
Actual Trends in Design, Construction, and Monitoring of Large-Span Bridges

Marjan Pipenbaher¹ ✉

✉ e-mail: marjan.pipenbaher@pce.si

¹ Pipenbaher Consulting Engineers, Slovenska Bistrica, Slovenia

DOI: <https://doi.org/10.14459/icbdb24.001>

Abstract Since the start of civilization, bridges have played an important role in economic growth and the development of societies. They are designed to connect people, reduce distances, and enhance both domestic and international trade. The evolution of bridge design and construction offers a window into the advancements of engineering over time. In less than 2000 years, we have progressed from ancient stone arch bridges with spans of only a few meters to contemporary cable-stayed bridges exceeding 1000 meters and suspension bridges spanning over 2000 meters.

Modern advancements in structural systems, high-strength materials, and computational technologies now allow engineers to design the most challenging bridge structures ever conceived. Current trends in this field focus on following main areas: inventive structural systems, high-strength materials, deep foundation systems, aerodynamic cross-section design for wind stability, and seismic resilience through soil-structure interaction (SSI) and seismic isolation technologies. The decision between suspension bridges and cable-stayed bridges is primarily driven by span length, structural efficiency, site-specific load-bearing and environmental conditions, and cost considerations.

The geotechnical design of large-span bridges, particularly those in complex terrains, requires the implementation of deep foundation systems to ensure the efficient transfer of loads from the superstructure to the underlying subsurface. An increasingly recognized factor in this process is the importance of soil-structure interaction (SSI), particularly for structures in seismically active regions. The interaction between the foundation system and surrounding soil can significantly influence the bridge's dynamic response, necessitating precise models that incorporate both the superstructure and substructure in a coupled analysis. Real-time seismic data and advanced laboratory testing inform dynamic SSI models, which are essential for optimizing foundation systems and mitigating risks.

In seismic zones, the design of large-span bridges requires a comprehensive understanding of SSI and the implementation of seismic isolation systems to protect structural integrity. Non-

linear dynamic analysis, often paired with time-history seismic simulations, provides insight into how the superstructure, foundation, and soil layers interact. Seismic isolation technologies, are commonly used to reduce the transfer of seismic energy from the ground to the bridge structure.

Wind-induced instabilities are a major design challenge for large-span bridges. Aerodynamic forces such as vortex shedding, flutter, and buffeting can cause significant oscillations in bridge decks, potentially jeopardizing structural safety and longevity. To address these challenges, modern bridge design focuses heavily on optimizing cross-sectional geometries. Wind tunnel testing, in combination with computational fluid dynamics (CFD), is commonly employed to analyze airflow around bridge decks. The use of aerodynamically optimized cross sections is crucial in preventing vortex-induced vibrations and torsional flutter, both of which can cause dynamic instabilities.

In addition to these aerodynamic refinements, tuned mass dampers (TMDs) and aerodynamic fairings are increasingly integrated into bridge designs to manage the dynamic response to wind loads. Together, these techniques create bridges that are capable of withstanding complex wind environments while minimizing fatigue-related damage and extending the structure's lifespan.

Historically, suspension bridges have been favored for spanning large distances. However, in the past 30 years, cable-stayed bridges have gained recognition as viable candidates for ultra-long spans due to their superior stiffness and aerodynamic stability. Notable examples include the Russky Bridge (Russia) with a navigation span of 1104 meters, the Sutong Bridge (China) with a span of 1088 meters, and the Stonecutters Bridge (Hong Kong) with a main span of 1018 meters—all of which broke the 1000-meter span barrier for cable-stayed bridges.

The ongoing advancement in the design, construction, and monitoring of large-span bridges is driven by innovative materials and technologies. Ultra-high-strength concrete with strengths exceeding 120 MPa, prestressed steel with guaranteed ultimate tensile strengths (G.U.T.S.) up to 2000 MPa, and lightweight, high-strength carbon fiber reinforced polymer (CFRP) cables with tensile strengths surpassing 3000 MPa, and densities of only 1600 kg/m³, enable the construction of bridges with spans of up to 4000 meters. By leveraging cutting-edge computational tools, materials, and structural systems, engineers continue to push the boundaries of large-span bridge design, ensuring that future infrastructure is safe, efficient, and resilient.