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Study on Fracture Delay of High-Strength Bolts in Road Bridge Maintenance

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Abstract: In the maintenance work of highway and bridge engineering structures, the fracture delay of high-strength bolts is a content that needs to be focused on and researched. Based on this, the paper analyzes the fracture delay of high-strength bolts in highway bridge maintenance, including an overview of the fundamental research on fracture delay and related specific studies. It is hoped that this study can provide scientific reference for the reasonable maintenance of high-strength bolts, so as to ensure the overall maintenance effect of highway bridge projects.

Keywords: Highway bridge engineering; Bridge maintenance; High-strength bolts; Fracture delay; Maintenance recommendations

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1. Introduction

For the high-strength bolts used for connecting and fixing in highway and bridge engineering, the scientific research of its fracture delay is crucial in the specific maintenance work. Therefore, we should first fully understand the basic situation of this research, including its basic research background, the necessity of the research and the main research content. Then based on this, in-depth research is conducted on the high-strength bolt fracture delay in the maintenance of highway bridges, focusing on the fracture delay mechanism, non-destructive testing technology for delayed cracks, the current state of fracture delay, research conclusions, high-strength bolts maintenance recommendations, and so on. This approach allows for scientific analysis of fracture delay, providing scientific reference for the maintenance of high-strength bolts in highway bridges.

2. Introduction to the study of high-strength bolt fracture delay in road bridge maintenance

2.1. Basic research background

In modern steel bridge engineering, high-strength bolt connection is one of the most commonly used connection methods. Since high-strength bolts have many advantages such as not easy to loosen under dynamic loading conditions, fatigue resistance, removable and replaceable, good stress performance and simple construction, they have been widely used in modern steel structure bridge engineering. However, in the practical application of highway bridge engineering, with the prolongation of its continuous operation time, high-strength bolts will also have certain damages, including loosening and falling, and ordinary maintenance is usually difficult to obtain satisfactory results. For example, Japan's Fukushima Prefecture Mishima Bridge was built in 1975, and the high-strength bolts began to fall in 1987. Despite key inspections and replacements of the damaged bolts by the maintenance unit, such incidents continued to occur. Through the practical application of highway bridge engineering and the summary of its operation and maintenance work, it was found that high-strength bolt breakage exhibits uncertainty and suddenness. The specific influencing factors and forms of failure also show various characteristics. Currently, there is no systematic research on this issue, either domestically or internationally, and no conclusive findings on the law governing delayed fracture of high-strength bolts [1].

2.2. The necessity of research

Due to the high-strength bolt damage in highway bridge structure is difficult to be solved by ordinary maintenance methods, coupled with the connection of steel structure bridge and its fixing effect is mainly determined by the high-strength bolt, so it is necessary for us to carry out an in-depth study on the delayed fracture of the high-strength bolt, so that we can find out the main mechanism of the delayed fracture and its reasons, and to provide scientific references for the subsequent maintenance work.

2.3. Main research content

In this study of high-strength bolt fracture delay in highway bridge engineering, the main research content includes the following aspects.

(1) Data collection: Mastering the delayed fracture cases of high-strength bolts of steel bridges in the current stage of highway bridge engineering at home and abroad.

(2) On-site research: On high-strength bolt fracture and shedding in the operation of highway bridge projects, including the environment where the bridge is located, the operation time, high-strength bolt type, the number of high-strength bolts broken, high-strength bolts broken parts, and management and maintenance units of the delayed fracture of high-strength bolts and other treatment measures.

(3) According to research data: The delayed fracture of high-strength bolts in steel bridges in highway bridge projects, shedding of macro-influencing factors and the law to carry out scientific analyses, to provide technical guidance for the design and inspection of high-strength bolts in subsequent such projects.

3. High-strength bolt fracture delay related research in highway bridge maintenance

In the study of high-strength bolt fracture delay in highway bridge maintenance project, its key work includes the following aspects.

(1) Research and analysis of the current situation of high-strength bolt fracture delay in steel bridges and the study of its relation to the environment, structural parts, parts of components, bolt parts and characteristics of macro-factors such as the influence of the law.

(2) From the product inspection, design, construction and other aspects of the prevention of high-strength bolt fracture delay in steel bridges, there is a need for effective measures to guide the actual project. In this specific research, several challenges were encountered, particularly in the following aspects.

(i) The study of highway bridge projects requires a certain level of representativeness and an adequate number of high-strength bolts of a certain scale.

(ii) Accurate information on the production, installation, and operational processes of the high-strength bolts in the bridge is necessary.

(iii) It is essential to integrate the research findings with actual engineering practices and propose effective measures to prevent the delayed fracture of high-strength steel bridge bolts [2]. Based on the above research focus and challenges, the team conducted its study on high-strength bolt fracture delay through the following approaches.

3.1. Fracture delay and occurrence mechanism

Fracture delay is a quality damage problem that can easily occur in the continuous application of high-strength bolts. Usually, the main characteristics of such problems are shown in the following aspects.

(1) When the tensile strength of the high-strength bolt fracture delay exceeds 1,226 MPa, the risk of fracture delay will occur.

(2) This situation usually occurs at room temperature conditions [3].

(3) High-strength bolts with delayed fracture usually do not have significant plastic deformation at the microscopic level.

(4) It is also likely to occur under static load conditions.

(5) Such cases also occur at stress levels much lower than the yield point [4].

The main mechanisms of fracture delay are typically manifested in the following aspects.

(1) Corrosion caused by the surrounding environment or hydrogen generated during fabrication entering the steel can lead to brittle failure.

(2) Once hydrogen penetrates the steel, it diffuses, moves, and accumulates at stress concentration points, triggering brittle failure.

(3) The chemical composition of the steel itself does not directly affect its susceptibility to cracking.

(4) The steel's tensile strength, the applied stress, and the environmental conditions all influence the fracture delay.

3.2. Non-destructive testing technology for delayed cracks

Non-destructive testing (NDT) is a key technology for detecting delayed fractures in high-strength bolts used in highway bridge structures. Typically, inspectors use ultrasonic non-destructive testing equipment. The principle of this method involves using an ultrasonic transmitter to send waves into the high-strength bolts and a receiver to capture the waves that return from within the bolts [5]. "Internal integrity and internal cracks in high-strength bolts produce distinct patterns in reflected ultrasonic waves. By analyzing these differences, inspectors can scientifically determine whether there is a fracture delay issue and provide a basis for subsequent replacement or maintenance.

3.3. The current situation of fracture delay

In this study, the researcher carried out non-destructive testing on the high-strength bolts in five major highway bridges in Chongqing, including Dongshuimen Yangtze River Bridge, Qianlizimen Jialingjiang River Bridge, Caiyuanba Yangtze River Bridge, Zengjiayan Jialingjiang River Bridge, and Hongyancun Jialingjiang River Bridge. **Table 1** shows the span composition of steel truss bridges and the number of high-strength bolts in the five major highway bridges studied.

Table 1. The span composition of steel truss bridges and the number of high-strength bolts of the five major highway bridge

Serial number	Name of highway bridges	Span composition (m)	Number of high-strength bolts
1	Dongshuimen Yangtze River Bridge	222.5 + 445.0 + 190.5	820,000 sets
2	Qianlizimen Jialingjiang River Bridge	88.0 + 312.5 + 80.0	645,000 sets
3	Caiyuanba Yangtze River Bridge	102.0 + 420.0 + 88.0	218,000 sets
4	Zengjiayan Jialingjiang Bridge	135.0 + 270.0 + 135.0	632,000 sets
5	Hongyancun Jialingjiang River Bridge	90.0 + 135.0 + 375.0 + 120.0	743,000 sets

Non-destructive testing (NDT) of high-tensile bolts in the highway bridge projects identified fracture issues in the bolts installed on the steel truss bridges of the five studied projects. The proportion of high-tensile bolts with fractures ranged from 0.4% to 26.8% of the total number of bolts in these bridges. The earliest fractures were detected 2 months after the bolts were put into official use, while the latest fractures occurred 9 years after installation.

In this study, fractured high-strength bolts were further tested using Rockwell hardness testing and chemical composition analysis. The results showed that some bolts had Rockwell hardness values exceeding their design specifications. Further analysis indicated that this discrepancy was likely due to the raw materials of the bolts not meeting the actual requirements of the bridge structure or the bolts being in a tensile state for an extended period, which increased their tensile strength [6]. Additionally, some high-strength bolts have chemical compositions that do not meet design specifications, primarily due to the raw materials used not conforming to design standards, as shown in **Table 2**.

Table 2. Results of high-strength bolts after fracture Rockwell hardness and chemical composition test

Serial number	High-strength bolt type	Rockwell hardness	Chemical composition
1	M24	Conformity	Mn content 1.37 (exceeds the specified range 0.50-0.90), V content 0.002 (below specified range 0.05-0.12),
2	M24	Conformity	C content 0.19 (below specified range 0.31-0.39), Mn content 1.47 (exceeds the specified range 0.50-0.90), V content 0.0003 (below specified range 0.05-0.12)
3	M30	Conformity	Conformity
4	M30	40.5 (exceeds specified range 33-39)	Conformity
5	M30	43.0 (exceeds specified range 33-39)	Conformity
6	M30	Conformity	Conformity
7	M30	43.0 (exceeds specified range 33-39)	
8	M30	Conformity	C content 0.18 (below specified range 0.31-0.39), Mn content 1.45 (exceeds the specified range 0.50-0.90), V content 0.0003 (below specified range 0.05-0.12)
9	M30	40.0 (exceeds specified range 33-39)	C content 0.21 (below specified range 0.31-0.39), Mn content 1.47 (exceeds the specified range 0.50-0.90), V content 0.0003(below specified range 0.05-0.12)
10	M30	40.0 (exceeds specified range 33-39)	Conformity
11	M30	43.0 (exceeds specified range 33-39)	Conformity

Note: Mn = Manganese, V = Vanadium, C = Carbon

3.4. Fracture delay research conclusions

After conducting fracture delay NDT and analyzing high-strength bolts from the steel truss bridges in five major highway bridge projects in Chongqing using the above methodology, the following research conclusions were obtained.

(1) The earliest bolt fractures occurred either before the bridges were opened or shortly after their opening, and no clear correlation between the operational time and fracture timing was found.

(2) Both M30 and M24 bolts experienced fractures, suggesting that the diameter of the bolts may not be directly related to delayed fracture issues.

(3) The main locations of high-strength bolt fractures were concentrated near the supports and the center of the span in arch ribs, while fractures in the main girders were more scattered [7].

(4) Test results for chemical composition and Rockwell hardness after fractures indicated that some bolts did not meet the specified values, highlighting the need for more rigorous testing during steel beam installation.

3.5. Recommendations for the maintenance of high-strength bolts

Based on the conclusions drawn from the study of delayed fractures in high-strength bolts used in highway and bridge projects, and considering the practical needs of modern highway and bridge applications, the following recommendations are proposed.

(1) Post-operational non-destructive testing: After the highway and bridge projects are officially put into operation, staff should implement non-destructive testing of high-strength bolts by means of random testing or regular testing to promptly identify any fractures. This testing helps detect fracture delays early and allows for timely intervention based on the actual conditions [8].

(2) Maintenance and environmental control: During the operation and maintenance of these structures, staff should ensure thorough cleaning of the bolt locations to prevent dust, oil, and other contaminants, creating a clean operating environment. Additionally, controlling environmental humidity and removing water from around the bolts are essential to prevent corrosion and subsequent fracture delays [9].

(3) Inspection of anti-corrosion coatings: Regular inspections of the anti-corrosion on high-strength bolts should be conducted. For bolts with damaged coatings, timely re-coating is necessary to protect against corrosion and maintain the bolts' quality and strength.

(4) Material selection for replacements: When replacing high-strength bolts, staff should select materials that meet the specific engineering design requirements to avoid fracture delays caused by poor material quality.

By implementing these measures, maintenance of high-strength bolts in steel structure beams of highway bridge projects can be effectively managed, reducing the incidence of fracture delays and ensuring the quality and safety of the structures [10].

4. Conclusion

In summary, high-strength bolts are critical connecting components in many modern highway and bridge projects. When high-strength bolts experience fracture delays, their quality and strength can be significantly compromised, potentially leading to damage that adversely affects the safe and stable operation of these projects. To prevent such issues, it is essential for operation and maintenance units to focus on researching the mechanisms and causes of high-strength bolt fractures. Based on this research and the specific conditions of highway and bridge projects, reasonable measures should be implemented to ensure effective maintenance of high-strength bolts. By doing so, the overall quality and performance of these bolts can be enhanced, contributing to the stability and safety of modern highway bridge steel girder structures and extending their service life.

Disclosure statement

The author declares no conflict of interest.

References

[1] Cao L, 2023, Research on Technical Condition Assessment and Maintenance Technology of High-Strength Bolts in Urban Bridges, thesis, Jiangsu University of Science and Technology.

[2] Zhu S, 2016, Analysis of High Strength Bolt Fracture of Steel Truss Girder Of High Speed Railway Special Bridge and Suggestions for Maintenance and Repair. Shanghai Railway Science and Technology, 2016(4): 79–80.

[3] Shen H, Jiang M, Wang Z, et al., 2020, Analysis of Factors Affecting the Force of High-Strength Bolts in Typical Nodes of Steel Truss Bridge. Journal of Nanjing University of Technology (Natural Science Edition), 2020(3): 373–379.

[4] Yi Z, Liu L, Tian B, et al., 2022, Experimental Study on the Application of Ring-Groove Rivets in Highway Bridges. Highway, 67(1): 104–108.

[5] Lv S, Yang G, Chen H, et al., 2023, Identification Method of Loosening Bolts in Steel Bridges Based on Key Point Detection. Low Temperature Construction Technology, 45(2): 56–59.

[6] Hang J, Yang L, Shen J, et al., 2022, Research on Preventive Maintenance Technology of Steel Truss Bridge. Chinese and Foreign Highway, 42(3): 80–84.

[7] Zhao W, Chang H, Ji C, et al., 2024, Numerical Simulation of Loosening Law of Bolted Nodes Under Transverse Vibration. Vibration and Shock, 43(8): 61–69, 88.

[8] Chen L, Zhou Q, 2022, Application of High-Strength Bolt Connection Technology in Steel Trestle Bridge Construction. Traffic World (Zhongdian), 2022(11): 153–155.

[9] Chen G, Yu J, Ma Z, 2022, Failure Analysis of Rear Axle Bolt Fracture. Highway and Motor Transport, 2022(6): 11–12.

[10] Ruan J, Shen X, Yang Z, 2023, Research on the technology of Measuring Axial Force of Steel Bridge Bolts by Ultrasonic Method. Jiangxi Building Materials, 2023(12): 182–185.