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Bridge Condition Assessment Over a Decade

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UAV-Visual Inspection: Bridge Condition Assessment Over a Decade

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Abstract

Bridges, essential for economic and social development, face significant deterioration due to aging and environmental factors. Consequently, assessing the condition of reinforced concrete bridges is essential to anticipate their future performance and optimize maintenance, rehabilitation, and replacement needs. While traditional visual inspections are widely used, the integration of unmanned aerial vehicles (UAVs) presents a more efficient approach, particularly in inaccessible areas. This article presents a comprehensive evaluation of the condition of a bridge over a decade through a case study in Ecuador. The assessment revealed significant deterioration in several structural elements, especially the substructure and road elements. These findings underscore the urgent need to improve maintenance practices and integrate advanced inspection techniques to ensure the safety and longevity of bridges in Ecuador.

Keywords: visual inspection; UAVs; deterioration; condition assessment; damage evaluation.

1 Introduction

Bridges are considered essential elements in the infrastructure of a country because they contribute significantly to its economic, social, and urban development. However, these structures can experience significant deterioration due to aging, prolonged use, environmental impacts, and other contributing factors [1]. For example, deterioration can be influenced by chemical processes such as alkali-silica reaction, carbonation, and corrosion, as well as mechanical factors such as temperature fluctuations, fatigue, overloading [2]. It is essential to note that degradation can compromise structural safety, increase maintenance, and repair costs and, in the worst case, result in collapse. Therefore, the condition assessment of an existing RC bridge has become essential to optimize bridge maintenance, rehabilitation and replacement requirements [3]. Also, to detect deterioration processes, indicating the severity and extent of the observed deficiencies, and to indicate the general condition of the bridge and its components [4]. It's crucial to note that the most important technical obstacle to the efficient management of highway bridges is the subjective or imprecise assessment of their condition [5].

With the purpose of safeguarding the safety, durability and optimal functionality of bridges, as well as optimizing available resources and reducing the risks of collapse or deterioration, several countries have adopted preventive and corrective actions through specialized control, maintenance and preservation programs of bridges through the implementation of bridge planning and management systems [6]. However, Ecuador does not have a specific system for the planning and administration of bridges. The absence of effective bridge management in Ecuador is aggravated by the lack of exhaustive regulations that comprehensively address all aspects necessary to guarantee the safety, maintenance and adequate planning of these infrastructures [6].

Various assessment methods, including visual inspections, load testing, non-destructive evaluation, and structural health monitoring, are available. However, visual inspections are the most commonly used method and play a crucial role in identifying damage and pinpointing its location on the structure [7]. Nevertheless, evaluating inaccessible critical structural elements during these inspections often requires specialized personnel or equipment. Consequently, using remotely controlled unmanned aerial vehicles (UAVs) offers a simplified approach to these complex inspection tasks [8]. However, there are certain limitations such as due to limited carrying capacity, only compact and lightweight digital cameras can be used for photo or video documentation. Additionally, the flight time is relatively short due to the need for batteries. Moreover, due to its low weight, the drone is very susceptible to changes in weather conditions, especially in critical wind situations. It is also important to note that in many places' security authorities require special flight permits or there are areas where fully autonomous flights are prohibited [8].

This paper provides a comprehensive assessment of the condition of a bridge over a ten-year period, employing both traditional visual inspections and modern methods using drones. The study highlights the importance of selecting appropriate drones for bridge inspections and emphasizes the critical role of condition assessment in ensuring the safety and longevity of bridges.

2 Drone and bridge selection

2.1 Drone selection

To conduct an effective and thorough bridge inspection, several key aspects must be considered when selecting the drone to use. A flight time greater than 25 minutes is essential to ensure uninterrupted inspection sessions by minimizing battery changes, thus improving the efficiency of bridge inspections. Additionally, the drone's camera requires high resolution to capture detailed images in low-light conditions, which are commonly found under bridge decks [9]. Additionally, the drone must be capable of recording high-quality video to perform video-based inspections as needed [9]. In addition, the inspection of bridges located in inaccessible locations requires the use of a drone equipped with a long-range remote-control system [9]. Moreover, payload capacity enables the carrying of additional equipment such as flashlights or additional cameras [9]. Finally, the availability of LED lights serves as an additional source of illumination [9].

Figure 1. Image of the DJI Air 2S

Considering the specifications mentioned above, the DJI Air 2S [10] was selected as the drone to be used in the inspection (see Fig. 1). It is important to note that opting for an affordable drone will provide a viable and cost-effective solution to implement and improve current inspection practices in Ecuador.

2.2 Bridge selection

The bridge chosen for the visual inspection was built in 1980 and is located over the Tambura ravine on the old Iluman-San Antonio highway, in the Province of Imbabura, Ecuador.

It is a continuous girder reinforced concrete bridge, as illustrated in Figure 2. The bridge has a total length of 34.3 m. In addition, it has a cross section formed by three T-type beams of 1.20 m height and a 0.20 m thick deck. In addition, according to the plans, it has a variable wearing course of 0.03 to 0.07 m and railings on the edges of the road for the safety of users. The substructure is made up of piers and abutments embedded at different heights.

The selection of this bridge was based on the availability of structural plans and data from a previous visual inspection [11], [12], thus allowing a comprehensive evaluation of its past and present condition.

Figure 2. Bridge selected for visual inspection

3 Methodology

The methodology used in this study involved a series of steps aimed at evaluating the condition of a bridge over time.

3.1 Bridge Information Review

First, a thorough review of the bridge's structural plans and documents related to previous inspections was conducted. The objective of this stage was to understand the design of the bridge and identify damages found in previous inspections. Information obtained from a visual inspection carried out in 2013 was considered, during which all damages found were documented.

3.2 Visual inspection using UAV

Subsequently, in 2024 a new visual inspection of the bridge was carried out; this time using a drone. The main objective of this second inspection was to evaluate the current state of the bridge and detect possible changes in its structural condition.

3.3 Bridge condition evaluation

This analysis was carried out following the criteria established in the "Guide to determine the condition of bridges in Costa Rica through visual inspection" which was based on an international bibliographic analysis and the experience acquired in inspections of existing bridges in Costa Rica [4]. This guide provides a structured approach to systematically evaluate the structural condition of the bridge and allowed for comparative analysis over time. The following sections present the sequence of the methodology used to evaluate the condition of the bridge on both dates.

3.3.1 Degree of damage (GD)

To report damage to structural elements, a classification of the elements was carried out according to whether they belong to the superstructure, substructure, road safety, accessories, or accesses. Subsequently, a degree of damage (GD) value is assigned to each element. The assessment of the extent and severity of the damage is reflected in this value [4]. For this study, a damage scale ranging from 0 to 3 was used, where 0 corresponds to no damage or very slight damage, 1 indicates slight damage, 2 denotes moderate damage, and 3 means severe damage.

3.3.2 Structural Relevance (RE)

Structural relevance (RE) is a measure that evaluates the importance of a component or element within the overall system of a bridge in terms of its structural function. This measure is used in civil engineering to prioritize attention and appropriately allocate resources in the inspection, maintenance, and rehabilitation of bridges [4]. For this study, a structural relevance scale ranging from 0 to 4 is used and it is determined based on the previously mentioned guide. The RE scale is shown in Table 1.

Table 1. Structural relevance (RE) of bridge elements

RE = 1	**RE = 2**	**RE = 3**	**RE = 4**
Expansion joints, signage, lighting, guardrails, sidewalks, drainage system, road surface	Vehicle barrier, approach fill	Deck, girders, supports, abutments	Piers

3.3.3 Failure type

Once the elements have been identified and GD and RE values have been assigned, it is necessary to determine how failure of the bridge system would be expected to occur due to damage to each element. This categorization can be done as follows:

A: Serviceability: Failure would affect the functionality of the bridge but would not cause structural collapse [4].

B: Failure of secondary element: Failure would affect secondary elements of the bridge but would not compromise its structural integrity [4].

C: Redundant: Element failure would not cause the bridge to collapse [4].

D: Non-redundant: Element failure would cause the bridge to collapse [4].

3.3.4 Failure Consequence Factor (FCF)

The failure consequence factor (FCF) is chosen for each element based on the consequences of its failure on the bridge and how failure of the bridge system would be expected to occur. This categorization can be done as follows:

Level 1 (Low): Mild consequences without risk of loss of life or injury, discomfort to users, the service may be affected in short periods [4].

Level 2 (Moderate): Moderate consequences. Slight risk of loss of life or injury. Considerable economic consequence [4].

After establishing the consequences levels, the FCF factors are determined using Table 2.

Table 2. Relationship between structural relevance RE, failure types and consequences levels

Failure Type	**Level 1 FCF=0.6**	**Level 2 FCF=0.8**
A	RE = 1	-
B	-	RE = 2
C	-	RE = 3/4
D	-	RE = 3/4

3.3.5 Element Rating (CE)

The element rating (CE) value is in the range of 1 to 6 and is determined using Eqn. (1) and rounding to the nearest integer.

$$CE_i = \begin{cases} 1 & \text{GD} = 0 \\ \{[(FCF * RE) - 1] + GD\} \leq 6 & \text{GD} \neq 0 \end{cases} \quad (1)$$

3.3.6 Overall Bridge Rating (CP)

Finally, the overall bridge rating (CP) is assigned based on the element with the highest score obtained using Eqn. (2).

$$CP = \max(CE_i) \quad (2)$$

4 Case study

4.1 Visual Inspection and Damage Assessment of the 2013 Bridge

4.1.1 Superstructure

The deck has a severe deterioration, with significant cracks, as show in Figure 3, possibly caused by settlement in the bridge piers so GD rating is assigned as 3.

Figure 3. Cracks in the deck of the bridge in 2013

Beams have a severe deterioration, with bending and shear cracks, exposure of the reinforcing steel, loss of cover and spalling of the concrete, reducing their flexural and shear capacity. Furthermore, the beams were built with poor quality concrete and poor construction techniques. GD rating is assigned as 3.

4.1.2 Substructure

Only one beam maintains the original bearings, and these are completely deteriorated. Furthermore, the other bearings were replaced with pieces of wood, which prevents them from performing their function correctly. All this can be seen in Figure 4. GD rating is assigned as 3.

Figure 4. Wooden supports of the bridge in 2013

The piers have severe deterioration with cracks due to settlement of this pile and scour. Also, the pier C has lost the support contact area due to scour. In addition, a loss of concrete material under the diaphragm is observed, as well as shear cracking, see Figure 5, 6 and 7 respectively. GD rating is assigned as 3.

Figure 5. Piers of the bridge in 2013

Figure 6. Piers of the bridge in 2014

Figure 7. Loss of support contact area in pier C 2014

Finally, the abutments have moderate deterioration with cracks and poor-quality concrete throughout the element, so GD rating is assigned as 2.

4.1.3 Road safety

Figure 8. Road safety and accessories elements of the bridge in 2013

The traffic signs have no visible damage, so GD rating is assigned as 0. The lighting was not present on the bridge, the vehicle barrier exhibited minor deterioration that did not compromise its integrity, and the sidewalks showed minimal wear but were still safe for pedestrian use. Hence, all these elements have a GD rating of 1. All this can be seen in Figure 8.

4.1.4 Accessories

The road surface has no cracks, potholes, or signs of deterioration. In addition, it provides a smooth and safe surface for vehicle traffic. Additionally, the bridge's drainage system because it is still able to drain water effectively to prevent pooling and structural damage and there is no sign of obstructions or deterioration. Hence, these elements have a GD rating of 0. On the other hand, the expansion joints have been completely covered with pavement, thus losing their ability to fulfill their function, so GD rating is assigned as 3. All this can be seen in Figure 8.

4.1.5 Access

The road surface has minor signs of deterioration. However, it is in safe and functional condition for vehicular traffic. Additionally, the approach fill is in optimal condition and have no presence of any deterioration that could compromise the stability or safety of access. Hence, these elements have a GD rating of 0. All this can be seen in Figure 8.

4.2 Visual Inspection and Damage Assessment of the 2024 Bridge

4.2.1 Superstructure

The deck has severe deterioration, with significant cracks, and carbonatation as show in Figure 9, possibly caused by settlement of the bridge piers, so GD rating is assigned as 3.

Figure 9. Beams of the bridge in 2024

Beams have severe deterioration, with bending and shear cracks, exposure of the reinforcing steel, loss of cover and spalling of the concrete, reducing their shear and flexural resistance. Furthermore, the beams were built with poor quality concrete and poor construction techniques. Additionally, there are pieces of wood attached to the beams in several places, apparently placed either as formwork during construction or as later repairs, as shown in Figure 9. Hence, beams have a GD rating of 3.

4.2.2 Substructure

The supports have excessive deterioration or non-existence. Also, pieces of wood are used as bearings, which prevents them from performing their function correctly. Hence, GD rating is assigned as 3. The piers have severe deterioration, with visible signs of deterioration such as pile settlement cracks and scour. In addition, a loss of concrete material under the diaphragm is observed as shown in Figure 10 and Figure 11. Hence, GD rating is assigned as 3.

Figure 10. Bridge piers in 2024

Figure 11. Bridge piers in 2024

Finally, the abutments have visible signs of deterioration such as cracks and poor-quality concrete throughout the element. Hence, GD rating is assigned as 2.

4.2.3 Road safety

The traffic signs are not visible due to complete paint loss on the bridge deck, so GD rating is assigned as 3. The lighting was not present on the bridge, the vehicle barrier exhibited minor deterioration that did not compromise its integrity, and the sidewalks showed minimal wear but were still safe for pedestrian use. Hence, all these elements have a GD rating of 1. All this can be seen in Figure 12.

Figure 12. Road safety and accessories elements of the bridge in 2024

4.2.4 Accessories

The road surface has lots of cracks, potholes, and signs of deterioration, so GD rating is assigned as 3. Moreover, the bridge's drainage system has obstructions and deterioration that prevent water from draining properly as shown in Figure 16, so GD rating is assigned as 2. Finally, the expansion joints have been completely covered with pavement, thus losing their ability to fulfill their function as shown in Figure 12, so GD rating is assigned as 3.

4.2.5 Access

The road surface has minor signs of deterioration. However, it is in safe and functional condition for vehicular traffic, so GD rating is assigned as 1. Additionally, the approach fill is in optimal condition and have no presence of any deterioration that could compromise the stability or safety of access. Hence, these elements have a GD rating of 0.

4.3 Bridge condition evaluation

The overall bridge rating was determined as described in the methodology. The results are presented in Table 2 and 3, respectively. Highlighted rows show elements whose condition worsened over time.

Table 3. Bridge condition in 2013

Element	RE	GD	Failure Type	FCF	CE
Road Signage	1	0	A	0.6	1
Lighting	1	1	A	0.6	1
Bridge Guardrail	2	1	B	0.8	2
Sidewalks	1	1	A	0.6	1
Road Surface	1	0	A	0.6	1
Bridge Drainage System	1	0	A	0.6	1
Expansion Joints	1	3	A	0.6	3
Road Surface	1	1	A	0.6	1
Approach Fill	2	0	B	0.8	1
Deck	3	3	C	0.8	5
Girders	3	3	C	0.8	5
Supports	3	3	C	0.8	5
Abutments	2	2	B	0.8	3
Piers	4	2	C	0.8	5
				CP	5

Table 4. Bridge condition in 2024

Element	RE	GD	Failure Type	FCF	CE
Road Signage	1	2	A	0.6	2
Lighting	1	1	A	0.6	1
Bridge Guardrail	2	1	B	0.8	2
Sidewalks	1	1	A	0.6	1
Road Surface	1	3	A	0.6	3
Bridge Drainage System	1	1	A	0.6	1
Expansion Joints	1	3	A	0.6	3
Road Surface	1	1	A	0.6	1
Approach Fill	2	0	B	0.8	1
Deck	3	3	C	0.8	5
Girders	3	3	C	0.8	5
Supports	3	3	C	0.8	5
Abutments	2	3	B	0.8	4
Piers	4	2	C	0.8	5
				CP	5

The assessment of the bridge's condition over the period spanning 2013 to 2024 reveals notable deterioration in substructure, road surface and signage. Furthermore, the lack of adequate maintenance and rehabilitation actions is evident, which significantly compromises the bridge's operation and safety. Additionally, during this period a lot of vegetation grew around and, on the structure, which complicated the assessment.

Substructure components, including supports, piers, and abutments, showed severe to moderate deterioration in 2013. Unfortunately, by 2024, deterioration of substructure elements continued, with no significant improvements observed. The supports and piers showed excessive deterioration, while the abutments showed a slight increase in deterioration.

Superstructure showed severe deterioration in 2013, which worsened in 2024. Deck and beams present significant cracks, exposure of the reinforcing steel, loss of coverage, spalling of the concrete and evidence of poor quality. Concretes and construction techniques. Additionally, pieces of wood are attached to the elements, further aggravating their condition.

In 2013, road safety elements such as traffic signals, lighting and vehicle barriers showed minor deterioration. However, by 2024, these elements experienced significant deterioration, with traffic signs showing a complete loss of paint on the bridge deck. The road surface also had large cracks, potholes, and visible signs of deterioration. Likewise, the drainage system deteriorated to such an extent that their operation was affected. Also, covering expansion joints with pavement can restrict their movement, causing increased stress on bridge components and potential structural damage. This practice also runs the risk of pavement deterioration, water infiltration, corrosion, and safety risks. Access elements such as sidewalks and access fills maintained relatively stable conditions between 2013 and 2024.

Overall, the analysis reveals a worrying lack of improvement in the bridge's condition over the decade. The continued deterioration in several components underscores the urgent need for comprehensive repair measures to ensure the continued safety and functionality of the bridge.

5 Discussion

Comprehensive assessment of bridge condition over a significant period, such as a decade, using both traditional visual inspections and modern methods using drones, reveals critical information about infrastructure maintenance requirements and the consequences of failing to do so.

Previous studies on bridge deterioration have highlighted factors such as environmental conditions, material degradation, and inadequate maintenance as contributors to structural deterioration [13]. Furthermore, studies have emphasized the importance of timely interventions and the use of advanced inspection techniques for accurate assessment of bridge condition [3]. The results of this paper suggest the need to reevaluate the maintenance strategies that are being used in Ecuador to guarantee their effectiveness [6].

The use of UAVs in the bridge inspection conducted in 2024 offers several advantages over the traditional inspection conducted in 2013. First, it allows for a more complete assessment of the bridge's condition, especially in areas that were previously inaccessible or difficult to inspect with traditional methods. The high-resolution images and videos captured provide detailed information on the extent of the deterioration, allowing structural deficiencies to be identified more effectively. In addition, inspection time and risk for inspectors are significantly reduced by preventing them from having to access dangerous or difficult access areas, thus reducing the costs associated with the inspection.

Future research should focus on advancing inspection techniques to improve the accuracy and efficiency of bridge evaluations. Additionally, comprehensive life cycle management strategies encompassing design, construction, maintenance, and rehabilitation should be explored to optimize resource allocation and minimize long-term costs, while ensuring time the safety and functionality of the bridge. Finally, it is necessary to promote the establishment of policies that promote the implementation of infrastructure management systems to ensure effective supervision and intervention of bridges throughout their life cycle.

6 Conclusions

In conclusion, selecting a suitable drone for bridge inspection is crucial to ensure efficient assessments. Factors such as flight time, camera resolution, payload capacity, and remote-control range are essential considerations when choosing a drone. In this study, the DJI Air 2S was selected for its suitability for capturing detailed images and performing extensive inspections.

Regarding bridge selection, the chosen bridge provided great evaluation opportunities due to the availability of the bridge's structural drawings, along with data from previous inspections, allowing for a comprehensive evaluation of its condition over time.

Finally, the analysis of the condition of the bridge over the decade revealed significant deterioration in several structural elements. The lack of substantial improvements despite visual inspections highlights the need to evaluate the maintenance strategies and interventions being used in Ecuador. Furthermore, the results align with previous studies on bridge deterioration, emphasizing the role of environmental factors, material degradation, and maintenance practices.

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