

Bridge Structural Design Simulation: Case Study of Nongsa Pura Bridge

Yehezkiel Immanuel¹, Andri Irfan Rifai^{2*}, Ade Jaya Saputra³, Joewono Prasetijo⁴

^{1,2,3}Universitas Internasional Batam, Riau Islands, Indonesia

⁴Universiti Tun Hussein Onn Malaysia, Johor, Malaysia

E-mail: yehezkielimmanuel17@gmail.com¹, andri.irfan@uib.ac.id^{2*}, adi.jaya@uib.ac.id³,
joewono@uthm.edu.my⁴

Abstract: The influence of various components, including the deck, girders, trusses, cables, and other structural elements, plays a significant role in determining the long-term stability and service life of bridges. With the increasing demands of traffic loads, environmental factors, and material degradation, it is crucial to reassess and enhance the existing calculations for bridge superstructure designs. This paper aims to redesign and reanalyze the superstructure of the Nongsa Pura Bridge by using secondary data for calculations. The results of this study include updated design specifications, specifically WF 500x200x10x16 and WF 800x300x14x22 structural profiles. The research methodology involves a detailed re-evaluation of the bridge's structural elements, focusing on adapting to contemporary standards and ensuring the bridge's resilience to evolving demands.

Keywords: Bridge Design, Steel Structure, Superstructure

INTRODUCTION

For a region to achieve economic development and social networks, people, goods, and services must move efficiently (Gonzalez et al., 2020). This is why bridges are indispensable. In an organized setup of living components, bridges are even more essential. Every part above the bridge piers or abutments is woven into it both structurally and functionally. The influence of components, such as the deck, girders, trusses, cables, and other structures, on the long-term stability and service life is apparent. The superstructure can bear diverse loads above it, such as vehicular and foot traffic. Wind, snow, temperature differences, or earthquakes beneath it and along its length rest on foundations that may include rock or soil. However, these materials must meet the criteria for service life and strength at a reasonable price. The materials for superstructure construction are selected according to both criteria. The available choices include steel, concrete with reinforcement, prestressed concrete, and composite materials (Zinke et al., 2021).

Indonesia has over 17,000 islands; some challenges in constructing and maintaining bridges are quite different. Some of the bridges in Indonesia are in bad shape: they suffer from old materials, lack maintenance, and are cruelly ravaged by a climate that encourages decay. For example, in a tropical country subject to frequent heavy downpours, the high humidity and sea air make all sorts of components rust and corrode (Kiraga & Wicaksono, 2020). The structural fatigue of reinforced concrete, in particular, takes advantage of this same state of things and the rapid dissolution of steel members into fragments. Then, in an area of active seismicity like Indonesia, where earthquakes periodically shake things up for a considerable time--there is no alternative but for many bridges to be built solidly and then especially heavily restored after seismic events such as these. Despite these disadvantages, there are instances when

a lack of funds and know-how has worsened things. It is urgently necessary to have an integrated approach to bridge maintenance and strengthening in Indonesia.

The Batam bridge network is essential for linking the islands in the Riau Archipelago and aiding the economic activities of the area, but it is dealing with significant superstructure obstacles. One major problem is the increased deterioration of steel components and concrete structures in the region due to high humidity and exposure to saltwater, leading to accelerated wear and tear (Bień & Salamak, 2022). Moreover, the quick industrial growth and urban expansion in Batam have caused higher traffic volumes, surpassing the initial capacities of several bridges and worsening structural fatigue and stress. Regular checks have uncovered fractures and chipping in multiple bridge decks and girders, underscoring the critical requirement for thorough maintenance and strengthening plans. Despite these urgent problems, funding limitations and a lack of technical expertise have hindered efficient efforts to address the issues, creating dangers for both safety and economic stability in the area. Dealing with these challenges necessitates a unified strategy that combines high-tech materials, up-to-date building methods, and robust upkeep procedures to guarantee the durability and dependability of Batam's bridge system (Li et al., 2021).

The Nongsa Pura Bridge, a critical link in Batam's tourism and maritime industries, faces significant challenges due to its specific vulnerabilities. Corrosion from the harsh marine environment, compounded by heavy monsoon rains, accelerates the degradation of both steel and concrete components. Additionally, the bridge is under increasing strain from rising traffic loads as the area experiences growth in tourism and nearby industrial activities. Addressing these issues requires using advanced materials such as corrosion-resistant alloys and high-performance concrete, alongside regular maintenance and monitoring. Furthermore, implementing modern technologies for continuous structural monitoring will allow for early detection of potential problems, helping to ensure the bridge's long-term durability and performance.

The structural planning of bridges is a crucial aspect of civil engineering, involving key stages like evaluation, design, and assessment to guarantee the safety, longevity, and efficiency of bridge parts. This paper examines essential research discoveries and progress in methodologies, materials, sustainability factors, seismic resilience, and technological incorporation (Zhao et al., 2020). Efficient planning is essential to build bridges that can endure different pressures and weather conditions. Advancements in design and materials have greatly improved the performance of bridges. These advancements are crucial in building a solid infrastructure that can meet contemporary requirements.

The importance of effective bridge design methodologies cannot be understated, especially in regions prone to structural challenges like the Nongsa Pura bridge, which experienced severe wear and degradation within its first 10 years due to increased traffic loads and environmental factors (Mishra, 2019). Traditional methods such as LRFD and ASD have long been the foundation of bridge engineering, but recent evaluations have shown that nearly 25% of bridges designed using older methodologies in Indonesia have required early maintenance or retrofitting due to unforeseen stresses (Aguilar et al., 2022). LRFD, for example, enables engineers to account for uncertainties in load and resistance using probability, improving the dependability of structural designs. In the case of the Nongsa Pura bridge, inadequate assessment of load factors contributed to early structural fatigue. Additionally, advancements in computational technologies like finite element analysis (FEA) have transformed structural analysis by replicating complex stress patterns and relationships within bridge components (Shadabfar et al., 2022).

FEA allows engineers to improve designs by forecasting how various materials and configurations will perform under specific environmental and load conditions, a critical factor that could have mitigated some of the issues faced by the Nongsa Pura bridge.

Adopting high-performance materials has significantly enhanced bridge durability and efficiency (Jalaei et al., 2024). Materials like high-strength steel, prestressed concrete, and fiber-reinforced polymers offer superior strength-to-weight ratios and resilience to environmental degradation. Sustainability considerations are increasingly integral to bridge planning, advocating using recyclable materials and energy-efficient construction practices. Life-cycle assessment (LCA) methodologies play a crucial role in evaluating the environmental impacts of bridges throughout their operational lifespan, ensuring sustainable infrastructure development (Martínez-Muñoz et al., 2021).

Strong seismic resilience is crucial, particularly in areas susceptible to earthquakes. Techniques like base isolation and energy dissipation devices help reduce seismic forces, improving bridge resilience and decreasing structural damage in earthquakes (Khan et al., 2023). Comprehending seismic risks and incorporating suitable design precautions are essential for protecting infrastructure from natural calamities. Furthermore, the incorporation of real-time monitoring systems and intelligent materials in bridge infrastructure has transformed due to technological progress. Infrastructure health monitoring systems offer ongoing information on how structures are performing, allowing for proactive upkeep and timely actions to prevent damage (MENDEZ-GALINDO et al., n.d.). Intelligent materials that can adjust to environmental changes improve the lifespan of bridges by accommodating dynamic loads and environmental fluctuations. These technological advancements not only enhance bridge structure reliability but also lower maintenance expenses and boost operational effectiveness.

The Indonesian National Standard, referred to as Standard Nasional Indonesia (SNI), is essential for building and keeping structures throughout the nation. These criteria aim to guarantee bridge structures' safety, longevity, and efficiency by considering factors like design loads, material specs, and construction techniques (Hidayat et al., 2020). Engineers and construction professionals in Indonesia can improve the

Specifying design loads and safety factors is a fundamental aspect of the SNI for bridges. These standards outline the minimum loads that bridge structures must support, including vehicular, pedestrian, wind, and seismic loads. Safety factors are added to make sure bridges can withstand unforeseen pressures and function in extreme situations. The SNI requires strict seismic design standards to protect against Indonesia's earthquake susceptibility, guaranteeing that bridges are strong and able to endure seismic activity (Simanjuntak et al., 2022). Following these guidelines can prevent structural failures and improve public safety.

Specifications for materials are also an essential aspect of the Indonesian National Standard for Bridges. The SNI specifies the utilization of top-notch materials like solid steel, fortified and prestressed concrete, and alloys resistant to corrosion (Yusuf & Hermawan, 2023). These materials are selected for their sturdiness and capability to endure the severe tropical weather conditions in Indonesia, such as high humidity and salinity near the coast. The standards stress the significance of routine maintenance and inspection to handle wear and tear and prolong the lifespan of bridge structures. The SNI guarantees the long-term safety and functionality of bridges through the use of durable materials and proper maintenance techniques.

Despite the thoroughness of the SNI for bridges, various obstacles are preventing its successful execution. A significant hurdle is the inconsistency in following standards among various regions and

project (Panggabean & Soekiman, 2021). Although urban areas might have the means and knowledge to adhere to SNI regulations completely, rural and remote areas are often challenged by inadequate funding, technical skills, and access to high-quality materials. Moreover, the fast growth of infrastructure projects in Indonesia can result in shortcuts and compromises in construction quality. To overcome these obstacles, construction professionals need better training, standards must be enforced more strictly, and more funding must be allocated to infrastructure projects to meet the SNI requirements in all regions (Willar et al., 2021).

Steel bridges are crucial in modern infrastructure, providing many benefits in terms of strength, durability, and design flexibility. Steel has been utilized in building bridges since the 1800s and has progressed alongside improvements in material science and engineering techniques. Steel bridges play a crucial role in transportation systems by carrying heavy weights over long distances (Rifai et al., 2015). This essay discusses the advantages of steel bridges, how they are built, and the difficulties in keeping and protecting these critical structures.

The outstanding strength and capacity to bear loads are among the main advantages of steel bridges. Steel's high strength-to-weight ratio permits the building of long-span bridges capable of holding significant loads. This characteristic makes steel perfect for bridges in urban areas and major transportation routes that have to handle heavy traffic. Furthermore, steel bridges offer a high level of flexibility and can be constructed in different styles, such as truss, arch, and suspension bridges (Rifai et al., 2016). This ability to be flexible in design allows engineers to develop unique structures that meet particular aesthetic and functional needs.

Building steel bridges requires accurate engineering and sophisticated fabrication methods. Construction of contemporary steel bridges usually begins with the thorough planning and simulation of the bridge's design then proceeds to the manufacturing of steel parts in designated factories. These parts are later taken to the building location, where they are put together and raised with the help of cranes and other large equipment (Ramli et al., 2017). Using prefabricated steel elements speeds up construction and cuts on-site labor, making steel bridges a budget-friendly choice for major infrastructure projects. Moreover, progress in welding and bolting techniques has enhanced the effectiveness and dependability of steel connections, guaranteeing the structural soundness of the bridges.

Although steel bridges have their benefits, they also encounter various difficulties, especially when it comes to upkeep and rust. Steel can easily corrode if it comes into contact with moisture and severe environmental conditions, resulting in the formation of rust and eventual deterioration. Protective coatings and regular maintenance are crucial to address this problem. Methods like galvanization, painting, and utilizing weathering steel have the potential to boost the ability of steel bridges to resist corrosion. Nevertheless, continuous monitoring and maintenance are needed to ensure the effectiveness of these protective measures. Furthermore, the upfront expenses for corrosion prevention and the ongoing costs for upkeep can present financial hurdles for bridge maintenance agencies (Sánchez-Garrido et al., 2024).

This paper aims to re-design and re-calculate the existing analysis of the Nongsa Pura Bridge Superstructure. The approach uses data to accurately predict the impact of various load types, including vehicular traffic, pedestrian movement, wind forces, and seismic activities. Given the evolving demands of increased traffic loads, environmental impacts, and material degradation, it is essential to revisit and refine the existing calculations that underpin bridge superstructure designs. Ultimately, this

comprehensive effort is meant to extend the lifespan, safety, and efficiency of bridges, addressing both present and future infrastructural challenges (Rus Jenni & Annan, 2019).

MATERIALS AND METHODS

This paper focuses on the design of a bridge superstructure, incorporating all applicable loads. The research was conducted at the Nongsa Pura Bridge, located in Nongsa, Batam, Riau Islands. Secondary data for this study was selected based on the relevance to the bridge's design requirements, including geographical, structural, and load-bearing criteria. The data was thoroughly analyzed to ensure its accuracy and applicability, using engineering standards and computational models to validate the selection and influence of the loads applied in the design process.

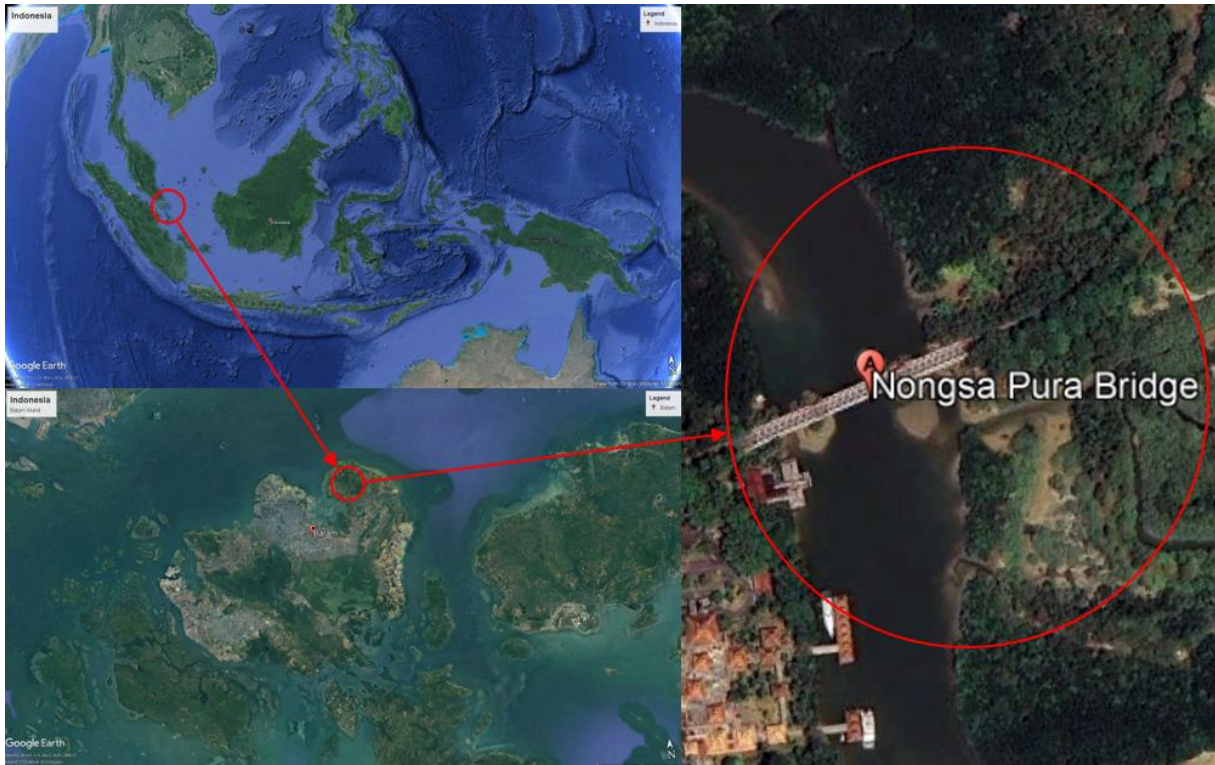


Figure 1. Nongsa Pura Bridge Location

Source: Google Earth (2024)

This research uses several parts of Indonesian national standards as design guidelines.

Table 1. Bridge Design Guidelines

No	Indonesian National Standard	Information
1	1727:2016	Loading for Bridges
2	2833:2016	Bridge Planning Against Earthquake Loads
3	1729:2020	Specifications For Structural Steel Elements

Source: Author (2024)

The data used is secondary data. This data was used again to design the Nongsa Pura Bridge.

Table 2. Bridge Secondary Data

No	Information	Data
1	Length	100 m
2	Width	12 m
3	Live Load (LL)	185.9 kN/m
4	Dead Load (DL)	285.2 kN/m

Source: Author (2024)

Indonesia is a country that has an earthquake ring. The data presented is secondary data that has been analyzed

Table 3. Seismic Data

PGA MCEG (g)	SS MCEr (g)	S1 MCEr (g)	TL (sec)
0.0564	0.1090	0.799	16
T0 (sec)	Ts (sec)	Sds (g)	Sd1 (g)
0.24	1.18	0.11	0.13

Source: SBC

RESULTS AND DISCUSSION

Longitudinal Girder

Longitudinal girders 100 m long must be designed in such a way that they can support the load safely and well. The results of the design can be seen in Table 4 and Table 5.

Table 4. Longitudinal Girder Result

No	Information	Result
1	Live Load (LL)	12.64 kN/m
2	Dead Load (DL)	11.03 kN/m
Local Buckling Control:		
3	Web	$42.8 \leq 88.54$ (Compact)
	Flange	$6.25 \leq 8.96$ (Compact)
4	Compact Cross Section (Mn)	754.56 kNm
Lateral Buckling Control (Lr):		
5	Lp	168.315 cm
	Lb	600 cm
6	Moment	$400.1 < 710.37$ (OK)
7	Vu (UDL and KEL)	169.2 kN
8	Deflection Control (Δ)	0.45 cm

Source: Author (2024)

Table 5. Longitudinal Girder Joint Result

No	Information	Result
1	Bolt Force Permission (Vu)	292.5 kN
2	Bolt Amount	3 pcs
3	Bolt Range	50 mm
4	Bolt Range from Edge Joint	30 mm
5	Shear Area (Anv)	8.5 cm ²

6	Shear Force Plan	292.5 kN < 561 kN (OK)
---	------------------	------------------------

Source: Author (2024)

From the data that has been displayed, the web and flange are safe from local buckling. The girder moment is still in a safe range with a deflection of 0.45 cm. For the joint, this girder will use three pieces of the bolt, with 50 mm between the bolt and 30 mm from the edge joint and a shear force that is safe. Therefore, steel WF 500x200x10x16 will be an excellent option for this girder.

Transverse Girder

The transverse girder is perpendicular to the longitudinal girder. with a length of 12 m, must be able to withstand the load carried. The result of the design can be seen in Table 6 and Table 7.

Table 6. Transverse Girder Result

No	Information	Result
1	Live Load (LL)	185.5 kN/m
2	Dead Load (DL)	41.66 kN/m
3	Concrete Effective Width (Mn)	3406.2 < 3690.72 kNm (OK)
4	Shear Control (VA):	
	Before Composite	249.96 kN
	After Composite	66.95 kN
8	Deflection Control (Δ)	0.15 cm

Source: Author (2024)

Table 7. Transverse Girder Joint Result

No	Information	Result
1	Bolt Force Permission (Vu)	994.45 kN
2	Bolt Amount	10 pcs
3	Bolt Range	50 mm
4	Bolt Range from Edge Joint	30 mm
5	Shear Force Plan	292.5 kN < 567.6 kN (OK)

Source: Author (2024)

From the data that has been displayed, the concrete effective width is safe. The girder moment is still in a safe range with a deflection of 0.15 cm. For the joint, this girder will use ten pieces of the bolt, with 50 mm between the bolt and 30 mm from the edge joint and a shear force that is safe. Therefore, steel WF 800x300x14x22 will be a perfect option for this girder.

CONCLUSION

This research was conducted on the case study of the Nongsa Pura Bridge, located in Nongsa, Batam, Riau Island, and was guided by the standards SNI 1727:2016, SNI 2833:2016, and SNI 1729:2020. Secondary data were utilized for the bridge design, which was then processed to determine the steel profiles for the bridge girders and connection elements. The steel profiles recommended based on the findings are WF 500x200x10x16 for smaller sections and WF 800x300x14x22 for larger sections.

It is recommended that WF 500x200x10x16 be applied for shorter spans or less heavily loaded sections of the bridge to ensure material efficiency without compromising structural integrity. For the connections, the use of WF 800x300x14x22 is suggested for sections requiring higher load-bearing capacity, ensuring stability and safety, especially in high-stress areas. Engineers and designers working on similar bridge projects should consider these profiles as starting points but adjust according to specific site conditions, load requirements, and environmental factors. Regular inspections should focus on the identified steel elements to ensure longevity and performance under real-world conditions, with potential adjustments based on long-term wear and load behavior analysis.

REFERENCES

- Aguilar, V., Nowak, A. S., & Anderson, J. B. (2022). History of Transition From Allowable Stress Design to Load and Resistance Factor Design and Beyond. *Transportation Research Record*, 03611981221116363.
- Bień, J., & Salamak, M. (2022). The management of bridge structures—challenges and possibilities. *Archives of Civil Engineering*, 5–35.
- Gonzalez, A., Schorr, M., Valdez, B., & Mungaray, A. (2020). Bridges: structures and materials, ancient and modern. *Infrastructure Management and Construction*.
- Hidayat, M. N., Rahmat, A. N., & Ronilaya, F. (2020). Feasibility analysis of a renewable autonomous power supply system at a coastal area in Indonesia. *International Journal of Energy Economics and Policy*, 10(3), 175–181.
- Jalaei, F., Zhang, J., Mcneil-Ayuk, N., & McLeod, C. (2024). Environmental life cycle assessment (LCA) for design of climate-resilient bridges—a comprehensive review and a case study. *International Journal of Construction Management*, 1–16.
- Khan, S. A., Kabir, G., Billah, M., & Dutta, S. (2023). An integrated framework for bridge infrastructure resilience analysis against seismic hazard. *Sustainable and Resilient Infrastructure*, 8(sup1), 5–25.
- Kiraga, M., & Wicaksono, A. Y. (2020). An overview of bridge pier construction solutions, including the Indonesian approach. *Acta Scientiarum Polonorum Architectura*, 19(2), 3–20.
- Li, L., Mahmoodian, M., Khaloo, A., & Sun, Z. (2021). Risk-cost optimized maintenance strategy for steel bridge subjected to deterioration. *Sustainability*, 14(1), 436.
- Martínez-Muñoz, D., Marti, J. V., & Yepes, V. (2021). Comparative life cycle analysis of concrete and composite bridges varying steel recycling ratio. *Materials*, 14(15), 4218.
- MENDEZ-GALINDO, C., MOOR, G., & BAILLÉS, B. (n.d.). *Optimizing the multi-hazard resilience of bridge and building structures*.
- Mishra, A. K. (2019). Role of Reliability Analysis in Structural Design. *Hydro Nepal: Journal of Water, Energy and Environment*, 24, 6–9.
- Panggabean, A. K., & Soekiman, A. (2021). Evaluasi Penerapan Standar Dan Pedoman Bidang Jalan Dan Jembatan. *Rekayasa Sipil*, 15(1), 60–68.

- Ramli, L., Mohamed, Z., Abdullahi, A. M., Jaafar, H. I., & Lazim, I. M. (2017). Control strategies for crane systems: A comprehensive review. *Mechanical Systems and Signal Processing*, 95, 1–23. <https://doi.org/10.1016/j.ymssp.2017.03.015>
- Rifai, A. I., Hadiwardoyo, S. P., Correia, A. G., & Pereira, P. (2016). Genetic Algorithm Applied for Optimization of Pavement Maintenance under Overload Traffic: Case Study Indonesia National Highway. *Applied Mechanics and Materials*, 845, 369–378.
- Rifai, A. I., Hadiwardoyo, S. P., Correia, A. G., Pereira, P. A. A., & Cortez, P. (2015). *The data mining applied for the prediction of highway roughness due to overloaded trucks*.
- Rus Jenni, L., & Annan, C.-D. (2019). Introduction: Extending the Design Life of Structurally Deficient Steel and Composite Bridges. In *Structural Engineering International* (Vol. 29, Issue 4, p. 506). Taylor & Francis.
- Sánchez-Garrido, A. J., Navarro, I. J., & Yepes, V. (2024). Sustainable preventive maintenance of MMC-based concrete building structures in a harsh environment. *Journal of Building Engineering*, 95, 110155. <https://doi.org/10.1016/j.jobbe.2024.110155>
- Shadabfar, M., Mahsuli, M., Zhang, Y., Xue, Y., Ayyub, B. M., Huang, H., & Medina, R. A. (2022). Resilience-based design of infrastructure: Review of models, methodologies, and computational tools. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, 8(1), 03121004.
- Simanjuntak, V. C., Imran, I., Moestopo, M., & Setio, H. D. (2022). The Evolution of Seismic Design Provisions in Indonesia's National Bridge Code. *J. Eng. Technol. Sci*, 54, 220614.
- Willar, D., Waney, E. V. Y., Pangemanan, D. D. G., & Mait, R. E. G. (2021). Sustainable construction practices in the execution of infrastructure projects: The extent of implementation. *Smart and Sustainable Built Environment*, 10(1), 106–124.
- Yusuf, M., & Hermawan, F. (2023). COMPARISON ANALYSIS OF EXISTING BRIDGE DESIGN BASED ON BMS 1992 AND SNI 1725-2016. *International Journal on Livable Space*, 8(2), 43–52.
- Zhao, R., Yuan, Y., Wei, X., Shen, R., Zheng, K., Qian, Y., Pu, Q., Zhang, Q., Liao, H., & Li, X. (2020). Review of annual progress of bridge engineering in 2019. *Advances in Bridge Engineering*, 1, 1–57.
- Zinke, T., Hechler, O., & Rademacher, D. (2021). Holistic Life-Cycle Analysis of Bridge Solutions. *Ce/Papers*, 4(2–4), 2393–2402.



© 2024 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY SA) license (<https://creativecommons.org/licenses/by-sa/4.0/>).