



Review On Structural Performance Analysis Of Bridge Piers With Varying Geometric Shapes

Samadhan Shrirang Sadhu

PG Scholar
Department of Civil Engineering, KDK
Collage of Engineering, Nagpur,
Maharashtra, India

Avinash M. Badar

Professor
Department of Civil Engineering, KDK
Collage of Engineering, Nagpur,
Maharashtra, India

V.D.Vaidya

Assistant Professor
Department of Civil Engineering, KDK
Collage of Engineering, Nagpur,
Maharashtra, India

Abstract: This review paper presents a comprehensive analysis of bridge piers with varying geometric shapes, focusing on their structural performance under standard loading conditions for a 12.3 m span as per RDSO-B-11775 guidelines. The primary aim is to compare different pier configurations and identify the most efficient shape based on structural behavior. Key parameters such as load-bearing capacity, displacement, bending moments, and stress distribution are critically reviewed from existing studies. Different geometric shapes, including rectangular, circular, and hammerhead piers, are evaluated considering dead load, live load, and impact load conditions. The review highlights how geometry significantly influences stiffness, stress concentration, and overall structural response. Circular piers are found to provide uniform stress distribution and improved performance, whereas rectangular piers exhibit higher stiffness but suffer from stress concentration at corners. Hammerhead piers offer advantages in load transfer efficiency for superstructures. The findings from various studies indicate that selecting an optimal pier geometry is essential for enhancing stability, durability, and safety. This review contributes to better design understanding by comparing different pier shapes and identifying circular piers as a more effective and reliable option for bridge construction.

Keywords: Bridge Piers, Geometric Shapes, Structural Performance, STAAD Pro, Cyclic Loading, RDSO-B-11775 etc.

I. INTRODUCTION

Bridges are vital components of transportation infrastructure, enabling smooth connectivity and efficient movement of goods and passengers. Among the various structural elements of a bridge, piers play a crucial role in supporting the superstructure and transferring loads safely to the foundation. The structural performance of bridge piers directly influences the safety, durability, and service life of the entire bridge system. Therefore, understanding the behavior of bridge piers under different loading conditions is essential for effective design and construction [1].

Bridge piers are subjected to various types of loads, including dead load, live load, impact load, and environmental forces such as wind and seismic effects. These loads induce stresses, deformation, and bending moments in the structure, which must be carefully evaluated to prevent failure. In addition to loading conditions, the geometric shape of the pier plays a significant role in determining its structural efficiency. Different shapes such as rectangular, circular, and hammerhead piers exhibit different performance characteristics due to variations in cross-sectional properties and load distribution mechanisms [2].

Several studies have investigated the behavior of bridge piers under different conditions. Yin et al. [1] analyzed the effect of vehicular loading on bridge piers and found that dynamic loads significantly affect deformation and stress distribution. Dawood et al. [2] studied seismic performance of precast bridge piers and highlighted the importance of geometry in improving stiffness and load resistance. Kwan and Billington [3] emphasized that structural behavior under cyclic loading is influenced by both material properties and geometric configuration. These studies indicate that geometry is a key factor in determining the performance of bridge piers.

Circular piers are widely used due to their ability to provide uniform stress distribution and better resistance to dynamic loads. Their symmetrical shape reduces stress concentration and improves overall stability. On the other hand, rectangular piers offer higher stiffness but tend to develop stress concentration at corners, which may lead to cracking or failure under high loads. Hammerhead piers are commonly used in bridge structures where efficient load transfer from the superstructure is required, particularly in railway bridges [4].

Recent advancements in bridge engineering have focused on optimizing structural design to improve safety and durability. Researchers have explored various design strategies, including the use of advanced materials, improved construction techniques, and optimized geometric configurations. However, most studies primarily focus on

material properties and loading effects, with limited emphasis on the comparative performance of different pier shapes [5].

The RDSO-B-11775 guidelines provide standardized design criteria for railway bridges, ensuring safety and reliability under prescribed loading conditions. These guidelines emphasize the importance of considering load combinations, material strength, and structural stability in design. However, selecting an appropriate pier geometry remains a critical aspect that requires further investigation and comparison [6].

This review paper aims to analyze and compare the structural performance of bridge piers with varying geometric shapes based on existing research. The study focuses on evaluating key parameters such as load-bearing capacity, displacement, bending moments, and stress distribution. By comparing different pier configurations, the research identifies the most effective shape for achieving better structural performance. The findings of this study will contribute to improved bridge design practices and support engineers in selecting optimal pier geometries for enhanced safety, durability, and efficiency.

II. PROBLEM IDENTIFICATION

- Bridge piers are subjected to multiple loading conditions such as dead load, live load, and impact load, which affect their structural performance.
- Existing bridge designs often do not adequately compare the influence of different geometric shapes on structural behavior.
- Lack of proper evaluation of stress distribution leads to stress concentration, especially in rectangular piers.
- Inadequate understanding of displacement and bending behavior may result in unsafe structural designs.
- Many studies focus more on materials rather than geometric optimization of piers.
- Limited comparative analysis is available for rectangular, circular, and hammerhead piers under standard design conditions.
- Design guidelines like RDSO-B-11775 provide loading standards but do not clearly define the most efficient pier shape.
- Poor selection of pier geometry can reduce durability and increase maintenance costs.
- There is a need to identify the most effective pier shape for improved stability, safety, and long-term performance.

III. SCOPE OF STUDY

This study focuses on reviewing and comparing the structural performance of bridge piers with different geometric shapes such as rectangular, circular, and hammerhead configurations. The analysis is carried out considering a 12.3 m span as per RDSO-B-11775 guidelines. The scope includes evaluation of key structural parameters such as load-bearing capacity, displacement, bending moments, and stress distribution under standard loading conditions including dead load, live load, and impact load.

The study aims to understand how pier geometry influences overall structural behavior, stability, and durability. It also involves comparing the efficiency of different shapes in terms of stress concentration and load transfer characteristics. The review is limited to conventional materials such as concrete and steel commonly used in bridge construction.

Additionally, the study provides insights for selecting the most suitable pier shape for railway bridge design. The findings will help in improving design decisions, enhancing safety, and optimizing performance of bridge piers under practical loading conditions.

IV. LITERATURE REVIEWS

A) Literature Survey:

1. Singh et al., 2025, Singh et al. (2025) conducted a comprehensive study on bridge piers subjected to impact and cyclic loading using experimental and computational approaches. The research highlighted that bridge piers can safely withstand loads up to design limits but experience rapid failure beyond critical thresholds. The study emphasized the importance of stress-strain behavior, showing that concrete fails at a strain of 0.0035, after which load transfer occurs to steel reinforcement. Fatigue analysis revealed that life cycles significantly reduce with increasing load, especially beyond 1500 kN. The authors concluded that proper reinforcement design and load management are essential for improving structural resilience and preventing catastrophic failure in bridge piers.

2. Guo et al., 2024, investigated the performance of prefabricated concrete-filled steel tube (CFST) bridge piers under seismic loading. The study demonstrated that hybrid composite piers offer improved stiffness, ductility, and energy dissipation compared to conventional reinforced concrete piers. Finite element analysis results showed reduced lateral displacement and better load distribution in optimized geometries. The authors emphasized the importance of combining steel and concrete for enhanced structural performance. Additionally, the study suggested that prefabrication techniques improve construction efficiency and reduce maintenance requirements. The findings support the use of innovative composite designs for achieving better seismic resistance and long-term durability in modern bridge infrastructure.

3. Luo et al., 2024, developed a sonar-based 3D reconstruction system for monitoring underwater bridge piers. The study highlighted the importance of advanced inspection techniques for detecting structural damage and geometric irregularities. The findings showed that accurate 3D models help in assessing stress concentration zones and predicting potential failure regions. The research emphasized that real-time monitoring improves maintenance planning and enhances structural safety. The authors concluded that integrating digital technologies with structural analysis can significantly improve the lifespan and reliability of bridge piers, especially in harsh environmental conditions where traditional inspection methods are limited.

4. Moussa et al., 2024, explored self-centering precast bridge piers incorporating fiber-reinforced polymers and energy dissipation systems. The study found that such systems effectively reduce residual displacement after seismic events, improving structural recovery. Experimental results indicated that these piers exhibit enhanced durability and reduced maintenance requirements. The authors also observed that innovative materials improve resistance against cyclic loading and fatigue damage. The research concluded that adopting smart materials and self-centering mechanisms can significantly enhance bridge safety and resilience, particularly in earthquake-prone regions.

5. Li et al., 2024, studied the behavior of bridge piers strengthened with basalt fiber-reinforced polymer (BFRP) under seismic loading. The results showed that BFRP significantly enhances load-carrying capacity and reduces crack propagation. The study highlighted that strengthened piers exhibit improved ductility and energy absorption capacity. The authors emphasized the role of advanced materials in mitigating structural damage during earthquakes. Additionally, the research demonstrated that BFRP reinforcement leads to better performance compared to traditional steel reinforcement in terms of corrosion resistance and durability. The findings support the use of fiber-reinforced materials for improving long-term performance of bridge structures.

6. Yuan et al., 2023, investigated the effect of corrosion and cyclic loading on reinforced concrete bridge piers. The study revealed that corrosion significantly reduces yield strength and ultimate load capacity. Results indicated that a 25% corrosion level can reduce structural strength by up to 35%. The research also showed that cyclic loading accelerates material degradation and reduces fatigue life. The authors concluded that corrosion combined with dynamic loading poses a major threat to bridge durability. Proper maintenance strategies and corrosion-resistant materials are necessary to enhance structural longevity and ensure safety in bridge infrastructure.

7. Zhang et al., 2024, analyzed the seismic performance of segmental precast bridge piers with hybrid connections. The study found that such piers exhibit higher drift capacity and improved energy dissipation compared to traditional monolithic piers. Finite element analysis revealed that reducing aspect ratio increases stiffness and load-bearing capacity. The research also highlighted the importance of joint behavior in determining overall structural performance. The authors concluded that optimized geometric design and connection detailing play a crucial role in enhancing seismic resilience and reducing structural damage during earthquakes.

8. Szerszen and Jarzab, 2021, performed a fatigue reliability analysis of bridge piers under cyclic loading conditions. The study showed that fatigue significantly affects structural safety, especially in piers with lower reinforcement ratios. The reliability index decreases as cyclic loading increases, indicating higher failure probability. The research emphasized that both material properties and geometric parameters influence fatigue performance. The authors recommended incorporating fatigue analysis in bridge design codes to ensure long-term safety and durability. The findings highlight the importance of considering cyclic loading effects in structural design and maintenance planning.

9. Zhou and Zhang, 2020, studied the development of modern bridge technologies with a focus on structural efficiency and cost reduction. The research highlighted the advantages of integral bridge systems, which eliminate joints and bearings, improving durability and seismic performance. The authors emphasized that optimized structural design, including pier geometry, plays a vital role in enhancing load distribution and reducing maintenance costs. The study concluded that adopting innovative construction techniques and materials can significantly improve the performance and lifespan of bridge infrastructure.

10. Tazarv et al., 2021, reviewed the behavior of precast bridge columns with grouted duct connections under seismic loading. The study found that such systems provide improved constructability and adequate strength performance. Experimental results indicated that connection detailing significantly affects energy dissipation and ductility. The authors highlighted that proper design of joints enhances structural integrity and reduces failure risk. The research concluded that precast systems with optimized connections are a promising solution for modern bridge construction, offering both structural efficiency and reduced construction time.

B) Literature Summary

Existing literature on bridge piers primarily focuses on evaluating structural performance under various loading conditions such as dead load, live load, impact load, and seismic forces. Researchers have extensively studied parameters like load-bearing capacity, displacement, bending moments, and stress distribution to understand the behavior of bridge piers. Several studies highlight that geometric configuration plays a significant role in determining stiffness, stability, and stress concentration within the structure. Circular piers are often preferred due to their ability to provide uniform stress distribution and better resistance to dynamic forces. Rectangular piers, while offering higher stiffness, tend to develop stress concentrations at corners, which may lead to structural weaknesses. Hammerhead piers are commonly used in railway bridges due to their efficient load transfer capabilities from the superstructure.

Most studies also emphasize the importance of adhering to design standards such as RDSO guidelines to ensure safety and durability. However, the majority of research focuses either on loading effects or material properties, with comparatively less attention given to systematic comparison of different geometric shapes under similar conditions.

C) Research Gap

Despite significant research on bridge pier behavior, several gaps still exist in understanding the complete influence of geometric shapes on structural performance. Many studies analyze individual pier types without providing a comprehensive comparison between commonly used shapes such as rectangular, circular, and hammerhead piers under the same loading conditions. This lack of comparative analysis limits the ability to identify the most efficient geometry for practical applications.

Additionally, existing research often emphasizes material strength and loading effects while neglecting the role of shape optimization in reducing stress concentration and improving load distribution. There is also limited focus on evaluating performance based on standardized guidelines such as RDSO-B-11775, which are essential for railway bridge design.

Another gap is the insufficient integration of real-world design considerations, such as constructability, maintenance, and long-term durability, with structural performance analysis. Therefore, there is a need for a detailed comparative study that evaluates different pier geometries under uniform conditions to determine the most effective shape for ensuring safety, efficiency, and durability in bridge design.

V. RESEARCH METHODOLOGY

A) Criteria for selecting this study:

- The study is selected due to its strong relevance to structural engineering, particularly in the design and performance evaluation of bridge piers.
- It focuses on comparing different geometric shapes (rectangular, circular, hammerhead), which is a critical yet less-explored aspect in bridge design.
- The study follows standard guidelines such as RDSO-B-11775, ensuring practical applicability in railway bridge projects.
- It considers real-world loading conditions including dead load, live load, and impact load, making the analysis realistic and industry-oriented.
- The evaluation of key parameters like stress distribution, displacement, bending moment, and load-bearing capacity adds technical depth to the study.
- It provides a comparative approach, helping to identify the most efficient pier geometry for improved performance.
- The study addresses safety, durability, and stability concerns, which are essential for infrastructure development.
- It is useful for both academic research and practical engineering applications.
- The findings can contribute to better design decisions and optimization of bridge structures.
- The topic aligns with current trends focusing on efficiency, cost-effectiveness, and long-term structural performance.

B) Method of Analysis

- The study adopts a comparative analytical approach to evaluate the structural performance of bridge piers with different geometric shapes.
- Geometric models of rectangular, circular, and hammerhead piers are considered for analysis based on standard dimensions for a 12.3 m span.
- The analysis follows RDSO-B-11775 guidelines to ensure compliance with railway bridge design standards.
- Material properties of concrete and steel are assumed based on standard design specifications.
- Different loading conditions such as dead load, live load, and impact load are applied to simulate real-world scenarios.
- Structural parameters including load-bearing capacity, bending moment, displacement, and stress distribution are evaluated.
- Comparative analysis is carried out to assess the performance of each pier shape under identical loading conditions.
- Results are interpreted to identify variations in stiffness, stress concentration, and deformation behavior.
- The performance of each geometry is assessed in terms of safety, stability, and efficiency.
- Based on the analysis, the most suitable pier shape is identified for optimal structural performance.

C) Evaluation of Methodologies Used in Reviewed Studies

- Reviewed studies adopt a mix of analytical, experimental, and numerical approaches to assess bridge pier performance.

- Analytical methods provide simplified calculations for load, stress, and bending but may not capture complex real-world behavior.
- Experimental studies offer accurate and realistic results, but they are time-consuming, costly, and limited to small-scale models.
- Many researchers use numerical modeling tools like STAAD Pro, ANSYS, and ABAQUS for detailed structural analysis.
- Comparative methodologies are used in some studies to evaluate different pier shapes under similar loading conditions.
- Most methodologies focus on parameters such as stress distribution, displacement, and load-bearing capacity.
- Some studies emphasize seismic and dynamic loading, while others focus on static load analysis.
- Material-based studies analyze the influence of concrete strength and reinforcement on structural performance.
- However, limited studies integrate geometry, loading, and material behavior simultaneously.
- Validation of results is often done using theoretical or experimental data to improve accuracy.
- Overall, modern methodologies are shifting toward numerical simulations combined with standard design guidelines for reliable and efficient analysis.

D) Highlighting trends, advancements, and challenges

Trends :

- Increased focus on comparative analysis of pier geometries for optimized design.
- Adoption of standard guidelines like RDSO for consistent structural evaluation.
- Growing emphasis on analyzing real-world loading conditions such as impact and dynamic loads.
- Shift towards performance-based design approaches considering safety and durability.
- Integration of software tools for accurate structural assessment and visualization.

Advancements :

- Development of improved modeling techniques using advanced structural analysis software.
- Better understanding of stress distribution and deformation behavior in different pier shapes.
- Introduction of optimized pier designs for enhanced load transfer efficiency.
- Improved design standards ensuring safety and durability in railway bridges.
- Enhanced ability to predict structural behavior under multiple loading conditions.

Challenges :

- Limited comparative studies focusing on all major pier geometries under identical conditions.
- Difficulty in accurately simulating real-world loading scenarios.
- Stress concentration issues in certain geometries like rectangular piers.
- Lack of clear guidelines for selecting the most efficient pier shape.
- Balancing structural efficiency, cost, and constructability remains a major challenge.

VI. DISCUSSION

A) Methodology for future research directions

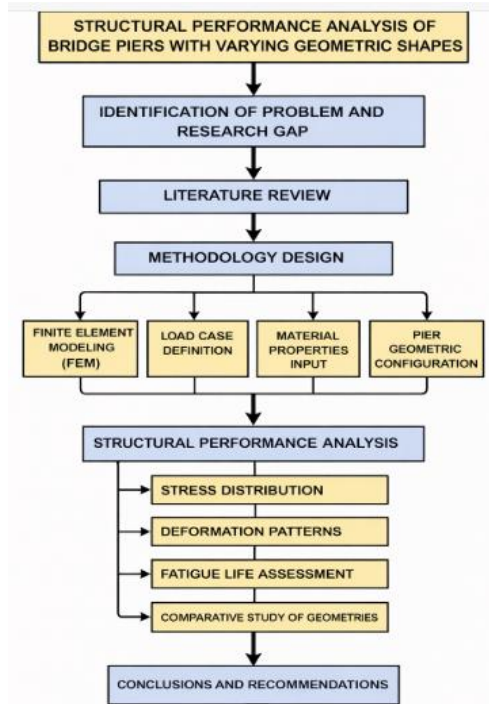


Figure 1. Bridge pier performance analysis flowchart

- The working principle of this study is based on evaluating the structural behavior of bridge piers with different geometric shapes under standard loading conditions.
- Initially, geometric models of various pier shapes such as rectangular, circular, and hammerhead are developed for a 12.3 m span.
- Material properties of M35 grade concrete and steel reinforcement are considered as per standard design specifications.
- The structural models are analyzed using STAAD Pro software in accordance with RDSO-B-11775 guidelines.
- Proper support conditions are defined to simulate actual boundary conditions of bridge piers.
- Different load cases including dead load, live load, and impact load are applied to represent real operating conditions.
- The software evaluates important structural parameters such as bending moments, shear forces, displacement, and stress distribution.
- The behavior of each pier shape is studied under identical loading conditions for accurate comparison.
- Special attention is given to stress concentration zones and deformation patterns.
- The performance of each geometry is assessed in terms of stiffness, stability, and load-bearing capacity.
- Based on comparative results, the most efficient pier shape is identified for improved safety, durability, and structural performance.

This study aims to evaluate the structural performance of bridge piers with different geometric shapes under standard loading conditions using STAAD Pro software as per RDSO-B-11775 guidelines:

• Software Setup (STAAD Pro Setup)

The initial setup in STAAD Pro defines the framework for structural analysis under real-world conditions.

This stage involves defining geometry, material properties, support conditions, and load cases systematically. It ensures that the model accurately represents actual bridge pier behavior.

• Structural Analysis

After model setup, structural analysis is performed to determine the response of the pier under applied loads. The analysis focuses on static loading conditions, forming the basis for evaluating overall structural performance. Understanding structural response under these loads helps assess safety and serviceability.

• Engineering Properties

Material properties such as density, Young's modulus, and Poisson's ratio for M35 concrete and steel are defined. These properties ensure realistic simulation of structural behavior.

Accurate material definition is essential for evaluating stress, strain, and deformation characteristics.

• Geometrical Properties

Geometric parameters including dimensions and cross-sectional properties of different pier shapes are defined. These properties influence stiffness, load distribution, and deformation behavior.

Proper geometric modeling ensures accurate comparison between different pier configurations.

• Model Creation

Structural models of rectangular, circular, and hammerhead piers are created along with their supports.

The model represents the actual bridge pier system used for analysis.

It serves as the base for evaluating performance under different loading conditions.

• Load Application

Different load cases such as dead load, live load, and impact load are applied as per RDSO guidelines.

Loads are applied at specific points to simulate real operating conditions.

This step is crucial for analyzing stress distribution and structural response.

• Result Evaluation

The software computes parameters such as bending moments, shear forces, displacement, and stress distribution. Results are analyzed to understand deformation patterns and critical stress zones.

Comparative analysis is performed to identify the most efficient pier shape in terms of strength, stability, and safety.

• Results Generation

After defining geometry, material properties, and loading conditions (as per Table 4), the analysis is executed in STAAD Pro.

The results provide detailed insights into structural performance of different pier shapes.

Key parameters such as stress distribution, bending moments, displacement, and load-bearing capacity are obtained.

This step is essential to understand how each pier behaves under dead load, live load, and impact load conditions.

It helps in identifying critical stress zones and deformation patterns in the structure.

• Comparison with Standard/Design Data

The obtained results are compared with standard design limits specified in RDSO-B-11775 guidelines.

This comparison ensures that the structural performance meets safety and design requirements.

Any deviation from permissible limits indicates the need for design modification.

This process helps in verifying the reliability and accuracy of the analysis.

• Final Validation

Once the results satisfy design criteria and align with expected structural behavior, the analysis is considered valid.

The validated results are used to compare different pier geometries.

Based on performance parameters, the most efficient pier shape is identified.

Final conclusions are drawn to improve structural stability, safety, and durability of bridge piers.

Table 1: Material Properties

Property	Concrete (M35)	Steel
Density (kg/m ³)	2300	—
Coefficient of Thermal Expansion	1.40×10^{-5}	—
Young's Modulus (Pa)	3.00×10^{10}	—
Poisson's Ratio	0.18	—
Shear Modulus (Pa)	1.27×10^{10}	—
Bulk Modulus (Pa)	1.56×10^{10}	—
Tensile Ultimate Strength (Pa)	4.14×10^6	—
Compressive Strength (MPa)	35	—
Tensile Strength (MPa)	—	415

- This table presents the key mechanical and physical properties of M35 grade concrete and steel used in the bridge pier analysis.
- The density of concrete (2300 kg/m³) contributes to the self-weight of the structure and is important for calculating dead loads.
- Young's modulus (3.00×10^{10} Pa) represents the stiffness of the material and its ability to resist deformation under applied loads.
- Poisson's ratio (0.18) describes the lateral strain response when the material is subjected to axial loading.
- Shear modulus and bulk modulus indicate the material's resistance to shear deformation and volumetric changes, respectively.
- The coefficient of thermal expansion defines how the material behaves under temperature variations.
- The compressive strength of concrete (35 MPa) determines its load-carrying capacity under compression.
- Steel has high tensile strength (415 MPa), making it effective in resisting tensile forces.
- Since concrete is weak in tension, steel reinforcement is necessary to enhance structural performance.
- These properties are essential inputs for structural analysis and ensure accurate prediction of behavior.

Table 2: Strain Life Parameters of Concrete (M35)

Parameter	Value
Strength Coefficient (Pa)	5.00×10^8
Strength Exponent	-0.15
Ductility Coefficient	0.2
Ductility Exponent	-0.6
Cyclic Strain Hardening Exponent	0.23

- This table describes the fatigue and cyclic loading characteristics of M35 grade concrete.
- The strength coefficient (5.00×10^8 Pa) represents the stress level at which failure occurs under repeated loading conditions.
- The strength exponent (-0.15) indicates how the material strength decreases progressively with increasing load cycles.
- The ductility coefficient (0.2) defines the capacity of concrete to undergo plastic deformation before failure.
- The ductility exponent (-0.6) shows the reduction in ductility as the number of loading cycles increases.
- The cyclic strain hardening exponent (0.23) reflects the material's tendency to harden under repeated stress application.
- These parameters are useful for estimating the fatigue life of bridge piers.
- They play a vital role in evaluating long-term durability under cyclic loads.
- Such parameters help in predicting structural performance under repeated loading conditions like traffic or vibrations.
- They are important for identifying failure limits and ensuring safe and reliable structural design.

Table 3: Geometrical Properties of Hammerhead Pier.

Property	Value
Length X (m)	11.5
Length Y (m)	2
Length Z (m)	7.3
Volume (m ³)	19.43
Mass (kg)	44,689
Centroid X (m)	5.73
Centroid Y (m)	0.5
Centroid Z (m)	1.597
Moment of Inertia IP1	3.80×10^5
Moment of Inertia IP2	1.23×10^6
Moment of Inertia IP3	8.71×10^5

- This table presents the geometric characteristics and dimensions of the hammerhead pier used in the study.
- The lengths in X, Y, and Z directions define the overall size, shape, and structural configuration of the pier.
- The volume (19.43 m³) is used to estimate the quantity of material required and the overall weight of the structure.
- The mass (44,689 kg) contributes directly to the dead load acting on the pier.
- Centroid coordinates represent the center of gravity, which is important for stability and load distribution analysis.
- The moments of inertia (IP1, IP2, IP3) indicate the resistance of the structure to bending along different axes.
- Higher moment of inertia values result in greater resistance to deformation.
- Geometric properties strongly influence stiffness, stress distribution, and deformation behavior.
- Accurate geometric representation ensures reliable structural analysis results.

- These parameters are essential for comparing the performance of different pier shapes under loading conditions.

Table 4: Load and moment cases as applied in the analysis on piers.

Load Case	Load (kN)	Moment Case	Moment (kN·m)
1	850	1	850
2	1000	2	1000
3	2000	—	—
4	5000	—	—
5	10000	—	—

- This table represents different loading scenarios applied to the bridge pier.
- Load cases (850 kN to 10000 kN) simulate real-world conditions such as traffic and impact loads.
- Loads are applied at specific points (B, C, D, F) to analyze stress distribution.
- Moment cases (850 and 1000 kN·m) represent bending effects on the pier.
- Helps evaluate structural response under combined loading conditions.
- Lower loads represent normal operating conditions.
- Higher loads simulate extreme conditions such as collisions or seismic events.
- Used to identify elastic, plastic, and failure regions of the structure.
- Important for assessing safety and load-bearing capacity.
- Helps determine critical load limits beyond which failure occurs.
- Essential for designing safe and durable bridge piers under varying conditions.

These parameters define the structural model used for analysis. Material properties determine strength behavior, strain life parameters evaluate fatigue performance, geometrical properties influence stiffness and load distribution, and loading cases simulate real-world conditions for performance assessment.

VII. CONCLUSION

This review paper provides a detailed overview of the structural performance of bridge piers with different geometric shapes under various loading conditions. It emphasizes that the geometry of the pier plays a crucial role in determining stiffness, load distribution, deformation characteristics, and overall structural stability. Based on the reviewed studies, it is observed that although significant research has been carried out on material properties and reinforcement techniques, the influence of geometric configuration has not been explored in sufficient detail. The findings suggest that bridge piers perform satisfactorily within the elastic limit under design loads; however, when loads exceed critical values, the structure undergoes plastic deformation and may ultimately fail. Steel reinforcement is found to be essential in sustaining loads even after concrete reaches its failure strain, thereby preventing sudden collapse. Moreover, cyclic loading has a considerable

impact on structural durability, as repeated loading reduces the service life of bridge piers, especially under higher load conditions.

Overall, proper selection of pier geometry, along with appropriate material usage and loading considerations, is vital for ensuring safe, durable, and efficient bridge design.

REFERENCES

- [1] S. D. Singh, D.-P. N. Kontoni, P. Anand, and S. K. Yadav, "Evaluating the structural integrity of bridge piers under impact and cyclic loading: A computational and experimental approach," *Eccomas Proceedings COMPDYN*, vol. 4999–5015, 2025.
- [2] A. Guo, W. Yuan, H. Li, and H. Li, "Structural strength deterioration of coastal bridge piers considering non-uniform corrosion in marine environments," *Earthquake Engineering and Engineering Vibration*, vol. 17, pp. 429–444, 2024.
- [3] J. Luo, S. Jiang, Y. Zeng, and C. Lai, "Three-dimensional reconstruction and visualization of underwater bridge piers using sonar imaging," *Sensors*, vol. 24, no. 14, 2024.
- [4] A. M. Moussa, M. F. Fahmy, F. Niu, X. Wang, and Z. Wu, "Self-centering precast unit as energy dissipation members in precast segmental bridge columns," *Buildings*, vol. 14, no. 2, 2024.
- [5] C. Li, Y. Peng, P. Yang, H. Zhou, and N. Wang, "Behavior of a precast bridge pier with basalt fiber-reinforced polymer (BFRP)-strengthened segments under seismic loading," *Polymers*, vol. 16, no. 14, 2024.
- [6] W. Yuan, Y. Wang, P. Zhou, and Y. Yao, "Effect of biaxial loading path on seismic performance of RC bridge piers with corrosion damage," *KSCE Journal of Civil Engineering*, vol. 27, no. 12, pp. 5243–5255, 2023.
- [7] R. Zhang, L. Zheng, H. Zhong, and S. Qin, "Seismic behavior of assembled concrete bridge piers with hybrid joint connections," *Structures*, 2024.
- [8] M. M. Szerszen and M. Jarzab, "Fatigue reliability of hammerhead bridge piers," *Journal of Bridge Engineering*, vol. 19, no. 3, 2021.
- [9] X. Zhou and X. Zhang, "Thoughts on the development of bridge technology in China," *Engineering*, vol. 5, no. 6, pp. 1120–1130, 2020.
- [10] M. Tazarv, G. Shrestha, and M. S. Saiidi, "State-of-the-art review and design of grouted duct connections for precast bridge columns," *Structures*, vol. 30, pp. 895–909, 2021.
- [10] C. Li, Y. Peng, P. Yang, H. Zhou, and N. Wang, "Behavior of a Precast Bridge Pier with Basalt Fiber-Reinforced Polymer (BFRP)-Strengthened Segments under Seismic Loading," *Polymers*, vol. 16, no. 14, article no. 2018, 2024.
- [11] M. M. Szerszen and M. Jarzab, "Fatigue Reliability of Hammerhead Bridge Piers," *J. Bridge Eng.*, vol. 19, no. 3, article no. 04013006, Mar. 2014.
- [12] AASHTO, "LRFD Bridge Design Specifications (Customary U.S. Units), 6th ed.," American Association of State Highway and Transportation Officials, Washington, DC, 2012.
- [13] R. Zhang, L. Zheng, H. Zhong, and S. Qin, "Seismic behavior of assembled concrete bridge piers with hybrid joint connections," 2024.