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Total Station-Reflective Target Pier Deviation Measurement Error Control

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Abstract: In bridge engineering, monitoring pier offsets is crucial for ensuring both structural safety and construction quality. The total station measurement method using a reflector is widely employed, offering significant advantages in specific scenarios. During measurements, errors are influenced by various factors. Initially, misalignment causes the lateral relative error to increase before decreasing, while longitudinal relative errors fluctuate due to instrument characteristics and operational factors. Lateral movements have a more pronounced impact on these errors. Investigating the positioning layout of pier offsets holds substantial importance as it enables precise displacement monitoring, prevents accidents, aids in maintenance planning, provides valuable references for design and construction, and enhances the pier's resistance to deflection. Controlling and correcting subsequent errors is essential to ensure the overall safety of the bridge structure.

Keywords: Reflector; Total station; Pier deviation measuring point; Error analysis

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1. Introduction

In contemporary bridge engineering, precise pier positioning and displacement monitoring play a crucial role in ensuring structural safety and construction quality. Total stations are extensively utilized in this domain [1]. During measurements, various factors can introduce errors, with the reflective plate being a primary influencing factor. Its installation location, reflection efficiency, and compatibility with the total station are directly linked to the accuracy of pier offset measurement points [2]. Pier deflection encompasses vertical, lateral, and longitudinal displacements. Lateral deflection may lead to bridge deformation, while longitudinal deflection affects overall alignment and stability. Monitoring these aspects is essential for maintaining the safe operation of bridges. Consequently, investigating the error sources and influence mechanisms of reflectors and total stations holds significant theoretical and practical value for enhancing measurement accuracy and ensuring bridge safety. This study conducts a systematic analysis of reflector applications in total station-based pier offset measurements, exploring error causes such as reflector characteristics, installation deviations, environmental interference, and system errors inherent to total stations [3]. By integrating real-world engineering examples, this paper proposes error control strategies and optimization approaches, aiming to provide guidance for bridge measurement practices, promote advancements in bridge measurement technology, improve the precision of bridge engineering measurements, and ensure the safety and stability of bridges.

2. Total station measuring point setting method

In engineering measurements, the total station serves as a frequently utilized high-precision instrument [4]. Its point layout methods primarily consist of three approaches: prism-based, prismless, and reflector-based. Each method possesses its own set of advantages and disadvantages, making them suitable for various measurement scenarios [5]. The prism-based approach represents a traditional measurement technique that leverages reflective prisms to bounce back laser signals, achieving extremely high accuracy at the millimeter level. This level of precision is indispensable in projects such as bridge and building construction, where positioning accuracy is paramount. Additionally, the use of prisms can substantially extend the range of the total station, theoretically reaching several kilometers. In practical applications, with high-quality prisms, the effective range typically spans 1 to 3 kilometers, surpassing the capabilities of prismless modes. Furthermore, the prism-based method imposes minimal environmental constraints, delivering reliable results even under low-light or poor reflection conditions. It exhibits high data repeatability and reliability, making it ideal for long-term monitoring tasks. Nevertheless, this method necessitates direct line-of-sight between the total station and the prism, which can be hindered in complex terrains or densely built environments due to obstructions. Moreover, the requirement for manual installation and adjustment of the prisms adds complexity to operations and increases costs.

The prism-free arrangement offers convenient operation, eliminating the need for installing and adjusting reflector prisms. Measurements can be taken directly at the target point, significantly enhancing operational efficiency. This method is versatile and well-suited for environments where prisms cannot be installed, such as high locations, water surfaces, and hazardous areas, including suspended piers and cable measurements in bridge monitoring. Additionally, the cost of prism-free measurement is relatively low since there is no requirement to purchase or maintain prisms. Nevertheless, the accuracy of this approach is restricted and generally falls below that of prism-based methods. Consequently, when utilizing a prism-free total station for measurements, it is advisable to keep the measurement distance within 60 meters to ensure the required level of accuracy is maintained [6].

The retroreflector demonstrates significant advantages in specialized scenarios and serves as a crucial tool for total station measurements [7]. By returning the laser signal, it assists the total station in rapidly identifying and measuring target points, with flexible positioning that can be modified according to requirements. For instance, during tunnel monitoring, it is commonly attached to crown and sidewall monitoring points to track real-time tunnel deformation. In bridge construction, it is typically placed on pier surfaces or predetermined locations for high-precision measurements. Unlike prisms, retroreflectors do not require intricate installation or adjustment but can be directly adhered to the target surface. This significantly reduces preparation time and labor costs, offering distinct benefits in challenging environments such as high-altitude areas, water surfaces, and complex terrains where prism installation is difficult.

3. Application of the total station in bridge pier deflection detection

This experimental design utilizes a total station and reflective stickers for monitoring pier deflection. During the preparation stage, reflective stickers are affixed at critical locations, such as the base of multiple piers, serving as fixed reference points. These stickers remain immobile throughout the testing period [8]. In the observation phase, measurements are conducted using a total station. The device is positioned in an initial location where it can clearly detect and reflect signals from each pier while also meeting safety and observational requirements. The signal from the total station is directed toward the reflective sticker, which then bounces the signal back to the total station, enabling the collection of baseline observational data [9].

To facilitate multi-angle observations, the total station is relocated to various predetermined stations based on planned angles and distances. For instance, measurement stations can be established at specific intervals (such as 0°, 30°, 45°, 60°, and so on, up to the maximum angle) in a circular pattern around the pier [10, 11]. At each newly established station, a total station is utilized to measure the reflective paste markers on each pier, recording the angle, distance, and other data obtained from various perspectives. Once the measurements are completed, the extensive data collected are processed.

By employing specialized measurement software and incorporating known station coordinates and additional information, the data gathered from different angles are consolidated into a unified coordinate system. This process calculates the three-dimensional coordinates of each reflective patch measurement point. These measured coordinates are then compared with the design coordinates of the pier to determine the offset data in various directions. Through a thorough analysis of the multi-angle measurement data, the deflection of the pier can be assessed comprehensively and precisely, providing a crucial foundation for bridge maintenance and safety evaluations.

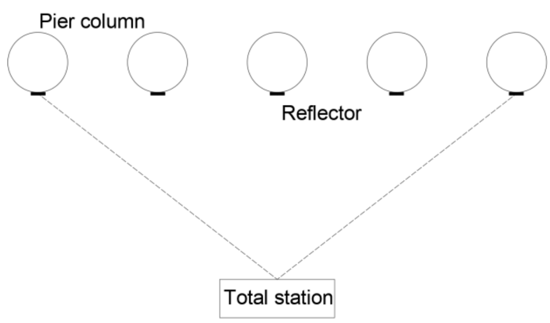

Figure 1. Schematic diagram of pier deflection observed by total station

4. Multi-angle observation pier deflection measurement point test

4.1. Test design

In the test design for the offset position of bridge piers, a method is employed where the total station is moved while the reflector plate remains stationary. Initially, at critical deflection measurement points on the pier, such as the pier top and midsection, reflective plates are evenly and securely attached as fixed reference points. This ensures their stability and prevents any displacement throughout the entire testing process [12].

In the planning of the total station's moving path, several stations are established based on specific angles, with the pier serving as the central reference point. At directions of 0°, 30°, 45°, 60°, and the maximum limit of 80°, the total station is positioned at a safe distance from the pier while ensuring clear visibility. The total station is sequentially set up at each station to measure the reflective plate measurement points located on the pier. Through this multi-angle observation method, comprehensive position information of the measurement points under various horizontal angles can be gathered, enabling precise analysis of the pier's horizontal deflection in all directions. The observation procedure adheres to an orderly approach. Initially, all reflector measurement points are measured at the 0° station, and the corresponding raw data, such as angles and distances, are documented. Subsequently, the total station is relocated to the 30° station, where the aforementioned measurement and recording steps are repeated. This process continues incrementally until measurements at the 80° station are finalized. Throughout the entire process, it is crucial to measure each reflective point strictly in accordance with the predetermined sequence at every station to prevent any omissions or duplicate measurements, thereby guaranteeing the completeness and precision of the collected data.

Following the test, the extensive raw data collected from various measuring stations are consolidated. With the aid of specialized measurement software referenced in Zhou's study [13], the three-dimensional coordinates of each measurement point are precisely determined within a unified coordinate system. This calculation leverages the measurement principles, known station coordinates, and other critical information. The obtained measurement coordinates are then meticulously compared against the designed coordinates of the pier, yielding the offset data for the pier. By conducting an integrated analysis of the data processing outcomes from multiple station angles, the deflection of the pier can be assessed comprehensively and with high precision. This process delivers robust and dependable data support for subsequent bridge maintenance decisions.

4.2. Test results

The graph illustrates the connection between longitudinal and lateral displacement and the relative error in the arrangement of bridge pier offsets when using a total station at various observation angles. Analyzing the pier displacement error data reveals that, generally, the lateral error exceeds the longitudinal error. The horizontal observation error at 0° is the highest (mean 1.13mm, standard deviation 0.74mm), whereas the horizontal error at 60° is notably minimized and remains the most consistent (mean 0.57mm, standard deviation 0.31mm). This suggests that enhancing the observation angle can efficiently mitigate lateral interference. Overall, within the angular range of 0–30 degrees, the lateral relative error surpasses the longitudinal relative error in most angular intervals. Additionally, the lateral relative error demonstrates significant variation, while the longitudinal relative error exhibits relatively mild fluctuations. These findings indicate that lateral movement considerably impacts the relative error under this measurement scenario [14].

Table 1. Displacement direction and relative error of pier under different observation angles

Observation angle	Pier displacement direction	Maximum error (mm)	Minimum error (mm)	Mean error (mm)	Standard deviation of error (mm)
0 °	Longitudinal	1.0	0.1	0.63	0.32
	Horizontal	2.0	0.3	1.13	0.74
30 °	Longitudinal	2.0	0	0.44	0.67
	Horizontal	1.9	0.2	1.06	0.62
45 °	Longitudinal	1.9	0.1	0.73	0.69
	Horizontal	1.2	0.1	0.73	0.42
60 °	Longitudinal	1.5	0.1	0.84	0.47
	Horizontal	0.9	0	0.57	0.31

5. Conclusion

The findings from the multi-angle observation experiment, where the total station was moved while the reflector remained stationary, are noteworthy. While the reflector lacks the precision of a prism, it offers significant advantages such as low cost, easy installation, and the ability to rapidly establish measurement points in challenging environments like narrow spaces or high altitudes, demonstrating strong adaptability [15]. In bridge safety evaluations, combining observations from multiple stations at varying heights enables comprehensive detection of deviations in bridge piers. This approach significantly enhances the accuracy of structural health assessments and provides critical evidence for identifying potential hazards and devising maintenance strategies. Regarding advancements in measurement technology, flexible station arrangements and the utilization of reflectors inspire researchers to refine measurement procedures and improve algorithms, driving the evolution of measurement techniques toward greater intelligence and precision. In practical applications, these results can support the lifecycle monitoring of various bridges, ensuring construction accuracy for new bridges and aiding in the upkeep and reinforcement of existing structures. In specialized bridge inspections or post-disaster emergency scenarios, the benefits of using reflective plates are evident, allowing for swift establishment of monitoring systems and safeguarding the integrity of transportation infrastructure.

Disclosure statement

The authors declare no conflict of interest.

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