iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 Issue: XI Month of publication: November 2023

DOI: https://doi.org/10.22214/ijraset.2023.56474

Floating Bridges: A Comprehensive Historical Review

Arko Pal[1], Dr. Hemant Sood[2]
[1, 2]Dept. of Civil Engineering, NITTTR Chandigarh

Abstract: Floating bridges, emerging as an ingenious response to geographical impediments, utilize the principle of water's buoyancy to create sustainable and environmentally conscious transportation networks. This comprehensive review explores the rich history, innovative design principles, and intricate structural analysis of floating bridges. Emphasizing their versatility, the paper sheds light on their ability to bridge communities across varied geographical and environmental contexts. Economically, the modular construction of floating bridges not only ensures resource efficiency but also offers a competitive edge in terms of reduced costs and expedited project timelines. A series of case studies are presented, corroborating their economic benefits and the ripple effects on regional economies. Beyond the mere architectural and economic implications, this research underscores the environmental stewardship intrinsic to floating bridges. By curtailing the environmental upheavals often associated with traditional bridge construction, they stand as guardians of aquatic habitats and ecosystems. Further enhancing their sustainability quotient, the paper delves into the potential integration of renewable energy solutions—such as harnessing water currents or solar power—to further diminish the carbon footprint of these structures, thereby making them a beacon for future infrastructure endeavors.

Keywords: Floating bridges, Sustainable infrastructure, Buoyancy force, Environmental considerations, Superstructure load.

I. INTRODUCTION

Floating bridges, while unique and less common globally, are particularly advantageous for specific geographical and environmental conditions. These bridges are predominantly found in areas with deep waters and soft seabed, where establishing conventional bridge piers becomes challenging. As such, when water depths exceed 30 meters and bridge spans go beyond 900 meters, floating bridges emerge as a more economical choice compared to their traditional counterparts. However, their construction becomes intricate in regions with strong winds or turbulent waters, which heighten the associated risks of failure. Furthermore, their design is shaped significantly by various factors including wind dynamics, water currents, and seismic activities, ensuring they withstand nature's challenges and maintain functionality. Historically, floating bridges have had significant mentions. The Persian king Xerxes, in 481 B.C., commissioned one to cross the 1.3 km wide Hellespont strait, which was later destroyed by a storm. During World War II, the US engineered different floating bridge types tailored to bear varying loads, employing either inflatable or aluminium-alloy pontoons. Concurrently, the Soviet Union introduced designs like the rapid-assembly PMP Floating Bridge. Another historic example includes Istanbul's Galata Bridge, the pioneer of modern floating bridges. Norway, with its expertise in offshore structures, has been a leader in floating bridge innovations, with remarkable examples like the Bergsoysund Bridge and Nordhordland Bridge, both constructed in challenging deep-sea conditions.

II. LITERATURE REVIEW

Seif, M. S. et al. (2002) offers a profound examination of the design and analytical considerations regarding the Lake Urmia Bridge in Iran, with an emphasis on the floating bridge as a favoured proposition. Historically, there have been multiple meticulous studies on this particular topic, as highlighted by the authors. In their exploration, they elucidate various bridge alternatives over Lake Urmia, including an array of fixed bridge designs. However, these were subsequently dismissed due to inherent technical and constructional constraints. Intricacies of highway construction in the locale, such as the challenges presented by water currents and the requisite complex systems of culverts and pipes, are meticulously discussed. Of particular note is the mooring system analysis executed via a numerical program, namely Maple software. Furthermore, the article sheds light on the region's environmental conditions, cataloguing factors like rainfall, wind velocities, and wave measurements. Significantly, the design and analytical phase associated with the floating bridge's anchors was carried out utilizing the UDEC Universal Discrete Element Code.

Jiang, D. et al. (2018) offers a comprehensive review of the analysis and design principles for floating prestressed concrete (PC) structures, especially those situated in coastal settings.

It delves into potential design intricacies and hurdles linked with these PC structures, subsequently introducing design recommendations to address these challenges. One notable suggestion is the integration of high-strength prestressing steel, which, by reducing the structure's weight, becomes especially beneficial for such weight-sensitive floating configurations. Furthermore, the paper emphasizes the unique material and design stipulations essential for these prestressed concrete floating constructs, shedding light on possible technical obstacles that designers might face. Concluding, the research consolidates its findings and advice, serving as a valuable reference for practitioners and researchers aiming to optimize the analysis and design of floating prestressed concrete structures in shallow aquatic environments.

Kim, M. et al. (2017) embarked on an extensive experimental exploration to ascertain the optimal mix proportions for structural lightweight concrete (SLWC), specifically tailored for floating concrete constructs within marine settings. A juxtaposition was made between SLWC mix designs historically utilized in prior floating concrete structures and those discerned within this study. The investigation delved deep into understanding how varying aggregates and supplementary cementitious materials influence SLWC's strength, density, and resilience. Notably, the study integrated lightweight aggregates such as 'Asano light' (an expanded shale aggregate) and both 'Stalite' and 'Liapor 48' (expanded slate aggregates). Furthermore, to enhance the mix designs, cement was partially substituted with additives like Silica Fume (SF) and Ground Granulated Blast-Furnace Slag (GGBS). Ultimately, the study's ambition was to pinpoint concrete mix ratios that aptly meet design stipulations, ensuring effective and efficient construction of marine floating concrete structures.

III. COMPREHENSIVE REVIEW

Floating bridges, with a centuries-old legacy, have continuously adapted to societal demands and engineering progress. They now play a pivotal role in global transportation, connecting people, cargo, and services across water. Detailed case studies of prominent floating bridges will follow, examining their design, construction, and regional influence. Each case reveals the planning and execution intricacies, underscoring their importance in contemporary transportation networks.

[Table 1. Types of Floating Bridges and Tunnels]

	Position		Type of Structure
1	Deeper than seabed		Underwater tunnel
2	Just beneath seabed		Immersed tunnel
3	Structure completely immersed in water		Submerged floating bridge or tunnel
4	Foundation completely submerged	Continuous foundation	Floating bridge with continuous submerged foundation
		Separated foundation	Floating bridge with separated foundations
5	Semi-submerged foundations		Floating bridge with semi-submerged foundations
6	Pontoon foundations		Floating bridge with pontoon foundations
7	Pontoon girders		Pontoon bridges
8	Trains running in water		Amphibious train
9	Foundations on seabed		Ordinary bridges

A. *Bergsoysund Bridge*

The Bergsoysund Bridge, also known as Bergsoysundbrua in Norwegian, is a pontoon bridge that stretches across the Bergsoysundet strait, linking the islands of Aspoya in Tingvoll and Bergsoya in Gjemnes, Norway. Spanning a total length of 931 meters (3,054 ft), it features its longest span measuring 106 meters (348 ft). The bridge maintains a maximum clearance of 6 meters (20 ft) above sea level and comprises 13 spans.

A notable feature of this bridge is its use of steel components in the superstructure. This design provides several advantages. When subjected to current from its convex side, it operates as an arch rib, offering greater structural rigidity compared to a similarly sized girder. Conversely, when the current flows in the opposite direction, it effectively functions as a catenary cable. This arch-catenary mechanism efficiently transforms hydraulic forces into axial forces within the superstructure and reactive forces at both ends.

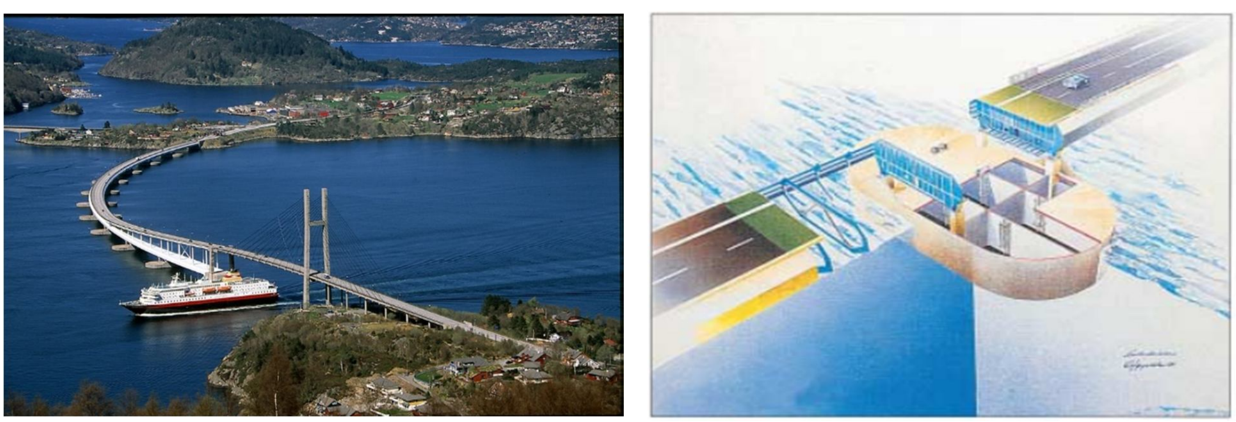
These ends are linked to the floating section by flexible rods, eliminating the need for seabed excavation during construction. These rods are engineered to transmit torsional moments, shearing forces, and axial forces at both ends while maintaining the flexibility required to accommodate vertical shifts caused by tidal variations.

[Fig. 1. Bergsoysund Bridge]

B. Nordhordland Bridge

The Nordhordland Bridge, is a distinctive fusion of cable-stayed and pontoon bridge technologies spanning the Salhusfjorden between Klauvaneset and Flatoy in Hordaland, Norway. This bridge boasts a total length of 1.6 kilometers, with the pontoon section extending over 1.25 kilometers. The cable-stayed segment features a single towering H-Pylon standing at 99 meters, spanning 368 meters, and featuring a primary span of 172 meters, providing a generous vertical clearance of 32 meters. The floating segment, constructed as a steel box girder bridge, rests upon ten unanchored pontoons due to the considerable depth of the fjord. An orthotropic deck supports vehicular traffic on the floating section, with both the pontoons and the cable-stayed bridge constructed from concrete. The main span is secured by 48 cables, and at the point where the two bridge types converge, a deep foundation supports the fjord end of the primary span.

The pivotal component of the structure is the box girder, characterized by an octagonal cross-section primarily composed of steel plates ranging from 14 to 20 millimeters in thickness. Trapezoidal stiffeners provide longitudinal reinforcement, braced by cross-frames spaced no more than 4.5 meters apart. The box girder was assembled in straight sections of varying lengths and subsequently joined into 11 large modules with a skew angle to align with the bridge's horizontal curvature. The girder maintains a constant cross-section along its length, except at reinforcement points where it connects to the pontoons and abutments. Variable tension exists along the bridge, necessitating different steel grades, with sections nearest the shore employing high-yield steel with a 540 MPa yield point.



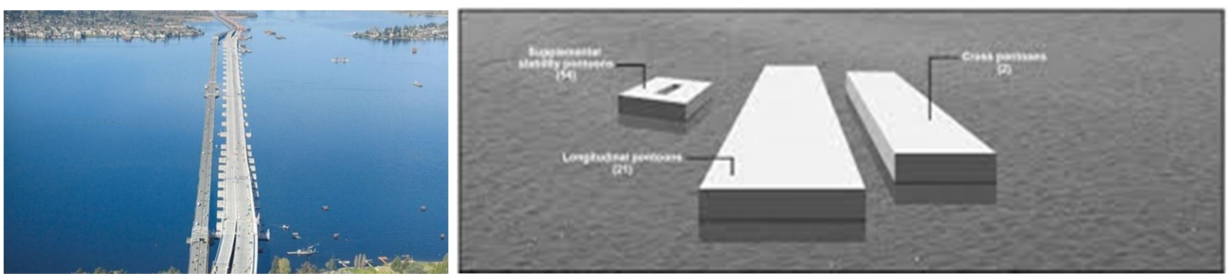
[Fig. 1. Nordhordland Bridge and its Pontoon Cross Section]

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue XI Nov 2023- Available at www.ijraset.com

The clearance between the box section's underside and the sea surface is 5.5 meters, allowing the passage of small boats between the pontoons. To prevent corrosion, the box section's interior surface is uncoated and maintained below 40% relative humidity with dehumidifiers. The bridge's foundations are supported by pre-tensioned rock anchors, providing stability even under extreme loads. The bridge is equipped with an array of sensors for monitoring, including corrosion, strain gauges, and weather information. Navigation lights and a racon are positioned on the cable-stayed section to aid navigation. The Nordhordland Bridge stands as the second-longest bridge in Norway, following the Drammen Bridge.

C. SR-520 Bridge

The SR-520, known as the world's longest floating bridge, links Seattle and Medina over Lake Washington, spanning an impressive 7708.5 feet or roughly 2.35 kilometers. This monumental structure replaced the former SR-520 Bridge, with construction initiated by the Washington State Department of Transportation (WSDOT) in 2012, and it opened to traffic in April 2016. The creation of individual bridge pontoons is a remarkable process. They are typically constructed on dry land near a waterway, then floated and towed like barges to the bridge site. These pontoons are linked to grounded approach structures on either end, starting at the edge of the floating structure and extending toward the bridge's center. Enormous steel cables, often hundreds of meters long, secure the pontoons and connect to anchors deeply embedded in the lakebed, effectively keeping the entire bridge afloat. A total of 77 concrete pontoons constitute this engineering marvel.



[Fig. 3. SR-520 Bridge and its Pontoons]

WSDOT's choice of a floating bridge over conventional fixed or suspension bridges is a product of Lake Washington's unique characteristics. The lake's considerable depth, reaching 214 feet, would necessitate support towers nearly 630 feet tall, disrupting the environment with noise and obstructions. Conventional fixed bridges are costly to construct in deep waters with soft beds, such as Lake Washington. Meanwhile, suspension bridges require a relatively straight path, which is incompatible with the curved trajectory of SR 520.

The floating bridge comprises various types of pontoons, each playing a vital role in its stability and support. Longitudinal Pontoons, the largest, form the bridge's backbone, each weighing over 11,000 tons. Cross Pontoons mark the bridge's ends and the transition to approach structures, with each weighing more than 10,000 tons. Supplementary Stability Pontoons, smaller in size, contribute to stabilizing and supporting the bridge when combined with the larger longitudinal pontoons, each weighing over 2,000 tons. The pontoons are anchored using a series of woven steel cables, with different anchors on the Lake Washington lakebed. Fluke Anchors, Gravity Anchors, and Drilled Shaft Anchors are strategically positioned based on the soil conditions.

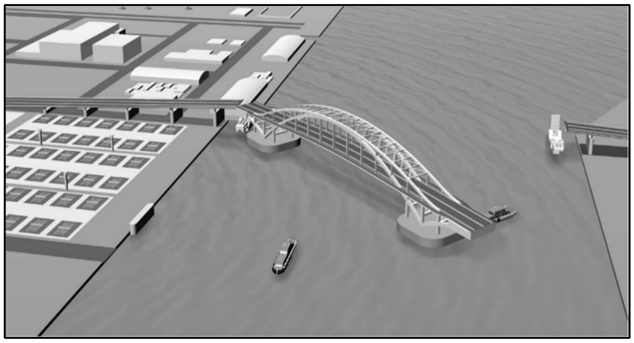
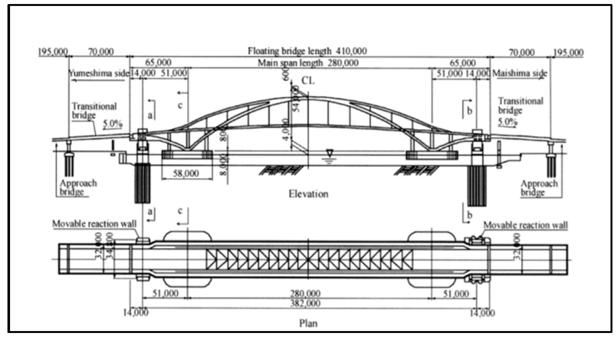
Additionally, the bridge's innovative stormwater system includes an extensive network of piping, catch basins, and "lagoons" within the supplemental pontoons. This system, spanning 15,450 feet, is designed to collect, filter, and properly manage pollutants from roadway runoff, exemplifying the bridge's commitment to environmental stewardship.

D. OSAKA Bridge

The Osaka municipal government has embarked on an ambitious project named 'Tech Port Osaka,' with the aim of transforming the waterfront areas adjacent to the Port of Osaka into the new epicenter of Osaka City. The project encompasses the development of three reclaimed islands that encompass not only a harbor but also residential and commercial zones, along with parks and sports stadiums. A pivotal component of this initiative is the Yumeshima-Maishima Bridge (provisional name), which links Yumeshima and Maishima reclaimed islands across the North Waterway (Fig. 31). The North Waterway, with a width of approximately 400 meters, serves as the main waterway in case of unforeseen accidents or events. To meet these requirements, the chosen bridge type is an arched skew floating highway bridge, featuring a total length of 940 meters and a width of 38.8 meters to accommodate six traffic lanes with a doubled-rib arch.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue XI Nov 2023- Available at www.ijraset.com

It is supported by two pontoons capable of pivoting near one end of the girder. Once completed, the bridge will play a pivotal role in facilitating the development of Yumeshima Island and serve as a vital transportation link to the waterfront districts.

[Fig. 4. Osaka Bridge Illustration and Plan]

Key characteristics of the Yumeshima-Maishima Bridge include its doubled-rib arch design with a width of 38.8 meters, accommodating six traffic lanes, and resting on two hollow steel pontoons vertically. The bridge is supported horizontally by rubber fenders and can swing around a pivot axis near the Maishima end (Fig. 32). The mooring system is designed to withstand typhoon-level wind and waves and comprises dolphins, movable reaction walls, and rubber fenders. The swinging operation involves the insertion of a pivot axis and the jacking up of transitional side bridges. The reaction walls are then released from their mooring function and rotated, allowing tugboats to swing the bridge about the pivot axis.

Construction involves assembling the superstructure, including the pontoons, at a dock and towing the completed bridge section to the site, where it is joined to the mooring systems. This approach significantly expedites the construction process. The mooring systems are essential to resist forces such as winds, waves, and earthquakes (lateral forces), while the buoyancy of seawater in the pontoons counters the dead and live loads of the floating bridge (vertical forces). Three types of mooring systems were explored for the bridge's design, with rubber fender mooring emerging as a cost-effective solution capable of limiting the movement of the floating bridge while offering energy absorption properties, commonly employed for ship berthing.

[Table 2. Comparative Analysis of Existing Floating Bridges]

	NAME OF BRIDGE	Bergsoysund Bridge	Nordhordland Bridge	Sr-520 Bridge	Osaka Bridge
	LOCATION	Norway	Norway	USA	Japan
	COMPLETED IN	1992	1994	2016	2000
	BRIDGE SPAN (M)	900+	1600+	2300+	400+
PONTOON	TYPE	Pontoon Foundation	Pontoon Foundation	Box Type Pontoons	Pontoon Foundations
	MATERIAL	Concrete	Concrete	Concrete	Concrete
	NUMBER OF PONTOON	7	10	77	2
	MOORING	None	None	Cable and Anchor Mooring	

CONNECTION	Flexible Rods with Abutments	Flexible Plates with Abutments	Transition Girder	Transition Girder
MAX WATER DEPTH (M)	320	500	65	12
NOTES	Arch-catenary mechanism	Fusion of cable-stayed and Pontoon bridge	Largest Floating Bridge in the World	Swing type Bridge

IV. CONCLUSION

Floating bridges offer a compelling combination of economic and environmental sustainability, making them a viable solution for overcoming water barriers in transportation infrastructure. A few notable reasons are as follows:

1) *Cost-effectiveness:* Floating bridges can be a cost-effective solution compared to traditional bridge types. They often require less complex and expensive foundation construction, as they rely on buoyancy rather than extensive piling or deep foundations. Modular construction techniques can also reduce costs by allowing for efficient assembly and disassembly, making them suitable for temporary or seasonal crossings.
2) *Reduced environmental impact:* Floating bridges have a smaller environmental footprint compared to conventional bridge types. They often involve minimal land disturbance since they traverse bodies of water without the need for extensive embankments or land acquisition. This characteristic can help preserve natural habitats, reduce deforestation, and maintain ecological connectivity.
3) *Adaptability and flexibility:* Floating bridges offer adaptability and flexibility in transportation infrastructure. They can be quickly deployed or relocated as needed, making them suitable for emergency situations, temporary crossings during construction or maintenance, and remote or isolated areas. This adaptability can contribute to efficient transportation networks and minimize disruptions.
4) *Minimal visual impact:* Floating bridges can have a minimal visual impact on the surrounding landscape. Unlike elevated or large-span bridges, floating bridges typically sit at or near the water surface, blending with the natural surroundings. This characteristic can be particularly beneficial in scenic or environmentally sensitive areas where preserving the aesthetic value is important.
5) *Potential for renewable energy integration:* Floating bridges provide an opportunity for renewable energy integration. For example, solar panels can be installed on the bridge deck to generate electricity, reducing the reliance on external power sources. The bridge structure itself can also serve as a platform for wind turbines or other renewable energy systems, further enhancing sustainability.
6) *Improved accessibility:* Floating bridges can enhance accessibility to previously isolated or underserved areas. By providing a direct link across water bodies, they facilitate the movement of people, vehicles, and goods, improving connectivity and promoting economic development in remote regions. This improved accessibility can have positive socio-economic impacts, such as increased tourism, trade, and employment opportunities.

Well-engineered and maintained floating bridges are efficient, safe, durable, and comfortable to ride on. They form important links in major transportation systems in different parts of the world. In summary, the research conducted in this paper demonstrates that floating bridges are indeed marvels of engineering and sustainability. Their unique design, construction techniques, economic viability, and environmental benefits make them an attractive option for crossing water bodies while minimizing ecological impact. By embracing floating bridge technology, we can create a more sustainable future for transportation infrastructure and contribute to the development of resilient and environmentally friendly systems.

REFERENCES

[1] Watanabe E., “Floating Bridges : Past and Present Types of Floating Bridge,” Struct. Eng. Int., no. 2, pp. 128–132, 2003.
[2] Watanabe E. and Utsunomiya T., “Analysis and design of floating bridges,” Prog. Struct. Eng. Mater., vol. 5, no. 3, pp. 127–144, Jul. 2003, doi: 10.1002/pse.151.
[3] Starr P. and Wainwright D. A., “Design and construction of a concrete floating berth,” Eng. Struct., vol. 18, no. 11, pp. 837–841, 1996, doi: 10.1016/0141-0296(95)00162-X.
[4] Seif M.S. and Paein Koulaei R.T., “Floating bridge modeling and analysis,” Scientia Iranica, vol. 12, no. 2. pp. 199–206, 2005. [Online]. Available: www.SID.ir

[5] Halkyard J., "Floating Offshore Platform Design," in Handbook of Offshore Engineering (2-volume set), 2005, pp. 419–661. doi: 10.1016/B978-008044381-2.50010-2.

[6] Ang K. K., Dai J., Hellan O., Want A., and Si M. B. I., "Design and Potential Applications of Floating Structures in Singapore," in Lecture Notes in Civil Engineering, vol. 41, Springer, 2020, pp. 135–154. doi: 10.1007/978-981-13-8743-2_7.

[7] Moan T. and Eidem M. E., "Floating Bridges and Submerged Tunnels in Norway—The History and Future Outlook," in Lecture Notes in Civil Engineering, vol. 41, Springer, 2020, pp. 81–111. doi: 10.1007/978-981-13-8743-2_5.

[8] Moe G., "Design philosophy of floating bridges with emphasis on ways to ensure long life," J. Mar. Sci. Technol., vol. 2, no. 3, pp. 182–189, 1997, doi: 10.1007/BF02489809.

[9] "Lwin, M. M. (1993). 'The lacey V. murrow floating bridge, USA.' Structural Engineering International, 3(3), 145–148.".

[10] Cheng Z., Gao Z., and Moan T.,"Numerical modeling and dynamic analysis of a floating bridge subjected to wind, wave, and current loads," J. Offshore Mech. Arct. Eng., vol. 141, no. 1, Feb. 2019, doi: 10.1115/1.4040561.