PERFORMANCE-BASED SEISMIC DESIGN OF CABLE-STAYED BRIDGE

Jianian Wen [(1)], Qiang Han [(2)], Xiuli Du [(3)]

[(1)] *Professor, Beijing University of Technology, wenjianian@bjut.edu.cn*
[(2)] *Professor, Beijing University of Technology, qhan@bjut.edu.cn*
[(3)] *Professor, Beijing University of Technology, duxiuli@bjut.edu.cn*

Extended Abstract

Cable-stayed bridges are widely used worldwide due to their excellent spanning capacity, high material efficiency, aesthetic appearance, and rapid construction. However, their high flexibility and low damping make them extremely sensitive to seismic dynamic loads. Severe damage was observed in past earthquakes: the Chi-Lu Bridge suffered plastic hinges and concrete cracks during the Chi-Chi earthquake, while pounding and displacement between the girder and tower occurred in the Great East Japan earthquake. Current research is limited by imperfect mechanical models for pylons, soil-pile/abutment-soil interaction, decks, and cables; unclear damage mechanisms of critical components; and insufficient investigation under spatially varying ground motions and multi-hazards. Traditional design is safety-based and only emphasizes structural strength and load-carrying capacity, while PBSD, which uses displacement and risk as key criteria, has not been widely applied to cable-stayed bridges.

To fill these gaps, the research systematically explores seismic damage mechanisms and develops a complete PBSD framework. Quasi-static tests and finite element (FE) analysis show that diamond-shaped pylons form two plastic hinges in the lower legs, with failure controlled by higher-order vibration modes. A 3D pounding model is established in OpenSees to simulate complex longitudinal deck deformation and pounding effects. Modal pushover analyses and Multi-Strip Analysis (MSA) reveal that spatially varying ground motions and larger main-approach span period ratios significantly increase damage probability. Under earthquake-flood scour coupling effects, pile moment demands rise, pier shear demands decrease, and failure modes shift from piers to piles and abutments, requiring re-evaluation of pile foundations at different scour depths.

The proposed PBSD framework optimizes damping devices using genetic algorithms to minimize the Repair Cost Ratio (RCR). Viscous dampers in the longitudinal direction and metallic dampers in the transverse direction are installed at deck-pylon connections, reducing RCR by approximately 70% and 20% respectively. A direct displacement-based design (DDBD) method for base-isolated bridges

achieves uniform deck displacement and reduces pylon base bending moment by 60% longitudinally. Tuned Inerter Dampers (TID) effectively suppress deck displacement, bending moment, and pile responses, with better performance at larger mass ratios. Research outcomes are applied to four landmark long-span bridges in China.

In conclusion, this study clarifies the seismic damage mechanisms of cable-stayed bridges, establishes a complete performance-based seismic design system and effective control strategies, and provides strong technical support for the seismic safety of long-span cable-supported bridges in engineering practice.

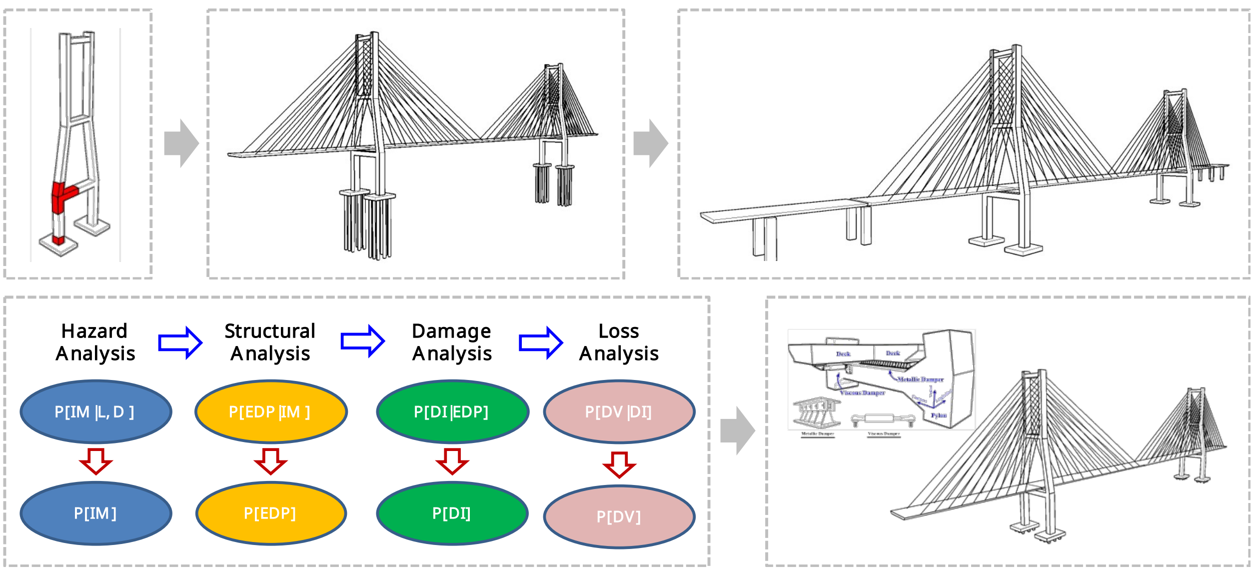

Figure 1- Details of research approach.

Keywords: *Cable-stayed bridge; performance-based seismic design; seismic control; optimization.*