Theory and Practice of Science and Technology
2025, VOL. 6, NO. 3, 116-119
DOI: 10.47297/taposatWSP2633-456922.20250603

Research on Seismic Applicability of Bridge Structures

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ABSTRACT
This paper systematically discusses the seismic performance and applicability of bridge structures under different seismic environments, aiming to provide theoretical basis and practical guidance for the seismic design of bridges. By reviewing the research results of scholars on eight types of typical bridges, such as double-column self-resetting bridges, beam-arch collaborative system bridges, and steel-tube concrete bridges, and combining the methods of finite element modeling, dynamic time-travel analysis, and scaled-down test, the mechanical response and optimization paths of the different structural forms under seismic effects are revealed. The study shows that the optimization of prestressing and aspect ratio of double-column self-restoring bridges can improve the seismic performance in high intensity zones; the beam-arch collaborative system bridges have both stiffness and durability under complex geological conditions; and the steel-pipe concrete structure significantly enhances the ductility and energy-consuming capacity of low piers and columns in steep-slope terrains. In addition, the study points out that there are limitations in the current seismic evaluation, such as oversimplification of models and single input of ground shaking, and proposes future research directions, such as refined modeling and multi-hazard coupled analysis.

KEYWORDS
Bridge structure seismic resistance; Bridge scope of application; Earthquake engineering

1 Introduction

Bridges, as key hubs of the transportation network, are usually located on major transportation routes and are indispensable core nodes in the lifeline system that sustains the normal functioning of society. Bridges often bear the brunt of natural disasters, especially destructive earthquakes. The huge energy released by earthquakes exerts unimaginable forces on bridge structures, which may lead to different degrees of bridge damage, from minor cracks to severe structural deformation, and in extreme cases may even trigger bridge collapse. Through seismic research, we can minimize the damage to bridges caused by earthquakes, reduce economic losses and speed up the post-disaster reconstruction process. Seismic research helps to explore and develop new bridge design concepts, materials and technologies, and improve the overall safety of bridges.

2 Materials and Methods

Scholars have carried out studies on the seismic performance of bridges with the help of different bridge structures. Zheng Jiguang et al [1] investigated the seismic performance of a double-column self-resetting bridge structure in the transverse direction, and utilized zero-length cell simulation to carry out PushOver analysis and hysteretic response analysis, and found that the increase of initial prestressing force can significantly improve the yield stiffness and load carrying capacity of the bridge, and improve the service life of the bridge. Li Ningbo et al [2] used Midas Civil software to construct a finite element numerical analysis model of the bridge and found that the displacement response of the beam-arch collaborative system bridge was reduced by 95% compared with that of the traditional girder bridge, and the displacement response was reduced by 93% compared with that of the traditional arch bridge. The torsional stiffness of the bridge structure of the collaborative beam-arch system is better than that of the conventional bridge, and the displacement fluctuation interval and vibration period fluctuation under seismic waves are better than that of the conventional single-type bridge, which helps to improve the safety and durability of the bridge in earthquakes, and to reduce the potential damage and casualties. Wang Kunlin et al [3] focused on analyzing the influence of adjacent structures, traveling wave effect and vibration isolation system on the internal force, using SAP2000 to construct the model, and adopting the reaction spectrum method and power time course analysis method to carry out the seismic response analysis, and found that the adjacent structures have a significant influence on the internal force of the transition piers, and have a smaller influence on the internal force of other piers and columns. After adopting the friction pendulum isolation bearing, the internal force and displacement response of the bridge are greatly reduced, and the force of each pier is more uniform. This study can provide a scientific basis for bridge design and improve the seismic safety of bridges. The research of Yanshin Wang[4] focuses on the effects of near-fault vertical earthquakes on the seismic performance of reinforced concrete (RC) double deck piers bridges. He used the OpenSees platform to construct the model and found that the downward tension of the piers due to vertical ground shaking is extremely obvious for RC double-deck piers bridges, and the residual deformations of the top and bottom bearings increase with the increase of the intensity of vertical ground shaking. It provides a basis for updating the bridge design code to ensure that the code can comprehensively reflect the effects of vertical ground vibration, fills the gap in the study of RC double-decked shelf pier bridges, and is of great significance in promoting the development of theoretical research and engineering practice in this field. Li Chenghong [5] studied the seismic performance of large-span continuous rigid-frame bridge girders, specifically analyzing the effects of different main girder widths and diagonal tension types on the vibration acceleration and overall seismic performance of the bridge under seismic action. MIDAS/Civil software is used for simulation to provide a scientific basis for bridge design, so as to improve the seismic capacity of the bridge and reduce potential safety hazards. The systematic analysis of the seismic performance of large-span bridges promotes the technological progress in the field of bridge engineering, facilitates the updating and development of seismic design concepts, and provides the theoretical basis and data support for subsequent research. Zhai Yuchen and his cooperative team [6] took the proposed airport viaduct on the steep-slope terrain in the mountainous area of Yunnan Province as the research object, and proposed the use of steel pipe concrete structure to enhance the seismic performance in response to the problem that the traditional low-profile piers and columns of reinforced concrete are prone to brittle shear damage in earthquakes. Through the finite element software ABAQUS to establish the whole bridge model, simulate the dynamic response under the action of E2 earthquake, and combined with the proposed static test of 1/12 scaled specimens, the stress distribution, plastic strain, hysteresis performance and ductility of steel pipe concrete piers are systematically analyzed. The results show that: steel pipe concrete pier columns in the earthquake steel pipe to maintain the elastic state, concrete compressive stress did not reach the limit value, plastic strain can be controlled, the damage can be repaired; test hysteresis curve full, reverse ductility coefficient of 4.27, the energy consumption capacity is significantly better than the traditional structure. This study provides theoretical support and practical guidance for the seismic design of bridges in steep terrain, which not only verifies the applicability of steel-tube concrete structure in complex terrain, but also makes up for the construction weaknesses through the optimization of anchorage suggestions (such as the integrated design of pile foundation and pier), and at the same time meets the requirements of the current seismic code, which is of great engineering significance and popularization value to enhance the seismic toughness of bridges and reduce the risk of seismic damage. Xie Xingyu, Li Rui and other scholars [7] for the mountainous complex terrain in the high and low pier extra wide bridge seismic response problems to carry out research, the use of time-range analysis method to explore different pier height uneven coefficients on the distribution of seismic force, and compare the lead-core rubber bearing (LRB), high-damping rubber bearing (HDR) and the friction pendulum bearing (FPS) of the performance of seismic isolation. It is found that: due to the characteristics of low pier stiffness and high pier flexibility, the seismic force is concentrated in the low pier, while the displacement of the top of the high pier increases significantly, exacerbating the risk of damage; the friction pendulum bearing effectively reduces the bottom bending moment and shear force of the pier, while the lead-core rubber bearing is better to reduce the displacement of the high pier; the radius of curvature has a small impact on the seismic response, and it can be used as a secondary parameter. This study provides an optimization direction for the seismic design of extra-wide bridges in complex terrain, which can significantly improve the seismic performance of bridges by reasonably selecting the type and parameters of the seismic isolation bearings, and has important reference value for engineering practice and specification improvement. Liang Kailun and Chen Yuanjiu [8] carried out a study on the dynamic characteristics and seismic performance of inclined single-arch rib under-bearing profiled arch bridges, established a finite element model through Midas/Civil, combined with the response spectrum method and time course analysis method to analyze the response under the seismic effects of E1 (50% probability of exceeding the 50-year probability) and E2 (2% probability of exceeding the 50-year probability). It is found that the bridge has a fundamental frequency of 0.823 Hz, weak transverse stiffness, significant vibration mode coupling, higher internal force and displacement under three-way seismic action than one-way seismic action, and the effect of vertical seismicity cannot be neglected; the maximum stress in the arch rib under the E2 seismicity is lower than the permissible value of Q420 steel, which indicates that the structure still maintains elasticity in the 7-degree seismic zone. The study confirms the seismic reliability of such bridges, and puts forward design suggestions such as strengthening the stiffness of the arch foot and optimizing the transverse bracing, which provide important references for the evaluation and optimization of the seismic performance of shaped arch bridges, and make up for the insufficiency of seismic research on bridges with complex space structures.

3 Results and Discussion

In the field of seismic evaluation of complex bridges, the existing studies have problems such as over-simplification of models, single input of ground shaking, insufficient experimental validation, narrow parameter analysis, and lack of long-term performance evaluation. Future research needs to improve the accuracy and reliability of bridge seismic evaluation through refinement of modeling, expansion of ground vibration inputs, strengthening of experimental validation, optimization of parameter analysis, deepening of long-term durability assessment, and construction of a multi-hazard coupling analysis framework, so as to provide a more scientific basis and technical support for engineering practice.

4 Conclusion

4.1 Double-column self-restoring bridges

It is suitable for urban bridges in high intensity seismic zones to enhance the seismic performance by optimizing the initial prestressing and aspect ratio. It is recommended to adopt stable foundation and combine C30 and above strength concrete with reasonable reinforcement design to meet the demand for rapid construction of segmental assembling.

4.2 Beam-arch collaborative system bridges

Applicable to high seismicity areas, large span requirements (>100m) and complex geological conditions, while meeting the structural rigidity, durability and landscape design requirements, need to pay attention to the synergistic force analysis of arches and beams and fine construction control.

4.3 Multi-span continuous girder-arch combined system bridges

For large-span bridges in high seismic intensity zones, seismic isolation design, traveling wave effect analysis, and coupled adjacent structures should be carried out, and the construction should strictly follow the seismic code (e.g., GB 50011) and implement the refinement of the construction process.

4.4 RC double-decked row of pier bridges

Applicable to complex terrain in mountainous areas and high seismic intensity areas, can meet the needs of large traffic flow, small and medium-sized span (20-50m). The design needs to optimize the bearing structure to reduce the cost, and take into account the road traffic efficiency and congestion relief needs.

4.5 Large-span continuous rigid bridge girders

It is applicable to the area with stable geology (Class I site) and seismic intensity VII. When the width of the main girder is ≤32m, single/double cable face can be used, and when it is >32m, double cable face design is preferred to meet the double-layer composite traffic function of highway and rail transportation.

4.6 Steel pipe concrete bridges

Dedicated to the scenario of low piers and columns (shear span ratio <2.5) in mountainous areas with seismic intensity of VIII degree or above and steep terrain. Through the steel pipe concrete combined structure to enhance the ductility and energy consumption capacity, to ensure damage controllability, in line with the high seismic defense (Class A bridges) and the specification (JTG/T 2231-01-2020) requirements.

4.7 High and low pier extra wide bridges

It is suitable for extra-wide bridges in mountainous areas (width of 160m, width-to-span ratio of 5.3) with severe terrain undulation and pier height difference of ≥77m. Seismic isolation measures such as friction pendulum bearings need to be adopted, combined with power time course analysis to optimize the design, in order to meet the seismic demand of medium and high intensity seismic zone.

4.8 Oblique single-arch rib under-bearing arch bridge

It is suitable for medium span (60-100m) highway bridges in 7 degree seismic zone, emphasizing landscape coordination. The design needs to strengthen the transverse stiffness and adopt BIM technology to assist the construction to ensure the stability and seismic performance of the complex spatial structure.

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