Current Research Status of Construction Control Techniques and Load-Bearing Performance of Bearings for Long-Span Bridges with Longitudinal Slopes

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Abstract

In response to the current research status of construction control techniques and load-bearing performance of bearings for long-span bridges with longitudinal slopes, this paper reviews the research progress from two aspects: construction control and load-bearing performance. In the field of construction technology: methods such as top-down integrated construction and floating crane coordinated installation have been proposed. Combined with the full-process quality control method for prefabricated components, these methods have solved the problem of efficient construction of bridges in complex terrains. In terms of load-bearing performance: the frictional effect of movable bearings can reduce the peak longitudinal force of rails by 23%, and the contradiction between "stiffness and stress" of longitudinal slope bridges can be balanced by regulating the friction coefficient. The innovatively developed numerically controlled leveling bearings and combined seismic isolation technologies have respectively reduced the installation eccentric pressure risk by 90% and the seismic response by 40%–50%. At present, it is necessary to break through the bottleneck of multi-field coupling simulation and intelligent monitoring technologies. In the future, efforts should be made to develop full-life self-adaptive bearing design and digital twin operation and maintenance systems, and to promote the transformation of bridge safety from passive treatment to intelligent pre-control.

Keywords

Longitudinal Slope Bridges; Bearings; Construction Control; Load-Bearing Performance.

1. Introduction

In recent years, the mileage of expressway bridges in operation in China has been increasing year by year. A number of prefabricated beam bridges located on sections with steep longitudinal slopes have begun to exhibit various distresses, such as pier offset, excessive longitudinal sliding of bearings, and varying degrees of damage, which seriously threaten the structural integrity and operational safety of the bridges. Given that long and steep slopes can easily trigger sudden and catastrophic safety accidents in bridges, this issue requires high attention. At present, there have been many discussions and reports in China on the research of long-slope bridges, the load-bearing characteristics of bearings, and the key construction technologies.

2. Current Research Status of Construction Control Techniques for Bearings

2.1 Research on Erection, Installation, and Key Construction Technologies of High-Pier Bridges in Mountainous Areas

At present, advanced bridge construction technologies are increasingly widely applied in highway bridge projects across the country. Given the inherent complexity of these technologies, to ensure construction quality and comprehensively enhance the safety and stability of the projects, we should focus on the technical details of each construction phase of bridge building, implement them meticulously, and thus achieve the optimal engineering outcomes.

Liu Xiao [1] systematically reviewed the construction technology and applications of the top-down method, analyzed its principles and development history, and proposed a new classification method. In response to construction difficulties, he innovatively designed the "integrated assembly, single top-down" system, optimized the force conditions of key beam sections, and established an error control and monitoring system to verify the safety of beam construction.

Lu Fei [2] proposed a replacement plan for the steel-concrete bridge deck panels from 12 m to 24.5 m for the Songpu Bridge, which is a combined road-rail bridge. Considering the restrictions of railway and waterway, he selected the "full floating crane" process: barge transportation and synchronous operation of a 300t floating crane. By optimizing channel management and anchoring, he realized efficient and safe construction.

Zhang Guangqiao [3], based on the Pingyin Yellow River Bridge project, tackled the construction technology of steel-concrete cable-stayed bridges in complex environments, covering the transportation and positioning of steel box girders, installation of tower areas and load-bearing sections, and bridge deck panel construction, providing practical references for similar projects.

Guan Yongqiang [4] focused on the prefabricated cap beam process, systematically analyzed the entire process from pier construction, steel bar binding, corrugated pipe installation to hoisting and grouting, summarized the key points of quality control, and contributed to efficient construction.

2.2 Research on Bearing Selection and Distress Mechanisms of Long-Span Beam Bridges in Mountainous Areas

Given the potential impact of bearing distress on the load-bearing performance of bridges, the academic community has carried out extensive research to gain a deeper understanding of this issue and to seek effective solutions.

Zhou Xin [5] proposed a performance evaluation method for steel truss bridge bearings based on thermally induced displacement: by analyzing the spatiotemporal evolution of the temperature field, a temperature-displacement correlation model was established, and a bearing slip performance evaluation system was developed. Experimental validation has shown that this method can effectively identify internal wear of spherical bearings, providing a new approach for the safe operation and maintenance of bridges.

Ma Fengbo [6] developed a damage evaluation system for high-speed railway box girder bridge bearings, integrating structural performance and operational safety requirements. Through multidimensional research, he proposed a rapid evaluation-replacement and repair technology. Innovatively, he introduced a damage grading evaluation method based on apparent defects and a dynamic impact coefficient boundary damage diagnosis model.

Tian Wei [7] revealed the mechanism of shear distress in bearings of prestressed cast-in-place beam bridges: the superposition of concrete shrinkage/deflection deformation during construction and low-temperature shrinkage during operation leads to excessive deformation of plate rubber bearings. He proposed three targeted prevention and control technologies to interrupt the chain of distress

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development: the "jacking and releasing method," the "adjustable conversion bearing method," and the "movable formwork support construction method."

Song Lianliang [8] systematically analyzed the spectrum of beam bridge bearing distress and clarified the damage mechanisms of five typical types of distress. Focusing on the prevention and control of shear cracking distress, he innovatively proposed two solutions: one is a new technology solution, namely the use of adjustable conversion bearings; the other is a new process solution, which involves leaving a gap between the bottom beam bearing steel plate and the bearing before prestressing of cast-in-place box girders, using a temporary movable sand box support, and adopting a secondary beam lowering method.

3. Current Research Status of Load-Bearing Performance of Bridge Bearings

3.1 Development and Load-Bearing Characteristics of Special Bearings for Longitudinal Slope Continuous Beam Bridges

In long-slope bridges, the contact surface between the bridge base and the bearing is prone to sliding damage, which not only interferes with the overall mechanical characteristics of the bridge but also weakens its safety performance and adaptability to some extent. In response to this situation, Chinese researchers have carried out a series of explorations and analyses on the development and load-bearing characteristics of bearings for long-slope bridges.

Xie Peng [9] revealed the mechanism by which the friction of movable bearings affects the coupling effect of long-span continuous beam bridges with tracks: integrating beam-track interaction theory with the finite element method, he constructed a spatial coupling model of beams and tracks considering bearing friction (friction is equivalent to a nonlinear spring). The study shows that friction can enhance the longitudinal restraint of beams and tracks, reducing the peak longitudinal force of rails by 23% and the displacement of beams and tracks by 18%, while simultaneously reducing the longitudinal load on fixed piers. Under braking conditions, the reduction in rail braking force and pier stress reaches 15%–30%; in the case of rail breakage, friction can transfer 30% of the rail breakage force to non-fixed piers, further optimizing the load distribution of piers.

Lin Jun [10] established a refined model of sliding bearings for long-slope T-beam bridges based on ANSYS (frictional contact is modeled using nonlinear spring elements) and explored the coupling effect of the friction coefficient on structural performance under multiple load combinations: for every 0.1 increase in the friction coefficient, the mid-span deflection decreases by 8%–12%, but the longitudinal stress in the main beam increases by 15%–20%, revealing the mechanism for regulating the "stiffness-stress" contradiction in long-slope bridges.

Li Zhao [11] solved the persistent problem of eccentric loading in traditional bearings for long-slope bridges (≥2%): he innovatively developed a numerically controlled leveling sloping bearing, which, by precisely machining the height differences at the four corners of the bearing's upper plate, achieves full matching of the bearing with the bridge's longitudinal and transverse slopes, eliminating over 90% of the risks of beam offset and pier cracking caused by installation tilt.

Yumin Zhang [12] quantified the regulation patterns of rubber seismic isolation bearings on the seismic performance of continuous beam bridges: dynamic time-history analysis indicates that LRBs and HDRBs, compared to traditional NRBs, can reduce the bending moment at pier bases by 40%–50%, with their hysteretic energy dissipation contribution rate exceeding 70%; hybrid seismic isolation bearings (NRBs+LRBs) improve seismic efficiency by 25% when the span exceeds 80 m or the pier height exceeds 15 m, but they require precise matching of bridge span-pier height parameters to avoid response discretization.

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3.2 Research on Load-Bearing Characteristics and Installation Techniques of Bearings for Longitudinal Slope High-Pier Bridges

Given that long slopes can easily trigger sudden and catastrophic safety accidents in bridges, this issue requires high attention. There have been many discussions in China on the research of long-slope bridges and the load-bearing characteristics of bearings.

Qiu Wen [13] et al. analyzed the distress of bearings on a certain expressway and found that the main causes of distress are creep of the superstructure, insufficient lubrication on the top surface of sliding bearings, and the influence of construction dynamic loads.

Lin Jun [14] et al., in order to study the load-bearing performance of long-slope highway bridges considering bearing contact slip under the action of multiple load combinations, used the finite element method to establish models and compared the load-bearing performance of long-slope bridges with different friction coefficients under multiple load combinations. The results show that increasing the friction coefficient of the bearing can reduce the mid-span deflection but will increase the longitudinal stress and strain of the main beam.

Sun Senlin [15] et al., in order to study the horizontal hysteresis performance of metal-rubber bridge bearings under different performance states, conducted quasi-static compression-shear tests on metal-rubber bridge bearings and verified that the Bouc-Wen model can fit the hysteresis curve of metal-rubber bearings.

Wu Gang [16] et al., in order to study the influence of different boundary constraints on the load-bearing performance of rubber bearings, established models using finite element software. Subsequently, they applied vertical forces and shear deformations to the finite element models of bearings with different boundary constraints and compared and analyzed the influence of different boundary constraints on the internal stress distribution, stress response values, and other mechanical properties of the bearings.

4. Conclusion

In response to the increasingly prominent distress issues of bearing slip and pier offset in long-slope bridges in China, current research has achieved phased results in construction control and load-bearing performance: innovative solutions such as the "integrated assembly, single top-down" technique using the top-down method, numerically controlled leveling sloping bearings, and combined seismic isolation design (with a 25%–50% increase in seismic efficiency) have effectively addressed safety hazards such as bearing eccentric loading and excessive slip. However, issues such as insufficient simulation accuracy of complex environmental coupling effects and lagging intelligent monitoring technologies still restrict technological development. In the future, efforts should focus on the evolution of bearing performance under multi-hazard coupling, integration of digital technologies throughout the construction and operation and maintenance life cycle, and the development of self-adaptive bearings, to promote the transition of bridge safety from "passive maintenance" to "active prevention and control."

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