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Comparison of Bridge Structure and Construction Characteristics

Hongkai Kang

School of Mechanics and Civil Engineering, China University of Mining and Technology, Xuzhou, China
khk0411@163.com

Abstract. As China's transportation infrastructure expands into geologically complex and long-span areas, the scientific selection of bridge structures and construction methods becomes critical to project quality and efficiency. This study systematically compares beam, arch, rigid-frame, cable-stayed, and suspension bridges, analyzing their mechanical properties, material choices, span adaptability, and application scenarios. Typical cases—such as mountain highway beam bridges, urban river arch bridges, and sea-crossing cable-stayed bridges—are used to evaluate key technical points, construction costs, environmental impacts, and safety risks of methods like cast-in-place, prefabrication, cantilever, and incremental launching. Findings indicate that matching structure and construction method is essential for economic efficiency and durability: beam bridges suit medium and small spans for highways and municipal projects; arch and suspension bridges enable kilometer-level spans for canyons and bays but require complex processes and equipment; cable-stayed bridges offer both efficiency and convenience for 200–800 m spans, ideal for river and sea crossings. These results provide theoretical guidance for bridge scheme selection and construction optimization across diverse regions and requirements, supporting improved quality and efficiency in transportation engineering.

Keywords: Bridge, Structure, Construction, Beam Bridge, Suspension Bridge

1. Introduction

Bridge structures and technologies significantly impact the quality and economic efficiency of engineering projects in transportation construction. Due to differences in topographical conditions, load requirements, and other factors, beam bridges, arch bridges, cable-stayed bridges, and suspension bridges coexist; however, their applicable scenarios and construction difficulties vary substantially. Therefore, it is essential to conduct a comparative analysis of their characteristics [1]. The research focuses on three categories: the differences in mechanical properties, span, and other aspects among bridge structures; the advantages and disadvantages of construction methods regarding technical difficulty, cost, and other elements; and how to achieve the optimal matching between structure and construction. Therefore, this study adopts a combined method of literature research, case analysis, and comparative analysis, and establishes an index system to conduct quantitative comparison.

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2. Analysis of main bridge structure types and their characteristics

2.1. Beam bridge

Beam bridges are primarily characterized by bending deformation under loads, and their core structural system consists of bridge span structures, deck systems, bearings, piers & abutments, and foundations. Together, these components form the main load-bearing framework, where each part undertakes specific functional roles to ensure the overall stability and serviceability of the bridge [2]. The bridge's main girders are classified as supported, continuous, or cantilever beams based on load-bearing systems and span requirements. The deck system includes pavement, railings, and drainage to ensure safe operation and longevity. Bearings transfer loads and accommodate structural deformation, reducing internal force impacts from temperature or displacement. Piers and abutments transfer superstructure loads to the foundation, which distributes them evenly to the ground, ensuring structural stability.

Beam bridges possess a straightforward mechanical model and structural system, facilitating design, calculation, and construction. For medium and small spans, prefabricated assembly allows for factory production, ensuring quality, reducing on-site time, and controlling costs. Thus, beam bridges are widely used in highways and railways, offering convenient maintenance. However, their span adaptability remains limited. When the span exceeds 150 meters, the cross-section of the main girder needs to be significantly enlarged to resist bending moments. This leads to a sharp increase in material consumption and limits economic efficiency [3]. It may reduce under-bridge navigation clearance and disrupt landscape coordination. Additionally, beam bridges require high foundation bearing capacity, limiting their use in soft soil areas where insufficient support increases foundation treatment difficulty and cost.

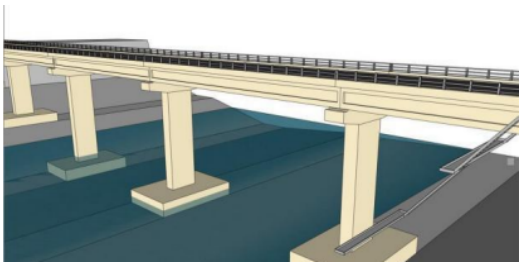

Figure 1. Beam bridge

2.2. Arch bridge

Arch bridges are mainly characterized by axial compression as their primary load-bearing form, and their core structure includes the arch ring, spandrel structure, piers & abutments, and foundation. Among these components, the arch ring serves as the key load-bearing element that transfers the upper structure load to the piers and abutments through axial compression, while the spandrel structure, piers, abutments, and foundation work together to ensure the overall stability and load-bearing capacity of the arch bridge [2]. The arch ring, as the main load-bearing element, is categorized into slab, rib, and box arches based on cross-section, selected according to span and load requirements. Spandrels are either solid, for small spans and construction simplicity, or hollow, for medium to large spans to reduce self-weight. Piers and abutments, bearing both vertical and horizontal forces, have larger cross-sections than those in beam bridges. Foundations require strong anti-overturning and anti-sliding properties, typically using spread footings or pile foundations.

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Arch bridges efficiently utilize compressive materials, consuming less material than beam bridges for 50–200 m spans, offering economic benefits. Their lower girder height enhances under-bridge space use, while varied arch forms balance function and aesthetics. Stone arch bridges, in particular, can last over 100 years, indicating outstanding durability [1]. However, from a personal perspective, the horizontal thrust of arch bridges, while optimizing arch ring forces, imposes strict substructure requirements. Insufficient foundation capacity necessitates costly reinforcement. Swivel construction for long-span arches demands high equipment precision and control, increasing susceptibility to environmental interference and construction risks. For spans over 500 meters, cable-stayed bridges become more economical. Additionally, temperature fluctuations induce extra internal forces, complicating arch bridge maintenance compared to beam bridges.

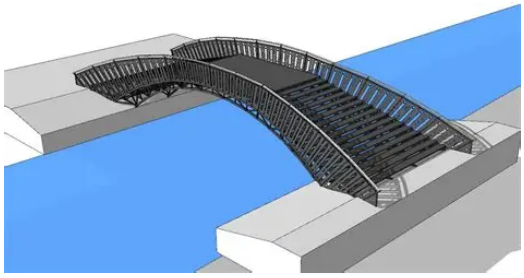

Figure 2. Arch bridge

2.3. Cable-stayed bridge

Cable-stayed bridges adopt a "tower-cable-girder" collaborative load-bearing system, and their core structure includes bridge towers, stay cables, and main girders. Bridge towers commonly adopt structural forms such as A-type and H-type, which require sufficient stiffness to support the stay cables. The stay cables are mostly made of high-strength steel strands or wire bundles, which not only undertake the function of load transmission but also can restrict the deformation of the main girders. The main girders are usually designed with thin and lightweight cross-sections to reduce self-weight and improve wind resistance performance, making them suitable for spans of 200-1000 meters. On the other hand, suspension bridges take the "tower-cable-anchorage" as their core load-bearing system [4], As the primary load-bearing components of suspension bridges, the main cables bear the tensile forces. The anchorages are required to fix the ends of the main cables through gravity or anchoring force to ensure the stable transmission of tensile forces to the ground. This structural system enables suspension bridges to be suitable for ultra-long-span scenarios with a span of more than 800 meters, as it can efficiently withstand large-span loads through the high tensile performance of the main cables [1].

From an engineering perspective, cantilever construction of cable-stayed bridges eliminates the need for ground supports, allowing adaptation to complex terrains and ensuring good navigation performance. However, stay cables endure long-term alternating loads, making them prone to fatigue damage; thus, real-time monitoring is necessary to control cable force and prevent girder deformation. Suspension bridges offer high main cable tensile efficiency and superior under-bridge clearance for ultra-long spans, but their construction is complex, involving high-altitude risks during catwalk erection, significant concrete use and strict foundation requirements for anchorages. Both bridge types require specialized wind load design, longer construction periods, and higher equipment precision than medium and small-span bridges.

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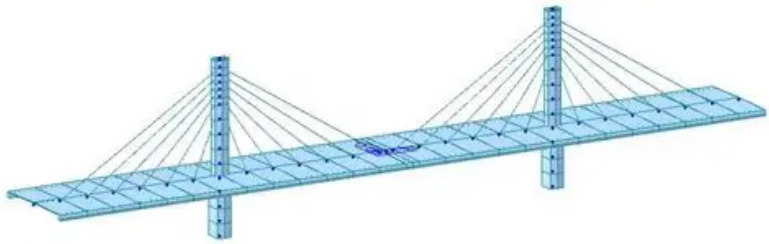

Figure 3. Cable-stayed bridge

3. Typical construction methods and technical characteristics of various types of bridges

3.1. Beam bridge

Beam bridge construction methods are mainly classified into four types. The prefabricated assembly method, dominant for spans ≤ 40 meters, involves factory-made components like T-beams and box girders, which are transported and assembled on-site. This ensures quality, shortens construction time, and minimizes environmental impact, but requires large hoisting equipment. The cast-in-place method, suitable for 40–100 meter spans and special-shaped girders, uses on-site concrete pouring with erected supports, offering strong structural integrity but incurring high support costs and being sensitive to curing time and weather.

The cantilever method employs a hanging basket for symmetrical segmental construction from the pier, eliminating the need for ground support and enabling use in challenging environments like deep valleys and waterways, suitable for 100–200 m spans. However, its complex equipment and high precision demands require strict segment positioning control. The incremental launching method prefabricates the beam behind the abutment and advances it segment by segment with jacks [4,5]. This method, suitable for 30-80 meter spans, concentrates operations on-site and minimally disrupts under-bridge traffic, but is limited to straight, constant cross-section beams. The main girder endures significant horizontal forces during launching, requiring reinforcement to enhance stiffness. The 1918 completion of Canada's Quebec Bridge, the world's longest-span steel truss cantilever beam bridge, demonstrates the cantilever construction method's feasibility for long-span beam bridges [1].

3.2. Arch bridge

Arch bridge construction methods include: (1) Scaffolding cast-in-place, suitable for spans ≤ 80 m, adapts to special arch shapes and ensures integrity, but requires extensive scaffolding, incurs high costs, and is limited by site and weather; (2) Swivel construction, for spans of 80–300 m, prefabricates the arch onshore and rotates it into position, reducing river interference but demanding high swivel equipment precision and real-time stress monitoring; (3) Cantilever assembly, for 150–500 m spans, uses segmental prefabrication and cantilever cranes, offering high efficiency and terrain adaptability, but requires precise assembly and involves higher safety risks at altitude.

The rigid frame method involves erecting a steel frame, then binding steel bars and pouring concrete on the outer side of the frame [4]. This method can effectively reduce the load during the arch ring construction process and is suitable for long-span concrete arch bridges; however, its construction procedures are cumbersome, the construction period is long, and it has high requirements for coordinating various links.

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Taking the Chaotianmen Yangtze River Bridge in Chongqing, China as an example, as the arch bridge with the longest main span in the world currently, the optimization of construction methods during its construction process has provided valuable experience for the construction of long-span arch bridges [1].

3.3. Cable-stayed bridge

The mainstream construction technology of cable-stayed bridges is the cantilever construction method. Centered on the bridge tower, this method uses a hanging basket to realize the segmental casting or assembly of the main girder. Meanwhile, the stay cables are synchronously tensioned to control the structural deformation, thereby ensuring the linearity and stability of the main girder during the construction process [2,4]. It is suitable for a span range of 200-1000 meters; this technology does not require ground-based supports and can adapt to complex construction environments such as rivers. However, it is necessary to strictly control the tension force of the stay cables and establish a real-time monitoring system to prevent the main girder from suffering from a force imbalance.

The core construction process of suspension bridges revolves around the catwalk and main cables. First, the catwalk is erected as a construction platform, which provides a safe operation space for subsequent operations such as main cable spinning and cable saddle installation [2,4]. Main cable strand erection and adjustment are followed by hanger and main girder installation, suitable for ultra-long spans of 800–2000 meters. Main cables offer efficient tensile performance and significant under-bridge clearance, but catwalk erection faces high-altitude wind risks, and anchorages require extensive work and stable foundations. Prefabrication of main girder segments improves assembly efficiency in cable-stayed bridges, while suspension bridges must control main cable sag deviation. Both bridge types need wind-resistant measures for vibration and have longer construction periods than medium and small-span bridges. The Akashi Kaikyō Bridge exemplifies advanced technology for ultra-long-span suspension bridges [1].

4. Multi-dimensional comparison and adaptability analysis

4.1. Performance dimension

Beam bridges, dominated by flexural forces, offer moderate stiffness and stable quality through prefabricated assembly, but spans over 150 meters increase self-weight, reducing wind and crack resistance. Arch bridges, mainly under compression, efficiently utilize material strength, provide high stiffness and deformation resistance, and can last up to 100 years, though horizontal thrust demands robust substructures and construction methods risk additional internal forces or overturning. Cable-stayed bridges use a tower-cable-girder system, featuring lightweight girders and superior wind resistance, with cantilever construction minimizing under-bridge interference; however, cable force deviations require real-time monitoring to prevent beam bending. Suspension bridges achieve high tensile efficiency and maintain wind stability for spans over 1000 meters, with adaptable construction, but anchorage settlement can alter cable sag and their seismic resistance is lower than arch bridges [1].

4.2. Economic dimension

Economically, beam bridges have simple design and calculations, suitable for spans ≤ 40m, allowing batch production and low equipment investment, with costs at 70%-80% of arch bridges and low

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maintenance expenses. For spans >100m, increased girder size raises material costs, making arch bridges more economical. In 50m-200m spans, concrete slab arches use 15%-20% less material than beam bridges, and mature construction technology gives medium-span arch bridges clear cost advantages [3]. Beam bridges, governed by flexural forces, provide moderate stiffness and stable quality via prefabrication, but spans over 150 meters increase self-weight, reducing wind and crack resistance. Arch bridges, mainly in compression, maximize material strength, offer high stiffness and deformation resistance, and can last up to 100 years, but require strong substructures due to horizontal thrust and face construction risks. Cable-stayed bridges, with tower-cable-girder systems, use lightweight girders and have excellent wind resistance, but require real-time cable force monitoring to prevent beam bending. Suspension bridges, efficient in tension and wind-stable for spans over 1000 meters, allow flexible construction, but anchorage settlement affects cable sag and seismic resistance is lower than arch bridges [6].

4.3. Scenario dimension

Beam bridges offer flexible design and are suitable for rural roads (5–20m), expressways (20–40m), and urban overpasses (40–100m), with low site requirements, making them ideal for medium and small spans. Arch bridges require strong foundations; stone arches fit mountainous rural areas (50–100m), hollow concrete arches suit urban rivers (100–150m), and swivel construction enables crossing busy waterways (150–300m). Arch bridges also provide excellent landscape value for cultural and tourism sites. Cable-stayed bridges are suitable for complex scenarios with medium spans. Concrete cable-stayed bridges are suitable for urban river-crossing projects (200m-500m), and steel cable-stayed bridges are suitable for cross-sea passages (500m-1000m). Cantilever construction can avoid deep valleys and navigable waters, balancing functionality and aesthetics. Suspension bridges are the first choice for ultra-long spans [1,4]. Specifically, they suit cross-strait projects (over 1500m) and wide river-crossing scenarios (800m-1500m). The anchorages of suspension bridges need to be built on stable rock formations to ensure structural stability. Moreover, the catwalk construction can adapt to harsh marine environments, making suspension bridges the core bridge type for connecting distant island reefs.

5. Conclusion

Studies reveal significant differences among bridge types: beam bridges suit medium and small spans, arch bridges adapt to complex terrains, cable-stayed bridges balance performance and cost for medium spans, and suspension bridges are ideal for ultra-long spans. These distinctions guide bridge selection to match construction needs and environments. The adaptability of construction methods, such as prefabricated beam bridges for small spans, affects engineering benefits. This study refines the theoretical framework for bridge selection, aids scheme decision-making, and helps engineers identify optimal technical paths, ensuring safety, economy, and efficiency throughout the project lifecycle. It reduces trial-and-error costs and offers direct reference for complex environments. However, limitations include a focus on typical domestic cases, mainly qualitative indicators, and insufficient research on new materials. Future research should expand case scope, establish quantitative evaluation systems, and explore new materials and intelligent, low-carbon, and hybrid technologies to enhance the theoretical and practical value of bridge type selection.

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