International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 17s, 2025
https://www.theaspd.com/ijes.php

Improving The Flexural Strength Of Precast Concrete Lintels Through Sustainable Steel Reinforcement Configuration: An Experimental Study

Sarfo Mensah[1*], Collins Ameyaw[2], James Pabi Bampoh[3]

[1]Department of Construction Technology and Quantity Surveying, Kumasi Technical University, Kumasi, Ghana
[2]Department of Construction Technology and Quantity Surveying, Kumasi Technical University, Kumasi, Ghana
[3]Department of Construction Technology and Quantity Surveying, Kumasi Technical University, Kumasi, Ghana
sarfo.mensah@kstu.edu.gh; collins.ameyaw@kstu.edu.gh ; bampohjames.bj@gmail.com
*Corresponding Author: sarfo.mensah@kstu.edu.gh

Abstract— Concrete lintels are indispensable structural components in buildings. However, lintel construction has been plagued by structural failure and deformation, especially in construction industries in tropical regions, such as Ghana. The objective of this study is to examine the impact of varying the precast lintel reinforcement design configuration on its flexural strength. Experimental research was conducted to achieve this goal. Three different reinforcement design configurations were prepared to mold six precast concrete lintel specimens with dimensions of 1200 mm × 150 mm × 225 mm. Silt, slum, and flexural strength tests were conducted on the specimens. The triangular reinforcement design exhibited the highest load-bearing capacity. The maximum loads that the rectangular and square configurations could carry were relatively low. The introduction of a triangular reinforcement design for precast lintel, which has demonstrated superior load-bearing capacity in the practice of precast lintel construction, has multifaceted returns of improving structural integrity, introducing cost efficiency, and fulfilling sustainability requirements. Triangular design is a novel approach in the context of precast concrete lintels, offering a fresh perspective on reinforcement strategies that deviate from conventional methods. By potentially reducing the amount of material required for reinforcement while achieving higher strength, triangular design contributes to more sustainable construction practices. This aligns with global trends towards sustainability in engineering and construction.

Keywords— experimental research, flexural strength, precast lintel, reinforcement sectional design, steel reinforcement.

I. INTRODUCTION

Precast concrete lintels are widely used in construction, owing to their ease of installation and cost-effectiveness. However, their flexural strength is a limitation, particularly in high-stress applications [1]. Enhancing the flexural strength of precast concrete lintels is crucial to ensure the structural integrity and safety of buildings. This study employed an experimental approach to investigate the use of sustainable reinforcement configurations to improve the flexural strength of precast concrete lintels. One innovative approach explored in recent literature is the use of fiber-reinforced polymer materials to strengthen reinforced concrete structures [2]. These materials offer significant advantages over traditional steel reinforcements, such as corrosion resistance, high tensile strength, and light weight. Previous studies have demonstrated the effectiveness of fiber-reinforced plastics (FRP) retrofitting in improving the flexural capacity of reinforced concrete beams subjected to damage [3]. Additionally, the confinement effect provided by FRP tubes has been shown to enhance the flexural performance of posttensioned concrete-filled FRP tube beams. ([1]). However, in the Ghanaian construction industry, where this study was conducted, the use of mild steel reinforcement bars as the traditional type of reinforcement is prevalent ([4], [5]). There is little awareness of the use of non-traditional reinforcements such as FRP tubes or fiberglass in developing construction industries.

Previous studies examined the use of different types of non-traditional reinforcements to enhance the flexural strength of beams and lintels [1]. However, in regions where there is no awareness or adoption of non-traditional types of reinforcements, it is necessary to find a more sustainable way of configuring traditional steel reinforcements to improve the flexural strength of beams and lintels. Therefore, the objective of this study was to examine the impact of varying the precast lintel steel reinforcement design configuration on its flexural strength.

II. Literature Review

Recent research has focused on understanding the behavior of fiber-reinforced polymer-reinforced concrete structures [3]. These advanced polymer composites offer several advantages over traditional construction materials, such as corrosion resistance, high tensile strength, lightweight, and ease of workability. Reinforcement sustainability is gaining traction, with materials such as bamboo, fiber-reinforced plastics (FRP), and hybrid designs being tested. For example, bamboo-reinforced concrete lintels exhibit potential for eco-friendly applications, although their flexural performance is lower than that of their steel-reinforced counterparts ([6], [7]). Similarly, FRP sheets are effectively used to enhance the flexural capacity of corbel beam-column connections, offering high durability and corrosion resistance, particularly under dynamic loading conditions [8].

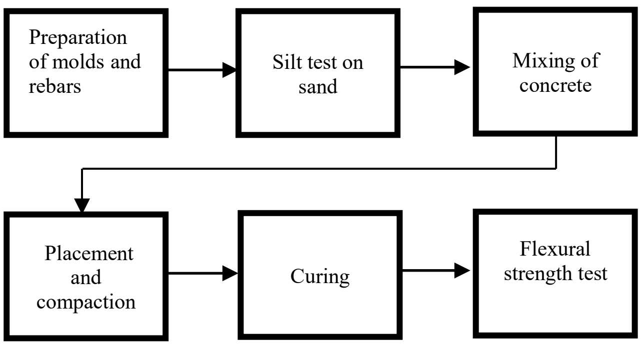
The use of reinforced in-situ and precast concrete lintels plays a major role in residential and commercial buildings in Ghana, where the construction industry is still developing [9]. Precast concrete is widely used because of its superior quality control, construction efficiency, and cost-effectiveness [10]. Reinforcement configurations significantly influence the structural performance of precast components, particularly in lintels, where flexural strength is critical for load bearing and durability [8].

In this study, researchers explored the use of mild steel reinforcement as a traditional approach to enhance the flexural strength of precast concrete lintels. This included investigating the optimal arrangement and quantity of steel reinforcement to maximize the flexural capacity of the lintels. Recognizing the potential of mild steel reinforcement, its application in improving the flexural performance of precast concrete lintels was also evaluated. In addition to the use of traditional mild steel reinforcements, their configurations are effective for enhancing the flexural strength of precast concrete lintels. Previous studies have demonstrated the potential of mechanical steel stitches, also known as the ‘crack locking system’, in strengthening reinforced concrete beams with shear deficiencies [11]. However, the effect of varying the design configuration on the flexural strength of horizontal reinforced concrete members has not been explored in previous studies. This is a primary measure for preventing the use of crack-locking systems in repairing crack failures in horizontal reinforced concrete members.

Precast Concrete and Reinforcement Configurations

Recent studies have examined the flexural implications of various shapes of beam reinforcement, including triangular and rectangular [6] and square [7]. Reinforcement has been explored for enhancing flexural and deformation behaviors owing to its unique stress distribution properties. Studies have demonstrated that beams with triangular reinforcement cages (TRC) exhibit reduced deflection and improved load-bearing capacities compared to conventional rectangular reinforcements. For instance, [6] observed that TRC beams exhibited up to 19.2% lower peak loads but 26.8% lower deflections, highlighting their potential for applications requiring higher ductility [12]. These recent studies focused on beams. This study focused on improving the flexural strength of lintels as structural members in buildings using a sustainable reinforcement design configuration.

III. Materials and Methods



International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 17s, 2025
https://www.theaspd.com/ijes.php

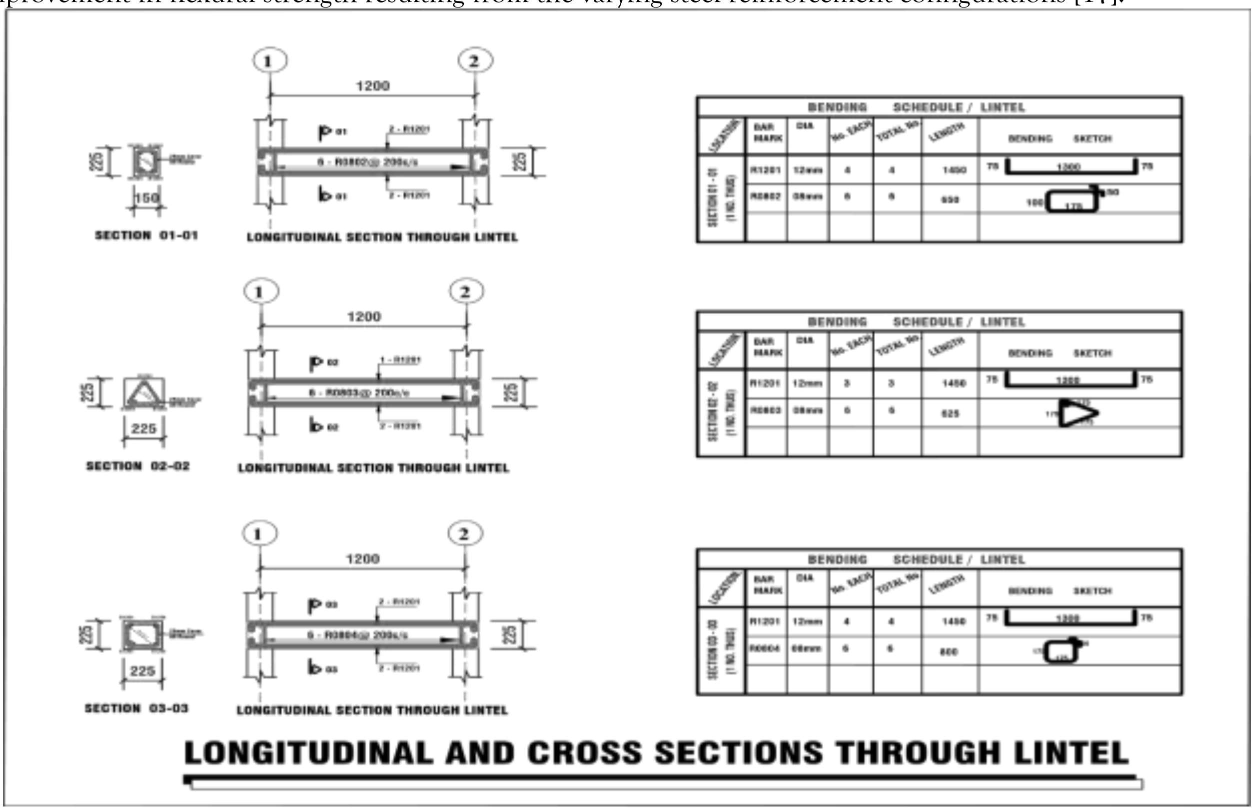
(Figure by authors)

Fig. 1: Experimental Procedure

This study aims to investigate the impact of various sustainable reinforcement configurations on the flexural strength of precast concrete lintels. An experimental research strategy was developed to simulate the resistance of lintels in different samples and assess the influence of key parameters, including the type and arrangement of the reinforcement, on the flexural behavior of the lintels. Following the computational analysis, an experimental program was designed to validate the findings and further explore the flexural performance of the precast concrete lintels. The experimental study involved testing a series of concrete lintels with different reinforcement configurations including triangular, rectangular, and square steel reinforcements. The experimental procedure is presented in Fig. 1 and is subsequently detailed.

Wooden molds were prepared according to the specified reinforcement design sections shown in Fig. 2. Reinforcement bars consisting of 12 mm and 8 mm diameter mild steel were cut into pieces. The main bars were cut to a length of 1100 mm, and the stirrups were spaced 200 mm c/c along the lintel length. The bars were fixed into molds measuring 1200 mm × 150 mm × 225 mm, serving as formworks. A silt test was conducted on the sand to ensure its suitability for concrete production. The sand and cement were mixed thoroughly in dry form to achieve a uniform color before the addition of coarse aggregates. The concrete mix was prepared at a ratio of 1:2:4 (cement: sand: coarse aggregates) with an appropriate amount of water to achieve the desired workability [13].

Before mixing the concrete constituents, the rebar sections were fixed into the molds, ensuring a 25 mm concrete cover. Fresh concrete was placed in the molds using a trowel to achieve a uniform surface [14]. It was then compacted thoroughly to avoid segregation and to remove entrapped air or voids, ensuring the compressive strength of the concrete [15]. After casting and removing the molds, the specimens were stored and cured for 7 or 28 days before conducting the flexural strength test [16]. A flexural strength test was performed experimentally on the cured specimens to evaluate the improvement in flexural strength resulting from the varying steel reinforcement configurations [17].



(Figure by author)

Fig. 2: Sectional design drawings of the three reinforcement configuration types

. Tools and Equipment

The tools and equipment used for mixing included a claw hammer, shovel, spade, trowel, nail, spirit level, float, and a construction pan. All the materials, including sand, cement, coarse aggregates, and water, were batched by volume using a construction pan on a level platform.

IV. RESULTS

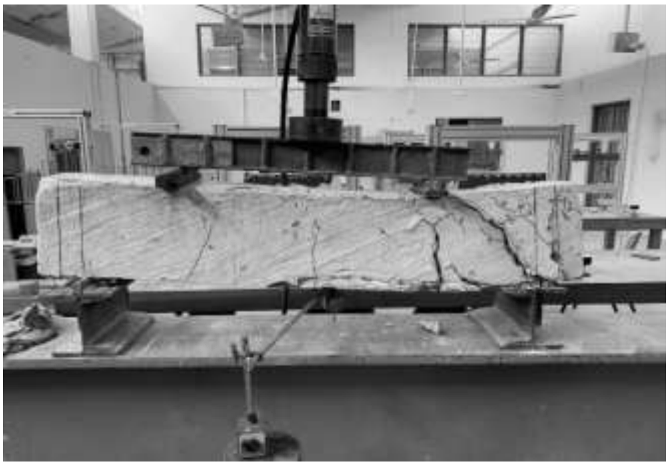
The purpose of the experiment was to determine the optimum steel reinforcement configuration that enhances the flexural performance of lintels [11]. The objective was to evaluate the effect of varying the steel reinforcement design configurations on the flexural strength of precast concrete lintels. The lintel-breaking testing machine conformed to the requirements of Sections 16, 17, and 18 of ASTM-E4 [18].

TABLE I:
DETERMINATION OF SILT (OBSERVATION SHEET)

S/N	DESCRIPTION	VALUE
1	Volume of sample (V_1)ml	7.8ml
2	Volume of silt (V_2) ml	142.2ml
3	Percentage of Silt V_1/V_2*100	5.48ml

(Table by author)

The results of silt tests are presented in Table I. Results obtained from the laboratory tests provide valuable insights into the performance of different reinforcement configurations under flexural loading.



(Picture by author)

Plate 1: Performance of the flexural strength test by means of gage-equipped hydraulic jack

TABLE II: MAXIMUM LOADS AT FRACTURE

Identification mark	Curing days	Max load in Ton*	Max load in *N	Effective length	Average width at fracture	Average depth at fracture
R1	7	13.00	127,400	1200mm	150mm	225mm
R2	28	21.64	212,072	1200mm	150mm	225mm

T1	7	18.00	176,400	1200mm	150mm	225mm
T2	28	26.97	261,562	1200mm	150mm	225mm
S1	7	14	137,200	1200mm	150mm	225mm
S2	28	23.2	227,360	1200mm	150mm	225mm
***1 Ton = 9800N**						

(Table by authors)

TABLE III OBTAINED MODULI OF RAPTURE

Identification mark	Modulus of rupture	Curing days
R1	30.19 N/mm^2	7
R2	50.26 N/mm^2	28
S1	32.5 N/mm^2	7
S2	53.8 N/mm^2	28
T1	41.83 N/mm^2	7
T2	61.99 N/mm^2	28

(Table by authors)

Determination of Modulus of Rapture (R)

The modulus of rupture (R) for each specimen was calculated using the following formula:

$$R = \frac{3PL}{2bd^2}$$

Where:

P is the maximum applied load (measured in N).
L is the effective span length (mm).
b is the average width of the specimen (mm).
d is the average depth of the specimen (mm).

The specimens were labelled R1, R2, S1, S2, T1, and T2, which represent rectangular sections 1 and 2, square sections 1 and 2, and triangular sections 1 and 2, respectively. After the laboratory tests, the maximum loads at which fractures occurred were recorded to determine the corresponding moduli of rupture. Tables II and III present the results.

V. ANALYSIS OF RESULTS

Effect of Curing Time: The results indicate a significant increase in the modulus of rupture with increasing curing time. For instance, the modulus of rupture for the rectangular section (R1) increased from 30.19 N/mm^2 at 7 days to 50.26 N/mm^2 at 28 days. This trend was consistent across all specimen types, highlighting the importance of adequate curing for enhancing the flexural strength of concrete.

Comparison of Reinforcement Configurations: Among the different reinforcement configurations, the triangular section (T2) exhibited the highest modulus of rupture (61.99 N/mm^2) after 28 days of curing. This suggests that the triangular reinforcement configuration provides superior flexural strength compared with the rectangular and square configurations. The rectangular section (R2) and square section (S2) also showed significant improvements in flexural strength, with values of 50.26 N/mm^2 and 53.8 N/mm^2, respectively, after 28 days.

Failure Modes: The common aspect of the failure modes observed in all specimens was the occurrence of fracture at the maximum load. This indicates that the specimens could sustain the applied loads up to their respective maximum capacities before failure, demonstrating the effectiveness of the reinforcement configurations in enhancing the flexural strength of the concrete lintels.

VI. Discussion of Results

The findings of this study align with existing literature on the flexural strength of precast concrete lintels. According to the National Concrete Masonry Association (NCMA), precast reinforced concrete member design must consider the flexural strength, shear strength, and deflection to ensure structural integrity [19]. Furthermore, the results support the recommendations of the Building Code Requirements for Structural Concrete (American Concrete Institute (ACI) 318), which emphasizes the importance of adequate reinforcement and curing in achieving the desired flexural strength [20]. The observed increase in the modulus of rupture with longer curing times was consistent with the principles outlined in the ACI 318 code, which advocates proper curing to enhance the mechanical properties of concrete.

Therefore, using precast lintels, a reinforced concrete member that has undergone extensive experimental research in previous studies, demonstrates that varying reinforcement configurations and curing durations significantly influence flexural performance. This experimental study provides valuable insights into the effects of varying steel reinforcement design configurations on the flexural strength of precast concrete lintels. The findings highlight the importance of adequate curing and the selection of appropriate reinforcement configurations to achieve optimal flexural performance.

Comparative Performance of Reinforcement Shapes

Recent experiments have confirmed the advantages of triangular design. Triangular-reinforced lintels generally outperform their square and rectangular counterparts in terms of load-bearing capacity and crack resistance, particularly during the early curing stages. Shen et al. [21] emphasized that optimized link spacing enhances the performance of TRC configurations. These previous findings align with this study, indicating a triangular reinforcement's capacity to sustain higher loads during the 7th and 28th-day curing periods compared to rectangular and square configurations [22].

Beyond confirming the established principles, this study provides new insights into the comparative effectiveness of various reinforcement configurations. The success of the triangular reinforcement design, which exhibited the highest modulus of rupture, suggests that alternative reinforcement strategies can optimize material efficiency and structural performance. These findings have practical implications for improving construction techniques, reducing material waste, and enhancing the durability of concrete lintels. This efficiency can be particularly beneficial in large-scale projects where material costs constitute a significant portion of the budget. The use of sustainable reinforcement configurations aligns with the growing emphasis on environmentally friendly construction practices [13]. This approach can reduce waste and promote the use of materials with lower environmental impact. The significant increase in flexural strength with longer curing times highlights the necessity of proper curing practices. Ensuring that concrete elements are adequately cured can enhance their mechanical properties, leading to more durable and reliable structures. This improved flexural strength contributes to the overall safety and longevity of the concrete structures. By minimizing the risk of sudden brittle failure and enhancing the resistance to external forces such as wind and load stress, structures can maintain their integrity over longer periods.

VII. Conclusion

This experimental study provides valuable insights into optimizing steel reinforcement configurations to enhance the flexural strength of precast concrete lintels. The findings demonstrate that variations in the reinforcement design significantly influence the structural performance, with the triangular reinforcement achieving the highest modulus of rupture. By carefully selecting reinforcement configurations, construction professionals can improve material efficiency, reduce structural failures, and lower long-term maintenance costs.

Beyond structural benefits, optimizing reinforcement design offers economic advantages, making construction more cost-effective and improving housing affordability. More efficient reinforcement strategies can lead to lower material usage without compromising safety, thereby supporting more sustainable building practices. These insights can also be applied to other structural elements subjected to bending stresses such as beams, slabs, and pavements. Understanding the flexural strength of these elements is crucial for designing structures that can withstand loads encountered in service.

The success of the triangular reinforcement configuration highlights the potential for further advancements in reinforcement design. The integration of triangular reinforcements with sustainable materials offers a promising pathway for optimizing the structural and environmental performances of precast components. By continuing to refine the reinforcement techniques, the construction industry can develop safer, more efficient, and more sustainable building solutions.

Future research should focus on the long-term durability of different reinforcement configurations under various environmental conditions as well as the integration of emerging materials to further enhance structural resilience. Future research should further explore the interaction between reinforcement configurations and innovative materials to maximize flexural efficiency while reducing environmental impact. This study provides a foundation for future research on the long-term performances and durabilities of different reinforcement configurations under various environmental conditions. This is expected to lead to the development of advanced and resilient construction materials and techniques.

REFERENCES

[1] Ahmed, A. A., Hassan, M., and Masmoudi, R. "Effect of concrete strength and tube thickness on the flexural behavior of prestressed rectangular concrete-filled FRP tubes beams", Engineering Structures, 205, 110112, (2020a). https://doi.org/10.1016/j.engstruct.2019.110112

[2] Ahmed, H. Q., Jaf, D. K., and Yaseen, S. A., "Flexural strength and failure of geopolymer concrete beams reinforced with carbon fibre-reinforced polymer bars" Construction and Building Materials, 231, 117185, (2020b).. https://doi.org/10.1016/j.conbuildmat.2019.117185

[3] Pradana, A. W., and Oesman, M., "Flexural Strengthening Reinforced Concrete Beams Subjected to Flexural Damage with CFRP", In 2nd International Seminar of Science and Applied Technology (ISSAT 2021) (pp. 130-136), (November 2021). Atlantis Press. https://doi.org/10.2991/aer.k.211106.021

[4] Ametepey, S. O., Akorli, K. S., Ansah, S. K., Aigbavboa, C., and Frempong-Jnr, E. Y, "Investigating the standard sizes of steel reinforcement used in the Ghanaian industry", Materials Today: Proceedings, 93, 447-452, (2023). https://doi.org/10.1016/j.matpr.2023.08.070

[5] Assiamah, S., Kankam, C. K., Banini, E. K., and Appiah, K. A., "Physical and Geometrical Characteristics of Reinforcing Steel Bars in the Construction Industry of Ghana". Journal of Materials Science Research and Reviews 6 (1):40-53, (2023). https://journaljmsrr.com/index.php/JMSRR/article/view/227.

[6] Ekolu, S. O., Thomas, T., Lawrence, W., De Freitas, L., van Vuuren, I., and Solomon, F., "Effects of triangular reinforcing on flexural and deformation behaviour of concrete beams', Journal of Building Pathology and Rehabilitation, 9(2), 123 (2024). https://doi.org/10.1007/s41024-024-00475-7

[7] Li, S., Khieu, H. H., Black, J. R., Nguyen-Xuan, H., and Tran, P., "Two-scale 3D printed steel fiber reinforcements strategy for concrete structures', Construction and Building Materials, 458, 139626 (2025). https://doi.org/10.1016/j.conbuildmat.2024.139626

[8] Rahgozar, N., and Rahgozar, V., "Experimental and numerical investigation on flexural strengthening of precast concrete corbel connections with fiber-reinforced plastic sheet. Buildings, 14(2), 387, (2024). https://doi.org/10.3390/buildings14020387

[9] Asamoah, R. O., Ankrah, J. S., Offei-Nyarko, K., and Tutu, E. O,. "Cost Analysis of Precast and Cast-in-Place Concrete Construction for Selected Public Buildings in Ghana', Journal of Construction Engineering, 2016(1), 8785129, (2016). https://doi.org/10.1155/2016/8785129

[10] Parskiy, N. D., Molodtsov, M. V., and Molodtsova, V. E., "Cost effectiveness of precast reinforced concrete roof slabs" In IOP Conference Series: Materials Science and Engineering (Vol. 262, No. 1, p. 012036) IOP Publishing, (2017). https://doi.org/10.1088/1757-899X/262/1/012036

[11] Urbański, M., Lapko, A., and Garbacz, A., "Investigation on concrete beams reinforced with basalt rebars as an effective alternative of conventional R/C structures." Procedia Engineering, 57, 1183-1191, (2013).. https://doi.org/10.1016/j.proeng.2013.04.149

[12] Sathya, R., "Effects of triangular reinforcing on structural behavior of concrete beams", Research Square (2017).. https://doi.org/10.21203/rs.3.rs-4155604/v1

[13] Shakir, Q. M., and Alghazali, A. F., "Innovative friendly-environmental hybrid model of precast reinforced concrete deep beams based on curved hybridization", Innovative Infrastructure Solutions, 9(12), 463, (2024). https://doi.org/10.1007/s41062-024-01664-6
[14] Truong, G. T., Roh, Y.-S., Huynh, T.-C., and Dinh, N. H., "Estimating flexural strength of precast deck joints using Monte Carlo Model Averaging of non-fine-tuned machine learning models', Frontiers of Structural and Civil Engineering, 18, 1888–1907, (2024). https://doi.org/10.1007/s11709-024-1128-9
[15] Rochman, A., Setiawan, B., Handayani, N. K., and Witjaksono, A., "Flexural strength of segmental precast concrete slabs with grouting", AIP Conference Proceedings, 2838, 060033, (2024). https://doi.org/10.1063/5.0180454
[16] Williams Portal, N., Lohmeyer, R., and Wallbaum, H., "Sustainability of Reinforcement Alternatives for Concrete. Chalmers University of Technology". (2024). Available at: https://core.ac.uk/download/pdf/70607596.pdf (accessed February 10, 2025)
[17] Setiawan, B. and Handayani, N. K., "Flexural strength of segmental precast concrete slabs with grouting", AIP Conference Proceedings, 2838, 060033, (2024). https://doi.org/10.1063/5.0180454
[18] ASTM [American Society for Testing and Materials] International, "Standard Practices for Force Verification of Testing Machines", ASTM E 4-23, Sections 16, 17, and 18, ASTM International, West Conshohocken, PA, (2023).
[19] NCMA [National Concrete Masonry Association], "Precast Lintels For Concrete Masonry Construction", Fendt precast concrete masonry lintels, (n. d.) Available at: precast_concrete_masonry_lintels.pdf (accessed March 14, 2025)
[20] ACI Committee, "Building code requirements for structural concrete (ACI 318-08) and commentary", American Concrete Institute, (2008).
[21] Shen, L., Li, Y., Zhao, H., Wang, J., and Xu, S., "Residual flexural behaviour of RC beams strengthened with TRC after ISO 834 exposure", Construction and Building Materials, 416, 135152, (2024). https://doi.org/10.1016/j.conbuildmat.2024.135152
[22] Ambroziak, A., and Ziolkowski, P., "Concrete compressive strength under changing environmental conditions during placement processes", Materials, 13(20), 4577, (2020). https://doi.org/10.3390/ma13204577

CONFLICT OF INTEREST STATEMENT

THE AUTHORS HAVE NO CONFLICT OF INTEREST TO DECLARE.