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Assessment of Bridge Deterioration Using The Bridge Management System Method and Its Maintenance Strategies (A Case Study of Miangas Bridge, Dendengan Luar, Tikala District, Manado City)

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ABSTRACT

Bridges are essential transportation infrastructures that play a significant role in supporting community mobility and economic activities. As their service life increases, bridge conditions may deteriorate due to various forms of damage that can potentially affect the safety and comfort of users. This study aims to identify the types of damage, assess the level of deterioration of the Miangas Bridge located in Dendengan Luar Village, Tikala District, Manado City using the Bridge Management System (BMS) method, and determine appropriate maintenance and rehabilitation measures. The research employed a quantitative approach, with data collected through visual inspections, field documentation, and concrete strength testing using the Hammer Test. The inspection results revealed several defects, including rough and pothole-ridden pavement surfaces, debonding of expansion joint connections, spalling and porous concrete, as well as reinforcement corrosion. Based on the BMS assessment, a condition rating (CR) of 2 was obtained for the roadway pavement, deck slab, diaphragm, and pier, while the main girders and expansion joints received a condition rating of 3. The overall bridge condition rating was 2, indicating minor damage and the need for routine and periodic maintenance. Hammer Test results indicated concrete compressive strengths of 28.2 MPa, 37.3 MPa, and 39.8 MPa for the girders; 39.3 MPa and 41.4 MPa for the deck slab; and 39.8 MPa for the pier. Recommended corrective actions include pavement rehabilitation, replacement of expansion joints, repair of damaged concrete, corrosion cleaning, and additional reinforcement in deteriorated structural components.

1. INTRODUCTION

Bridges are essential infrastructures that support economic, social, and cultural activities, contributing to balanced regional development. A bridge is a structural facility designed to connect two points separated by obstacles such as rivers, valleys, or roadways. Consequently, bridge failure can significantly reduce or disrupt traffic flow, leading to interruptions in transportation, logistics, and public services, thereby affecting the efficiency and continuity of regional connectivity and economic activities [1–2].

Bridge inspections are conducted to ensure the safety and comfort of road users while maintaining the asset value of bridge infrastructure. Through these inspections, physical damage data can be collected and utilized as a basis for determining appropriate maintenance measures, including repair, strengthening, or structural replacement. As bridges age and continue to operate under service loads, their structural components become increasingly susceptible to deterioration, such as cracking, corrosion, and deformation, which may compromise structural integrity and pose safety risks if not promptly addressed.

The Miangas Bridge is one of the bridges in Manado City that has been in operation for approximately 28 years, making it susceptible to structural deterioration over time. Therefore, an evaluation of the bridge's damage level is necessary to determine its current condition and identify appropriate maintenance and rehabilitation measures. This study aims to identify the types of damage, assess the level of deterioration using the Bridge Management System (BMS) method, and provide technical recommendations for bridge maintenance and rehabilitation. The assessment was carried out through visual inspections and concrete strength testing using a hammer test on both the superstructure and substructure elements of the Miangas Bridge.

2. LITERATURE REVIEW

The Bridge Management System (BMS) is a management framework developed to control and monitor bridge conditions, ensuring that bridges continue to function safely and efficiently while facilitating the determination of appropriate maintenance and rehabilitation actions. Within the BMS framework, bridge components are categorized into five hierarchical levels based on element coding systems. Bridge inspections are conducted systematically by evaluating the condition of each structural element and identifying visible defects or deterioration. The assessment is primarily based on visual observations obtained from field survey results, which serve as the basis for determining the condition rating of individual bridge elements [3].

The assessment of deteriorated bridge elements is conducted using five evaluation criteria that are designed to determine the severity and impact of the observed damage, namely:

A. Structure (S): Whether the damage poses a structural hazard.
B. Severity (R): Whether the damage is severe or not.
C. Quantity (K): Whether the extent of damage exceeds the specified threshold percentage.
D. Function (F): Whether the bridge element remains functional.
E. Effect (P): Whether the damage has an impact on other bridge elements.

Each assessment criterion is assigned a value of either 1 or 0 according to the severity and characteristics of the observed damage. The criteria used for determining the bridge condition rating are summarized in Table 1.

Table 1 Condition Rating Assessment Criteria

Assessment System	Criteria	Score
Structure (S)	Hazardous	1
	Non-hazardous	0
Severity (R)	Severe	1
	Not Severe	0
Quantity (K)	Greater than x%	1
	Less than x%	0
	x = 30% for structural elements and 50% for non-structural elements	
Function (F)	Element is not functional	1
	Element is functional	0
Effect (P)	Affects other elements	1
	Does not affect other elements	0
Condition Rating (CR)	CR = S + R + K + F + P	0 - 5

Source: Bridge Inspection Guidelines

Based on the condition assessment criteria presented above, the resulting condition ratings can be interpreted as follows:

1. CR = 0: The bridge is in good condition.
2. CR = 1: The bridge is in a minor deterioration condition, and the observed defects can be addressed through routine maintenance without affecting the safety or functionality of the bridge.
3. CR = 2: The bridge is in a moderate deterioration condition, and the defects require continuous monitoring and future maintenance interventions.
4. CR = 3: The bridge is in a major deterioration condition, and the damage requires attention as it may develop into a more serious condition within the next 12 months.
5. CR = 4: The bridge is in a critical condition, and the severe damage requires immediate corrective action.
6. CR = 5: The bridge is in a failed condition or is no longer functional.

Table 2 Screening of bridge conditions

Condition Rating	Condition Category	Recommended Action
0-2	Good to Minor Deterioration	Routine and Periodic Maintenance
3	Major Deterioration	Rehabilitation
4-5	Critical or Failed Condition	Replacement

The remaining service life of a bridge is determined based on its existing condition rating. Various factors may influence bridge performance and condition, ranging from environmental exposure to the level of deterioration occurring in individual bridge elements. Therefore, an accurate assessment of bridge condition is essential for estimating the remaining service life and establishing appropriate maintenance and rehabilitation strategies to ensure long-term structural safety and functionality [4].

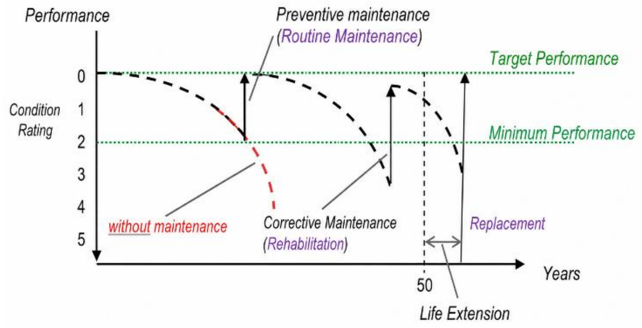

Figure 1 Remaining Service Life of the Bridge

Based on the relationship illustrated in the graph above, the remaining service life of the bridge can be calculated using the following equation:

$$CR = 5 - \left(\frac{\left(100 - \frac{Y}{N\%}\right)}{a}\right)^{\left(\frac{1}{b}\right)}$$

CR	= Condition rating	
Y	= Bridge Age	
N	= Design Life	
a	= 4,66	
b	= 1,9051	

Non-Destructive Test

The Rebound Hammer Test is a Non-Destructive Testing (NDT) method used to estimate the quality and compressive strength of concrete. One of the primary advantages of this method is its ability to provide rapid and practical information regarding the condition and strength of concrete without causing damage to the tested structure. The operating principle of the rebound hammer is based on the rebound distance of a spring-controlled mass that impacts the concrete surface. The rebound value obtained from the impact is used as an indicator of the surface hardness of the concrete.

In a rebound hammer test, only the concrete located in the vicinity of the plunger significantly influences the rebound value. If the plunger impacts a hard material, such as reinforcing steel embedded within the concrete, the rebound value tends to be higher. Conversely, if the plunger is positioned over a void, honeycombing, or an air pocket within the concrete, the rebound value will be lower. Therefore, proper selection of test locations is essential to ensure accurate and representative test results [5-6].

3. METHODOLOGY

This study employed a quantitative research method aimed at evaluating the condition and level of deterioration of Miangas Bridge based on visual inspections, field measurements, and numerical data analysis. The research was conducted at Miangas Bridge, located in Dendengan Luar, Tikala District, Manado City, North Sulawesi. The research procedure consisted of the following stages:

1. Determination of the research location.
2. Site survey and preliminary inspection.
3. Collection of primary and secondary data.
4. Assessment of bridge condition using the Bridge Management System (BMS) guidelines.
5. Concrete strength evaluation using the Rebound Hammer Test.
6. Selection of appropriate maintenance and rehabilitation measures.

The data used in this study consisted of both primary and secondary data. Primary data were obtained through direct inspections of the bridge superstructure, substructure, and ancillary components, whereas secondary data were collected from relevant literature, technical guidelines, and previous studies. Data collection was conducted through field surveys involving visual inspections using a checklist-based assessment form, accompanied by concrete hardness testing using a Rebound Hammer Test. Documentation of observed defects and deteriorated bridge elements was also carried out during the inspection process.

The data analysis involved identifying various types of damage, including cracking, concrete spalling, reinforcement corrosion, and excessive deformation. Subsequently, the level of deterioration was classified using the Bridge Management System (BMS) method and categorized into condition levels ranging from good, minor deterioration, moderate deterioration, to major deterioration. The results of the analysis were then used to formulate recommendations for appropriate maintenance actions, including routine maintenance, rehabilitation, and replacement of bridge elements exhibiting significant deterioration.

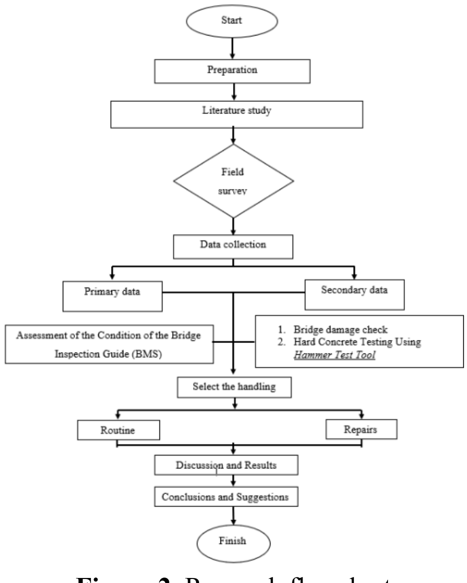

Figure 2. Research flowchart

4. RESULT AND DISCUSSION

4.1 Bridge Technical Data

Miangas Bridge, located in Dendengan Luar, Tikala District, Manado City, serves as an important component of the road transportation network connecting various areas within Manado City. The bridge facilitates both private and public transportation while supporting economic and social activities in the region.

The technical specifications of Miangas Bridge are presented as follows:

1. Bridge Name	: Miangas
2. Bridge Number	: 50.004.001.0.12
3. Road Section	:JLN.R.MARTADINATA (MANADO)
4. Year of Construction	: 1998
5. Superstructure Type	: GTI (I-Girder Type)
6. Span Length	: 47 m
7. Bridge Width	: 13,7 m
8. Sidewalk Width	: 1 m
9. Number of Spans	: 3 spans

4.2 Inspection Results

Bridge inspections were conducted by examining the condition of individual bridge elements. The inspection data were subsequently evaluated using a scoring system based on predefined condition categories. A score of 0–2 indicates a condition ranging from good to minor deterioration, a score of 3 indicates major deterioration, while scores of 4–5 indicate a critical to failed condition, where the bridge may no longer function as intended.

1. Assessment of the Deck Surface Layer

Based on the field inspection results, several defects were identified on the deck surface layer, including the following:

a. Road Pavement

The road pavement exhibited signs of deterioration, including a rough surface texture and localized potholes. However, other sections of the pavement remained in satisfactory condition. Based on the Bridge Management System (BMS) assessment criteria, the flexible pavement was assigned a Condition Rating (CR) of 2, indicating a minor deterioration condition.

Figure 3. Damage to the Road Pavement

b. Asphalt Expansion Joint

The asphalt expansion joint exhibited signs of deterioration, including a loss of movement capability and debonding from the adjacent pavement surface. These defects may reduce the effectiveness of the joint in accommodating bridge movements caused by traffic loads and temperature fluctuations. Based on the Bridge Management System (BMS) assessment criteria, the asphalt expansion joint was assigned a

Condition Rating (CR) of 3, indicating a major deterioration condition.

Figure 4 Damage to the Asphalt Expansion Joint

2. Assessment of the Bridge Deck Slab

Based on the field inspection results, the bridge deck slab exhibited signs of deterioration, including concrete spalling that resulted in exposed reinforcing steel. However, the deck slab remains functional and continues to perform its intended structural role. According to the Bridge Management System (BMS) assessment criteria, the bridge deck slab was assigned a Condition Rating (CR) of 2, indicating a moderate deterioration condition.

Figure 5. Damage to the Bridge Deck Slab

3. Assessment of Bridge Girders

Based on the field inspection results, several types of deterioration were identified in the bridge girders, including the following:

a. Main Longitudinal Girder

The main longitudinal girder exhibited signs of deterioration, as evidenced by concrete spalling that resulted in exposed reinforcing steel. The exposure of the reinforcement has led to deterioration of the steel bars, potentially affecting the long-term durability of the structural element. However, the girder remains functional and continues to perform its intended structural role. Based on the Bridge Management System (BMS) assessment criteria, the main longitudinal girder was assigned a Condition Rating (CR) of 3, indicating a major deterioration condition.

Figure 6. Damage to the Main Longitudinal Girder

a) Diafragma

The bridge diaphragm exhibited signs of deterioration, as indicated by concrete spalling that resulted in exposed reinforcing steel. Although the reinforcement became visible due to the loss of concrete cover, the diaphragm remains functional and continues to perform its structural role. Based on the Bridge Management System (BMS) assessment criteria, the diaphragm was assigned a Condition Rating (CR) of 2, indicating a moderate deterioration condition.

Figure 7. Damage to the Bridge Diafragma

4. Assessment of Bridge Piers

Based on the field inspection results, the bridge piers exhibited signs of deterioration, as evidenced by concrete spalling that resulted in exposed reinforcing steel. Although the reinforcement became visible due to the loss of concrete cover, the piers remain functional and continue to adequately support the bridge structure. Based on the Bridge Management System (BMS) assessment criteria, the bridge piers were assigned a Condition Rating (CR) of 1, indicating a minor deterioration condition.

Figure 8. Damage to the Bridge Pier

Table 3. Bridge Condition Ratings and Recommended Maintenance Actions

Bridge Elements	Condition Score (CR)	Recommended Action
Wearing Surface (Road Pavement)	2 (two)	Mill and resurface the damaged pavement sections, particularly in areas affected by potholes.
Wearing Surface (Asphalt Expansion Joint)	3 (three)	Replace the deteriorated asphalt expansion joint.
Deck Slab	2 (two)	Remove deteriorated concrete, clean corrosion and/or install additional reinforcing

		steel, apply bonding agents, and perform concrete patch repairs.
Bridge Girder (Main Girder)	3 (three)	Remove deteriorated concrete, clean corrosion and/or install additional reinforcing steel, apply bonding agents, and perform concrete patch repairs.
Bridge Girder (Diaphragm)	2 (two)	Remove deteriorated concrete, clean corrosion and/or install additional reinforcing steel, apply bonding agents, and perform concrete patch repairs.
Bridge Pier	2 (two)	Remove deteriorated concrete, clean corrosion and/or install additional reinforcing steel, apply bonding agents, and perform concrete patch repairs.
Overall Condition Rating (CR)	2 (two)	Routine and periodic maintenance

Table 3 Checklist of Bridge Damage Based on the Bridge Management System (BMS)

No	Bridge Element	Damage Code	Type of Damage	Present (✓) / Absent (×)	Remarks
1	Road Pavement	722	Rough or pothole-ridden surface	✓	Damage was observed at the joint area, including debonding and cracking.
2	Expansion joint	804	Debonding	✓	The expansion joint exhibited debonding and cracking.
3	Deck Slab	201	Spalled and porous concrete	✓	On the floor slab, there is damage to porous concrete until reinforcement is visible
4	Girder	201	Spalled and porous concrete	✓	Deteriorated and porous concrete was observed on the deck slab, exposing the reinforcing steel.
5	Girder	203	Spalled and porous concrete	✓	Corrosion occurred due to concrete spalling, which exposed the reinforcing steel.
6	Diaphragm	201	Spalled and porous concrete	✓	Deteriorated and porous concrete was observed on the diaphragm, exposing the reinforcing steel.
7	Pier	201	Spalled and porous concrete	✓	On the pillars, porous concrete is damaged until reinforcement is visible
8	Railing	-	-	×	No visible damage was observed.
9	Sidewalk	-	-	×	No visible damage was observed.

4.3 Remaining Service Life Prediction

Based on the bridge inspection results and the calculated condition rating, the remaining service life of the bridge can be predicted using the following equation:

$$CR = 5 - \left(\frac{\left(100 - \frac{Y}{N\%}\right)}{a}\right)^{\left(\frac{1}{b}\right)}$$

CR = Condition Rating
Y = Bridge Age
N = Design Service Life
a = 4,66
b = 1,9051

$$CR = 5 - \left(\frac{\left(100 - \frac{Y}{N\%}\right)}{a}\right)^{\left(\frac{1}{b}\right)}$$

$$2 = 5 - \left(\frac{\left(100 - \frac{Y}{50\%}\right)}{4.66}\right)^{\left(\frac{1}{1,9051}\right)}$$

$$2 = 5 - \left(\frac{\left(100 - \frac{Y}{50\%}\right)}{4.66}\right)^{(0.525)}$$

$$3\ x\ 4.66^{0.525} = \left(100 - \frac{Y}{50\%}\right)^{0.525}$$

$$6.73 = \left(100 - \frac{Y}{50\%}\right)^{0.525}$$

$$\sqrt[0.525]{6.73} = \left(100 - \frac{Y}{50\%}\right)$$

$$37.772 = \left(100 - \frac{Y}{50\%}\right)$$

$$100 - 37.772 = \frac{Y}{50\%}$$

$$62.228 = \frac{Y}{50\%}$$

$$Y = 31.114\ Years\ \approx 32\ Years$$

The predicted service life of the bridge corresponding to a condition rating of 2 is 32 years. Therefore, the remaining service life of the bridge is estimated to be 18 years, calculated as: Remaining Service Life = 50-32=18 years.

4.4 Non-Destructive Test

This test was conducted to determine the current compressive strength of the concrete, thereby enabling an assessment of the structural capacity of the existing bridge components in the field. The results provide an indication of the in-situ concrete strength without causing damage to the structure. The following are the results of the Non-Destructive Testing (NDT) conducted in the field.

Table 4 Concrete Strength Assessment of Bridge Girders Using the Hammer Test

Structural Element	Girder		
Impact angle	0	0	0
	→	→	→
Test area code	1	2	3
Concrete hammer rebound number (r)	42	34	47
	48	36	40
	41	34	51
	43	36	48
	35	36	49
	44	40	40
	41	39	45
	41	30	39
	36	30	47
	40	31	36
	50	40	38
	40	40	41
r maximum	50	40	51
r minimum	35	30	36
r average	41.8	35.5	43.4
Standard deviation	4.27	3.80	4.96
Coefficient of variation	10.2	10.7	11.4
r + 6	47.8	41.5	49.4
r - 6	35.8	29.5	37.4
Accepted rebound number	41.8	35.5	43.4
Estimated compressive strength (mpa)	37.3	28.2	39.8
Corrected concrete strength (KG/Cm^2	380.2	287.2	405.9

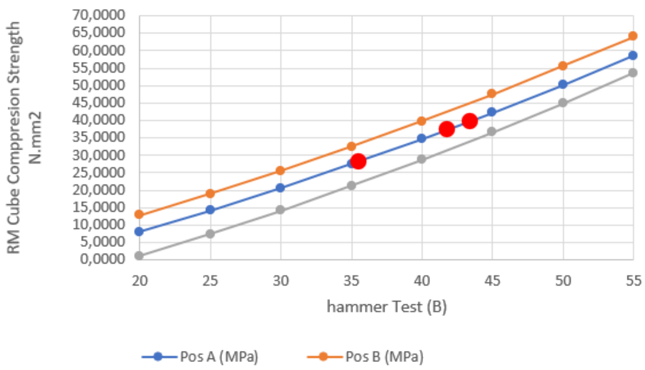

Figure 9. Bridge Girder Concrete Strength Graph

Based on the results summarized in Table 5 and illustrated in Figure 9, the estimated compressive strengths of the bridge girder concrete were 37.3 MPa, 28.2 MPa, and 39.8 MPa. These values indicate the in-situ concrete strength of the girder elements as determined from the Hammer Test evaluation.

Table 5 Hammer Test Results on Bridge Deck Slabs

Structural Element	Slab	
Impact angle	+90	+90
	↑	↑
Test area code	1	2
Concrete hammer rebound number (r)	50	48
	48	46
	50	40
	44	49
	40	52
	35	52
	46	48
	49	51
	52	47
	48	49
	50	42
	48	51
r maximum	52	52
r minimum	35	40
r average	46.7	47.9
Standard deviation	4.87	3.78
Coefficient of variation	10.4	7.9
r + 6	52.7	53.9
r - 6	40.7	41.9
Accepted rebound number	46.7	47.9
Estimated compressive strength (mpa)	39.3	41.9
Corrected concrete strength (KG/Cm^2)	400.1	421.3

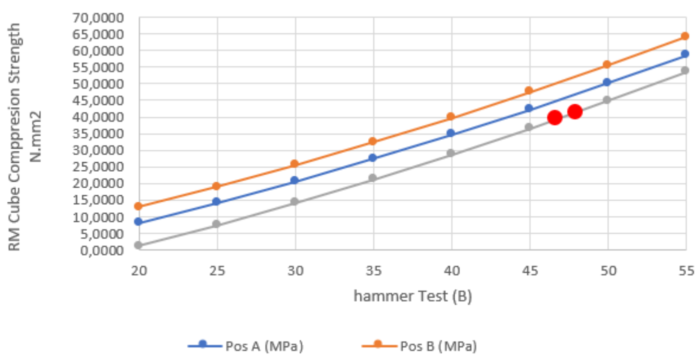

Figure 10 Bridge Slab Concrete Strength Graph

Based on the processed data presented in Table 6 and the graph shown in Figure 10, the estimated concrete compressive strengths of the bridge deck slab were found to be 39.3 MPa and 41.4 MPa, respectively.

Table 6 Hammer Test Results on Bridge Piers

Structural Element	Pier
Impact angle	0
	→
Test area code	1
	47
	40
	51
	48
	49
	40
Concrete hammer rebound number (r)	45
	39
	47
	36
	38
	41
r maximum	51
r minimum	36
r average	43.4
Standard deviation	4.96
Coefficient of variation	11.4
r + 6	49.4
r - 6	37.4
Accepted rebound number	43.4
Estimated compressive strength (mpa)	39.8
Corrected concrete strength (KG/Cm^2	405.9

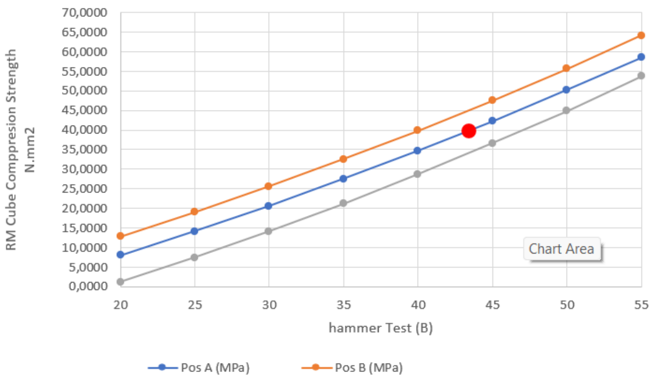

Figure 11 Bridge Pier Concrete Strength Graph

Based on the data presented in Table 7 and the graph shown in Figure 11, the average concrete compressive strength of the bridge pier structure was determined to be 39.8 MPa.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Based on the visual inspection and condition assessment of the Miangas Bridge, the following conclusions can be drawn:

1. Various forms of deterioration were observed on the Miangas Bridge, including rough and pothole-ridden pavement surfaces, debonding of expansion joints, concrete spalling and porosity, as well as corrosion of reinforcing steel.
2. Based on the Bridge Management System (BMS) assessment, the condition ratings were determined as 2 for the wearing surface, 2 for the deck slab, 3 for the main girder, 2 for the diaphragm, and 2 for the pier. In addition, the Hammer Test evaluation revealed estimated concrete compressive strengths of 37.3 MPa, 28.2 MPa, and 39.8 MPa in the girder elements; 39.3 MPa and 41.4 MPa in the deck slab; and 39.8 MPa in the pier structure.
3. The recommended corrective measures include routine and periodic maintenance, comprising pavement repair, replacement of deteriorated expansion joints, rehabilitation of damaged concrete elements, corrosion cleaning and treatment, provision of additional reinforcement where required, and concrete patching to restore the structural integrity and serviceability of the bridge.

5.2 Recommendations

1. The responsible agencies are advised to implement routine maintenance and regular inspection programs for the Miangas Bridge, with particular attention to the asphalt expansion joints and main girders, which exhibited the highest condition ratings. Such measures are essential to prevent the progression of deterioration and to ensure the long-term safety and serviceability of the bridge
2. Immediate rehabilitation of concrete elements exhibiting spalling, surface deterioration, and exposed reinforcing steel is recommended to prevent the progression of corrosion, which could adversely affect the structural integrity, load-carrying capacity, and service life of the bridge.

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