

Integrated Bridge Assessment Using TLS and Load Rating: Case Study of Citarum Baru Bridge

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ABSTRACT

Bridges are critical components of transportation infrastructure that support mobility, economic activity, and public safety. Continuous exposure to traffic loads, environmental effects, and material aging requires regular inspection and evaluation to ensure structural performance and serviceability. This study assesses the Citarum Baru Bridge by integrating Load Rating Analysis using the Rating Factor (RF) approach with Terrestrial Laser Scanner (TLS)-based inspection. Structural capacity was evaluated using the Factored Load Method in accordance with national bridge design standards and technical guidelines. Numerical modeling was conducted using CSI SAP2000 v.14 to simulate structural behavior and calculate RF values for critical bridge components. The results show that the Citarum Baru Bridge remains structurally safe, with RF values exceeding 1 for all evaluated elements. Diagonal trusses (A1), longitudinal girders (A2), transverse girders (A3), and diaphragms (A4) and (A5) demonstrate adequate load-carrying capacity under factored loading conditions. Nevertheless, visual inspection and high-resolution TLS data identified moderate structural deterioration, including surface defects and minor geometric deviations. Based on these observations, the bridge was assigned a Condition Rating of 3, indicating satisfactory performance but a clear need for scheduled maintenance. In conclusion, integrating TLS-based inspection with Load Rating Analysis improves assessment accuracy, maintenance planning, service life, and safety.

Keywords: bridge evaluation, load rating, Terrestrial Laser Scanner (TLS), citarum baru bridge, structural capacity, maintenance, RF analysis.

INTRODUCTION

Bridges are essential transportation infrastructure components that connect separated roadways across obstacles like valleys, rivers, and ravines [1]. While crucial for economic development and transportation efficiency, bridges face continual deterioration from environmental factors including temperature fluctuations, rainfall, and wind [2,3]. In Indonesia, approximately 7% of the country's 89,000 bridges require immediate maintenance or rehabilitation according to the Ministry of Public Works and Housing [4], highlighting the critical need for effective inspection and assessment methodologies.

Indonesian regulations mandate structured bridge inspection schedules: inventory inspections for new bridges, annual routine inspections, and detailed inspections every five years [5]. However, traditional manual inspection methods present significant challenges, including subjectivity, limited accessibility, and time constraints [6,7].

Recent technological advancements have introduced more efficient inspection approaches. Terrestrial Laser Scanning (TLS) enables rapid data acquisition with high accuracy, reducing inspection time by up to 90% compared to traditional methods [8], while detecting defects as small as 2 mm [9]. Multiple studies have validated TLS reliability for measuring bridge dimensions and detecting structural defects [10,11].

Complementing physical inspection, bridge load rating provides a standardized approach for evaluating structural capacity. The Load and Resistance Factor Rating (LRFR) methodology offers a probabilistic framework to determine safe load-carrying capacity while accounting for uncertainties in both load and resistance factors [12,13].

While TLS has been successfully implemented for several Indonesian bridges [14-16], the critical Citarum Baru Bridge in West Bandung Regency—a vital economic link between northern and southern Bandung—requires comprehensive assessment [17].

This study aims to evaluate the Citarum Baru Bridge condition by integrating TLS technology with Load Rating Analysis, addressing the research gap where limited studies have combined both approaches [18]. This integrated methodology provides a more holistic assessment of bridge condition and structural capacity, enabling informed decision-making for maintenance and rehabilitation strategies applicable to similar infrastructure throughout Indonesia and other developing regions.

RESEARCH METHODS

Materials

As shown in Figure 1, the Citarum Baru Bridge, located in West Bandung Regency, Indonesia, was selected as the object of this research. This bridge is situated at coordinates -6.991084, 107.626544 to -6.991297, 107.626414, spanning the Citarum River, one of Indonesia's most significant waterways [1]. The bridge is 60 meters in length and 9 meters in width, and plays a critical role in connecting the northern and southern regions of Bandung. According to archival records from the Ministry of Public Works and Housing [4], the bridge was constructed in 1951, making it over 70 years old at the time of this study.



Figure 1. Citarum Baru Bridge

The Citarum Baru Bridge is a steel truss structure, which has experienced deterioration due to its age and the continuous load of traffic over the years. According to traffic survey data collected by the local transportation authority, the bridge serves approximately 2,458.80 Equivalent Single Axle Loads (ESAL) daily, including both passenger vehicles and commercial trucks [18]. The bridge is situated in a geographically challenging area, which exacerbates its exposure to environmental factors such as weathering, temperature changes, and mechanical stresses [2]. The surrounding region experiences an average annual rainfall of 2,000 mm, with a humid tropical climate that accelerates corrosion processes in steel structures [19]. Due to these factors, regular inspections are essential to ensure the bridge's structural integrity and safe use [3].

Methods

Terrestrial Laser Scanning (TLS)

The assessment of the Citarum Baru Bridge was carried out using Terrestrial Laser Scanning (TLS), as prescribed by national bridge inspection regulations [5]. A Stonex X120GO handheld TLS was employed during the assessment, with a scanning range between 0.5 m to 120 m and a scanning point frequency of 320,000 points per second. This device was selected based on its high accuracy (± 2 mm at 10 m range) and portability, making it suitable for field operations in challenging environments [20].

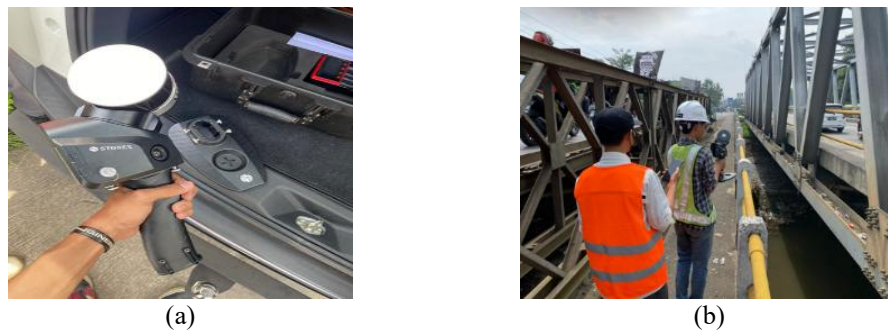


Figure 2. Data Acquisition Using TLS; (a) Stonex X120GO handheld TLS; (b) Acquisition in the field

The scanning process followed the methodology proposed in bridge inspection studies [21], with multiple scanning positions established to ensure comprehensive coverage. A minimum of 30% overlap between adjacent scans was maintained to facilitate accurate point cloud registration [22]. Control points were established using a total station with an accuracy of ± 1 mm to georeference the scans and verify dimensional accuracy [23].

In addition to TLS, Light Detection and Ranging (LiDAR) Simultaneous Localization and Mapping (SLAM) was used to capture aerial imagery of the bridge components that could not be scanned directly by TLS. This dual technology approach enhances the accuracy and completeness of the bridge inspection process [24]. The SLAM-based LiDAR system, mounted on a DJI Matrice 300 RTK drone, provided complementary data for areas with limited ground accessibility, such as the underside of the bridge deck and connection points between trusses [25].

Visual Inspection

Following the guidelines from Regulation No. 01/P/BM/2022, the bridge's structural and non-structural components were visually inspected and rated on a scale of 0 to 5 based on their condition. Components with severe damage received higher ratings, while those in good condition were rated 0, indicating no need for maintenance. The visual inspection was conducted by a team of three certified bridge inspectors to minimize subjectivity [5].

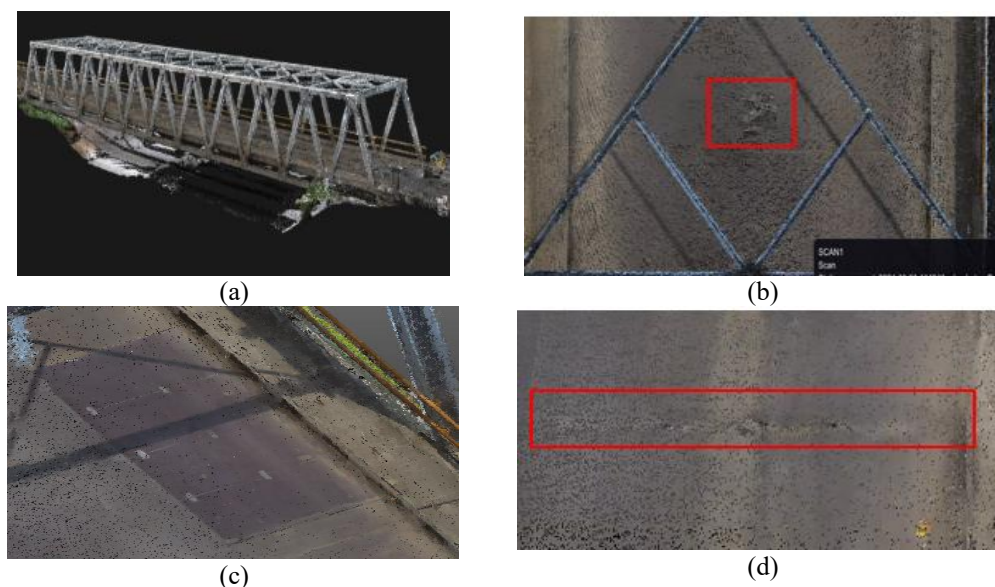


Figure 3. Visual Inspection with TLS; (a) bridge 3d model; (b) holes in the vehicle floor; (c) Steel plate to cover vehicle potholes; (d) cracks in the vehicle floor

The inspection team documented visible defects using high-resolution photography, with each photograph georeferenced and linked to the corresponding location on the TLS point cloud. This integrated approach to documentation facilitated more comprehensive damage assessment and improved spatial understanding of defect patterns [26].

Data Analysis

Bridge Inspection Using Guideline [3]

The bridge inspection consists of inventory inspection, routine inspection, and detailed inspection of the superstructure components, river flow, and approach road. The inventory inspection is conducted to obtain administrative data, load capacity information, traffic information, and bridge elements such as type, material, and characteristics following the form provided by guideline [3]

In routine inspection, the bridge's condition is assessed including safety, security, and comfort aspects using the inspection form adopted from guideline [3]. The maintenance and rehabilitation history of the bridge was also assessed using the aforementioned form. If during routine inspections a more in-depth observation is required, a detailed inspection of the bridge should be carried out. Detailed inspection aims to archive all damage and assess the condition of each bridge component. The overall condition of the bridge is determined based on the condition of each bridge component.

Determination of the condition rating is based on the bridge's actual condition, as defined in Table 1, which follows the criteria established by the Indonesian Ministry of Public Works and Housing [4]. This rating system is comparable to that used by the Federal Highway Administration (FHWA) in the United States [27], but has been adapted to reflect Indonesian engineering practices and environmental conditions.

Table 1. Criteria for Determining Condition Rating

Rating System	Criteria	Rate
Structure (S)	Dangerous	1
	Not Dangerous	0
Damage (R)	Severe	1
	Not Severe	0
	More than x %	1
	Less than x %	0
Quantity (K)	X = 30 % for structural elements and 50% for nonstructural elements	
Function (F)	Element not functioning	1
	Element functioning	0
Influence (P)	Affects other elements	1
	Does not affect other elements	0
CONDITION RATE (NK)	$NK = S + R + K + F + P$	0 - 5

The condition rate is the sum of the variables including S (hazardous condition), R (severity of damage), K (quantity of damage), F (function of the element), and P (impact on other elements). The condition rate varies from 0 to 5 with the following descriptions:

1. NK = 0, indicating the bridge is in good condition;
 2. NK = 1, indicating the bridge is slightly damaged, where the damage can be repaired through routine maintenance, and does not impact safety or bridge function;
 3. NK = 2, indicating the bridge is moderately damaged, where the damage requires monitoring or maintenance in the future;
 4. NK = 3, indicating the bridge is severely damaged, where the damage requires attention as it may become serious within 12 months;
 5. NK = 4, indicating the bridge is in a critical condition, where the serious damage requires immediate attention;
- NK = 5, indicating the bridge is collapsed, rendering it non-functional.

In this study, the damage assessment was performed on the superstructure components only, focusing on critical structural elements [6].

Rating Factor

Rating factor (RF) is the ratio between the available capacity of the structure and the specific live load value (rating vehicle) that imposes a load on the bridge [28]. A rating vehicle can be either a standard load or a daily vehicle load. Rating factor score should be greater than one (1) to ensure that the bridge structure has sufficient capacity towards daily vehicle loads. According to AASHTO: The Manual for Bridge Evaluation [11], rating factor analysis only considers the effects of dead load (bridge structure self-weight) and live load. Loads induced by environmental effects such as temperature, wind, and earthquakes are not taken into account in the rating factor analysis.

The data required for Rating Factor (RF) analysis can be obtained from as-built drawings and on-site inspection data, and/or from in-situ load testing. However, in-situ load tests involve higher costs, longer implementation periods, and complex traffic management measures to minimize traffic disruption. Therefore, in this study, the Rating Factor was determined using as-built drawings and on-site data, including bridge administrative records, material properties, geometric dimensions, and structural profiles. This approach is consistent with the methodology proposed by Wang, Li, Hao, and Parry [29]. The Rating Factor (RF) is calculated using:

$$RF = (\phi \cdot R_n - \sum(\gamma \cdot DL)) / (\gamma \cdot LL \cdot (1 + I))^{1.1}$$

Where RF is the rating factor – the comparison value between the remaining capacity of the structural element (against tension, compression, moment, shear) and the internal forces generated by the live load applied (rating vehicle), R_n is the nominal capacity of the structural element (moment, tension, compression, shear, and flexure), and ϕ is the system factor. Furthermore, γD refers to dead load factor (1.3 for inventory rating and operating rating), γL is the live load factor (2.17 for inventory rating and 1.3 for operating rating), DL is the internal forces due to dead load, LL is the internal forces due to live load (rating vehicle), and I refers to impact/shock factor. Where all variables follow standards specified for Load and Resistance Factor Rating (LRFR) [12].

Data obtained from on-site inspection, including the geometric and dimension of the Citarum Baru Bridge was used to build the 3D structural model. The bridge was modeled using SAP2000 v.14 to calculate the internal forces of the bridge component towards applied loads. Several bridge components that is diagonal trusses (A1), longitudinal girders (A2), transverse girders (A3), and diaphragms (A4 & A5) was created on the bridge structural model, as can be seen on Figure 4.

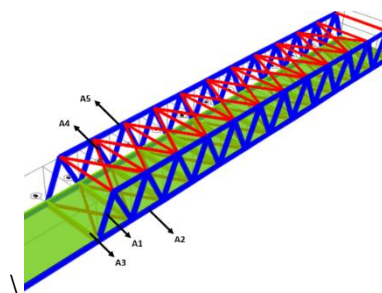


Figure 4. 3D Bridge Model Using SAP2000

The modeling approach followed the recommendations of Huang, Yu, and Li [31]. All connections were modeled as rigid joints to reflect the behavior of welded and bolted connections in the actual structure, based on the findings of Koch, Klein, and Zobel [32]. Material properties for structural steel were defined according to SNI 1729:2020 [33], with appropriate reductions applied to account for age-related degradation as suggested by Adhikari, Moselhi, and Bagchi [5].

Loads applied on the bridge structure were adopted from SNI 1725:2016 (Loading for bridges), that covers permanent loads (covering self-weight, asphalt, sidewalks, and other elements) and live vehicle loads. The load combinations followed the requirements of SNI 1725:2016, which specifies different load factors for various limit states similar to those in AASHTO LRFD Bridge Design Specifications [12].

For permanent loads, a detailed inventory of all bridge components was created based on the TLS data, with material unit weights assigned according to SNI 1725:2016. Live loads were applied according to the "T" loading system, with an impact factor calculated according to span length [12]. The dimension of each bridge component was derived from the on-site survey using TLS. Hand calculations were conducted to determine the axial capacity (due to tension and compression) of the steel bridge truss component as per SNI 1729:2020 [33] -specifications for structural steel buildings.

For tensile members, the nominal tensile strength (P_n) was calculated according to Section 5.1 of SNI 1729:2020. For compression members, the nominal compressive strength was determined considering both flexural buckling and local buckling, following Section 5.3 of SNI 1729:2020 [33]. Flexural members were analyzed for limit states of yielding, lateral-torsional buckling, and local buckling as specified in Section 6 of SNI 1729:2020 [33].

Capacity reduction factors (ϕ) were applied according to SNI 1729:2020 [33], with values of 0.9 for tension and flexure, and 0.85 for compression. Additional system factors were applied based on bridge condition following the recommendations of Muslikh, Hamdani, and Kusumah [28].

RESULT AND DISCUSSION

Bridge Inspection Results

The comprehensive inspection of the Citarum Baru Bridge was conducted using visual assessment methods supplemented by Terrestrial Laser Scanner (TLS) technology. The bridge is located at coordinates -6.991084, 107.626544 to -6.991297, 107.626414, with a total length of 93 meters. It permits a Gross Axle Weight of 8 tons and experiences an average daily traffic load of 2458.80 ESAL (Equivalent Single Axle Load) [18].

Inspection revealed a truss bridge structure with components dimensioned as detailed in Table 2, verified through both physical measurements and TLS data.

Table 2. Bridge Component Dimensions

No	Structural Element	Profile Dimension	Code	Profile Type
1	Diagonal Truss	HB 400.400.11.18	A1	H Beam
2	Longitudinal Girder	HB 400.400.11.18	A2	H Beam
3	Cross Girder	IWF 700.300.13.24	A3	IWF

4	Upper Diaphragm	HB 175.175.5.5.11	A4	H Beam
5	Lower Diaphragm	HB 175.175.5.5.11	A5	H Beam
6	Concrete Deck Slab	Thickness 250 mm	-	Reinforced Concrete
7	Sidewalk	Width 950 mm, Height 250 mm	-	Reinforced Concrete

Visual inspection identified numerous structural deficiencies across various bridge components, as summarized in Table 3. These damages ranged from surface deterioration to structural defects requiring immediate attention.

Table 3. Bridge Damages

No	Component	Type of Damage	Location	Area / Extent	Condition Rating
1	Road Surface	Void covered by steel plate	Road Surface	-	Visual Damage
2	Pavement Layer	Cracking	Road Surface	-	Visual Damage
3	Bridge Slab	Spalling on edge and underside	Underside	±7 m ²	Needs Action
4	Top Chord Member	Rust and corrosion protection degradation	B2	14 m ² / 143 m ² (10%)	2 (Level 5)
5	Diagonal Member	Paint degradation	B2	2.1 m ² / 374.4 m ²	1 (Level 5)
6	Steel Joint	Rust	B2	-	2 (Level 5)
7	Concrete Deck Plate	Surface decay underneath	B2	±7.17 m ²	Urgent Action Needed
8	Floor System	Combination of rust, deformation, corrosion	B2	-	3 (Level 3)
9	Overall Bridge	Excessive dynamic deflection under heavy vehicle	-	-	3 (Level 1)

Following the Bridge Management System (BMS) protocol established by Direktorat Jenderal Bina Marga [4], the bridge condition was evaluated based on five critical parameters: structural damage level (S), damage severity (R), damage quantity (K), element functionality (F), and impact on adjacent elements (P). The comprehensive assessment results are presented in Table 4.

Table 4. Bridge Element Condition Assessment

Element		Condition Rate					Condition Rate
Code	Description	S	R	K	F	P	
1.000	Bridge	1	1	1	0	0	3

The condition rating of 3 indicates serious deterioration requiring immediate rehabilitation interventions, with damage affecting more than 50% of critical elements. Koh, Lee, and Kim [34] emphasized that this classification necessitates comprehensive rehabilitation efforts without requiring complete structural replacement.

Rating Factor Calculation

The structural adequacy of key load-bearing elements against axial forces was evaluated using the Load Rating Method in accordance with SNI 1725:2016 and Bina Marga Guidelines (024/BM/2011) [12]. The Rating Factor (RF) calculations for diagonal truss members (A1), longitudinal girders

(A2), and upper diaphragms (A4) are presented in Table 5.

Table 5. Evaluated Element for Axial Tension / Compression Forces

	Element		
	Diagonal Truss (A1)	Longitudinal Girder (A2)	Upper Diaphragm (A4)
Profile Dimension	HB 400.400.11.18	HB 400.400.11.18	HB 175.175.5,5.11
Compression Capacity (kN)	3,270.93	1,194.38	123.28
Tension Capacity (kN)	5,760	2,695.5	2,880
Permanent Load (kN)	-2,468.93	-655.77	-0.92
Live Load (kN)	-529.97	-129.25	-0.19
RF compression (RFC)	10.83	14.31	641.23
RF Tension (RFT)	-	1.15	22,372.79

The analysis reveals RF values significantly greater than 1 for all evaluated elements, indicating substantial reserve capacity despite the observed physical deterioration. Tarighat and Miyamoto [35] demonstrated that steel bridge structures typically maintain significant residual capacity even when exhibiting surface deterioration.

Bending capacity evaluation was conducted for transverse girders and lower diaphragms. The RF calculations for moment resistance are presented in Table 6.

Table 6. Evaluated Element for Bending Moment Forces

	Element	
	Transverse Girder (A3)	Lower Diaphragm (A5)
Profile Dimension	IWF 700.300.13.24	HB 175.175.5,5.11
Moment Capacity (kNm)	234.99	2,295
Permanent Load (kNm)	-77.37	-97.4
Live Load (kNm)	-93.58	-81.19
RF Moment (RFM)	3.34	29.47

The calculated RF values for bending elements demonstrate substantial reserve capacity, with transverse girders exhibiting an RF of 3.34 and lower diaphragms showing an exceptionally high RF of 29.47. These results indicate that despite visible deterioration, the structural components maintain sufficient strength to resist the applied loads with a significant margin of safety.

The Citarum Baru Bridge assessment reveals a significant contradiction between visual deterioration and analytical capacity that merits deeper examination. While the bridge exhibits poor visual condition (rating 3), its structural elements demonstrate robust load-carrying capacity with RF values far exceeding critical thresholds. This discrepancy extends beyond the observations of Chen, Su, and Zhang [37], suggesting that in steel truss bridges, visual deterioration often has minimal impact on actual structural performance. The exceptionally high RF values for compression elements (10.83–641.23) likely reflect conservative design philosophies prevalent during Indonesia's infrastructure development period, when bridges were designed with substantial safety margins to accommodate uncertain loading conditions and limited maintenance resources [38].

Despite the study's methodological strengths in integrating TLS technology with visual inspection and applying appropriate system factors, several limitations exist. The assessment may inadequately capture the effects of highly localized deterioration at critical connection points, which Gheitasi and Harris [39] note can disproportionately impact overall structural performance. The study lacks quantitative correlation between local environmental factors and observed deterioration rates, and provides only qualitative observations of excessive dynamic deflection without instrumented testing.

Additionally, the assessment offers a static snapshot without projecting deterioration progression, features limited connection capacity analysis despite identifying connections as critical elements, and appears to lack material testing that would confirm actual in-situ properties of aged materials [40].

These limitations present valuable research opportunities, including developing deterioration-adjusted Rating Factor methodologies specific to tropical environments, investigating how deteriorated connections perform under combined loading conditions, and field-validating analytical predictions to calibrate system factors more precisely. Future research could incorporate non-destructive material characterization, establish long-term monitoring frameworks combining periodic TLS scanning with targeted sensor placement, and integrate analytical capacity assessment with life-cycle cost modeling [41]. Creating a regional deterioration pattern database specific to Indonesia's climatic regions and exploring machine learning applications for defect detection would further enhance bridge evaluation methodologies.

By addressing these limitations, future studies can develop more comprehensive and predictive assessment approaches tailored to Indonesia's infrastructure challenges, moving beyond the current discrepancy between visual assessment and analytical capacity evaluation.

CONCLUSION

This assessment of the Citarum Baru Bridge provides important insights into its structural condition and load-carrying performance. Although visible deterioration was identified and reflected by a condition rating of 3, the analytical results show that all evaluated structural elements still maintain adequate load-carrying capacity. Rating Factor (RF) values for critical components consistently exceed 1.0, indicating that sufficient safety margins are preserved under current traffic loading conditions. This finding suggests that visible surface deterioration does not necessarily imply an immediate reduction in structural capacity, particularly for steel truss bridges designed with conservative safety factors. The integration of visual inspection and Terrestrial Laser Scanning (TLS) proved effective in delivering a comprehensive bridge assessment. Visual inspection enabled the identification of defects such as concrete spalling, steel corrosion, cracking, and localized deformation, while TLS provided accurate three-dimensional geometric data and quantitative measurements of structural components. This combined approach improved the reliability of geometric input data used for numerical modeling and enhanced the spatial understanding of damage distribution across the bridge. In addition, the application of the Load Rating Method using CSI SAP2000 successfully evaluated the residual structural capacity of the bridge, offering a reliable and cost-effective alternative to in-situ load testing, which generally requires higher costs, longer implementation periods, and complex traffic management. The discrepancy between the visual condition rating and analytical capacity highlights the importance of integrated bridge assessment methodologies. Relying solely on visual inspection may lead to conservative maintenance decisions, while analytical evaluation without detailed inspection may overlook localized deterioration. Therefore, combining visual inspection, TLS-based geometric assessment, and load rating analysis provides a more balanced basis for maintenance planning. Rehabilitation efforts should prioritize mitigating concrete spalling, controlling-steel corrosion, and addressing excessive dynamic deflection under heavy vehicle loading. These findings are consistent with previous studies emphasizing the effectiveness of Load Rating methods and the importance of considering traffic loading and environmental effects in bridge condition assessment. The proposed integrated approach offers a practical framework for managing aging bridge infrastructure, particularly in developing countries with similar operational and climatic conditions.

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