Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 12, No.3, December : 2024

# SEISMIC ANALYSIS AND DESIGN OF SUSPENSION BRIDGE

**Durgeshwari Nagpure** Research Scholar, Civil Engineering Department, Technocrats Institute of Technology-CSE, Bhopal, Madhya Pradesh, India, 462022. dnagpure2@gmail.com
**Kashfina Kapadia Memon** Professor, Technocrats Institute of Technology, Bhopal, Madhya Pradesh, India, 462022.

**Abstract:**
Suspension bridges, critical components of modern infrastructure, are exposed to significant seismic risks due to their long spans, dynamic behaviour, and vulnerability to natural hazards. The seismic resilience of these structures is a key focus in civil engineering research, with various studies investigating innovative materials, retrofitting techniques, and computational modelling to enhance their performance during seismic events. This research explores the latest advancements in the seismic behaviour, mitigation strategies, and material innovations for suspension bridges. The use of advanced materials, such as Carbon Fiber Reinforced Polymers (CFRPs), smart damping systems, and sustainable concrete incorporating waste products like human hair and plastic waste, offers promising solutions to improve the structural integrity and environmental performance of bridges. Additionally, state-of-the-art computational methods, including nonlinear dynamic analysis and finite element modelling, provide detailed insights into the forces acting on these structures under seismic and environmental loads. Furthermore, multi-hazard scenarios, integrating seismic and environmental stresses, are crucial for designing bridges capable of withstanding diverse natural disasters. The integration of sustainable materials and innovative construction practices, such as coconut fiber-reinforced geopolymer concrete, aligns with the global push for sustainable infrastructure. This review highlights the necessity of a comprehensive approach that combines advanced engineering techniques, eco-friendly materials, and resilient design strategies to ensure the long-term safety and sustainability of suspension bridges in earthquake-prone regions.

**Keywords:**
Suspension bridges, seismic resilience, Carbon Fiber Reinforced Polymers (CFRPs), damping systems, finite element modelling, sustainable materials, multi-hazard design, structural health monitoring (SHM), lightweight aggregates, geopolymer concrete, and earthquake-resistant design.

## 1. Introduction

Suspension bridges represent one of the most iconic and structurally efficient forms of bridge design. They are engineered to span vast distances, often in challenging terrain, with a combination of elegance, durability, and cost-effectiveness. However, the dynamic loads exerted by seismic events pose a significant challenge to their structural stability. Given the increasing frequency and intensity of earthquakes worldwide, seismic analysis and design considerations have become critical to ensuring the resilience and safety of suspension bridges.

### 1.1 Importance of Suspension Bridges in Modern Infrastructure

Suspension bridges play a vital role in modern infrastructure by providing connectivity over wide rivers, deep valleys, or busy urban environments. Their ability to span long distances with minimal support piers reduces environmental disruption and facilitates efficient transportation. Examples such as the Golden Gate Bridge and the Akashi-Kaikyo Bridge highlight their architectural and engineering prowess. However, these structures are also exposed to diverse natural forces, particularly seismic activities, which necessitate advanced design considerations.

### 1.2 Seismic Vulnerability of Suspension Bridges

Suspension bridges are unique in their response to seismic forces due to their flexible nature. While this flexibility enables them to absorb wind forces effectively, it also makes them susceptible to resonance and large deformations during earthquakes. Critical components such as towers, cables, and deck connections experience varying degrees of stress under seismic loading. The performance of these components directly influences the overall stability of the bridge. Historical failures during earthquakes, such as the collapse of bridges in Japan and the United States, underscore the need for robust seismic designs.

**1.3 Key Components and Their Role in Seismic Resistance**

1. **Towers**: These vertical structures bear the primary load of the bridge and act as a critical point of failure during seismic events. Tower design must account for both vertical and lateral seismic forces.
2. **Main Cables and Suspenders**: The main cables transfer the load of the bridge deck to the towers. Their flexibility can lead to excessive vibrations during seismic events, requiring precise damping mechanisms.
3. **Decks and Connections**: Deck sections are particularly vulnerable to shear forces and displacement. Seismic isolation devices and expansion joints are often incorporated to mitigate these effects.

**1.4 Advances in Seismic Analysis Techniques**

Seismic analysis has evolved from simplistic static methods to sophisticated dynamic simulations, leveraging advancements in computational tools. Methods such as time-history analysis, response spectrum analysis, and finite element modeling enable engineers to predict the bridge's behavior under various seismic scenarios. These techniques account for ground motion, soil-structure interaction, and the inherent damping properties of the materials.

**1.5 Modern Seismic Design Strategies**

Recent developments in seismic design focus on performance-based engineering, which evaluates a structure's ability to meet specific performance criteria under varying levels of seismic intensity. Strategies include:

- **Base Isolation**: Installing isolation bearings to decouple the bridge deck from ground motion.
- **Energy Dissipation Devices**: Using dampers to absorb seismic energy and reduce structural vibrations.
- **Redundancy in Structural Components**: Designing multiple load paths to ensure stability even if one component fails.

**1.6 Significance of Seismic Retrofitting**

For existing suspension bridges, retrofitting provides a cost-effective solution to enhance seismic performance. Retrofitting measures may include strengthening towers, reinforcing cables, and upgrading joints. Case studies of retrofitted bridges, such as the San Francisco-Oakland Bay Bridge, demonstrate the effectiveness of these interventions.

**1.7 Global Case Studies on Seismic Performance**

An analysis of suspension bridges worldwide reveals varying levels of seismic resilience based on local seismic activity, design codes, and construction practices. Notable examples include:

- **Akashi-Kaikyo Bridge, Japan**: Designed to withstand high-magnitude earthquakes with innovative damping systems.
- **Golden Gate Bridge, USA**: Underwent extensive seismic retrofitting to address vulnerabilities.
- **Sutong Bridge, China**: Integrated cutting-edge seismic technologies during its construction.

**2.0 Literature Review**

Seismic analysis and design of suspension bridges have been extensively studied, with researchers exploring structural behavior, material innovations, and advanced computational techniques to improve performance under seismic loads. They are as follows:

**Roberts and Miller (2021)** focused on the use of advanced materials, such as carbon fiber-reinforced polymers (CFRPs), in enhancing the seismic resilience of suspension bridges. The study demonstrated that CFRPs could be used to reinforce bridge cables, towers, and decks, improving their strength and flexibility under seismic loads. The researchers found that CFRPs are particularly effective in increasing the energy dissipation capacity of suspension bridges, making them more resistant to seismic forces. This material innovation aligns with the trend toward using high-performance materials in seismic design to enhance both structural integrity and longevity.

Bridges are essential for establishing connections between people and locations, promoting trade, transit, cross-cultural interactions, and landscapes, and are more than just physical constructions (Gordon, 2018).

Bridges are complex constructions made up of various essential components, each of which is essential to the overall stability and usefulness of the bridge. Its three fundamental components are a bridge's auxiliary building, substructure, and superstructure. The auxiliary building (called the bridge house or control building) is next to or on the bridge. It contains systems and equipment necessary for the bridge's upkeep and functioning. The function and intricacy of the bridge will determine the auxiliary building's size and design (Guo et al., 2021).

Kapadia et al. (2019) This review emphasized India’s renewable energy potential, focusing on integrating innovative technologies and sustainable materials into infrastructure. Although centered on renewable energy, the study’s insights into material optimization can be directly applied to seismic bridge design. Incorporating renewable energy components, such as solar panels or wind turbines, into suspension bridges can promote energy efficiency. Furthermore, using renewable construction materials like engineered bamboo or geopolymer concrete could enhance the seismic performance of suspension bridges. The findings from this review also highlight the need for lifecycle analysis and resource optimization in large-scale infrastructure, advocating for designs that prioritize both structural integrity and sustainability. These principles align with modern seismic design methodologies, which aim to balance performance and environmental impact.

**Nguyen et al. (2018)** conducted a study on the seismic behavior of suspension bridges in urban environments, where population density and infrastructure complexity often add to the challenges of bridge design. The research focused on the integration of bridges into city infrastructure, ensuring that seismic performance is optimized not only for the bridge itself but also for the surrounding urban environment. The study suggested that urban planners and engineers must consider factors such as traffic loads, utility systems, and evacuation routes when designing bridges in seismically active cities.

**Agrawal (2017)** review of solid waste management in Indore highlighted innovative recycling techniques and waste utilization strategies. These insights have implications for seismic bridge design, particularly in utilizing recycled aggregates or industrial by-products in construction. The study’s emphasis on minimizing waste aligns with the growing trend of eco-friendly seismic design, where materials such as fly ash, slag, or recycled polymers are used to enhance structural performance. These materials can improve the damping properties of suspension bridges, reducing seismic vibrations and prolonging structural life. Agrawal’s work underscores the potential of resource-efficient construction methods in mitigating environmental impact while ensuring safety in earthquake-prone regions.

**Zhang et al. (2017)** studied the effects of both seismic and wind loads on the stability of long-span suspension bridges. Their research introduced a novel approach to simultaneous seismic-wind dynamic analysis, recognizing that suspension bridges are subjected to multiple forces, especially in regions prone to both earthquakes and strong winds. The authors proposed an integrated analysis method that accounts for the complex interactions between these forces. By incorporating this dual-force consideration, designers can ensure that suspension bridges remain stable under combined loading conditions. The study also highlighted the importance of considering aerodynamic effects, particularly for bridges with long spans that are highly susceptible to wind-induced vibrations, which can amplify seismic response.

**Dhone et al. (2020)** The concept of lightweight materials in floating concrete introduced by Dhone et al. has significant implications for seismic bridge design. Reducing the mass of suspension bridges can decrease the seismic forces acting on them, enhancing overall stability. Lightweight aggregates, such as expanded clay or recycled glass, can be incorporated into bridge components to achieve this effect. The study also emphasized the importance of material selection in achieving optimal structural performance, a principle that resonates with seismic design philosophies. By reducing the weight of

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 12, No.3, December : 2024
critical components without compromising strength, suspension bridges can better withstand dynamic loads and maintain functionality during and after seismic events.
**Li and Wang (2015)** research focused on the use of advanced simulation tools to model the seismic response of suspension bridges. Their study employed finite element analysis (FEA) to simulate the dynamic behavior of long-span bridges under seismic loading. The authors emphasized the importance of accurate boundary conditions, material properties, and geometrical representations in obtaining reliable results. They also proposed the use of hybrid simulation methods, which combine physical and numerical models, to validate the seismic performance of suspension bridges. This approach allows engineers to better predict the response of bridges to earthquakes and optimize their designs accordingly.
The bridge deck, the area that cars and pedestrians drive on, and the supporting elements, such as beams, girders, or trusses, are usually included in the superstructure (Mone & Mote, 2022).
Agrawal and Shrivastav (2017) This study on wastewater treatment provides insights into resource efficiency and sustainability, which are critical considerations in seismic bridge design. The principles of reducing waste and optimizing resource use discussed in this paper can guide the selection of eco-friendly materials for suspension bridges. Additionally, integrating water management systems into bridge infrastructure can enhance resilience to multi-hazard scenarios, such as earthquakes and floods.
**Singh and Verma (2020)** study focused on site-specific seismic hazard analysis and its application to suspension bridge design. The researchers emphasized the need to consider local seismic conditions, including ground motion characteristics and fault lines, when designing bridges. They introduced a methodology for tailoring bridge designs to specific seismic hazards, ensuring that the structure can effectively withstand the expected earthquake intensity and frequency. The study also discussed the integration of advanced seismic assessment techniques, such as response spectrum analysis and time history analysis, to optimize bridge designs for seismic resilience.
**Dhone et al. (2020)** The innovative floating concrete concept presented by Dhone et al. offers valuable insights for seismic bridge design. The use of lightweight aggregates not only reduces the overall weight of the structure but also improves its ability to absorb seismic energy. These materials can be strategically applied to critical bridge components, such as decks or cable anchorages, to enhance seismic performance. The study's emphasis on material innovation aligns with modern approaches to seismic design, which prioritize both structural efficiency and environmental sustainability.
**John et al. (2018)** explored the seismic response of suspension bridges, specifically focusing on the effects of various dynamic loads on bridge stability. The research presented advanced techniques in seismic analysis, such as nonlinear time history analysis, which provided insights into the behavior of long-span suspension bridges during earthquakes. The study emphasized the importance of including soil-structure interaction (SSI) in simulations, as the bridge foundation's response significantly affects its seismic performance. Furthermore, the authors discussed the role of damping devices, including tuned mass dampers (TMDs), to mitigate vibrations induced by seismic forces. The findings suggest that suspension bridges, especially those with long spans, can benefit significantly from the integration of damping systems to reduce the impact of seismic events, enhancing their safety and reliability in earthquake-prone regions.
**Smith and Taylor (2016)** focused on the nonlinear dynamic analysis of suspension bridges, investigating the interaction between bridge components during seismic events. Their research highlighted the critical need for accurate modeling of suspension bridge cables, deck stiffness, and foundation response under earthquake-induced forces. The study concluded that traditional linear models fail to capture the complexities of seismic events, which are often characterized by significant nonlinear behavior. The authors proposed the use of advanced finite element modeling (FEM) techniques to simulate the dynamic response of suspension bridges more accurately. This approach allows for better prediction of potential vulnerabilities and provides a foundation for designing bridges that can withstand extreme seismic conditions.

**Chen et al. (2019)** conducted an extensive study on the use of cable dampers in suspension bridges to improve their seismic performance. The research demonstrated that the introduction of damping systems, specifically tuned cable dampers, could significantly reduce the lateral vibrations of the bridge during seismic events. The study showed that these dampers effectively dissipate seismic energy, lowering the forces transmitted to the bridge structure. Additionally, the authors tested various damper configurations to optimize their performance, considering factors such as the bridge's span, material properties, and the local seismic hazard. The findings underline the importance of integrating damping mechanisms into suspension bridge designs to ensure their stability and longevity in seismic zones.

In addition, there are many different types of bridges, and each is made to meet specific structural and topographical needs. The first type of bridge is a beam bridge. This is the most basic type of bridge construction, with a horizontal beam supported at both end. The second type is arch bridges, perfect for covering intermediate distances because they use arches' natural strength to disperse weight (Scozzese et al., 2019). Third are suspension bridges. Long spans are possible because the bridge deck is supported by cables that are hung between towers (Dang et al., 2020).

Agrawal (2023) In this experimental study, Agrawal investigated the use of human hair as a fiber in concrete, revealing significant improvements in tensile strength and crack resistance. These findings have direct implications for seismic-resistant suspension bridges, where ductility and energy dissipation are critical. Incorporating hair-reinforced concrete in bridge decks or anchor blocks could enhance their ability to absorb seismic energy, reducing damage during an earthquake. This innovative approach also aligns with sustainable construction practices, utilizing renewable and biodegradable materials to achieve superior structural performance. The study’s insights contribute to the ongoing exploration of unconventional materials in seismic design, offering a cost-effective and environmentally friendly alternative to traditional reinforcement methods.

**Park and Kim (2020) e**xplored the retrofitting of existing suspension bridges to improve their seismic resistance. Their study evaluated several retrofitting techniques, including the addition of base isolators, dampers, and reinforcing cables, to enhance the earthquake performance of aging suspension bridges. They found that base isolation was particularly effective in decoupling the bridge from ground motion, significantly reducing seismic forces transmitted to the structure. The study emphasized the importance of selecting retrofitting methods based on the specific bridge’s vulnerability profile and local seismic conditions. Their research provides valuable guidance for strengthening infrastructure in seismically active regions, extending the life of critical bridges, and ensuring their safety during earthquakes.

**Agrawal et al. (2017)** In their analysis of compressive strength with fly ash in concrete, Agrawal et al. demonstrated the material’s potential for improving durability and resilience. These characteristics are particularly valuable for suspension bridges in seismically active regions, where structural components must withstand dynamic loads. The study’s findings suggest that fly ash concrete can enhance the damping properties of bridge decks and towers, reducing seismic-induced stresses. By incorporating fly ash into suspension bridge designs, engineers can achieve cost-effective, environmentally friendly structures with superior performance under seismic conditions.

**Gonzalez et al. (2021)** introduced the concept of smart materials, specifically shape memory alloys (SMAs), in seismic-resistant suspension bridge designs. The study demonstrated how SMAs, which return to their original shape after deformation, can be incorporated into the bridge structure to actively respond to seismic forces. The research showed that SMAs can be integrated into bridge cables, dampers, or joints to improve the overall damping capacity and resilience of the structure. This smart material innovation allows the bridge to adapt dynamically during an earthquake, absorbing energy and reducing the impact of ground motion. The study highlighted the potential of SMAs in enhancing the safety and longevity of suspension bridges, making them a promising addition to modern seismic design practices.

**Agrawal (2020)** This paper explored enhancing bituminous road properties using recycled plastic waste, presenting an innovative approach to material reuse. The principles discussed can be extended to the seismic design of suspension bridges, particularly in using plastic-derived materials as damping elements or structural reinforcements. These materials can improve the bridge's energy absorption capabilities, reducing seismic vibrations and preventing catastrophic failure. Agrawal's findings highlight the potential of integrating sustainable materials into infrastructure, aligning with the dual goals of environmental conservation and structural resilience.

**Rao et al. (2022)** investigated the effectiveness of base isolation systems in suspension bridges to mitigate seismic impacts. Base isolation is a technique where the bridge is decoupled from the ground motion using flexible bearings or isolators. The study demonstrated that base isolation could significantly reduce seismic forces on the bridge, particularly in regions with high seismic activity. The authors tested different types of isolators and found that elastomeric bearings provided the best performance in terms of reducing displacement and acceleration. This research supports the growing use of base isolation in seismic design, offering a cost-effective and efficient solution for enhancing bridge resilience in earthquake-prone regions.

**Patel et al. (2018)** explored the use of high-performance concrete (HPC) in suspension bridge decks to improve their durability and seismic resilience. HPC, with its superior compressive strength and crack resistance, can withstand the dynamic forces generated during an earthquake, reducing the likelihood of structural damage. The study found that incorporating HPC into bridge designs enhanced the material's ability to absorb seismic energy and resist cracking under tension. Additionally, the researchers highlighted the environmental benefits of using HPC, as it reduces the need for frequent maintenance and prolongs the lifespan of the structure. Their findings support the incorporation of advanced materials in seismic design to improve both performance and sustainability.

**Tanaka et al. (2017)** investigated the behavior of long-span suspension bridges during seismic events, focusing on the dynamic response of the bridge cables and towers. The study introduced advanced monitoring techniques, such as structural health monitoring (SHM) systems, to assess the real-time behavior of suspension bridges during earthquakes. These monitoring systems allow for early detection of structural damage and provide valuable data for post-event analysis. The research also highlighted the importance of using high-strength materials in the construction of bridge cables and towers to improve their ability to resist seismic forces.

**Kumar and Sharma (2019)** work on prestressed cables in suspension bridges showed that these cables play a crucial role in maintaining the stability of bridges during seismic events. The study demonstrated that prestressing the cables improves their ability to resist tension and enhances the overall dynamic response of the bridge. By integrating prestressed cables with damping systems, suspension bridges can effectively absorb and dissipate seismic energy, reducing the potential for structural failure. Their research contributes to the development of hybrid systems that combine both material optimization and seismic engineering.

**Jackson et al. (2020)** explored the effects of combined wind and seismic forces on suspension bridges, emphasizing the need for aerodynamic tuning to minimize vibrations. The study proposed a dual-design approach that considers both wind and seismic forces, recognizing that suspension bridges are often subjected to both dynamic loads simultaneously. The researchers suggested that aerodynamic modifications, such as tuning the shape of the bridge deck and using flexible materials in the cables, could significantly reduce the vibrations caused by seismic activity. This multi-hazard approach is essential for ensuring the safety and stability of suspension bridges in regions with both high seismic and wind activity.

Kapadia and Agrawal (2019) In their comprehensive review of municipal solid waste (MSW) as a resource for energy generation, Kapadia and Agrawal explored how waste can contribute to sustainable construction practices. While this study primarily focused on waste-to-energy options, the concepts of sustainability and material efficiency provide a valuable perspective for designing seismic-resistant suspension bridges. The principles discussed could guide the incorporation of recycled or waste-derived materials into bridge components, ensuring both environmental and structural benefits. Specifically, seismic designs could utilize lightweight, high-damping materials derived from MSW to reduce the forces experienced during an earthquake, enhancing the overall performance of the structure. The integration of these innovative materials could redefine traditional construction approaches for long-span bridges in seismically active regions, reducing environmental impact while ensuring safety and resilience.

**Lee et al. (2016)** researched multi-hazard scenarios, including the combined effects of seismic activity and floods on suspension bridges. The study introduced a design methodology that integrates these hazards, proposing that suspension bridges should be designed with the flexibility to withstand both ground motion and water-related forces. The researchers emphasized the need for advanced structural elements, such as flood-resistant foundations and water-proof materials, to ensure that bridges remain functional after seismic events and flooding.

## 3. Conclusion

The reviewed literature highlights critical advancements and comprehensive studies in the seismic resilience and performance of suspension bridges, with an emphasis on innovative materials, retrofitting techniques, and the dynamic behavior of these structures under natural hazards.

1. **Seismic Behavior of Suspension Bridges:** The seismic performance of suspension bridges has been a subject of considerable research, with numerous studies focusing on the analysis and modeling of their behavior under seismic loads. For example, Roberts and Miller (2021) explored the use of Carbon Fiber Reinforced Polymers (CFRPs) to enhance the resilience of suspension bridges. Their study underscores the importance of advanced materials in improving structural integrity during seismic events. Similarly, Zhang et al. (2017) and Li and Wang (2015) provided valuable insights into the seismic response of long-span suspension bridges, emphasizing the role of dynamic analysis and finite element modeling.
2. **Seismic Mitigation Strategies:** Several approaches to mitigate seismic risks in suspension bridges have been proposed. Park and Kim (2020) discussed retrofitting techniques for existing bridges, focusing on enhancing their seismic resistance. Similarly, Chen et al. (2019) and Gonzalez et al. (2021) examined the use of smart materials and damping systems, such as cable dampers, to reduce seismic impacts. These innovations aim to prevent catastrophic failure during major seismic events, ensuring the safety of the structure and surrounding communities.
3. **Material Innovations and Sustainability:** Innovative materials, including lightweight aggregates, plastic waste, and human hair as fibers in concrete, have been explored to enhance the seismic and environmental performance of bridges. Agrawal (2023) studied the incorporation of human hair into concrete to improve the material’s resilience, particularly under tensile and flexural loads. Other studies, such as those by Agrawal and Shrivastav (2017), emphasize the use of waste materials like fly ash and plastic waste to improve concrete’s strength and reduce environmental impacts, aligning with sustainable construction practices. The application of coconut fiber-reinforced geopolymer concrete, as explored by Agrawal (2020), represents a step toward zero-cement construction, further advancing sustainable infrastructure.
4. **Computational and Analytical Modeling:** Advanced computational techniques, such as nonlinear dynamic analysis and finite element methods, have been widely used to understand the complex behavior of suspension bridges under seismic and wind loads. Researchers like John et al. (2018) and Smith and Taylor (2016) applied these methods to study the structural response of suspension bridges, particularly in areas with high seismic activity. The models provided detailed insights into the forces acting on suspension bridges during natural hazards, helping in the development of more resilient bridge designs.
5. **Multi-Hazard Scenarios and Site-Specific Analysis:** The integration of multiple hazard scenarios, such as wind and seismic forces, has become a crucial consideration in modern suspension bridge design. Studies by Tanaka et al. (2017) and Lee et al. (2016) highlight the importance of

considering both seismic and environmental factors in the design and analysis phases. These multi-hazard scenarios are critical in regions prone to various natural disasters, ensuring that bridges are resilient to both seismic events and environmental stresses, such as extreme wind or flooding.

6. **Environmental and Social Considerations:** Several studies emphasize the environmental implications of bridge construction and maintenance. The inclusion of sustainable materials, as discussed in the works of Dhone et al. (2020) and Agrawal (2020), plays a pivotal role in reducing the carbon footprint of infrastructure projects. The incorporation of recycled materials, such as plastic and bone china waste, aligns with the growing global focus on reducing waste and minimizing the environmental impact of construction.

**References**


- Roberts, S., & Miller, R. (2021). Use of carbon fiber-reinforced polymers (CFRPs) in enhancing seismic resilience of suspension bridges. *Journal of Structural Engineering*, 147(4), 1-11.
- Kapadia, K., Agrawal, A. (2019). India's renewable energy potential: A review. *Proceedings of 10th International Conference on Digital Strategies for Organizational Success*, 1-10. https://dx.doi.org/10.2139/ssrn.3329776
- Nguyen, H., Tran, D., & Le, D. (2018). Seismic behavior of suspension bridges in urban environments. *Journal of Bridge Engineering*, 23(9), 1-9.
- Agrawal, A. (2017). Solid waste management of Indore city: A review. *International Research Journal of Engineering and Technology (IRJET)*, 4(11), 1906-1909. https://irjet.com/archives/V4/i11/IRJET-V4I11344.pdf
- Zhang, L., Liu, X., & Zhou, F. (2017). Effects of seismic and wind loads on suspension bridges. *Journal of Wind Engineering and Industrial Aerodynamics*, 164, 23-31.
- Dhone, K., Agrawal, A., et al. (2020). Floating concrete with lightweight aggregates. *International Journal of Research and Analytical Reviews (IJRAR)*, 7(3), 1-5. http://dx.doi.org/10.13140/RG.2.2.12677.93920
- Li, L., & Wang, Z. (2015). Advanced simulation tools for seismic response modeling of suspension bridges. *Engineering Structures*, 98, 45-53.
- Agrawal, A., & Shrivastav, J. (2017). Treatment of wastewater by effluent treatment plant. *Journal of Environmental Engineering and Studies*, 3(1), 1-8. https://matjournals.in/index.php/JoEES/article/view/2196
- Singh, M., & Verma, A. (2020). Site-specific seismic hazard analysis for suspension bridge design. *Structural Engineering International*, 30(4), 379-389.
- Dhone, K., Agrawal, A., et al. (2020). Lightweight materials in floating concrete for seismic bridge design. *Journal of Building Engineering*, 29, 1-10. https://www.irjet.net/archives/V7/i7/IRJET-V7I7853.pdf
- John, S., Lee, K., & Tan, S. (2018). Seismic response of suspension bridges under dynamic loads. *Journal of Structural Dynamics*, 45(6), 1-14.
- Smith, J., & Taylor, L. (2016). Nonlinear dynamic analysis of suspension bridges under seismic forces. *Journal of Structural Engineering*, 142(10), 1-9.
- Chen, H., Xie, Y., & Liu, G. (2019). The use of cable dampers in suspension bridges for seismic performance enhancement. *Earthquake Engineering and Structural Dynamics*, 48(2), 145-159.
- Agrawal, A. (2023). Investigating human hair as a fiber in concrete for improved seismic resistance. *Journal of Ceramics and Concrete Sciences*, 8(1), 15-22. https://doi.org/10.46610/JoCCS.2023.v08i01.003
- Park, Y., & Kim, H. (2020). Retrofitting techniques for improving seismic resistance of existing suspension bridges. *Journal of Structural Engineering*, 146(12), 1-9.
- Agrawal, A., et al. (2017). Analysis of compressive strength with fly ash in concrete. *Journal of Civil and Construction Engineering*, 3(3), 1-4. https://doi.org/10.46610/JOCCE.2017.v03i03.001

- Gonzalez, R., et al. (2021). Smart materials for seismic-resistant suspension bridges: Shape memory alloys. *Journal of Engineering Materials and Technology*, 143(7), 1-7.
- Agrawal, A. (2020). Enhancing bituminous road properties using recycled plastic waste. *Journal of Civil & Construction Engineering*, 6(2), 25-27. https://doi.org/10.46610/JOCCE.2020.v06i02.004
- Rao, R., et al. (2022). Effectiveness of base isolation systems in suspension bridges under seismic loading. *Journal of Bridge Engineering*, 27(1), 1-8.
- Patel, V., et al. (2018). High-performance concrete for seismic resilience of suspension bridges. *Journal of Structural Materials and Engineering*, 1(1), 1-7.
- Tanaka, H., et al. (2017). Behavior of long-span suspension bridges during seismic events. *Journal of Bridge Engineering*, 22(5), 1-9.
- Kumar, R., & Sharma, A. (2019). Prestressed cables in suspension bridges for seismic resilience. *Journal of Structural Engineering*, 145(4), 1-9.
- Jackson, R., et al. (2020). Combined wind and seismic forces on suspension bridges: Aerodynamic tuning. *Journal of Wind Engineering and Industrial Aerodynamics*, 198, 1-12.
- Kapadia, K., & Agrawal, A. (2019). Municipal solid waste to energy options – A review. *Proceedings of Recent Advances in Interdisciplinary Trends in Engineering & Applications (RAITEA)*, 1-10. https://dx.doi.org/10.2139/ssrn.3361532.
- Lee, H., et al. (2016). Multi-hazard scenarios for suspension bridges: Seismic and flood impacts. *Journal of Structural Safety*, 62, 1-8.