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Condition Assessment and Recommended Interventions for the Sungai Pegeh Rural Bridge Using the Bridge Management System (BMS) Method

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ABSTRACT

Bridges are transportation infrastructure, which plays a crucial role in promoting regional connection, community mobility and distribution of agricultural products notably in rural areas. Environmental variables and lack of proper maintenance can cause a degradation of bridge conditions, disruption of service operations and an increase in the danger of structural failure. The objectives of this research are to evaluate the state of the Pegeh River Bridge and to provide recommendations for its management using the Bridge Management System (BMS) approach. The research is carried out by using descriptive quantitative approach using case study design. Data were collected by field observations, ocular measurements and recording of all bridge elements and then analyzed following the BMS criteria. The research results indicate that the Pegeh River Bridge has a general condition value of 3, which means the condition is in the range of moderate to severe damage. The main damage was detected on the approach slab parts sustained landslides owing to the overflow of river and the abutment experienced structural damage due to scouring. The drainage elements and floor slab are meanwhile still in fine condition. This work highlights the main reason for bridge deterioration is the hydrological elements which require structural renovation, riverbank protection and periodical BMS-based inspections for sustainable operation of the bridge.

INTRODUCTION

Bridge infrastructure is a strategic component of the global transportation system, as it plays a critical role in ensuring regional connectivity, population mobility, and the sustainable distribution of goods and logistics. The availability of reliable bridge infrastructure is an essential prerequisite for economic growth, regional integration, and improved accessibility, particularly in countries characterized by complex geographical conditions. However, many countries continue to face challenges related to bridge structural degradation caused by infrastructure aging, increasing traffic loads, climate change, and the inadequate implementation of condition-based maintenance systems [1]. In this context, data-driven bridge asset management systems have become increasingly important for ensuring user safety while preserving the long-term value of infrastructure investments[2], [3].

In Indonesia, bridges play a vital role in maintaining the continuity of transportation networks, particularly in an archipelagic country where geographical barriers such as rivers, valleys, and hilly terrain are widespread[4] . Nevertheless, the general condition of bridges in Indonesia indicates a tendency toward declining structural performance due to service age, corrosion, erosion, increasing traffic loads, and insufficient periodic maintenance[5], [6], [7]. The Ministry of Public Works and Housing has also reported that budget constraints, the lack of integrated data, and the uneven implementation of bridge management systems have resulted in many bridges not receiving timely interventions, thereby increasing the potential for further deterioration [8]. This situation highlights a persistent gap between technical infrastructure management standards and actual maintenance practices in the field [9].

Similar conditions have been identified at the Sungai Pegeh Bridge, which is located in a rural area and serves as a key infrastructure facility supporting community mobility and the distribution of agricultural products. Preliminary field observations revealed several indications of deterioration in bridge components, including damage to the abutments, cracking of the concrete railings, missing horizontal railing elements, and landslides at the road–bridge approach caused by river overflow. Furthermore, the bridge's location within a riverine environment makes the structure particularly vulnerable to hydrological processes such as flooding and scour, which may gradually reduce its structural stability [10], [11]. If these conditions are not promptly evaluated and addressed, they may reduce the serviceability of the bridge, disrupt the socioeconomic activities of local communities, and potentially increase the risk of structural failure [12][13]

With advances in technology, bridge infrastructure management has undergone a transformation toward more integrated and data-driven approaches through the implementation of the Bridge Management System (BMS). This method enables bridge condition assessments to be conducted systematically, objectively, and quantitatively, thereby supporting decision-making processes for maintenance planning and rehabilitation[14], [15] . BMS has been demonstrated to be effective in identifying the existing condition of bridges and determining appropriate intervention measures. Visual inspections based on BMS enable a comprehensive evaluation of bridge condition and functionality [14], while Simanjuntak et al. (2024) found that the BMS method can classify different levels of bridge deterioration in detail and provide a basis for developing rehabilitation strategies[16].

Despite these developments, previous studies have predominantly focused on bridges located on national and provincial road networks or in urban areas, whereas research on rural bridges remains relatively limited [16], [17]. Consequently, an empirical gap exists due to the limited availability of empirical data concerning the actual condition of rural bridges, particularly in Sungai Pegeh Village, where the bridge has not previously been systematically investigated through scientific research. In addition, most previous studies have primarily emphasized the identification of physical bridge conditions without explicitly examining the relationship between structural deterioration and local hydrological influences. This represents a theoretical gap in understanding the deterioration dynamics of rural bridges located within riverine environments. From a methodological perspective, previous studies have generally examined bridges with different structural characteristics and infrastructure scales, indicating the need to verify the applicability of BMS to rural bridges characterized by limited resources and specific environmental conditions.

Based on these research gaps, this study is positioned as an evaluative investigation that integrates visual inspection using the Bridge Management System (BMS) with an assessment of local hydrological conditions to provide a more comprehensive understanding of bridge performance. The novelty of this study lies in the application of BMS to a rural bridge affected by river hydrological dynamics and in the development of condition-based intervention recommendations derived from actual field observations. This approach is expected to extend the application of BMS to rural infrastructure, which has received comparatively limited attention in the existing literature.

Accordingly, this study aims to assess the condition of the Sungai Pegeh Bridge using the Bridge Management System (BMS), identify the types and severity levels of deterioration affecting each structural element, and formulate appropriate intervention recommendations based on the bridge's actual condition. From a theoretical perspective, this study is expected to contribute to the existing body of knowledge regarding the application of BMS to rural infrastructure and to broaden the empirical database related to bridge asset management. From a practical perspective, the findings are expected to provide a scientific basis for local governments and relevant authorities in determining maintenance and rehabilitation priorities and in developing more effective, efficient, and sustainable bridge management policies.

RESEARCH METHODS

This study employed a descriptive quantitative approach using a case study design to evaluate the condition of the Sungai Pegeh Bridge based on the Bridge Management System (BMS) method. The study was conducted on the Sungai Pegeh Bridge, a rural single-span reinforced concrete beam bridge constructed in 2014. The bridge has a total length of 25 m, a width of 2 m, and a design service life of 50 years. This approach was selected because it enables a systematic assessment of bridge conditions based on actual field conditions without manipulating the research object. From a philosophical perspective, the study is grounded in a post-positivist paradigm, which emphasizes empirical observation and objective measurement of the physical condition of infrastructure [16], [18].

Research data were collected through direct field observations, visual measurements, and photographic documentation of all bridge components, including the superstructure, substructure, bridge deck, drainage system, protective structures, and bridge approach areas. Data collection was conducted using a visual inspection form referring to the Bridge Management System (BMS) guidelines issued by the Directorate General of Highways. The research instruments consisted of BMS inspection forms, a digital camera, and measuring tapes. Primary data included the type, location, dimensions, and severity of damage observed in each bridge element, while secondary data were obtained from literature reviews and relevant technical documents [19], [20].

Data analysis was conducted by identifying all forms of deterioration observed during the field inspection and subsequently assigning a condition rating to each bridge element in accordance with the assessment criteria specified in the BMS guidelines. The resulting condition ratings were then used to classify the overall level of bridge deterioration and to formulate appropriate intervention recommendations, including routine maintenance, rehabilitation, and structural repair measures. To enhance the validity and reliability of the findings, methodological triangulation was applied by comparing the results of field observations, direct measurements, and photographic documentation.

RESULTS AND DISCUSSION

The results indicate that the overall condition of the Sungai Pegeh Bridge falls within the moderate-to-severe damage category, with an overall condition rating of 3 based on the Bridge Management System (BMS) assessment. The most significant deterioration was identified in the bridge approach and abutment elements, which were strongly influenced by river hydrological dynamics, particularly flooding and scour. In contrast, most superstructure components remained in good condition. These findings confirm that hydrological factors are a major determinant of deterioration in rural bridge infrastructure. Therefore, intervention strategies should prioritize the rehabilitation of critical elements and the strengthening of river protection systems to ensure the long-term functionality and serviceability of the bridge.

1. Characteristics of the Sungai Pegeh Bridge

   The Sungai Pegeh Bridge is a rural transportation infrastructure facility that plays an important role in supporting community mobility and the distribution of agricultural products in the surrounding area. The bridge serves as a primary access route connecting adjacent areas and therefore has a strategic function in supporting local social and economic activities. Structurally, the Sungai Pegeh Bridge is classified as a single-span reinforced concrete beam bridge, with reinforced concrete as its primary construction material. The bridge was constructed in 2014 with a design service life of 50 years.

   Based on field observations, the Sungai Pegeh Bridge has a total length of 25 m, a width of 2 m, and consists of a single span. The bridge crosses the Sungai Pegeh River, which is approximately 15 m wide, while the vertical distance between the bridge deck and the riverbed is estimated to be approximately ±6 m. The hydrological characteristics of the river indicate that discharge increases significantly during the rainy season, creating the potential for scour around the bridge substructure. Although the river water level has never reached the bridge deck, increased river discharge has caused erosion and slope failure in the bridge approach area. These conditions indicate that environmental factors, particularly river hydrological dynamics, exert a considerable influence on the long-term performance and sustainability of the bridge structure.

   To provide a clearer overview of the technical characteristics of the Sungai Pegeh Bridge, its specifications are presented in Table 1.

Table 1. Technical Characteristics of the Sungai Pegeh Bridge

Parameter	Description
Bridge Name	Sungai Pegeh Bridge
Location	Sungai Pegeh Village
Year of Construction	2014
Design Service Life	50 years
Bridge Length	25 m
Bridge Width	2 m
Number of Spans	1 span
Bridge Type	Single-Span Reinforced Concrete Beam Bridge
Main Material	Reinforced concrete

River Width	±15 m
Bridge Height above Riverbed	±6 m
Hydrological Condition	River discharge may increase significantly during the rainy season
Bridge Function	Supports community mobility and the distribution of agricultural products

2. Bridge Condition Assessment Based on the Bridge Management System (BMS)

The condition of the Sungai Pegeh Bridge was assessed through visual inspection of all structural and non-structural bridge components in accordance with the Bridge Management System (BMS) guidelines issued by the Directorate General of Highways. The inspection was conducted to identify the type and severity of deterioration and to determine the condition rating of each bridge element. The inspection results showed that most bridge components remained in good condition, although several elements exhibited varying degrees of deterioration. The most significant damage was observed in the bridge approach and abutment areas, which were strongly influenced by river hydrological processes, particularly flooding and scour during the rainy season. The condition assessment results for each bridge element are presented in Table 2.

Table 2. Condition Assessment of the Sungai Pegeh Bridge Based on the BMS Method

No.	Bridge Element	Type of Damage	Damage Extent	Condition Rating (CR)	Condition Category
1	Bridge Approach	Landslide caused by river overflow	40 m³	4	Severe Damage
2	Drainage System	No damage identified	–	0	Good
3	Bridge Deck Slab	No significant damage identified	–	0	Good
4	Concrete Railing	Minor cracking	1.5 m	1	Minor Damage
5	Abutment	Concrete breakage at the upper and lower sections	0.8 m³	4	Severe Damage
6	Horizontal Railing Member	Missing / Detached	1 unit	2	Moderate Damage
7	Area Around the Abutment	Scour	0.6–0.8 m	3	Moderate Damage

As shown in Table 2, the most severe deterioration occurred in the bridge approach and abutment elements, both of which received a condition rating of 4 and were classified as severely damaged. Damage to these two elements may affect the stability and long-term functionality of the bridge if appropriate intervention is not undertaken promptly. In contrast, the drainage system and bridge deck slab were rated 0, indicating that both components remained in good condition and continued to function adequately without requiring specific repair measures other than routine maintenance.

The inspection also identified minor-to-moderate deterioration in several non-structural elements, including cracks in the concrete railings and the loss of one horizontal railing member. Although these defects do not directly affect the load-carrying capacity of the main bridge structure, they still require attention because of their relevance to user safety. These findings indicate that deterioration of the Sungai Pegeh Bridge is influenced more strongly by external factors associated with river hydrological dynamics than by degradation of the bridge superstructure. Similar conditions have been reported in previous studies, which identified flooding and scour as major causes of bridge performance deterioration, particularly in rural areas with limited riverbank protection systems [21].

Overall, the condition assessment resulted in a general condition rating of 3 for the Sungai Pegeh Bridge, indicating a moderate-to-severe level of deterioration. This condition requires rehabilitation of several priority elements, particularly the bridge approach and abutment. According to the BMS guidelines, bridges within this condition category require rehabilitation and structural repair measures to prevent further deterioration and more serious structural problems in the future.

3. Damage Analysis of Individual Bridge Elements

To obtain a more comprehensive understanding of the condition of the Sungai Pegeh Bridge, each bridge element was analyzed based on the results of the field visual inspection. This analysis was intended to identify the characteristics and possible causes of deterioration, assess its impact on bridge performance, and determine appropriate intervention measures. Field documentation and the analysis results for each bridge element are presented in Table 3.

The inspection findings showed that the most significant deterioration occurred in the bridge approach and abutment elements, both of which were strongly influenced by river hydrological processes, whereas most components of the bridge superstructure remained in good condition. This finding demonstrates that environmental dynamics around the bridge contribute substantially to the deterioration process of rural bridge infrastructure.

Table 3. Damage Analysis of Individual Elements of the Sungai Pegeh Bridge

No.	**Field Documentation**	**Element**	**Condition and Analysis**
1	 	Bridge Approach	The inspection results showed that the bridge approach experienced a landslide with an estimated volume of approximately 40 m³ due to river overflow during the rainy season. This damage may disrupt vehicle accessibility and reduce the serviceability of the bridge. According to BMS (1993), damage to the bridge approach area should be addressed promptly because it may develop into localized structural failure. Therefore, reconstruction of the embankment and installation of gabions are recommended to protect the riverbank and stabilize the approach area.
2		Drainage System	The drainage system was found to be in good condition, with no evidence of blockage or structural damage. It continues to function effectively in conveying surface runoff and therefore requires only routine maintenance.
3	 	Bridge Deck Slab	The bridge deck slab showed no signs of cracking, deformation, or surface delamination. This condition indicates that the deck element remains capable of performing its intended function adequately.
4		Concrete Railing	Minor cracking of approximately ±1.5 m in length was identified in the concrete railing. Although the damage has not yet affected the capacity of the main structural system, it may deteriorate further if left untreated. Localized repair is recommended to prevent water ingress and subsequent reinforcement corrosion.

5		Abutment	Damage in the form of concrete spalling and breakage was observed at the upper and lower sections of the abutment, with an estimated volume of approximately 0.8 m³. The deterioration is suspected to be influenced by river scour and lateral earth pressure around the structure. As the abutment is a primary structural component, rehabilitation and structural strengthening are required to prevent further reduction in bridge stability.
6		Horizontal Railing Member	One horizontal railing member was found to be missing or detached. Although this condition does not affect the load-carrying capacity of the main bridge structure, it may reduce user safety. Therefore, replacement of the missing element is recommended.
7		Area Around the Abutment	Scour was identified around the base of the abutment, with an estimated depth of approximately 0.6–0.8 m. Progressive scour may reduce foundation bearing capacity and increase the risk of structural instability. Therefore, riverbank and foundation protection measures using gabions or stone masonry are recommended.

In general, the analysis indicates that deterioration of the Sungai Pegeh Bridge is predominantly driven by external environmental factors, particularly river flooding and scour. These findings are consistent with the studies of Saputra et al. (2023) and Hariry and Savitri (2024)[22], which reported that flooding and scour are among the primary factors responsible for declining bridge performance in areas characterized by dynamic river systems. Therefore, rural bridge maintenance strategies should not focus solely on repairing structural components but should also incorporate hydrological management measures and riverbank protection.

4. Implications for Bridge Intervention and Maintenance

The condition assessment of the Sungai Pegeh Bridge indicates that several bridge components require intervention at different levels of priority. According to the Bridge Management System (BMS) guidelines, bridge intervention strategies should be determined based on the severity of deterioration, the function of each element, and the potential consequences for user safety and continuity of bridge service. Consequently, the prioritization of maintenance and rehabilitation measures is particularly important for rural bridges, where financial, technical, and institutional resources are often limited.

Based on the inspection results and condition analysis, the recommended intervention measures for each element of the Sungai Pegeh Bridge are presented in Table 4.

Table 4. Recommended Intervention and Maintenance Measures for the Sungai Pegeh Bridge

No.	Bridge Element	Type of Damage	Priority Level	Recommended Intervention
1	Bridge Approach / Road Connection	Landslide	Very High	Reconstruction of the embankment, soil compaction, and installation of gabions or stone masonry for slope and riverbank protection.
2	Abutment	Damage at the upper and lower sections	Very High	Structural rehabilitation, repair of damaged concrete, and strengthening of the foundation area.
3	Area Around the Abutment	Scour	High	Installation of gabions, riprap, or other riverbank protection measures to reduce the potential for further scour.
4	Horizontal Railing Member	Missing / Detached	Moderate	Replacement and reinstallation of the missing railing element.
5	Concrete Railing	Minor Cracking	Moderate	Localized crack repair and periodic maintenance.
6	Drainage System	No Damage Identified	Low	Routine maintenance and periodic cleaning.
7	Bridge Deck Slab	No Significant Damage Identified	Low	Routine maintenance and periodic inspection.

As presented in Table 4, the highest intervention priority should be assigned to the bridge approach, abutment, and areas surrounding the bridge foundations. These three components are directly associated with structural stability and user safety. Slope failure in the bridge approach may disrupt vehicle accessibility, while deterioration of the abutment and scour around the foundation may reduce the supporting capacity and overall stability of the bridge structure if not addressed promptly. According to BMS (1993), deterioration affecting primary structural elements requires immediate rehabilitation to prevent progressive damage that could eventually lead to structural failure.

The findings of this study suggest that rural bridge maintenance strategies should not be limited to the repair of structural components but should also incorporate environmental considerations, particularly river hydrological conditions. The deterioration observed at the Sungai Pegeh Bridge demonstrates that river flow dynamics, flooding, and scour contribute significantly to bridge degradation. These findings are consistent with Saputra et al. (2023) and Hariry and Savitri (2024), who reported that hydrological processes are among the dominant factors influencing bridge service life, particularly in rural areas with limited river protection systems.

Therefore, the preservation of the Sungai Pegeh Bridge should be implemented through an integrated combination of routine maintenance, structural rehabilitation, and continuous improvement of river protection measures. In addition, periodic inspections based on the Bridge Management System (BMS) should be conducted consistently to enable early detection of potential deterioration and ensure that appropriate intervention measures can be implemented in a timely, effective, and efficient manner.

CONCLUSION

This study demonstrates that the Sungai Pegeh Bridge is generally in a moderate-to-severe deterioration condition, with an overall condition rating of 3 based on the Bridge Management System (BMS) method. The most significant damage was identified in the bridge approach, which experienced landslide failure due to river overflow, and in the abutment, where deterioration was observed in both the upper and lower sections. In contrast, the drainage system and bridge deck slab remained in good condition and required only routine maintenance. These findings indicate that hydrological factors, particularly flooding and scour, are the dominant contributors to the deterioration of the Sungai Pegeh Bridge.

From a theoretical perspective, this study extends the application of the BMS method to the context of rural bridges, which has received relatively limited attention in previous studies. From a practical perspective, the findings can provide a basis for local governments and relevant authorities to establish more effective priorities for bridge maintenance and rehabilitation. However, this study is limited to visual inspection and does not include material testing or detailed structural analysis. Therefore, future research is recommended to integrate the BMS method with non-destructive testing (NDT), numerical structural analysis, or sensor-based structural health monitoring systems to obtain a more comprehensive assessment of bridge condition and performance.

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