applied sciences

Editorial

Special Issue on Recent Challenges and Innovations in Long-Span Bridges

Bin Sun *, Rucheng Xiao and Chaolin Song

Department of Bridge Engineering, Tongji University, Shanghai 200092, China; xiaorc@tongji.edu.cn (R.X.); songcl@tongji.edu.cn (C.S.)
* Correspondence: sunbin@tongji.edu.cn

Citation: Sun, B.; Xiao, R.; Song, C. Special Issue on Recent Challenges and Innovations in Long-Span Bridges. *Appl. Sci.* **2023**, *13*, 9694. https://doi.org/10.3390/app13179694

Received: 23 August 2023
Revised: 27 August 2023
Accepted: 24 August 2023
Published: 28 August 2023

Bridges are typical structures that provide connections between destinations and therefore achieve transportation functionality. Millions of bridges have been built around the world, becoming an essential part of the modern transportation system. The determination of a bridge span arrangement should satisfy requirements for shipping, construction, and mechanical performance [1], and the engineering economics [2] should also be considered in the process. Therefore, long-span bridges are necessary in some major engineering projects crossing valleys, rivers, or canals. Girder bridges, arch bridges, cable-stayed bridges, and suspension bridges are the most basic types of bridges. Taking advantage of the developments of material properties, construction method and equipment, computational ability, and design theory, the applicable span range for these types of bridges has showcased significant increases.

Girder bridges are one of the oldest bridge types. In ancient times, wood and stone were used to build girder bridges. The longest girder bridge is the Shibanpo Parallel Yangtze River Bridge [3], with a main span of 330 m, completed in 2006 in Chongqing, China. The Taoer River Bridge, which is currently under construction in Shandong Province, China, will break this record, with a main span of 338 m after completion. Arch bridges first appeared in the form of masonry arches in Ancient Egypt, Ancient Greece, and later in Ancient Rome. Currently, the longest steel, concrete, and concrete-filled steel tube arch bridges are the Chaotianmen Bridge (552 m) [4], the Shanghai-Kunming High-speed Railway Bridge over the Beipan River (445 m) [5], and the Third Pingnan Bridge (560 m) [6], respectively. The Lantian Fifth Yangtze River Bridge, a steel-box arch bridge of 578 m, the Fenglai Bridge, a steel-truss arch bridge of 580 m, and the Tiane Longtan Bridge, a stiff-skeleton concrete arch bridge of 600 m, will further break these records after completion. All the above arch bridges are located in China. The Swedish Strömsund Bridge, built in 1955 with a main span of 183 m, is often recognized as the first modern cable-stayed bridge [7]. After this, the maximum span of cable-stayed bridges increased rapidly due to their excellent crossing ability. In the 21st century, the span record for the cable-stayed bridge has exceeded 1000 m with the completion of the Sutong Bridge (1088 m) [8], the Stonecutters Bridge (1018 m) [9], and the Russky Bridge (1104 m) [10]. The Changtai Yangtze River Bridge, which is under construction in Nanjing, China, will set a new record with an anticipated span of 1176 m after completion. Modern suspension bridges, characterized by the use of steel wires to fabricate the main cables, began with the Brooklyn Bridge, which was completed in 1883 in the United States, with a span length of 486 m. In 1931, the George Washington Bridge, with a span of 1067 m, was completed, becoming the world's first bridge with a span longer than a kilometer [11]. In 1998, the Akashi Kaikyo Bridge, which has a main span length of 1991 m and adopted prefabricated parallel-wire strands, was completed in Japan [12]. In 2022, the 1915 Canakkale Bridge, which has a main span length of 2023 m and adopted a twin-box stiffening girder to enhance the stability under wind loads, was completed in Turkey [13]. Moreover, the Shiziyang Bridge, with a main span of 2180 m, and the Zhangjinggao Bridge, with a main span of 2300 m, are currently under construction in China [14].

Despite the above achievements, there are still some major strait projects in the planning stage, for instance the Bohai Strait, Taiwan Strait in China, the Gibraltar Strait in Italy, and the Bering Strait between the Pacific and Arctic oceans. Therefore, there still exists genuine demand for the construction of record-shattering long-span bridges, and bridge engineers will have to grapple with new unique challenges, such as bridge foundations in deep waters and aerodynamic challenges for long-span cable-supported bridges, to name a few. Researchers and engineers are investigating multiple techniques and innovations to deal with these challenges, including the combination and innovation of bridge structural systems [15], innovation in passive or active control techniques [16], and improvements in structural system resilience. Ge et al. [17] investigated the aerodynamic stability of super-long span suspension bridges with a main span of 5000 m. Xiao et al. [18] discussed the design scheme for cable-stayed bridges with a main span length of nearly 1500 m. Bridge engineers have also achieved developments in several key technologies, including multi-functional large-span bridges [5], steel box or truss girder and steel-concrete composite beam [19,20], design and construction of deep-water foundations [21], etc.

On the other hand, after the completion of construction, bridges can face severe challenges in terms of life-cycle maintenance, disaster prevention, and mitigation. To address these issues, engineers and researchers have developed portable, non-destructive detection equipment and bridge loading experimentation for various types of bridges [22]. Structural health monitoring systems and the field of sensing, data storage, and processing have also made progress [23,24]. In terms of intelligent maintenance, fast identification and intelligent analysis of bridge inspection data have been realized, and the building information model [25] is gradually becoming the technical basis for the integration of construction, management, and maintenance. Moreover, developments in computational methods, such as artificial intelligence and machine learning, have provided a new approach for assessing structural performance, therefore tracking and managing the evolving risks [26,27].

In conclusion, great achievements have been made in the construction of long-span bridges, but bridge engineers still need to embrace new challenges. Bridge engineers should work together to reasonably tackle these challenges with technical innovations and developments, therefore driving more sustainable, high-quality, safe, and effective engineering construction.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tang, M.-C. Super-long span bridges. *Struct. Infrastruct. Eng.* **2017**, *13*, 722–730. [CrossRef]
2. Zhang, L.; Xiao, R.; Sun, B.; Jiang, Y.; Zhang, X.; Zhuang, D.; Zhou, Y.; Tu, X. Study on economic performances of multi-span suspension bridges part 1: Simple estimation formulas. *Struct. Eng. Mech. Int. J.* **2013**, *47*, 265–286. [CrossRef]
3. Tang, M.-C. The New Shibanpo Bridge, Chongqing, China. *Struct. Eng. Int.* **2010**, *20*, 157–160. [CrossRef]
4. Cheng, J. Optimum design of steel truss arch bridges using a hybrid genetic algorithm. *J. Constr. Steel Res.* **2010**, *66*, 1011–1017. [CrossRef]
5. Qin, S.; Gao, Z. Developments and prospects of long-span high-speed railway bridge technologies in China. *Engineering* **2017**, *3*, 787–794. [CrossRef]
6. Zheng, J.; Wang, J. Concrete-filled steel tube arch bridges in China. *Engineering* **2018**, *4*, 143–155. [CrossRef]
7. Tang, M.C. Cable-stayed bridges. In *Bridge Engineering Handbook*; CRC Press: Boca Raton, FL, USA, 2000.
8. You, Q.; He, P.; Dong, X.; Zhang, X.; Wu, S. Sutong Bridge—The longest cable-stayed bridge in the world. *Struct. Eng. Int.* **2008**, *18*, 390–395. [CrossRef]
9. Falbe-Hansen, K.; Hauge, L.; Kite, S. Stonecutters bridge-detailed design. *IABSE Rep.* **2004**, *88*, 150.
10. Pipinato, A. Case study: The Russky bridge. In *Innovative Bridge Design Handbook*; Elsevier: Amsterdam, The Netherlands, 2016; pp. 671–680.
11. Buonopane, S.G.; Billington, D.P. Theory and history of suspension bridge design from 1823 to 1940. *J. Struct. Eng.* **1993**, *119*, 954–977. [CrossRef]
12. Kitagawa, M. Technology of the akashi kaikyo bridge. *Struct. Control. Health Monit.* **2004**, *11*, 75–90. [CrossRef]
13. Kroon, I.B.; Polk, H.; Fuglsang, K. 1915 Çanakkale Bridge–Meeting the Challenge. In Proceedings of the Developments in International Bridge Engineering: Selected Papers from Istanbul Bridge Conference 2018, Turkey, Istanbul, 5–6 November 2018; Springer: Berlin/Heidelberg, Germany, 2021; pp. 55–69.

14. Xiao, R.; Song, C.; Sun, B.; Dai, W.; Liu, J. Reliability-assisted determination of partial factors for the design of main cables considering secondary stress effect. *Structures* **2023**, *48*, 1479–1490. [CrossRef]
15. Zhuang, D.; Xiao, R.; Sun, B.; Yang, L. Concept and preliminary static analysis of hybrid anchored suspension bridge. *J. Bridge Eng.* **2021**, *26*, 4021032. [CrossRef]
16. Tao, T.; Wang, H.; Yao, C.; He, X. Parametric sensitivity analysis on the buffeting control of a long-span triple-tower suspension bridge with MTMD. *Appl. Sci.* **2017**, *7*, 395. [CrossRef]
17. Ge, Y.-J. Aerodynamic challenge and limitation in long-span cable-supported bridges. In Proceedings of the Advances in Civil, Environmental, and Materials Research (ACEM16), Jeju Island, Republic of Korea, 28 August–1 September 2016; Volume 16.
18. Xiong, W.; Cai, C.; Zhang, Y.; Xiao, R. Study of super long span cable-stayed bridges with CFRP components. *Eng. Struct.* **2011**, *33*, 330–343. [CrossRef]
19. Shao, X.; Yi, D.; Huang, Z.; Zhao, H.; Chen, B.; Liu, M. Basic performance of the composite deck system composed of orthotropic steel deck and ultrathin RPC layer. *J. Bridge Eng.* **2013**, *18*, 417–428. [CrossRef]
20. Xiao, R.; Song, C.; Sun, B.; Guo, R.; Chen, H. Design and experimental study of a replaceable steel-UHPC composite bridge deck. *Structures* **2022**, *40*, 1107–1120. [CrossRef]
21. Wei, K.; Zhou, C.; Zhang, M.; Ti, Z.; Qin, S. Review of the hydrodynamic challenges in the design of elevated pile cap foundations for sea-crossing bridges. *Adv. Bridge Eng.* **2020**, *1*, 1–30. [CrossRef]
22. Dan, D.; Ge, L.; Yan, X. Identification of moving loads based on the information fusion of weigh-in-motion system and multiple camera machine vision. *Measurement* **2019**, *144*, 155–166. [CrossRef]
23. Sun, L.; Shang, Z.; Xia, Y.; Bhowmick, S.; Nagarajaiah, S. Review of bridge structural health monitoring aided by big data and artificial intelligence: From condition assessment to damage detection. *J. Struct. Eng.* **2020**, *146*, 4020073. [CrossRef]
24. Surace, C. Special issue on novel approaches for structural health monitoring. *Appl. Sci.* **2021**, *11*, 7210. [CrossRef]
25. Xiao, R.; Lian, Y.; Sun, B.; Zhao, X.; Liu, Z.; Tang, P. Method of bridge structural analysis based on bridge information modeling. In Proceedings of the 2017 ASCE International Workshop on Computing in Civil Engineering, IWCCE 2017, Seattle, WA, USA, 25–27 June 2017; pp. 92–100.
26. Song, C.; Zhang, C.; Shafieezadeh, A.; Xiao, R. Value of information analysis in non-stationary stochastic decision environments: A reliability-assisted POMDP approach. *Reliab. Eng. Syst. Saf.* **2022**, *217*, 108034. [CrossRef]
27. Wang, X.; Mazumder, R.K.; Salarieh, B.; Salman, A.M.; Shafieezadeh, A.; Li, Y. Machine learning for risk and resilience assessment in structural engineering: Progress and future trends. *J. Struct. Eng.* **2022**, *148*, 3122003. [CrossRef]