Journal of World Architecture, 2024, Volume 8, Issue 4
https://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN: 2208-3480

Application of Earthquake-Proof Design in Highway Bridge Design

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Abstract: Highway bridges are an important part of transportation infrastructure. With the rapid development of transportation, the design of bridge construction has received significant attention. The complex environment of some regions necessitates the selection of seismic design to improve the stability of the structure during the design phase of highway bridge construction. This article briefly discusses bridge structures that may be subject to seismic hazards and analyzes seismic design standards to explore their application in the design process of highway bridges, with the aim of providing support for bridge construction.

Keywords: Seismic design; Highway bridges; Design

Online publication: September 2, 2024

1. Introduction

Seismic design is very important during the construction of highway bridges. Since an earthquake will threaten the safety of the bridge structure, the seismic design should be considered to ensure the stability of the bridge structure in the earthquake environment. The safety of highway bridges in operation can be improved by reasonably selecting anti-seismic measures according to the requirements of bridge construction and the characteristics of the environment where the bridge is located [1].

2. Earthquake hazard of bridge structure

When an earthquake occurs, the bridge structure will be affected by seismic waves and there will be various damages. Simultaneously, under the influence of an earthquake, the sand of the bridge foundation may be liquefied, and the bearing capacity of the foundation is insufficient, causing the structure to sink, fracture, and even displacement in other directions. If the bridge foundation is damaged due to an earthquake, the damage is permanent and difficult to recover [2]. Among bridge structures, abutments and piers are important load-bearing structures, which can transfer the seismic load of the structure above the bridge to the foundation. If the bridge is located in a special terrain such as on a mountain, its abutment and pier elevation is relatively large.

Once an earthquake occurs, seismic waves will have a serious impact on abutments and piers, the components will be damaged under the influence of shear force and the plastic hinge will be destroyed. If the earthquake force is repeated, it will also cause serious damage to the abutments and piers and may lead to the collapse of the bridge. Under the influence of earthquake force, the bridge plate is subjected to shear failure, and relative displacement may occur, which will destroy the beam and plate members. If the width of the cover beam is not scientifically designed, the beam structure will collide with each other and the bridge will be damaged under the influence of the earthquake [3]. If it is an arch structure bridge, the earthquake acts on the arch and belly arch, and cracks appear at the arch foot and arch top. In the design stage of some bridges, the seismic performance of the bearing position is not taken into account, resulting in insufficient seismic capability. After the earthquake, the deformation and displacement of the support are relatively large, resulting in damage to the overall structure of the bridge and the gradual expansion of a large number of transverse and longitudinal cracks, which affect the safety of the bridge [4].

3. Analysis of seismic design standards for bridges

When the highway bridge is affected by an earthquake, the structure is seriously damaged, which may affect the safety of people's lives and property. Therefore, it is very important to adopt seismic design for highway bridges. The seismic design standards mainly include the following points.

The first is earthquake probability. According to the historical seismic activity data of the area where the bridge is located, the analysis of the probability that an earthquake may occur within a specific number of years can be designed according to the standards of once every 50 years, once every 100 years, and other intervals.

The second is the action frequency of earthquakes. Earthquake frequency will have an impact on the bridge structure. During the bridge design period, the natural frequency and seismic wave frequency of the structure should be taken into account to prevent resonance phenomena and damage to the structure.

The third is acceleration. Based on the characteristics of seismic wave intensity and frequency, the maximum horizontal acceleration of the bridge is determined when an earthquake occurs. The impact on the bridge structure is reflected through seismic acceleration, which lays the foundation for seismic design.

The fourth is the seismic targets. According to the purpose of the bridge, the performance objectives are determined, including safety limits, critical states, damage limits, and so on. These objectives comprehensively reflect the bridge's deformation and bearing capacity.

The fifth is materials and structure. Depending on the purpose and type of highway bridge, the construction mode and materials are selected. If necessary, reinforced concrete materials should be used for reinforcement structures, or the ductile design of bridge piers and columns should be implemented.

4. Application of earthquake-proof design in highway bridge design

4.1. Earthquake design principles and key points

With the rapid development of technology over time, the design technology of bridge structures is also constantly progressing. The seismic design principle is to consider the strength and stiffness of the bridge and adopt the seismic isolation design at the key position of the structure. This improves the seismic resistance of the bridge structure, ensures the aesthetics and economy of the structure, and meets the operation of the bridge. Based on general earthquake protection design, the following aspects should be adhered to.

Firstly, the reasonable selection of locations. Before highway bridge construction, site selection should be in good geological conditions, flat terrain, and high bearing capacity of the bridge. Before the design, technical personnel should conduct a reasonable analysis of the construction site, master the geological conditions of the site, and make an anti-earthquake design on the premise of clear seismic activity information to prevent the bridge structure from being affected by earthquakes [5].

Secondly, the design of the structural scheme. In terms of the selection of highway and bridge routes and control points, the areas with greater earthquake hazards or areas with relatively high earthquake intensity should be avoided. The design scheme should be determined by taking into account changes in site conditions to ensure the earthquake resistance level of the structure and maximize the control of earthquake hazards.

Thirdly, the analysis of the seismic performance of the structure and the strength of the seismic performance of the bridge structure should be considered from many aspects, including earthquake action and structural characteristics. Seismic wave amplitude, direction, and frequency are the key factors affecting the overall stress of bridge structure. Designers can record the seismic spectrum and analyze it to grasp the possible impact of earthquakes on bridge structures and provide data support for anti-earthquake design. To evaluate the seismic resistance of the bridge, it is important to consider various factors such as structural materials, types, and shapes. Designers can use mechanical analysis and structural simulation to conduct a comprehensive analysis of the stress and deformation of the bridge, and then evaluate its seismic resistance. Considering that the structure is not easy to be damaged under an earthquake attack, this is taken as the basis for anti-earthquake design [6]. For the existing bridge structure, the strength of its seismic performance can be completed through on-site investigation, monitoring, and other ways. After measurement and observation, the damage to the structure can be mastered, and its seismic resistance can be accurately analyzed to guide the subsequent maintenance and reinforcement work.

4.2. Master the main points of structural seismic design

4.2.1. Superstructure

In the process of highway bridge construction, the form and characteristics of the superstructure can have a direct impact on the normal use of the bridge. When designing the superstructure, it is necessary to consider the mechanical properties of the structure, the structure construction, late maintenance, and so on. If the superstructure of the bridge is cracked or worn, it will affect the structural characteristics. To prevent such problems, it is required to improve the performance of the upper structure through design. In the event of an earthquake, large displacements may occur above and below the bridge structure, resulting in structural damage or collapse in severe cases [7].

In this regard, the relative displacement of the upper and lower structures should be taken into account when designing the upper part of the bridge structure. It is necessary to identify common earthquake damage in different parts. For example, under the influence of an earthquake, collisions can occur between the joint of the cover beam and the adjacent beam, potentially damaging the main beam. The bridge joints are affected by earthquakes, with support and expansion joints likely to be damaged. The structure under the bridge can also be impacted, potentially damaging the pier. Additionally, the bridge foundation structure may experience soil slip or sand liquefaction. Therefore, in designing the superstructure, it is essential to ensure that relative displacement remains within a reasonable range to prevent common issues.

4.2.2. Support design

Bridge bearings, located at the upper and lower structural connection points, serve to transfer bridge loads and accommodate structural displacement caused by contraction, temperature changes, and other factors. During seismic events, they also help protect the bridge abutments. Typically, bearings are made from materials such as rubber or steel, which help mitigate lateral vibrations of the bridge structure during an earthquake. Bearings should be selected based on regional environment and bridge characteristics.

When setting bearing capacity, factors such as the number of bearings, bearing point reaction force, bridge constant load, and live load should be considered to calculate the bearing capacity. Generally, the ratio of the maximum reaction force of the bearing to its load capacity should be within 0.05, while the ratio of the minimum reaction force to its load capacity should be above 0.8. At the design stage, the minimum reaction force size is limited to ensure adequate slip capacity of the bearing. There is no need for redundant reserves in the bearing design. For example, if the maximum reaction force is 4,100 kN and the minimum reaction force is 3,700 kN, the bearing capacity should be selected as 4,100 kN [8].

4.2.3. Basic design

The bridge foundation structure design is very important and is relatively hidden. Research shows that more than 70% of the buildings damaged from an earthquake are related to the foundation design, especially since the bridge foundation is in a complex geological environment. Therefore, to control the liquefaction of bridge foundations during earthquakes, design methods are used to improve the bearing performance of the foundation structure and ensure the safety of the structure.

4.2.4. Pier column design

In the design of highway bridges, the pier column is also the focus of the design, which has the function of supporting bridge structure and anti-seismic. During the design of the pier column, the emphasis is on quality control, which can be started from the following aspects.

First, during the design phase, compare the strength of the pier column with the structural strength during an earthquake. This comparison is crucial for optimizing the design of the pier column to ensure adequate bearing capacity. Second, in the reinforcement design of the pier column, calculate the required reinforcement area first, then select the appropriate reinforcement type to ensure the flexural strength and bearing capacity of the structure. This approach improves the stability of the pier column and ensures its seismic performance.

4.3. Application of conventional anti-earthquake design measures

There are several conventional seismic design methods for bridges. Firstly, the strength design. In the initial phase of seismic design, design factors need to be taken into account. Since this design method only considers the seismic acceleration as a factor of bridge structure damage, and cannot consider the influence of the structure itself on the strength of the bridge, there are still limitations in this design method, which may result in the stiffness and strength of the bridge being difficult to meet the demand for earthquake protection.

Secondly, the ductile design. When an earthquake occurs, the bridge structure may produce elastic-plastic damage, at this time we can use the ductile design method. The designer analyzes the characteristics of the bridge structure, taking into account the deformation conditions of the bridge such as plasticity and elasticity under the earthquake action environment, conducts in-depth research on different vibration curves, and accurately calculates the earthquake response force.

Thirdly, is the performance of anti-seismic. Designers carry out seismic design according to the performance of the bridge to ensure the stability of the structure during an earthquake. This design approach is more performance-oriented, close to the specific use of the bridge, and can improve structural safety to a certain extent. The prerequisite of performance design is to define the seismic design objectives, including seismic deformation, overturning, and displacement, and set the seismic performance objectives according to the purpose of the bridge, the use of the environment, and the safety requirements.

According to these specific objectives, we can determine the seismic loads, analyze the bridge structure, and evaluate the seismic performance of the structure according to the changes in displacement and bending produced by the structure under different seismic environments. During this period, designers can simulate the structural changes of the bridge seismic process with the help of numerical analysis. Finite element analysis is also a commonly used analysis method. According to the results of the analysis, the seismic structure is optimized, such as changing the materials, component sizes, structural arrangement, and so on to achieve the design objectives of the seismic performance of the bridge, and to improve the feasibility of the design scheme [9].

4.4. Reasonable selection of earthquake-proof design methods

Conventional seismic design methods are as follows. The first is foundation treatment. For highway bridges located in areas with poor geological conditions, it is necessary to improve the geology through design measures to restore the performance of the foundation and meet operational requirements. For instance, if the rock layer beneath the bridge foundation is shallow, the foundation can be expanded. In cases of uneven geological hardness and high-water tables, to prevent foundation liquefaction, the strength of the bridge can be increased by designing reasonable aperture sizes. This helps avoid geological instability and allows the bridge piles to penetrate deeper into the rock layer, enhancing foundation strength. Additionally, increasing the foundation area can improve seismic performance and ensure integrity during earthquakes.

The second is seismic isolation design. A vibration isolation device is placed between the foundation and the bridge structure to reduce earthquake-induced vibrations. Proper selection of the isolation device and its connection method helps control the bridge's deformation and displacement. Pipeline and accessory parts should be designed to adapt to the movements of the isolation system.

The third is abutment processing. During the design phase, choosing uniform-section piers and avoiding conical structures helps control longitudinal wave stress and maintain structural integrity. If the pier's diameter is large and experiences significant tensile forces, embedded steel bars can connect the pier and the bridge structure to prevent damage to the pier from the bridge deck during an earthquake. Additionally, buffer components like springs can be installed near supports to protect the pier from damage caused by the falling bridge floor [10].

4.5. The use of shock absorption and isolation measures

The design of highway bridges is characterized by its particularity and complexity. The structural height of some bridges may vary, which may increase the influence of earthquake impact. To ensure bridge safety, designers should conduct in-depth analyses of pier structures and incorporate damping and isolation components to strategically arrange the frame. This approach ensures sufficient deformation resistance during an earthquake, helping the structure withstand seismic forces and minimizing damage.

The stability of a highway bridge is closely related to shock absorption design. Designers can use isolation bearings or shock absorption bearings to enhance overall damping, optimize flexibility, and limit earthquake impact. Isolation and damping supports are typically installed at the connections between the abutments, piers, and bridges. Proper use of these supports ensures an effective connection between the abutment and beam, maximizes damping effects and improves overall structural stability.

During an earthquake, the bridge structure will shake due to seismic waves. Isolation or damping supports and dampers can mitigate the force of these waves, reducing their impact. At the design stage, designers should consider factors such as the maximum acceleration of the structure and support displacement to ensure the appropriate selection of isolation and shock absorption supports. The use of lead-core rubber bearings in bridge design can enhance overall seismic resistance. These bearings increase yield shear forces under seismic action, improve structural stiffness, and protect the bridge.

5. Conclusion

To sum up, in the design stage of highway bridges, no matter the selection of seismic design or the application of seismic isolation measures, the principle of local conditions should be upheld. Also, the damage caused by earthquakes to the bridge structure should be clearly defined, the seismic design points should be understood according to the seismic design standards, and the reasonable selection of seismic measures should be combined with seismic isolation and damping measures to ensure the seismic design effect of bridges and improve the effectiveness of structural seismic design.

Disclosure statement

The author declares no conflict of interest.

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