.

![Figure 1:Structure of an OTDR distributed optical fiber vibration sensing system.](image)

It is composed of a laser source, an optical modulator and demodulator to convert the input light into a range of pulse light, an Erbium-doped fiber amplifier (EDFA) to amplify and generate a synchronized pulse light after the modulated light been object of losses and dispersions according to the phenomenon of scattered light with the Rayleigh scattering light which is the most dominant elastic scattering light. an optical coupler to collect the series of pulse light in order to transmit the final pulse light simultaneously throughout the fiber under test (FUT) for disturbance detection; a photodetector to convert the returned optical signal into an electrical signal; a data acquisition card equipped with an A / D accessory (analog-to-digital converter) to pre-process and finally transfer the signals to a computer information management system. Through the analysis of the disturbance information the system alerts the main controller system for a pre-warning. Therefore, after emitting
a high-power narrow linewidth optical pulse, the Rayleigh scattering light signal is sampled at high speed, and the data collected is sent to a computer for further analysis. According to the analysis result, the system can determine whether there is any illegal intrusion event.

3. Application of vibration monitoring in Hongqiao high-speed railway station

3.1 Case study

As shown in Figure 2, the site is located on the east side of the Shanghai-Hangzhou railway overpass at the intersection of the Shanghai Songjiang highway and Jiamin elevated road, and is about 10 km from the Hongqiao high-speed railway station. The north side of the site is the highway interchange and the west side is the Puhuitang River. The monitoring section is 15 m in length and is located on the east side of Puhuitang River Bridge. It includes a double track railway. The results of the field investigation show that two track plates numbered respectively L00526 and L00528 have more visual defects. This section of the track plate has been in operation after a long period of deterioration (existence of segregation and cracks) in the CA mortar layer. L00526 visual defect is the most serious with 28.41% of defect rate. Segregation and cracks can be located visually in the CA mortar layer (see Figure 3 and 4). The Field-testing was implemented during two days. In the first day, the quality of the CA mortar remained defective and been repaired in the next day. Twenty trains were passing through the monitoring site, including 10 times in the left and right track line each.

Figure 2: Monitoring site.                      Figure 3: Repair work of the defect in the CA mortar.

Firstly, impact imaging method was used to detect the track plate[7]. The offset is 25 cm. Figure 5 are the results of the tests using impact imaging method before and after the repairing of L00526 track plate. As can be seen from the graph, the compactness of CA motor between two rail tracks before the repairing of L00526 track plate is poor. After repair, the compactness of CA motor between two rail tracks of the L00526 track plate increased significantly, and the void area before the repair disappeared.
3.2 Sensor arrangement

The DOVS fiber continuous distributed vibration monitoring system developed by Shanghai B &
A Technology Co. Ltd is used in this monitoring project (Figure 6).

The main technical indexes of DOVS optical fiber sensor analyzer are listed below:

- Measurement distance: 1~40 km
- Positioning accuracy: ±8~20 meters
- Detection rate: >97%
- False alarm rate: <3%
- Mode of connection: single end connection
- Communication interface: network interface, RS232, USB
- Working voltage: AC100~40V, 50~60Hz
- Working power: < 30W
- Working environment temperature: -40℃~70℃
- Mainframe size: standard 19 inch 3U chassis

As shown in the Figure 7, the track plates (number L00526, L00527, L00528) have been selected
as monitoring objects and as well, three track plates with a good structural quality in the opposite
direction are also chosen for reference. Considering that the positioning accuracy of the current op-
tical fiber vibration measurement is about 8m, in order to improve the positioning accuracy a 10m
fiber disc is used to form a ring of 15cm diameter and the optical fiber ring is fixed to the central
part of the track plate respectively (Figure 8). When measuring the vibration, a sample is collected
every 0.4m along the fiber under test, and the distance between the sampling point corresponding to
each fiber ring is shown in table 1.
3.3 Vibration monitoring results

The amplitude of waveform method is used to process the monitoring data by comparing the waveform measured before and after the repair work on the different track plates. The results shown in Figure 10 and 11 reveals that as the train approached the wheel has no effect to the track plate, therefore, the vibration mainly reflects to the amplification effect of the track plate defects; when the train passes through the monitoring site the vibrations mainly reflect the defects in the CA mortar layer. The L00526 track plate with the most visual defect in the CA mortar layer notices strong vibration when the train is passing (Figure 12). After the repair work took effect, the vibration response has significantly lessened. The vibration response of the track plates selected for reference mostly didn’t notice mediocre invariability and that indicates that the segregation of the cement asphalt is a direct consequence of the enlargement of the vibration when the train is passing through the monitoring site.
4. Conclusion

This research paper has presented the working principle of Phase-sensitive Optical Time domain reflectometer plate. OTDR depends mainly on the monitoring of the Rayleigh backscattering to determine the transmission loss in the fiber under test. The purpose of the research was to prospect the application of distribution optical fiber sensor based on an Optical Time Domain Reflectometer (OTDR) in Hongqiao high-speed railway station for vibration monitoring.

The OTDR optical fiber vibration sensor is applied on the Hongqiao high-speed railway station, through a continuous real-time vibration monitoring of different track plate with different percentage of defect, the monitoring results were very compatible with the results of impact imaging method approving the influence of the segregation of CA mortar layer on the track plate vibration during operation of the train.

REFERENCES