Wireless Monitoring System of Super-long Pile Foundation in Bridge Engineering

QIAO Sheng-fang1,3a, CHEN Hang1, TANG Meng-xiong*, HU He-song1
1Guangzhou Institute of Building Science, Guangzhou 510440, China
2Guangzhou Construction Engineering Co., Ltd, Guangzhou 510000, China
3South China University of Technology, Guangzhou 510641, China
a1050577552@qq.com; *E-mail: tmx@gibs.com.cn.

Abstract. The load-carrying properties of super-long pile were important to bridge engineering in construction and operation phases, however, the research of its load-carrying properties was imperfect. The wireless monitoring system of super-long pile foundation in bridge engineering was presented in this paper. The intelligent vibrating wire steel stress gauges were used to reflect the axial stress of pile foundation, then the sensor data was acquired using wireless intelligent acquisition instrument. The LoRaWAN was used to establish the local area network, which was long range wide area network. Thus the monitoring data of each sensor was collected by Lora modules. Furthermore, the collected data was uploaded to the cloud platform using 4G wireless communication technology. Finally, the wireless monitoring system was applied in actual bridge engineering. The results indicated that the change of monitoring data was synchronized with the progress of actual working conditions, which could reflect the dynamic process of construction to a certain extent. It could provide an important reference for similar projects in the future.

1. Introduction
Super-long pile foundation has been widely used in soft soil areas such as coastal and riverside areas[1-2]. Its mechanical property was crucial to bridge engineering in construction and operation phases. Therefore, relevant research was highlighted. Mei et al. [3] carried out model tests of super-pile foundation and established a calculation model of vertical bearing capacity. Zhao et al. [4] analyzed the load transfer mechanism of super-long pile foundation. Liu et al. [5] carried out model tests of pile foundation to explore vertical bearing capacity of pile foundation. At present, abundant research achievements had been made on the vertical bearing capacity of super-long pile foundation, but most of the research was limited to model test, and the analysis of super-long pile foundation in actual engineering was few. Moreover, the bearing capacity of pile foundation was studied using traditional manual monitoring method, which has disadvantages such as poor continuity, great environmental impact, and no real-time warning, so it was difficult to timely warn the dangerous situation. Hence, wireless monitoring system was meaningful[6-9].

In this paper, wireless monitoring system of super-long pile foundation in actual bridge engineering was studied. The massive data obtained from the long-term monitoring of the system could provide a data basis for the bearing mechanism of super-long pile foundation, and also provide reference for other similar engineering projects.
2. Wireless monitoring system of super-long pile foundation

Wireless intelligent monitoring system of super-long pile foundation includes monitoring parameter analysis, monitoring instrument analysis, data acquisition and transmission analysis, cloud platform analysis, as shown in Figure 1.

![Flow chart of wireless monitoring system](image)

Figure 1 Flow chart of wireless monitoring system.

2.1. Monitoring parameter analysis

The monitoring task of super-long pile foundation could be divided into construction stage and operation stage. Monitoring parameters include pile strain and temperature.

2.2. Monitoring instrument analysis

In this paper, the steel stress gauge was used to monitor the reinforcement axial stress of pile foundation. The steel stress gauge has the advantages of high survival rate, excellent waterproof performance and automatic temperature correction. The steel stress gauge represents the force change of the monitored object through the change of its own frequency. The calculation formula was as follows.

\[ P_i = K_i K_0 (f_i^2 - f_0^2) \]  

\( P_i \) is axial stress value of reinforcement; \( K_i \) is calibration coefficient of each steel stress gauge; \( K_0 \) is conversion coefficient, which is 0.00071186 generally; \( f_i \) is frequency value collected under each working condition; \( f_0 \) is the initial frequency of the steel stress gauge.

2.3. Data acquisition and transmission analysis

Wireless intelligent acquisition instrument was used to collect data, and the data was sent to the monitoring cloud platform through the 4G wireless module.

2.4. Cloud platform analysis

Based on browse and server framework, the intelligent monitoring cloud platform was developed to receive real-time monitoring data of pile foundation. The monitoring data could be processed and analyzed (such as frequency converted into stress), which could be compared with the warning value and alarm value to reflect the stress condition of the monitored pile foundation.

3. Case Study

3.1. Project background and monitoring content

The overpass project is located in Zhuhai City, China. The deep soft soil layer is distributed in the site, and the thickness is about from 30 meters to 90 meters. The bored pile foundation was used according
to the rock-socketed pile design. Therefore, one representative pile foundation was selected to carry out intelligent monitoring, which was introduced in Figure 2.

According to the mechanical characteristics of the super-long pile foundation, the variation of steel stress in pile foundation could be monitored to reflect the variation of mechanical properties of the pile foundation, and could also represent the development of lateral friction resistance of the surrounding soil to some extent. Therefore, a group of steel stress gauges, three in each group, was set at the bottom of each soil layer, a total of four groups.

![Figure 2 The Intelligent monitoring system of pile foundation.](image)

3.2. Instrument selection and installation process

The steel stress gauges were welded to steel reinforcement cage according to the specified position, as shown in Figure 3(a). The performance of steel stress gauge was detected before and after welding and during the construction of pile foundation. Wireless vibrating string monitor with four channels was used to receive data in Figure 3(b).
3.3. Data acquisition analysis

After the sensor data was gathered by the wireless intelligent acquisition instrument, the wireless intelligent acquisition instrument was connected with the gateway through the LAN formed by the Lora module, and the collected data was uploaded to the cloud platform through the 4G wireless module. In addition, the mixed form of power supply of the 12V lithium battery and 220V voltage was used in monitoring system. Generally, the 220V power supply was used and the lithium battery was charged. The 12V lithium battery standby was invoked when the 220V power supply was failure. Thus, the continuous and uninterrupted online monitoring was achieved. The monitoring frequency at the initial stage was 10 minutes per time, and the monitoring frequency could be set at the later stage through the cloud platform according to the actual engineering needs.

3.4. Data analysis on cloud platform

The monitoring data could be displayed on cloud platform in real time, and also exported in the form of EXECL table. The display of monitoring data on the cloud platform was shown in Figure 4(a). 330025905 was the number of a four-channel vibrating string acquisition instrument, which could display frequency, temperature and voltage. In Figure 4(a), the monitoring data of the frequency value of steel stress gauge was shown on July 18, 2019. In addition, the frequency monitoring curve could be transformed into the stress monitoring curve through Equation (1), as shown in Figure 4(b).

![Figure 3](image-url) The installation process of instrument.

(a) Steel stress gauge installation  
(b) Wireless intelligent acquisition instrument installation

(a) The monitoring curve with frequency (Hz)
4. Results and Discussion
The stress change curve in Figure 4(b) was from July 18 to July 26, 2019, in which the stress value changed greatly from July 18 to July 21, while the stress value fluctuated slightly from July 22 to July 26. According to the on-site construction condition, the superstructure construction of pile foundation was carried out from July 18 to July 21, and the superstructure construction was completed on July 22. This indicated that the change of monitoring data was synchronized with the progress of actual working conditions, which could reflect the dynamic process of construction to a certain extent. Therefore, it could provide data support for further stress analysis of pile.

5. Conclusion
The wireless monitoring system of super-long pile foundation in bridge engineering was presented in this paper, which was also used in an actual bridge. Some conclusions could be derived.

Wireless intelligent monitoring system for super-long pile foundation was studied in this paper, which included monitoring parameter analysis, monitoring instrument analysis, data acquisition and transmission analysis, cloud platform analysis. It could provide an important reference for similar projects in the future.

The sensor data was gathered by the wireless intelligent acquisition instrument, and the wireless intelligent acquisition instrument was connected with the gateway through the LAN formed by the Lora module, and the collected data was uploaded to the cloud platform through the 4G wireless module.

The change of monitoring data was synchronized with the progress of actual working conditions, which could reflect the dynamic process of construction to a certain extent. Therefore, it could provide data support for further stress analysis of pile.

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