Journal of World Architecture, 2024, Volume 8, Issue 2
https://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN: 2208-3480

Seismic Design Strategy of High Pier Bridge

Jianmin He*

China Merchants Chongqing Communications Technology Research & Design Institute Co., LTD., Chongqing 400067, China

Corresponding author: Jianmin He, hojampl@sina.com

Abstract: China's infrastructure construction has been continuously improving in recent years, especially its highway construction, which spans from north to south and connects east to west. Some special areas are also interconnected through bridges, but constructing highway bridges through complex terrains or across valleys and mountain gullies presents significant challenges, requiring an increase in the height of bridge piers. These bridge piers generally reach tens or even hundreds of meters in height. Furthermore, the construction of these high-pier bridges is becoming increasingly widespread. Not only do they pose greater construction challenges, but they also have higher requirements for seismic resistance. This article primarily analyzes the characteristics of high-pier bridges and proposes seismic design schemes, calculation methods, and design strategies to enhance the construction quality of high-pier bridges.

Keywords: High-end bridge; Characteristic; Seismic design; Calculation method

Online publication: May 21, 2024

1. Introduction

Earthquakes occur frequently in China, and almost every administrative region has experienced earthquakes of magnitude 6 and above. These earthquakes usually last for a long time and can cause significant damage to buildings. During the construction of highway bridges, issues like bridge damage and collapse are common during earthquakes. Particularly in the construction of concrete bridges, the collapse of bridge piers is a major concern. Therefore, earthquake resistance is an important consideration in bridge construction By adopting ductility-based design for bridge piers, the deformability of bridges can be enhanced. The weight of the superstructure of high-pier bridges is comparable to that of the piers, making traditional design methods for low-pier bridges inadequate for high-pier bridges. It is necessary to further calculate and optimize seismic design methods based on the structure of high-pier bridges.

2. Characteristics of high-pier bridges

Based on the current state of engineering projects, high-pier bridges exhibit several characteristics: Firstly, most of these bridges employ continuous steel structures and girders in their upper sections. Secondly, they typically have relatively small horizontal and vertical curvature radii. Lastly, their lower structures often feature special thin-walled hollow pier designs [1]. Considering these traits, it's crucial to conduct comprehensive evaluations when selecting sites for high-pier bridges. In seismic design analysis, attention should be paid to factors such as the inclination and potential breakage of bridge piers and piles. This helps prevent collisions between bridge components during earthquakes and ensures the stability of the bridge's foundation against seismic forces.

High-pir bridges are commonly found in mountainous areas or valleys, where the terrain is challenging. To overcome these terrain obstacles effectively, bridge designs often incorporate irregular structures. Research indicates that earthquakes can significantly impact bridges, potentially altering their original shapes. Additionally, seismic activity affects the structural integrity of bridge piers. In areas with unique terrain features, high-pier bridges often utilize a combination of tall and short piers, making them vulnerable to seismic forces. The inclined position of bridge piers causes seismic forces to be transferred to the upper structure at an angle, resulting in an oblique intersection between axial lines. This allows for planar rotation of the bridge's upper structure. If the rotational force on the upper structure exceeds the resistance provided by seismic blocks, bridge damage may occur. The seismic forces acting on bridge piers increase the displacement at the pier caps. Numerous studies have shown that the main reason for increased displacement at pier caps is the inadequate mass and stiffness of the piers. The distribution of horizontal seismic forces affects the mass and stiffness of bridge segments. Additionally, there is a unique linear relationship between the stiffness of the bridge and its ability to withstand horizontal and seismic forces. Therefore, in the structural design of continuous beams, it is essential to ensure uniformity between adjacent spans to enhance the structure's seismic resistance.

When subjected to strong earthquakes, bridges experience immediate dynamic responses. During such events, the high piers transmit vibrations to other parts, causing the entire bridge to vibrate. Under the impact of strong earthquakes, bridges may undergo structural shearing or bending, resulting in fractures or damage. Hence, in the design of high-pier bridges, multiple elements must be carefully considered to enhance their seismic resistance. Furthermore, considering bridge durability and load-bearing capacity, it's crucial to ensure bridges maintain strong load-bearing capabilities during seismic events. Therefore, in optimizing bridge seismic performance, emphasis should be placed on enhancing both material quality and structural design.

3. High-pier bridge seismic design program

In the seismic design of high-pier bridges, it is crucial to consider various factors like construction environment and requirements comprehensively. From the perspective of seismic design for high-pier bridges, it is essential to optimize the overall layout of bridge design and ensure the effectiveness and rigidity of pier supports. Additionally, the selection of pier types is also an important aspect, as different pier structures generate different forces. When deciding on specific plans and methods, factors such as pier height and construction requirements should be carefully considered.

(1) Optimizing the overall arrangement

High-pier bridges are susceptible to pier displacement during earthquakes, resulting in decreased structural stiffness. Earthquakes cause uneven distribution of horizontal seismic forces between piers. This can result in increased load-bearing capacity for rigid piers. In the case of inclined piers, seismic forces lead to oblique interactions with axial lines. When the bridge structure is distorted, the structure's center shifts, causing horizontal movement and structural damage to the bridge. This underscores the importance of designing bridge structures with equal pier height, span, and width. By adjusting pier supports and diameters, a balance between bridge quality and stiffness can be maintained [2].

(2) Reasonable choice of bridge piers

High-pier bridges often exhibit significant variations in pier height and are frequently curved, resulting in an irregular overall structure. Moreover, their geometric configuration is significantly influenced by seismic activity. Therefore, when designing the seismic resistance of high-pier bridges, it is essential to consider the specific circumstances and choose the appropriate pier type accordingly. From a theoretical standpoint, the coupling between high and low piers is relatively weak, leading to potential displacement during earthquakes or displacement of upper structure beam supports. Considering the geological and topographical constraints of bridge construction, a dual-cylinder pier model may be suitable if the pier is shorter than 30 meters. For pier heights exceeding 40 meters, an irregular pier model is recommended. During earthquakes, the bridge's planar curvature may experience torsional-coupled vibration. The pier section must possess high resistance to torsion and bending. While a dual-cylinder pier design can enhance bending resistance, it may not adequately address longitudinal stiffness. As the pier height increases, the effects of shear force and bending moment on the bridge intensify, potentially leading to instability for dual-cylinder piers. Therefore, if the pier height exceeds 30 meters, the dual-cylinder pier structure should be avoided.

Single-column T-shaped piers and hollow thin-walled piers exhibit strong resistance to torsion and bending. Typically, single-column T-shaped high piers utilize single-column piers combined with prestressed cantilevered cap beams. This construction method reduces the cross-sectional size and stiffness, making it suitable for piers with heights of less than 60 meters. Hollow thin-walled piers, similar in external structure to T-shaped high piers but with larger cross-sections, are mainly employed for high-pier structures with heights less than 80 meters [3]. Portal piers possess considerable height and stiffness. However, their lateral stiffness is relatively poor due to the need for lateral beam connections between piers. They are suitable for bridges with pier heights less than 90 meters.

4. High pier bridge seismic calculation method

High-pier bridges, mid-pier bridges, and low-pier bridges exhibit significant differences in load-bearing capacity and have varying seismic requirements. Therefore, traditional seismic design calculation methods for bridges cannot be directly applied. Instead, seismic design calculations for bridges must be re-evaluated based on their seismic requirements and characteristics. Common calculation methods include the response spectrum method, the macroscopic mechanics method, time history analysis, and random vibration testing. Next, specific calculation methods for seismic resistance of high-pier bridges will be analyzed to ensure accuracy in calculations.

(1) Response spectrum method

In seismic calculations for high-pier bridges, numerous parameters are involved, and it is crucial to control certain key parameters effectively. These include critical sliding friction force and the relationship between lateral elastic shear force at the bearings. Exceeding specified ranges for these data could result in significant sliding and displacement between the bridge top and the ground, posing a safety threat. Therefore, implementing scientifically grounded adjustment measures is necessary for optimization.

(2) Macro-mechanics method

It is essential to use macroscopic mechanics for calculations to ensure the seismic resilience of high-pier bridges, which in turn improves the accuracy of dynamic design in bridge engineering. Before conducting dynamic analysis on bridges, it is crucial to establish a comprehensive linear elastic model of the entire bridge, which is vital for the stable operation of high-pier bridges. Additionally, applying lateral soil springs to the pile units of high-pier bridges helps observe the interaction between the bridge piles and the soil. By employing scientific methods to collect and analyze specific numerical data and combining investigations with resonance frequency and mode shapes, a robust framework can be developed.

(3) Time history analysis method

In the design and calculation of high-pier bridges, time history analysis offers clear advantages in capturing elastic-plastic seismic responses. This approach enhances design effectiveness by integrating the bridge's inherent structural characteristics and seismic input, However, time history analysis has limitations due to its computational demands. Deterministic seismic input methods can generate multi-point excitation time histories, creating a well-defined spatial seismic field. Yet, it is crucial to verify this field against actual conditions. With technological advancements, our understanding of seismic fields has deepened. Time history analysis remains important despite its limitations, especially considering the nonlinear responses high-pier bridges can exhibit under multi-point seismic motion.

(4) Random vibration testing

The ground movements triggered by earthquakes are unstable, and this calculation method can assess the probability of earthquake occurrences. However, the stochastic vibration method also has its limitations, particularly in dealing with nonlinearity. The best approach to ensure accurate calculations and handle the extensive computational workload effectively is the stochastic vibration virtual excitation method [4]. This method can enhance the efficiency of bridge calculations and optimize and supplement the deficiencies of the response spectrum method, thereby ensuring the optimization of bridge structural design.

5. High-pier bridge seismic design strategy

There are various ways to enhance the seismic resistance of high-pier bridges, and the appropriate seismic design strategies should be adopted based on the requirements of bridge construction. Examples of seismic design strategies include longitudinal continuity beams, lateral elastoplastic dampers, pier ductility reduction, and the use of new materials.

(1) Bridge-oriented connecting girders

The seismic design of longitudinal bridge-to-beam connecting devices involves linking adjacent beams to create a unified structure. This helps prevent displacement of the beams relative to the pier cap beam in the longitudinal direction during earthquake vibrations, thus avoiding beam dislodgment. To ensure strength in the design of longitudinal bridge-to-beam connecting devices, methods like using longitudinal connections for restraint and reinforcement can be employed [5]. For example, the tensile strength can be enhanced using hot-rolled thread bars.

(2) Transverse elastic-plastic block

To enhance the seismic resistance of bridges, lateral elastoplastic dampers can be installed at the pier positions. These dampers have a simple internal structure and are easy to install, making them widely used in construction. However, this construction method involves a rigid approach. If the seismic intensity is high and the damping force is insufficient, there is a risk of crushing the dampers, rendering them ineffective [6]. Therefore, it is essential to strengthen construction management and maintenance at the damper locations to ensure their effectiveness.

(3) Ductility damping of bridge pier

During intense seismic shaking, high-pier bridges often display noticeable nonlinear behavior. Traditional linear-elastic calculation methods are insufficient to ensure the structural integrity and safety of bridges under such conditions. Therefore, conventional calculation approaches are not applicable. To address this, nonlinear methods can be explored in the analysis of high-pier structures to mitigate lateral vibrations and their impact on the piers [7]. Additionally, careful selection and implementation of lateral elastoplastic dampers are essential to protect the bridge from horizontal stresses and effectively control lateral displacement.

(4) The use of new building materials

In the design of high-pier bridges, it is crucial to ensure the scientificity of the design structure to enhance seismic resistance. At the same time, it is necessary to scientifically select new energy-absorbing materials during construction to improve the seismic resistance of the structure and achieve a balanced analysis of forces on various parts of the bridge [8]. To enhance the seismic resistance of the bridge, the absorption capacity of the bridge for seismic energy can be utilized to inspect the overall structure of the bridge. In the selection of new seismic-resistant materials for bridge construction, it is essential to ensure the rationality of deformation and displacement. The selection of new seismic-resistant materials mainly considers the functionality of the materials to ensure that they can dissipate seismic energy effectively, reduce the damage of earthquakes on the bridge, and ensure that the deformation of the building structure is within a reasonable range [9]. Extensive research data shows that steel is the most effective seismic-resistant material in bridge construction. The high density and strong compression ability of steel structures make them suitable for this purpose, although they have limited plasticity [10]. By mixing steel bars with concrete during construction, a new type of material can be formed to reduce the antagonistic effect between steel and concrete, thereby enhancing the seismic resistance and plasticity of the new material. If the project manager fails to pay sufficient attention to the selection of new materials or does not prioritize material control, it may result in widespread collapse of the bridge during earthquakes. Therefore, in the seismic design of high-pier bridges, it is essential to exercise strict control over the materials used.

6. Conclusion

With the improvement of highway construction in China, the construction projects and scale of high-pier bridges have been expanding, providing convenient transportation in areas with complex terrains. However, this also imposes higher requirements on engineering construction, and traditional bridge design methods can no longer meet current design needs. Before designing high-pier bridges, it is essential to consider the geographical environment, construction requirements, and the frequency of local seismic events to ensure effective seismic design. Through comprehensive considerations such as optimization of bridge structures and selection of materials, the rationality of the bridge's seismic resistance mode is guaranteed. This helps reduce damage to high-pier bridges caused by earthquakes, ensuring bridge safety, and minimizing casualties resulting from earthquakes.

Disclosure statement

The author declares no conflict of interest.

References

[1] Wen T, 2022, Research on Seismic Design of Bridge High Pier. Engineering Technology Research, 7(15): 182–184.

[2] Huang D, Feng J, 2023, Seismic Design Method for High Pier Bridges. Transportation World, 2023(35): 128–130.

[3] He Y, 2021, Seismic Design of High Pier Bridges. Heilongjiang Transportation Science and Technology, 44(7): 135 + 137.

[4] Peng K, 2020, Design of High Pier Bridge Based on Seismic Performance. Science and Technology Innovation and Application, 2020(18): 38–39.

[5] Chen P, He J, 2023, Seismic Design Strategy of High Pier Bridge Based on Tension Cable Damping Bearing. Urban Road and Bridge and Flood Prevention, 2023(4): 111–114.

[6] Li Y, Kang Y, Liu K, et al., 2023, Design Study on Longitudinal Seismic System of Yellow River Special Bridge of Xiongshang High-speed Railway. Railway Construction, 63(9): 59–64.

[7] Zhao H, 2022, Study on Elastic-Plastic Seismic Response of Railroad High-Pier Bridges Based on OpenSees. Railway Construction Technology, 2022(3): 32–37.

[8] Kong L, Chen Y, Ning X, Seismic Isolation Design and Research on Hong Kong-Zhuhai-Macao Non-Navigable Bore Bridges. Technology and Innovation, 2022(7): 13–15.

[9] Deng Z, 2023, Research on Seismic Response Analysis and Seismic Measures of Cable-Stayed Bridges with Ultra-High Piers. Engineering Construction and Design, 2023(17): 96–99.

[10] Feng Q, 2023, Optimization and Structural Analysis of High Pier and Large Span Continuous Rigid Bridge Piers. Transportation World, 2023(4): 198–200.