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Analysis of pier mechanical properties in construction stage adjacent to deep foundation pit

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Abstract: *The deep foundation pit of Dongming Yellow River Highway Bridge is adjacent to the pier of the original bridge. In this paper, the stress and displacement of bridge pier are studied by experiments. The results show that temperature is the main factor affecting the pier, and the excavation adjacent to deep foundation pit has no obvious effect on the pier. The research results have practical significance for deep foundation pit construction and bridge design.*

Keywords: *Bridge reinforcement, Mechanical properties, Deep foundation pit, Box girder bridge*

1. Introduction

The Dongming Yellow River Highway Bridge, which was completed and opened to traffic in October 1993, faced significant issues just four years later. Cracks and deflection in the girder body became apparent, prompting the need for immediate attention. Starting from 1997, continuous monitoring revealed the worsening condition of the main bridge box girder, including the development and deterioration of cracks. Efforts were made to address these concerns, and in 2003, the main bridge underwent reinforcement measures. These measures involved increasing the cross section of the web, incorporating external cables within the box, and introducing diaphragms to enhance the overall integrity of the box girder[1-2].

The reconstruction and expansion project of the G106 Beijing-Guangzhou Dongming Yellow River Highway Bridge commences at the junction of Dongmin Road near the toll station of the existing G106 Beijing-Guangzhou Yellow River Highway Bridge in Yuanji Town, Dongming County, Shandong Province. It follows the course of the existing G106 Beijing-Guangzhou Road, heading north and crossing the Yellow River downstream of the current Dongming Yellow River Highway Bridge. After crossing the river, the project continues its reconstruction and expansion along the existing G106 Beijing-Guangzhou Road until it reaches K7+917.694, G106, Langzhong Township, Puyang County, Henan Province. The construction process often employs the use of continuous beam bridge technology and pier bottom rotation when crossing existing lines[3-4].

The bridge expansion serves the purpose of minimizing disruptions to the existing traffic flow, optimizing resource allocation, and generating substantial social and economic benefits[5]. When designing the supporting structure for deep foundation pit engineering, considerations must be given to both strength requirements and deformation control[6]. Deformation control of the foundation pit engineering should be aligned with the surrounding environment, deformation standards, construction control measures, and deformation monitoring practices[7]. Due to the proximity of the new bridge to the existing one, the excavation of the deep foundation pit may impact the piers of the current bridge. Hence, this study analyzes the mechanical properties of the existing bridge piers through long-term strain monitoring, settlement observations, and deflection measurements. Comprehensive preparatory work is crucial to prevent significant quality issues, ensuring a smoother subsequent construction process and significant cost reduction in future projects[8].

To assess the impact of the foundation construction of the G106 Beijing-Guangzhou Line Dongming Yellow River Highway Bridge on the safety of the old bridge structure, settlement and deflection monitoring are conducted on the piers of the Dongming Yellow River Highway Bridge. The measured data on pier settlements over the years are used to analyze the safety conditions of the old bridge piers during different stages of the reconstruction and expansion project. This analysis ensures the structural integrity and safety of the old bridge throughout the construction process of the new

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bridge[9]. It is essential to prioritize safety while also optimizing costs, shortening the construction period, and minimizing pollution and damage to the surrounding ecological environment[10].

2. Pier stress monitoring scheme

Considering the prolonged construction duration of the original pier, its deformation has reached a stable state. Based on the actual conditions, rear view prisms were installed on both the upper and lower piers of 55#, referred to as East Ming Rear view Point 1 and East Ming Rear view Point 2, respectively. In the Puyang direction, rear view prisms were installed on the downstream lateral side of pier 67# and 68#, named Puyang Rear view Point 1 and Puyang Rear view Point 2, respectively.

A total of 10 prisms were placed on the piers across the entire bridge, specifically on pier 57# to 66#. For pier monitoring purposes, a prism was affixed to each monitored pier as the measurement point, allowing the settlement and displacement of the piers to be reflected through changes in the prism's center coordinates. Subsequently, using the Tianbao SX10 laser mapping robot, a station was established, and relative parameters were set to create a spatial coordinate system. The robot measured the relative height of the rear view points and determined the pier positions of 57# to 66# using the rear intersection method. This approach ensures accurate and stable monitoring of the settlement and displacement of the main bridge piers of the Dongming Yellow River Highway Bridge.

3. Pier monitoring results

3.1. Test results of pier displacement difference

3.1.1. Detection result of longitudinal displacement difference

Upon comparing the results of six longitudinal displacement measurements conducted on October 19, 2022, it was observed that pier No. 63 exhibited the most significant shift distance towards the eastern Ming direction. The maximum displacement occurred on December 23, 2022. In general, the displacement measurements of the majority of pier columns showed minimal variance compared to those taken on October 19, 2022. Figure 1 illustrates the line chart depicting the difference in longitudinal displacement based on the results of the six measurements conducted on October 19, 2022.

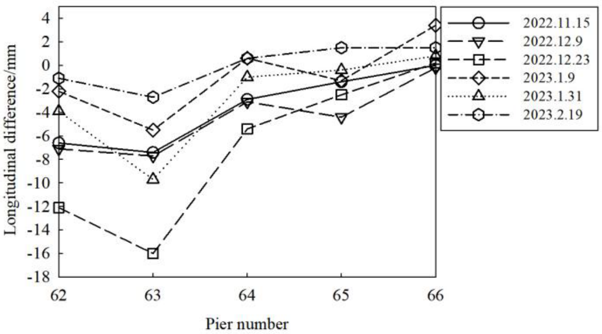

Figure 1: Line chart of longitudinal displacement difference of six piers.

3.1.2. Transverse displacement difference detection results

Upon comparing the results of the six transverse displacement measurements taken on October 19, 2022, it was observed that pier No. 63 displayed the least variation in lateral displacement. Additionally, the transverse displacement difference of the piers exhibited a pattern of decreasing and then reverse increasing as the detection dates progressed. Figure 2 presents a broken line diagram illustrating the difference in longitudinal displacement compared to the results of the six longitudinal displacement measurements conducted on October 19, 2022.

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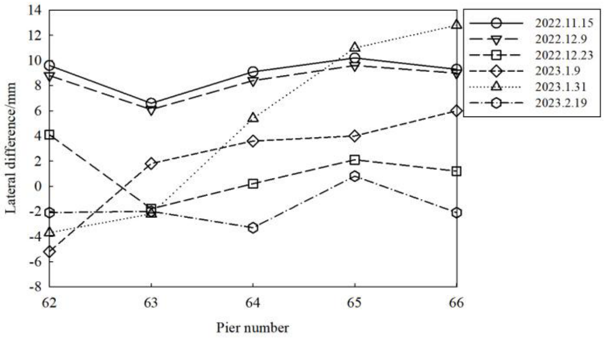

Figure 2: Broken line diagram of lateral displacement difference of six piers.

3.1.3. Height displacement difference detection results

By comparing the results of six height displacement measurements on October 19, 2022, it is found that the height displacement difference of pier No. 62 has the smallest change range, and only on December 9, 2022, the detected difference value of pier No. 62 is positive, and the displacement difference value is negative increasing, and the change range is small. Comparing the results of six longitudinal displacement measurements on October 19, 2022, the longitudinal displacement difference line chart is shown in Figure 3.

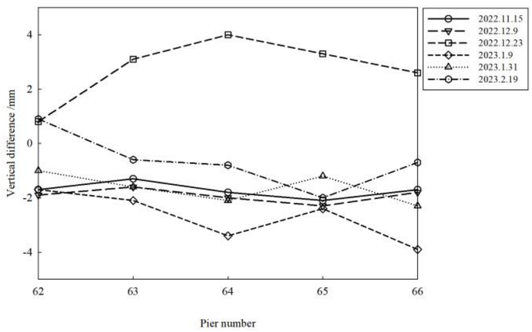

Figure 3: Line chart of six pier height displacement difference.

3.2. Strain monitoring results

On August 16, 2022, a comparison was made between six strain difference measurements. The findings indicated that the upstream and downstream differences in strain for pier 64 were quite similar, whereas pier 65 exhibited a larger disparity between the upstream and downstream differences. Furthermore, on December 23, 2022, the strain difference between the upstream and downstream measurements was the greatest for each pier. Additionally, a line chart illustrating the longitudinal displacement difference based on the comparison of the six strain difference measurements conducted on October 19, 2022, is presented in Figure 4.

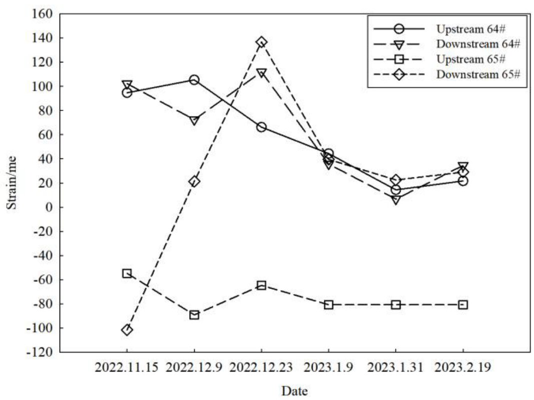

Figure 4: Line chart of lateral displacement difference of six piers.

By conducting temperature detection six times on both the upper and lower sections of pier 64, and combining the results with the six strain difference measurements for pier 64, a comparison was made between the strain and temperature measurements taken on October 19, 2022. The findings indicate that the changes in strain are primarily proportional to the variations in temperature. In other words, the greater the temperature difference, the larger the corresponding strain difference. The maximum strain difference occurs when the temperature difference is at its peak. Additionally, a line chart depicting the longitudinal displacement difference was generated based on the comparison of the six temperature difference measurements conducted on October 19, 2022, as shown in Figure 5.

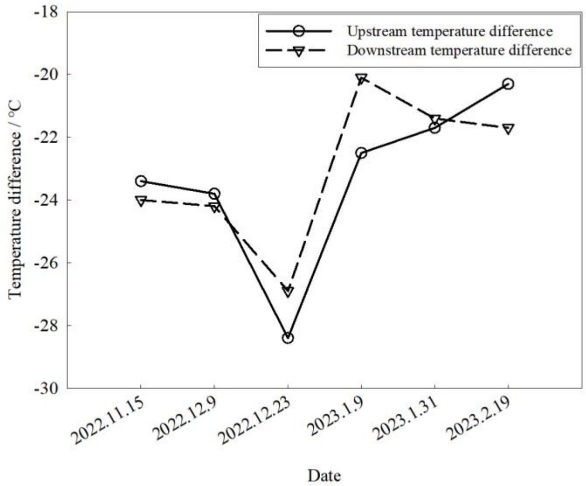

Figure 5: Line chart of the height displacement difference of six piers.

4. Conclusion

By comparing the six displacement difference values with the data measured on October 19, it was observed that the maximum displacement difference occurred on December 23, 2022, coinciding with the lowest temperature. During this time, the corresponding bridge exhibited a larger displacement difference. However, the latest data measured on February 19, 2023 indicated that as the temperature increased, the bridge gradually recovered to a level similar to that measured on October 19, 2022. Based on the existing data, annual data, and structural calculation model analysis, it is evident that temperature is the primary factor contributing to the settlement and deflection of the 62#~66# pier columns, followed by water flow, weather conditions, wind speed, and other factors. The monitoring results confirm that the lateral displacement of the bridge piers is not caused by the construction of the pile foundation.

Comparing the data with that of August 16, 2022, it was found that the maximum strain occurred at the downstream 65# pier on December 23, 2022, with a value of 136.8με. The change in stress is primarily proportional to the temperature fluctuations. Larger temperature differences correspond to greater variations in stress. As the temperature gradually increased, the stress difference measured on February 19, 2023 significantly reduced. Analysis suggests that the stress of the bridge piers decreases or increases with temperature changes. Considering the previous data, the overall difference between temperature and stress diminishes over time, primarily due to temperature-related effects.

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