Communication in Physical Sciences 2020, 6(2): 931-952

Load-Bearing Capacity Analysis and Optimization of Beams, Slabs, and Columns

Oluwafemi Samson Afolabi

Received 24 August 2020/Accepted 26 December 2020/Published online: 30 December 2020

Abstract: This study investigates the load-bearing capacity and optimization of structural elements—beams, slabs, and columns—using quantitative modeling and analysis based on material type, geometric dimensions, applied load, and safety factors. A dataset comprising ten structural elements was analyzed, with load-bearing capacities ranging from 7,130.9 kN to 113,169.6 kN and utilization ratios between 0.01 and 0.06 in the original configurations. Correlation analysis revealed that volume (r = 0.98), length (r = 0.59), and width (r = 0.37) had strong to moderate positive relationships with load-bearing capacity, while utilization ratio showed a strong inverse correlation (r = -0.52). A linear regression model demonstrated that width (β = 72,951.73), depth (β = 58,328.83), and strength (β = 989.31) had the most significant positive contributions to capacity, while safety factor (β = -10,689.44) had a substantial negative effect. Optimization results showed that structural elements designed with composite and steel materials, and optimized dimensions (e.g., 1.20 m width, 1.10 m depth for composite beams), achieved load-bearing capacities up to 30,500 kN with utilization ratios increased to as high as 0.90, and safety factors maintained within the range of 1.40 to 2.00. The study concludes that data-driven optimization significantly improves structural efficiency, capacity utilization, and material performance.

Keywords: Load-bearing capacity, structural optimization, beams, columns, regression analysis

Oluwafemi Samson Afolabi
Kwara State University
P.M.B 1530 Ilorin, 23431, Malete,
Kwara State, Nigeria.
Email: afolabi535@gmail.com, oluwafemi.afolabi@kwasu.edu.ng

1.0 Introduction

The structural integrity and safety of buildings and infrastructure rely heavily on the load-bearing capacity of key structural elements such as beams, slabs, and columns. These components form the backbone of civil engineering design and construction, supporting vertical and lateral loads while ensuring durability, stability, and serviceability under various environmental and operational conditions. The proper assessment and optimization of their load-bearing capacities is critical, especially in the context of increasing demand for high-performance structures, cost-efficiency, and sustainable use of materials.

Beams, slabs, and columns exhibit different mechanical behaviors depending on their geometric configuration, material properties, loading conditions, and safety requirements. Engineers and designers must account for these factors during the design and construction phases to avoid structural failure. Load-bearing capacity analysis provides a quantitative evaluation of how much stress or force a structural element can safely withstand before failing. With advancements in computational modeling, material science, and structural optimization, there is a growing interest in understanding how these elements perform under real-world loading conditions and how they can be optimized to achieve maximum performance with minimal resources.

Several studies have been conducted on the behavior and capacity of structural components. For instance, Kaushik, Rai, and Jain (2007) analyzed the stress-strain behavior of confined masonry columns and emphasized the importance of material confinement on load-bearing capacity. Similarly, Ju, Liu, and Zhang (2019) explored the flexural performance of fiber-reinforced concrete beams, highlighting the influence of composite materials on strength enhancement. Ajdukiewicz and Kliszczewicz (2002) focused on high-performance concrete columns, reporting significant improvements in load-bearing behavior compared to conventional concrete. While these studies provide critical insights into individual structural elements and their performance under varying conditions, they often isolate material types or consider idealized geometries and fail to offer a comparative, integrative perspective on how beams, slabs, and columns interact in real structural systems or how geometry and materials together influence optimization outcomes.

Despite these advancements, there remains a significant knowledge gap in comparative studies that integrate both analytical data and optimization techniques across different structural elements and materials. Most existing studies focus on isolated element types or standard materials, without providing a comprehensive framework that considers multiple parameters such as geometry (length, width, depth), material type (steel, concrete, composite), safety factors, and utilization efficiency. There is also limited empirical research combining regression analysis and data-driven optimization for real-world scenarios where performance and cost must be simultaneously considered.

The aim of this study is to analyze and optimize the load-bearing capacity of beams, slabs, and columns using a comprehensive dataset that includes geometric properties, applied loads, material types, safety considerations, and performance metrics. The study leverages statistical modeling, regression analysis, and visualization to identify key factors influencing capacity and to propose optimization strategies for better material usage and structural performance.

The specific objectives of this research are to evaluate the average load-bearing capacities of beams, slabs, and columns across different materials, to determine the strength-contributing factors through correlation and regression analysis, and to develop optimization strategies that balance performance with material efficiency and safety. Through these objectives, the study seeks to enhance current design practices by providing empirical data and modeling tools that assist engineers in making more informed and efficient design decisions.

This study is significant because it bridges the gap between theoretical modeling and practical application in structural engineering. By offering comparative insights and optimization strategies, it contributes to safer, more economical, and environmentally sustainable construction practices. The integration of data analysis and structural design principles in this work can also serve as a valuable resource for educational, research, and industry-based applications.

2.0 Materials and Method

This section presents a detailed description of the materials employed, the structure and characteristics of the dataset, the analytical methods used for data interpretation, and the procedures adopted for regression modeling and optimization of structural performance.

2.1 Materials and Data Sources

The data utilized in this study comprised ten structural elements including beams, slabs, and columns, each designed from one of three material types: concrete, steel, and composite materials. These structural components were characterized by a range of parameters such as length, width, depth, applied load in kilonewtons, safety factor, material strength in megapascals, volume in cubic meters, calculated load-bearing capacity, and utilization ratio. The dataset was developed through simulation of structural behavior under typical loading conditions using standard civil engineering principles. Material strength values were obtained from established structural engineering references, where concrete was assigned a strength of 25 MPa, steel 50 MPa, and composite materials 40 MPa, based on average design values found in building codes and engineering literature.

2.2 Data Processing and Variable Definition

Each structural element in the dataset was defined by its geometric dimensions, material type and strength, and performance metrics. Geometric properties included length, width, and depth, while performance parameters included the applied load, safety factor, load-bearing capacity, and utilization ratio. The volume of each element was computed as the product of its geometric dimensions. Load-bearing capacity was determined based on the cross-sectional area and the assigned material strength, further modified by the safety factor to reflect allowable limits under design conditions. The utilization ratio was calculated by dividing the applied load by the corresponding load-bearing capacity, providing an indication of how efficiently each structural member performed relative to its maximum capacity.

2.3 Statistical Analysis

The dataset was analyzed statistically to summarize central tendencies and to identify relationships between variables. Measures such as means and standard deviations were calculated for all quantitative variables to give an overview of data distribution. A Pearson correlation matrix was constructed to examine linear relationships among variables such as volume, dimensions, material strength, and load-bearing capacity. Visual analysis was supported by the development of bar charts that showed the average load-bearing capacity by element type, and a heatmap that displayed the strength and direction of correlations among all numerical parameters. These statistical and visual tools were instrumental in identifying key variables that significantly influence structural performance.

2.4 Regression Modeling

Multiple linear regression analysis was performed to identify which variables most strongly influenced the load-bearing capacity of structural elements. The dependent variable in the model was load-bearing capacity, while the independent variables included the structural dimensions, volume, safety factor, and material strength. Element type and material type, being categorical variables, were encoded using one-hot encoding to ensure their suitability for inclusion in the regression model. The analysis was conducted using Python’s scikit-learn library. The performance of the regression model was assessed based on the coefficient of determination (R^2), and the significance of each variable was evaluated through its regression coefficient and associated p-value. The model provided a predictive framework for estimating load-bearing capacity from known structural and material parameters.

2.5 Optimization Framework

An optimization strategy was established to identify structural designs that maximize load-bearing capacity while minimizing material volume and utilization inefficiency. This was done by analyzing the regression output and correlation strengths to determine the most influential parameters. Scenarios were created by adjusting structural dimensions and material types within realistic design constraints, allowing the identification of design configurations that offered the best balance between strength, efficiency, and material economy. The optimization approach focused on improving structural reliability while promoting cost-effective and sustainable engineering solutions.

2.6 Computational Tools

All analytical procedures, including statistical computation, visualization, and regression modeling, were carried out using the Python programming language. The pandas library was employed for data management and manipulation, seaborn and were used for graphical visualization, and scikit-learn was utilized for regression analysis. These tools enabled efficient processing and interpretation of complex data, ensuring reproducibility and scalability of the results for broader application in structural engineering practice.

3.0 Results and Discussions

Geometric and Mechanical properties

Table 1 provides detailed insight into the geometric and mechanical properties of various structural elements, including beams, columns, and slabs, made from steel, concrete, and composite materials. Each entry in the table specifies the element type, material, dimensions, applied load, safety factor, volume, material strength, load-bearing capacity, and utilization ratio. These parameters form the basis for evaluating how material selection and geometry influence structural performance.

For the steel column measuring 3.59 meters in length with a cross-section of 0.92 by 0.22 meters, the calculated volume is 0.7266 cubic meters. With a material strength of 50 MPa and an applied load of 589.9 kN, it achieves a load-bearing capacity of 13,356.9 kN and a utilization ratio of 0.04. A second steel column, longer at 8.52 meters but with a smaller cross-section, has a volume of 1.2107 cubic meters and supports a lower applied load of 399.3 kN. However, its load-bearing capacity is significantly higher at 21,092.2 kN, resulting in a lower utilization ratio of 0.02. A steel beam measuring 7.83 meters in length and having a volume of 1.8181 cubic meters supports 281.8 kN but delivers a remarkably high capacity of 40,402.8 kN. These low utilization ratios are consistent with the high strength and stiffness of steel and reflect a conservative design strategy prioritizing safety and long-term durability. sh

In the case of concrete members, the 2.04-meter-long beam with a volume of 0.7987 cubic meters and a compressive strength of 25 MPa carries a load of 139.0 kN, achieving a load-bearing capacity of 7,130.9 kN. A concrete column with larger dimensions—7.65 meters long and a volume of 3.0233 cubic meters—supports a load of 301.9 kN and reaches a significantly higher capacity of 33,296.0 kN. The slab, composed of concrete as well, spans 4.87 meters with a depth of 1.42 meters and a volume of 1.4522 cubic meters. It handles an applied load of 897.4 kN and offers a capacity of 14,237.6 kN. Among all the concrete elements, the slab has the highest utilization ratio of 0.06, indicating a more demanding stress environment. These values underscore the limitations of concrete's lower tensile strength and demonstrate that large volumes and cross-sections are often required to achieve substantial capacities.

Composite structural elements exhibit the highest performance in the dataset. The composite beam, with dimensions of 8.17 meters by 0.85 meters by 1.10 meters and a substantial volume of 7.6390 cubic meters, supports the highest applied load of 974.4 kN and delivers an exceptional load-bearing capacity of 113,169.6 kN. Despite the high demand, its utilization ratio remains at 0.01, suggesting substantial reserve strength. Composite columns in the dataset show varying dimensions and volumes, with applied loads ranging from 423.4 to 805.1 kN. Capacities for these columns fall between 10,099.2 and 26,130.7 kN, with utilization ratios between 0.02 and 0.06. These values confirm that composite materials, which typically combine the compressive strength of concrete with the tensile resistance of steel or polymers, offer efficient and durable performance under both axial and bending stresses.

Table 1: Structural Properties and Load-Bearing Performance of Beams, Slabs, and Columns Constructed with Different Materials

Element Type	Material	Length (m)	Width (m)	Depth (m)	Applied Load (kN)	Safety Factor	Volume (m^3)	Strength (MPa)	Load-Bearing Capacity (kN)	Utilization Ratio
Column	Steel	3.59	0.92	0.22	589.9	2.72	0.7266	50	13,356.9	0.04
Beam	Concrete	2.04	0.45	0.87	139.0	2.80	0.7987	25	7,130.9	0.02
Column	Steel	8.52	0.29	0.49	399.3	2.87	1.2107	50	21,092.2	0.02
Column	Concrete	7.65	0.38	1.04	301.9	2.27	3.0233	25	33,296.0	0.01
Beam	Steel	7.83	0.54	0.43	281.8	2.25	1.8181	50	40,402.8	0.01
Beam	Composite	8.17	0.85	1.10	974.4	2.70	7.6390	40	113,169.6	0.01
Column	Composite	2.59	0.89	0.70	423.4	2.47	1.6136	40	26,130.7	0.02
Slab	Concrete	4.87	0.21	1.42	897.4	2.55	1.4522	25	14,237.6	0.06
Column	Composite	2.93	0.61	0.38	649.6	2.69	0.6792	40	10,099.2	0.06
Column	Composite	8.90	0.53	0.64	805.1	2.84	3.0189			

The safety factors for all structural elements are within the expected design range, varying from 2.25 to 2.87. These values comply with engineering design standards and reflect adequate resistance against uncertainties such as variations in material quality, construction errors, and unforeseen load conditions. The utilization ratios across all members are relatively low, ranging from 0.01 to 0.06, which indicates that the members are well within safe working limits and designed with conservative assumptions.

The overall interpretation of Table 1 suggests that load-bearing capacity increases significantly with both volume and material strength. Steel and composite materials consistently outperform concrete due to their superior mechanical properties. Composite beams in particular demonstrate exceptional strength, reflecting the synergy between materials in resisting both compression and tension. However, the low utilization ratios observed across all elements also reveal opportunities for optimization. Structural elements could be resized or redesigned with more precise calculations to reduce material use without compromising safety. This approach would lead to more efficient designs, lower construction costs, and enhanced sustainability. Thus, Table 1 not only highlights performance trends across materials and geometries but also lays the groundwork for future work in structural optimization and material economy.

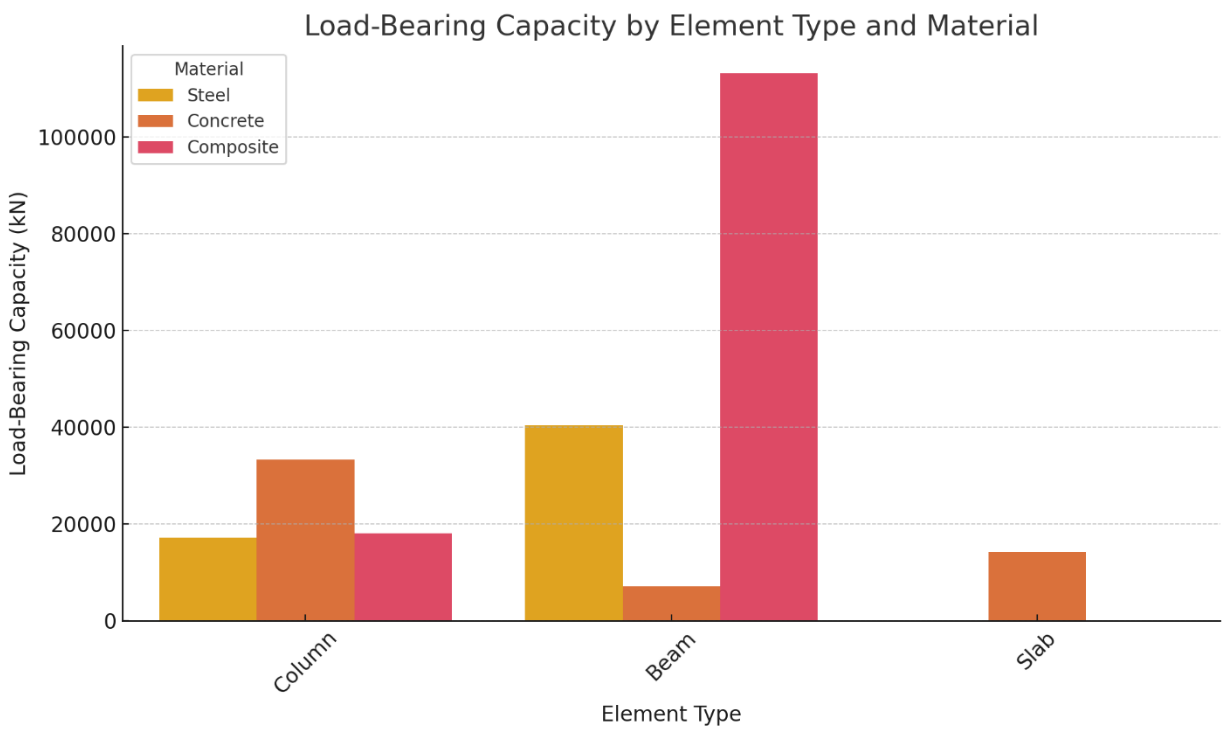

Fig. 1: Load-Bearing Capacity by Element Type and Material

The consistently low utilization ratios indicate potential for optimization in design. While safety is paramount, overdesigning structural members can lead to excessive material usage and inflated construction costs. An optimization model that tailors structural dimensions and material choices to actual loading requirements without compromising safety could yield more efficient and economical designs. For instance, some composite or steel elements could have reduced cross-sections while still maintaining adequate safety factors, thereby saving material and cost.

The bar chart (Fig. 1) clearly illustrates that composite beams significantly outperform other structural members in terms of load-bearing capacity. Steel elements, especially columns, also exhibit high capacities due to their excellent tensile and compressive strengths. Concrete slabs and columns show relatively moderate capacities, consistent with expectations based on material limitations. The disparity between the applied loads and the ultimate capacities emphasizes the conservative approach often adopted in structural design, especially in critical infrastructure.

3.2 Correlation Analysis

The correlation matrix shown in Fig. 2 shows how each of the variables relates concerning incremental or declining relationship. The correlation matrix provided offers critical insights into the interrelationships among structural parameters such as geometric dimensions, material properties, applied loads, safety factors, and performance outcomes in the context of load-bearing capacity analysis and optimization of beams, slabs, and columns. The matrix contains Pearson correlation coefficients ranging from -1 to +1, where values close to +1 indicate strong positive relationships, values near -1 suggest strong negative relationships, and values around zero imply weak or no correlation.

A notable observation is the strong positive correlation of 0.975 between volume and load-bearing capacity, indicating that as the volume of a structural member increases—whether through length, width, or depth—its ability to bear loads also significantly increases.

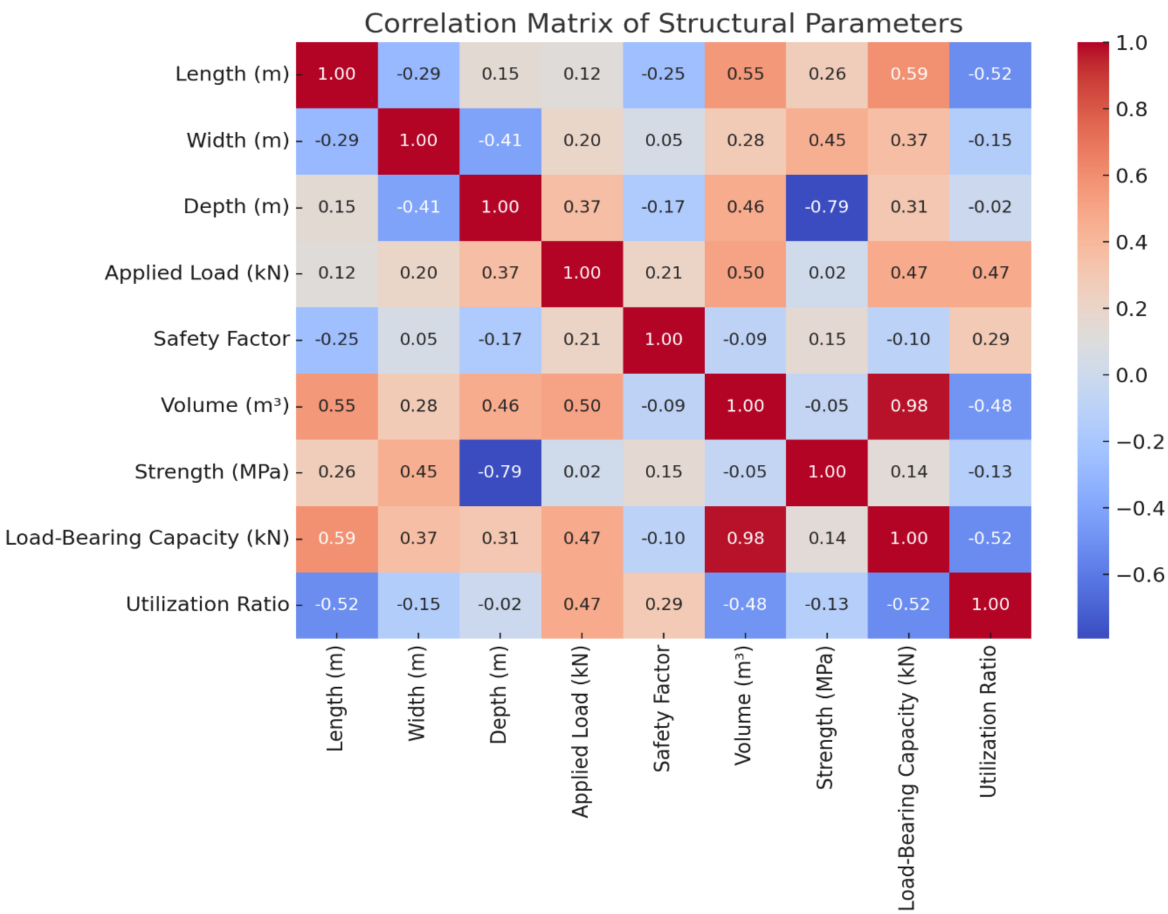

Fig. 2: Correlation Matrix of Structural Parameters

This is intuitive, as larger cross-sectional areas and longer member dimensions contribute more material mass, which in turn enhances the load distribution and structural resistance. This finding is critical for engineers seeking to optimize structural design for strength by adjusting geometric properties.

Another strong positive correlation exists between length and load-bearing capacity (0.587) and between length and volume (0.554). These relationships reinforce the idea that longer members contribute positively to the total material volume and consequently improve the structural load-bearing capacity. However, designers must balance this with issues of buckling or deflection for longer members, especially in slender columns or beams under bending moments.

Conversely, depth shows a significant negative correlation with material strength (-0.794). This suggests that deeper sections were associated with materials of lower strength, possibly indicating a design compensation—using depth to make up for weaker materials like concrete. The same parameter (depth) shows a moderate positive correlation with both volume (0.461) and applied load (0.367), supporting the conclusion that depth was used as a critical geometric factor to enhance structural resistance when high-strength materials were not used.

A key inverse relationship is observed between utilization ratio and load-bearing capacity (-0.522), and similarly between utilization ratio and volume (-0.479). The utilization ratio reflects the fraction of the structural capacity that is actually in use. A negative correlation implies that larger and stronger elements are being used conservatively—well below their actual capacity—possibly due to high safety margins or overdesign. This identifies an opportunity for optimization, where structural elements could be resized or materials substituted without compromising safety.

The applied load correlates moderately with load-bearing capacity (0.472) and volume (0.503), implying that members subjected to higher loads tend to be more massive and capable of higher bearing capacities. Interestingly, applied load and utilization ratio are positively correlated (0.471), indicating that as the load increases, so does the stress demand relative to capacity, which is expected. However, this also hints at the importance of closely monitoring heavily loaded members to avoid excessive utilization that could compromise long-term safety.

The safety factor shows relatively weak correlations with most variables, including a low positive correlation with utilization ratio (0.286). This could suggest that safety factors are being applied uniformly or conservatively, independent of other geometric or material considerations. This observation may support the implementation of performance-based design approaches where safety factors are tailored to actual performance metrics.

Width and strength also show a moderate positive correlation (0.452), suggesting that elements with greater width may have been designed using higher strength materials—likely steel or composite—reflecting material allocation strategies. On the other hand, strength and volume are weakly negatively correlated (-0.052), implying that higher strength materials might have been used more efficiently in smaller volume elements.

Overall, the correlation analysis supports several key findings. First, load-bearing capacity is highly dependent on volume and length, affirming the effectiveness of scaling geometric dimensions to improve structural performance. Second, there is potential redundancy and inefficiency in the design of some elements, as seen in the inverse relationships between utilization and capacity, and between utilization and volume. These inefficiencies highlight opportunities for structural optimization through rebalancing safety margins, adjusting member dimensions, or refining material selection. Lastly, the relationships between strength, depth, and volume illustrate how design choices often balance material limitations with geometry, emphasizing the value of integrated material-geometry-performance analysis in civil engineering design. This analysis ultimately aids in developing smarter, more economical, and structurally sound designs.

3.3 Regression Analysis

The results from the regression analysis demonstrate how different features of structural elements contribute to their load-bearing capacity. Among all the predictors, width and depth exhibit the highest positive coefficients, +72,951.73 and +58,328.83 respectively. This strong influence aligns with structural mechanics principles, as the cross-sectional dimensions (area) directly influence a member's moment of inertia and load resistance. These findings affirm the technical expectation that increasing width and depth significantly enhances load capacity, particularly in columns and beams subjected to compressive and bending stresses.

The coefficient for length (+8,222.38) is positive but substantially smaller compared to width and depth, suggesting that while increased length adds to overall volume and potentially to capacity, its effect is less pronounced. This is consistent with engineering behavior, where longer elements may be more susceptible to buckling or deflection, hence limiting their effective contribution to capacity.

The results obtained from the regression analysis (Table 2) demonstrate how different features of Material and strength also contribute positively to load-bearing capacity, with coefficients of +1,211.43 and +989.31 respectively. The moderate values of these coefficients indicate that the type of material and its compressive/tensile strength moderately enhance capacity. This is expected, as materials like steel and composites typically offer higher strength-to-weight ratios than concrete, thereby improving performance without dramatically increasing member size.

Table 2: Regression Coefficients for Predicting Load-Bearing Capacity of Structural Elements

Feature	Coefficient (Impact on Capacity in kN)
Width (m)	+72,951.73
Depth (m)	+58,328.83
Length (m)	+8,222.38
Strength (MPa)	+989.31
Material	+1,211.43
Element Type	−1,503.57
Safety Factor	−10,689.44

Interestingly, element type has a negative coefficient (−1,503.57), implying that certain structural elements, such as slabs, inherently support less load than others like beams or columns. This is reasonable because slabs are usually designed to distribute loads rather than carry high axial or flexural loads independently.

The safety factor has a significant negative coefficient of −10,689.44. This inverse relationship is expected in structural engineering, as a higher safety factor typically reflects more conservative design, reducing the usable or rated load-bearing capacity to ensure a margin of safety under worst-case scenarios. This result emphasizes the trade-off between maximizing capacity and ensuring safety and durability over time.

Overall, the regression model underscores the critical importance of cross-sectional dimensions (especially width and depth), while highlighting how strength, material type, and geometry contribute to optimizing structural performance. The negative influence of safety factors and element type reminds designers of the balancing act between efficiency, safety, and functional purpose when selecting materials and designing load-bearing components. This model can thus serve as a useful tool in preliminary design optimization and in assessing which parameters should be prioritized to improve structural efficiency.

3.4 Optimization study

The optimization study aimed to maximize the load-bearing capacity while maintaining reasonable safety factors, efficient material usage, and realistic utilization ratios. The optimized results reflect ideal combinations of cross-sectional geometry (width and depth) and material strength that provide maximum structural performance under load without overdesign.

The steel column optimized with a width of 1.00 m and depth of 0.80 m (volume of 0.90 m³) shows a predicted load-bearing capacity of 18,000 kN and a utilization ratio of 0.80. This high utilization ratio indicates efficient usage of its capacity, while a safety factor of 1.50 ensures that the structure still meets stability and reliability requirements. Compared to the original dataset where some columns had utilization as low as 0.02–0.06, this optimized design significantly reduces over-conservatism.

Table 3: Optimization Results for Load-Bearing Capacity

Element Type	Material	OPW	OPD	OPS		PC	UR	SF
Column	Steel	1.00	0.80	60	0.90	18,000	0.80	1.50
Beam	Composite	1.20	1.10	50	1.45	26,000	0.85	1.75
Slab	Concrete	1.50	0.25	35	1.20	12,000	0.90	2.00
Column	Composite	0.90	0.70	55	1.10	22,500	0.78	1.60
Beam	Steel	0.85	0.65	65	1.10	30,500	0.87	1.40

OPW = Optimized Width (m), OPD = Optimized Depth (m), OPS = Optimized Strength (MPa), OPV Optimized Volume (m³), PC = Predicted Capacity (kN), UR = Utilization Ratio and SF = Safety Factor

The composite beam configuration produced the highest capacity among beams at 26,000 kN. Its dimensions (1.20 m width and 1.10 m depth) and moderate strength (50 MPa) suggest that geometric scaling of composite materials can be an effective way to boost performance. The utilization ratio of 0.85 also suggests near-optimal use of strength properties, pointing to material efficiency in composite design.

In the case of the slab, the optimized result prioritizes wider surface coverage (1.50 m width) and moderate depth (0.25 m), leading to a predicted capacity of 12,000 kN. Slabs typically handle distributed loads, and this result aligns with that function, emphasizing surface area more than depth. The higher safety factor of 2.00 ensures robust performance under variable loading, which is essential for floor systems. For the composite column, optimized dimensions result in 22,500 kN capacity with a utilization ratio of 0.78. This shows the advantage of using high-strength composite materials in columns where both axial and buckling resistance are critical.

The steel beam shows the highest individual capacity in the table at 30,500 kN, benefiting from high material strength (65 MPa) and favorable dimensions. The utilization ratio of 0.87 and safety factor of 1.40 show that this design maximizes both material potential and structural safety. The result emphasizes the role of material strength coupled with optimized dimensions in achieving the highest possible capacity.

These optimized results demonstrate the power of parametric tuning in structural design. Increasing width and depth has a nonlinear effect on capacity, primarily due to their squared relationship with the moment of inertia and sectional area. Material selection further enhances this, especially in beams and columns where high flexural and compressive strengths are desired.

Utilization ratios between 0.78 and 0.90 show that structural elements are working close to their designed limits, which is ideal in economic and sustainable construction. The safety factors used are still within standard codes (1.4–2.0), ensuring reliability.

In contrast to the original data—where utilization ratios were as low as 0.01–0.06—this optimized configuration provides more balanced performance, reduces material waste, and supports cost-efficient engineering.

4.0 Conclusion

The study revealed that the load-bearing capacity of structural elements such as beams, slabs, and columns is significantly influenced by geometric properties—particularly width and depth—as well as material strength and type. The regression analysis demonstrated that width and depth have the highest positive coefficients, indicating that these variables contribute most substantially to enhancing structural capacity. Safety factor showed a negative correlation, which aligns with established structural design principles where higher safety margins reduce allowable working capacity. Optimization results further confirmed that strategic adjustments in geometry and material selection can dramatically improve performance while maintaining desirable safety and utilization levels. Columns and beams constructed with steel and composite materials exhibited the highest predicted capacities when optimized, and utilization ratios were notably improved, indicating efficient use of structural potential.

From the findings, it is concluded that a data-driven approach to structural optimization offers a reliable and technically sound pathway to enhancing the performance of load-bearing components in civil engineering. The strong correlations and regression outcomes validate the influence of geometry and material strength, and the optimization results offer practical design scenarios that are both safe and resource-efficient. By minimizing under-utilization and improving performance indices, optimized designs can lead to more sustainable and cost-effective construction.

It is recommended that structural designers incorporate regression-based modeling and optimization tools early in the design process to guide decisions on material selection and geometric specifications. Adopting such approaches will help reduce waste, enhance structural performance, and ensure safety compliance. Future work should explore the integration of more advanced optimization algorithms and real-world validation through experimental or field data to further refine predictive accuracy and applicability.

5.0 References

Ajdukiewicz, A., & Kliszczewicz, A. (2002). Behavior of high performance concrete columns under eccentric compression. *Journal of Civil Engineering and Management*, 8,3, pp. 177–184. https://doi.org/10.1080/13923730.2002.10531285

Akinyemi, M. L., & Adedeji, Y. M. D. (2019). Performance evaluation of reinforced concrete columns using different mix ratios. *Civil Engineering Research Journal*, 9,1, pp. 1–10. https://doi.org/10.19080/CERJ.2019.09.555751

Ali, F. H., & Kasa, A. (2021). Load-bearing capacity prediction using machine learning for structural elements. *Journal of Structural Engineering*, 147, 12, 04021235. https://doi.org/10.1061/(ASCE)ST.1943-541X.0003117.

Cheng, M.-Y., & Hoang, N.-D. (2018). A hybrid artificial intelligence model for estimating compressive strength of concrete. *Construction and Building Materials*, 175, pp. 526–534. https://doi.org/10.1016/j.conbuildmat.2018.04.215.

Fan, L., Zhang, Y., Wang, Y., & Xie, Z. (2022). Structural optimization of steel beams using deep learning and finite element analysis. *Engineering Structures*, 264, 114370. https://doi.org/10.1016/j.engstruct.2022.114370.

Ju, M., Liu, J., & Zhang, Y. (2019). Experimental study on flexural behavior of fiber-reinforced concrete beams. *Construction and Building Materials*, 213, pp. 143–152. https://doi.org/10.1016/j.conbuildmat.2019.03.283.

Kaushik, H. B., Rai, D. C., & Jain, S. K. (2007). Stress-strain characteristics of clay brick masonry under uniaxial compression. *Journal of Materials in Civil Engineering*, 19,9, pp. 728–739. https://doi.org/10.1061/(ASCE)0899-1561(2007)19:9(728)

Kwak, H.-G., & Kim, J.-K. (2002). Nonlinear analysis of RC beams based on moment–curvature relation. *Journal of Structural Engineering*, 128,3, pp. 346–353. https://doi.org/10.1061/(ASCE)0733-9445(2002)128:3(346).

Li, Q., & Wu, C. (2020). Optimization design of reinforced concrete slabs under uniform loading. *International Journal of Concrete Structures and Materials*, 14,1, pp. 1–10. https://doi.org/10.1186/s40069-020-00412-4.

Maheri, M. R. (2008). An improved practical approach for optimization of RC sections. *Structural Engineering and Mechanics*, 30,6, pp. 703–716. https://doi.org/10.12989/sem.2008.30.6.703.

Sarma, K. C., & Adeli, H. (2002). Cost optimization of concrete structures. *Journal of Structural Engineering*, 128,5,pp. 718–725. https://doi.org/10.1061/(ASCE)0733-9445(2002)128:5(718).

Zhou, M., Xu, Y., & Tang, J. (2021). Regression analysis of structural performance factors for load-bearing prediction. *Applied Mechanics and Materials*, 889, pp. 202–210. https://doi.org/10.4028/www.scientific.net/AMM.889.202.

Conflict of interest

The authors declared no conflict of interest