

Comparative Analysis of Advanced Bridge Inspection Practices and Bridge Management Systems: Insights from India, the United States, and China

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Abstract— Bridges are essential components of transportation infrastructure, requiring effective inspection and management to ensure safety and durability. This study presents a comparative analysis of bridge inspection practices and Bridge Management Systems (BMS) in India, the United States, and China. It evaluates key aspects such as inspection methodologies, rating systems, inspector qualifications, and the use of advanced technologies. The results indicate that the United States follows a standardized and data-driven approach, India adopts a centralized and evolving system, and China demonstrates a technology-driven framework with real-time monitoring and predictive maintenance. The study highlights the growing role of advanced tools such as Structural Health Monitoring and non-destructive testing in improving inspection efficiency. It concludes that adopting modern technologies and standardized practices can significantly enhance bridge management systems.

Keywords: Bridge Inspection, Bridge Management System (BMS), Structural Health Monitoring (SHM), Non-Destructive Testing (NDT), IBMS, NBIS, JTG

I. INTRODUCTION

Road transport is the most widely used and cost-effective mode of transportation, making it essential for economic development. Its accessibility and operational efficiency have led governments to invest significantly in transportation infrastructure. Among its components, bridges play a critical role in maintaining network continuity and ensuring efficient movement [1].

With time, bridges are subjected to aging, increased traffic loads, and environmental deterioration, making maintenance a major concern. In the United States, the average bridge age is about 42 years, with most designed for a 50-year service life [3]. Over 40% of bridges have exceeded this limit, resulting in a rehabilitation backlog estimated at \$123 billion.

In India, the Ministry of Road Transport and Highways (MoRTH) launched the Indian Bridge Management System (IBMS) in 2015 to support inventory creation, condition assessment, and maintenance planning. The average bridge age ranges from 30 to 40 years, with many designed for 50–75 years. More than 200 bridges have exceeded 75 years, indicating the need for significant repair and rehabilitation investments. Accordingly, about ₹2.70 lakh crore has been allocated for road infrastructure [4].

China, in contrast, has rapidly developed a vast bridge network through large-scale infrastructure programs. Although many bridges are relatively newer, challenges related to durability and lifecycle management persist due to rapid construction. China has addressed these through advanced inspection technologies and national standards (JTG codes), supported by the Ministry of Transport[8]. The use of Structural Health Monitoring (SHM), UAVs, and AI-based systems enables real-time condition assessment and predictive maintenance [9].

Overall, while the United States focuses on aging infrastructure, India deals with both aging and expansion, and China emphasizes technology-driven management. A comparative analysis of these systems offers valuable insights into effective bridge inspection and management practices.

II. LITERATURE REVIEW

The literature presents a comprehensive evaluation of bridge inspection practices and bridge management systems across India, the United States, and China[8]. It examines the operational frameworks, technological approaches, and policy mechanisms adopted in these countries. Existing studies highlight both commonalities and key differences in inspection methodologies, data management systems, and maintenance strategies. While the United States emphasizes standardized inspection protocols and data-driven decision-making, India focuses on developing centralized inventory

systems such as IBMS. In contrast, China demonstrates a technology-oriented approach, integrating advanced monitoring systems and intelligent inspection techniques. Collectively, the literature underscores the evolving nature of bridge management and the need for efficient, adaptive, and sustainable practices across different national contexts.

American bridge management agencies and funding

The expansion of the interstate highway system in the United States during the 1950s and 1960s led to rapid growth in bridge construction (Federal Highway Administration) [4]. However, systematic inspection and maintenance gained prominence only after the collapse of the Silver Bridge in 1967, which triggered the enactment of the Federal-Aid Highway Act of 1968. Subsequently, the Federal Highway Administration (FHWA) established the National Bridge Inspection Standards (NBIS) in 1971. These standards defined uniform requirements for inspection procedures, frequency, personnel qualifications, and reporting systems, forming the foundation of the National Bridge Inventory (NBI) (FHWA, 2018; AASHTO [3].

To support data-driven bridge management, the FHWA funded the development of the Pontis Bridge Management System in 1991, which has been widely adopted across more than 40 states with varying implementation levels. Bridge funding in the United States is a shared responsibility between federal, state, and local agencies. Financial resources are primarily derived from fuel taxes, toll revenues, and government allocations. Programs such as the Highway Bridge Replacement and Rehabilitation Program (HBRRP), evolved from earlier initiatives in the 1970s, provide significant federal assistance. Typically, up to 80% of eligible bridge projects are funded through federal programs, with states managing the allocation based on NBIS-compliant inspection data [5].

In India, bridge management is primarily governed by the Ministry of Road Transport and Highways (MoRTH) and supported by agencies such as the National Highways Authority of India (NHAI). The introduction of the Indian Bridge Management System (IBMS) in 2015 marked a major step toward centralized bridge inventory and condition assessment. Funding for bridge construction and maintenance is derived from central and state government budgets, fuel cess, and public-private partnership (PPP) models.[1] Unlike the United States, funding mechanisms in India are more centralized, with increasing emphasis on national infrastructure programs and dedicated budget allocations for maintenance and rehabilitation.

China follows a more centralized and state-driven approach to bridge management and funding. The Ministry of Transport oversees bridge infrastructure under national standards such as the JTG codes. Large-scale infrastructure development is financed through a combination of central government funding, provincial investments, and state-owned enterprises. China's model emphasizes long-term infrastructure planning, with substantial investment directed toward both new construction and maintenance of strategic transport networks. Advanced Bridge Management Systems integrated with digital platforms and real-time monitoring technologies further support efficient allocation of maintenance resources [7].

Overall, while the United States employs a decentralized yet standardized framework supported by federal funding programs, India is transitioning toward centralized digital management with mixed funding sources. In contrast, China adopts a highly centralized, investment-intensive model with strong integration of technology and policy, enabling efficient management of its rapidly expanding bridge network.

Table No. 1 Bridge Infrastructure Particulars

Country	Total structures	Total length
USA	6,17,000+	6,586,610 km
India	1,73,000+	6,617,100 km
China	900,000+	5,490,000+ km

Indian Bridge Management Systems and Fundig

The Government of India, through the Ministry of Road Transport and Highways (MoRTH), established the Indian Bridge Management System (IBMS) to enable systematic evaluation of bridge conditions across the National Highway Network. The system utilizes Mobile Bridge Inspection Units (MBIU) along with indigenously developed software to conduct inventory and condition assessments. IBMS has documented over 169,000 bridge structures and culverts, including more than 200 bridges older than 75 years, indicating aging infrastructure and potential vulnerability. The system has also identified 147 critically distressed bridges requiring rehabilitation or reconstruction, while a portion of the assessed bridges remains in good condition, reflecting targeted maintenance effectiveness.

In comparison, the United States employs the Pontis Bridge Management System, developed under the Federal Highway Administration (FHWA), which provides a more comprehensive and decision-oriented framework. In addition

to maintaining bridge inventory and condition data, Pontis incorporates cost analysis, deterioration modeling, and optimization tools for maintenance planning.[4] This enables agencies to prioritize interventions based on both structural condition and economic considerations, supporting long-term asset management.

China adopts a more technologically advanced and integrated approach to bridge management. Under the supervision of the Ministry of Transport, China utilizes digital Bridge Management Systems aligned with national standards (JTG codes), combining centralized databases with real-time monitoring technologies. These systems incorporate Structural Health Monitoring (SHM), big data analytics, and AI-based evaluation tools to assess bridge performance continuously. Unlike IBMS, China’s framework emphasizes predictive maintenance, lifecycle cost analysis, and automated condition assessment, particularly for large and strategically important bridges [8].

Table No 2: Features of India US & China BMS

National	Name	Bridge details		Breakdown model	Cost information
		Bridge context	Bridge security		
U.S	PONTIS	Y	Y	Y	Y
INDIA	IBMS	Y	N/A	N/A	Y
China	Integrated DBMS	Y	Y	Y	Y

(Source:- Author)

III. BRIDGE INSPECTION METHODOLOGY

American Inspection Reference Manuals

Bridge inspection practices in the United States are governed by well-established and standardized manuals. Key references include the FHWA Bridge Inspector’s Reference Manual published by the Federal Highway Administration (FHWA) and the AASHTO Manual for Bridge Evaluation. These documents provide comprehensive guidance on inspection procedures, condition rating systems, defect identification, and reporting formats. The U.S. system emphasizes periodic inspections, strict compliance with National Bridge Inspection Standards (NBIS), and defined qualification requirements for inspectors. Inspection data is further integrated with advanced Bridge Management Systems to support informed maintenance and rehabilitation planning.

Indian Inspection Reference Manuals

In India, bridge inspection guidelines are issued by the Indian Roads Congress (IRC) and the Ministry of Road Transport and Highways (MoRTH). IRC SP:35 outlines procedures for

routine inspection and timely maintenance to ensure structural safety and serviceability. IRC SP:18 provides standardized methods for inspection, reporting, and record management of highway bridges. These manuals establish a structured inspection framework; however, recent developments are gradually incorporating digital tools and modern techniques aligned with the Indian Bridge Management System (IBMS).

Chinese Inspection Reference Manuals

China follows a standardized and technology-driven approach to bridge inspection under the Ministry of Transport. Inspection practices are guided by national standards such as the JTG/T H21 Specifications for Maintenance of Highway Bridges and Culverts and related JTG codes. These standards define inspection frequency, condition evaluation methods, and maintenance procedures.

China places strong emphasis on advanced inspection technologies, including Structural Health Monitoring (SHM), unmanned aerial vehicles (UAVs), and sensor-based systems for continuous monitoring. Inspection processes are supported by digital platforms that enable real-time data analysis and condition assessment. Additionally, structured training and certification systems ensure the competency of inspectors, particularly for complex bridge structures. This approach enables predictive maintenance and efficient lifecycle management.

Overall, the United States adopts a regulation-driven and standardized inspection system, India follows a structured yet evolving framework supported by IBMS, and China implements a technology-intensive and data-oriented methodology. This comparison highlights the transition from conventional inspection practices toward more advanced and predictive bridge management approaches.

IV. BRIDGE INSPECTION CATERGOTY AND FREQUENCY

In the United States, bridge inspections are defined under NBIS and categorized into seven types, including initial, routine, damage, in-depth, fracture-critical, underwater, and special inspections. Routine inspections are conducted at intervals not exceeding 24 months, forming the basis of systematic bridge evaluation.

In India, inspections are classified mainly by frequency into routine, detailed, and special inspections. Routine inspections are generally carried out annually, while detailed inspections involve comprehensive assessment of all components. Special

inspections are conducted after unusual events. This approach supports condition assessment and maintenance planning within the IBMS framework.

China follows a structured inspection system including routine, periodic, special, and emergency inspections under JTG standards. Periodic inspections are typically conducted within 1–3 years. A key feature is the integration of Structural Health Monitoring (SHM), enabling continuous and real-time assessment of bridge performance.

Table No.3 Bridge Inspection Frequency Comparison

Parameter	USA	India	China
Inspection Types	7	3	4
Maximum Frequency	24 Months	12-24 Months	24-36 Months
SHM	Limited	Emerging	Extensive

(Source: - Author)

The comparison highlights distinct approaches to bridge inspection across the three countries. The United States adopts a highly standardized and detailed classification system, ensuring consistency and regulatory compliance in inspection practices. India follows a simplified, frequency-based approach, which facilitates large-scale implementation and efficient inventory management, although it involves comparatively less categorization. In contrast, China integrates structured inspection frameworks with advanced technologies such as Structural Health Monitoring (SHM), enabling continuous and real-time evaluation of bridge performance. This reflects a transition from conventional periodic inspection methods toward more advanced, technology-driven, and predictive maintenance strategies.

Inspection recording & reporting

In the United States, bridge inspection data is recorded using standardized FHWA guidelines, including inventory, condition ratings, load capacity, and maintenance history. The use of uniform coding systems ensures consistency and supports decision-making through Bridge Management Systems such as Pontis.

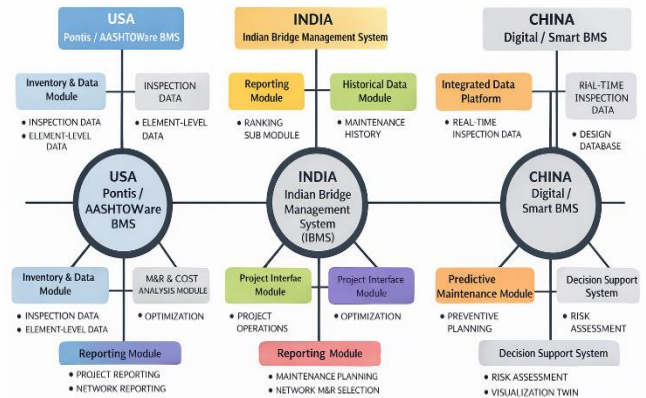
In India, inspection data is managed through the Indian Bridge Management System (IBMS), a centralized platform that stores information from construction to inspection. It includes modules for reporting, historical data, maintenance planning, and lifecycle cost analysis, enabling systematic bridge management. China employs a digital and technology-driven approach, integrating inspection records with real-time data

from Structural Health Monitoring (SHM) systems and sensors. Centralized platforms and data analytics support continuous monitoring and predictive maintenance.

Overall, the U.S. focuses on standardized reporting, India on centralized data management, and China on real-time, technology-based systems.

Bridge management systems

Bridge Management Systems (BMS) are systematic frameworks developed to support the efficient management, maintenance, and operation of bridge infrastructure throughout its lifecycle. These systems integrate data related to bridge inventory, inspection, condition assessment, and maintenance history to facilitate informed decision-making. The primary objective of BMS is to ensure structural safety, optimize resource allocation, and extend the service life of bridge assets.



Dia. No1 Comparison of BMS US, India & China (Source;- Author)

The diagram highlights a progression in bridge management practices across the three countries. The United States adopts a data-driven and optimization-based approach, focusing on standardized inspections and cost-efficient decision-making. India represents a transitional stage with a centralized and modular system (IBMS), emphasizing systematic data management and maintenance planning. In contrast, China demonstrates a technologically advanced framework integrating real-time monitoring, AI, and predictive maintenance. This progression reflects a shift from conventional, periodic inspection methods toward intelligent, data-driven, and predictive bridge management systems, emphasizing the growing role of digital technologies in modern infrastructure management.

Bridge Inspector Qualifications

Bridge inspector qualification standards are essential to ensure accuracy, consistency, and reliability in bridge inspection practices. Training programs for inspection team leaders and program managers are provided through courses. Team leaders are also expected to undergo certified training and possess sufficient field experience, ensuring technical competency and adherence to standardized inspection procedures.

Table No 4 Bridge Inspector Qualification Standards

Parameter	USA	India	China
Education	Bachelor's (preferred)	Diploma/Bachelor's (varies by role)	Bachelor's (mandatory)
Training	FHWA-certified training	IRC/MoRTH guidelines (limited formal training)	Government-approved technical training (JTG)
Certification	PE license required for senior roles	Not strictly mandatory	Mandatory licensing/certification
Experience	Defined (2-10+ years based on role)	Experience-based hierarchy	Experience linked to complexity level
Advanced Skills	Limited (project-specific NDT)	Emerging	Extensive (SHM, UAV, AI tools)
Continuing Education	Mandatory (every 5 years)	Limited/Informal	Regular skill upgradation required

(Source;- Author)

Inspection Technology

Inspection technologies are essential for accurate evaluation of bridge condition and structural performance. In the United States, AASHTO and FHWA guidelines provide a comprehensive framework for material testing and non-destructive testing (NDT), including ultrasonic, magnetic, radar, radiographic, and infrared techniques. These methods are supported by standardized procedures and ASTM specifications. Visual inspection remains fundamental, with detailed guidance on component-level assessment and defect documentation.

In India, inspection practices are largely based on visual assessment, supplemented by limited NDT methods such as ultrasonic testing and rebound hammer tests. While IRC guidelines establish standard procedures, the adoption of advanced inspection technologies is still developing, with gradual integration through systems like IBMS.

China adopts a technology-intensive approach, combining conventional NDT methods with advanced tools such as Structural Health Monitoring (SHM), UAV-based inspections, and AI-driven defect detection. Real-time data acquisition and

analysis enable continuous monitoring and support predictive maintenance strategies.

The United States employs standardized NDT-supported inspection practices, India relies on conventional methods with gradual technological advancement, while China demonstrates a shift toward advanced, real-time, and intelligent inspection systems.

V. BRIDGE INSPECTION RATING SYSTEMS

Bridge inspection rating systems in the United States, India, and China demonstrate distinct methodologies reflecting their respective infrastructure management practices. In the United States, the National Bridge Inspection Standards (NBIS) utilize a quantitative rating scale ranging from 0 to 9, where 0 indicates failure and 9 represents excellent condition. Structural components such as decks, superstructures, and substructures are systematically evaluated through routine, fracture-critical, and underwater inspections. The approach emphasizes consistency, safety, and data-driven assessment of structural performance.

Table No 5 Bridge Condition Rating System Comparison

Rating Level	Usa	India	China
Excellent	9	Very good	Grade 1
Good	7-8	good	Grade 2
Fair	5-6	Fair	Grade 3
poor	3-4	Poor	Grade 4
Critical/Failed	0-2	Very Poor	Grade 5

(Source;- Author)

In India, bridge condition assessment follows a qualitative classification system based on IRC guidelines, such as IRC:SP:35. Bridges are categorized into five condition states: Very Good, Good, Fair, Poor, and Very Poor. The evaluation primarily relies on visual inspection, focusing on identifying visible defects, assessing structural safety, and understanding durability under varying environmental conditions. Non-destructive testing methods are applied selectively to support detailed assessment when required.

China adopts a standardized and semi-quantitative rating system guided by national codes such as JTG/T H21. Bridges are typically classified into condition grades ranging from Grade 1 (excellent) to Grade 5 (critical condition). The evaluation involves component-level assessment of superstructure, substructure, and deck systems, with overall condition determined through weighted analysis. In addition to visual inspection and conventional testing, China integrates

advanced technologies such as Structural Health Monitoring (SHM), enabling real-time data incorporation into the rating process[9].

U.S. emphasizes a highly quantitative and standardized approach, India follows a qualitative and experience-based system, and China combines quantitative evaluation with advanced monitoring technologies. This reflects a transition toward more data-driven and predictive bridge condition assessment methodologies.

VI. NOVEL TECHNOLOGY FOR BRIDGE INSPECTION

Accuracy and reliability in bridge inspection are essential for effective Bridge Management Systems. Traditional visual inspection methods, widely used in both the United States and India, are often subject to human error and limitations in accessibility[10]. To address these challenges, modern inspection practices increasingly incorporate advanced technologies such as Structural Health Monitoring (SHM) and Non-Destructive Testing (NDT). While these technologies are being adopted in both countries, their level of implementation varies, with China demonstrating more extensive integration.[9]

Key emerging technologies include

- **Unmanned Aerial Vehicles (UAVs/Drones):** Enable high-resolution imaging and thermal data collection in inaccessible areas, improving safety and reducing inspection time.
- **LiDAR (Light Detection and Ranging):** Facilitates the development of precise 3D models for detecting deformation and alignment issues.
- **Acoustic Emission Testing (AET):** Allows early detection of structural damage through real-time monitoring of stress-induced acoustic signals.
- **Digital Twin Technology:** Provides virtual simulation of bridge performance for predictive maintenance and lifecycle analysis.
- **Thermal Imaging:** Uses infrared techniques to identify hidden defects such as cracks, moisture ingress, and material degradation.

These technologies significantly enhance inspection accuracy and reduce dependence on manual methods. While the United States is progressively integrating such tools within established frameworks, and India is in the early stages of adoption, China has advanced toward large-scale

implementation of intelligent and automated inspection systems.

The integration of novel technologies marks a transition from conventional inspection practices to more precise, efficient, and data-driven approaches, with increasing emphasis on automation and predictive maintenance in bridge management.

VII. DISCUSSION

The present study evaluates bridge inspection practices and Bridge Management Systems in the United States, India, and China to assess the benefits of advanced inspection techniques. The comparison indicates that while both the United States and India have developed structured and reliable BMS frameworks over time, their approaches differ in terms of technological integration and implementation depth.

The U.S. system emphasizes standardized procedures and data-driven decision-making, whereas India focuses on centralized data management with evolving analytical capabilities.[10] China, in contrast, demonstrates a more advanced, technology-oriented approach with extensive integration of real-time monitoring and intelligent systems[9].

All three countries maintain comprehensive documentation and reporting procedures, ensuring systematic recording of inspection data. However, differences arise in the application of modern technologies. Periodic inspection remains effective for conventional bridges, particularly in the United States and India, while continuous Structural Health Monitoring (SHM) is more suitable for critical and long-span structures, as widely adopted in China.

Advanced techniques such as Non-Destructive Testing (NDT), LiDAR, and SHM complement each other by improving accuracy and enabling detailed assessment of structural performance. While SHM provides continuous, bridge-specific data, technologies like LiDAR support large-scale evaluation across multiple structures. The integration of these methods enhances bridge inventory management and supports predictive maintenance strategies.

In essence, the study highlights that the future of bridge management lies in the combined application of conventional inspection methods and advanced technologies, with increasing emphasis on automation, real-time monitoring, and data-driven decision-making.

VIII. CONCLUSION

This study concludes that bridge management practices in the United States and India exhibit similarities in terms of development, structure, and scale, enabling both countries to benefit from advancements in bridge inspection and management technologies. The Indian Bridge Management System (IBMS) demonstrates strong potential to incorporate and adapt proven methodologies from the U.S., particularly in areas of data-driven decision-making and lifecycle-based management.

In comparison, China represents a more advanced stage of implementation, characterized by the integration of real-time monitoring, intelligent systems, and predictive maintenance approaches. This highlights the direction toward which modern bridge management systems are evolving.

Based on the findings, it is recommended that Indian agencies adopt advanced international practices, including standardized inspection protocols, enhanced non-destructive testing methods, and digital technologies such as Structural Health Monitoring and data analytics. Such integration would strengthen the effectiveness of IBMS and support the transition toward a more efficient, technology-driven bridge management framework.

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