

## Bridge infrastructure in Ecuador: challenges and solutions *Infraestrutura de pontes no Equador: desafios e soluções*


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**Autor/a 1:** Estefanía Cervantes , Universidad San Francisco de Quito, Ecuador, [ecervantes@usfq.edu.ec](mailto:ecervantes@usfq.edu.ec).

**Autor/a 2:** José Matos , Universidade do Minho, Portugal, [jmatos@civil.uminho.pt](mailto:jmatos@civil.uminho.pt).

**Autor/a 3:** Eva Lantsoght, Universidad San Francisco de Quito; Delft University of Technology, Ecuador, [elantsoght@usfq.edu.ec](mailto:elantsoght@usfq.edu.ec).

### Abstract

Bridges are critical components of a nation's infrastructure, vital for efficient transportation and economic stability. However, they are susceptible to aging, increased traffic load, inadequate maintenance, and natural disasters, causing significant human and economic losses. Therefore, it is imperative to take measures to ensure the safety and longevity of the bridges. Developed countries have successfully implemented bridge management systems (BMS) for decades, while developing nations, such as Ecuador, still lack comprehensive systems and regulations. Through an extensive literature review and analysis of bridge collapses in the United States, China, Colombia, and Ecuador, this research highlights the predominant human factors that contribute to bridge failures in Ecuador, such as overloading, impact, and maintenance deficiencies. Additionally, a comprehensive content analysis of national regulations is performed to evaluate how they address and regulate critical aspects related to the causes of bridge collapses. Additionally, the study examines the current state of Ecuadorian bridges, revealing significant deficiencies in data, inspection, and maintenance practices. The results identify the need for a robust bridge management system and regulatory reforms adapted to local conditions to improve the safety, durability, and functionality of bridge infrastructure in Ecuador and similar developing countries.

**Keywords:** BMS; Bridges; Collapse; Ecuador; Regulations.

### Resumo

As pontes são componentes críticos da infraestrutura de uma nação, vitais para um transporte eficiente e para a estabilidade econômica. No entanto, são suscetíveis ao envelhecimento, ao aumento da carga de tráfego, à manutenção inadequada e a catástrofes naturais, causando perdas humanas e econômicas significativas. Portanto, é imperativo tomar medidas para garantir a segurança e longevidade das pontes. Os países desenvolvidos implementaram com sucesso sistemas de gestão de pontes (BMS) durante décadas, enquanto nações em desenvolvimento como o Equador ainda carecem de sistemas e regulamentações abrangentes. Através de uma extensa revisão da literatura e análise de colapsos de pontes nos Estados Unidos, China, Colômbia e Equador, esta pesquisa destaca os fatores humanos predominantes que contribuem para falhas de pontes no Equador, como sobrecarga, impacto e deficiências de manutenção. Além disso, é realizada uma análise abrangente do conteúdo das regulamentações nacionais para avaliar como elas abordam e regulam aspectos críticos relacionados com as causas dos colapsos de pontes. Além disso, o estudo examina o estado atual das pontes equatorianas, revelando deficiências significativas em dados, inspeção e práticas de manutenção. Os resultados identificam a necessidade de um sistema robusto de gestão de pontes e de reformas regulamentares adaptadas às condições locais para melhorar a segurança, a durabilidade e a funcionalidade da infraestrutura de pontes no Equador e em países em desenvolvimento semelhantes.

**Palavras-Chave:** BMS; Colapso; Equador; Pontes; Regulamentos.

## 1. Introduction

Bridges constitute a fundamental part of a country's infrastructure heritage due to their fundamental role in transport networks within the modern economy. Today, bridges can be affected by aging, increased traffic load, deficiencies in maintenance practices, and natural disasters (Weise et al., 2023). Therefore, the deterioration

and collapses of these structures are of great interest today because they entail enormous human and economic losses and require significant repair costs (Omar & Nehdi, 2018).

To ensure the safety, durability, and optimal functionality of bridges, as well as to make efficient use of resources and minimize the risks of collapse or deterioration, many countries have implemented preventive and corrective measures by implementing bridge management systems (BMS). A BMS includes the complete record of all bridges, which serves as a database compiled from information collected during periodic inspections and maintenance activities. This toolkit allows stakeholders to access detailed information about the condition of bridges and make decisions about their maintenance and operation (Ryall, 2001).

Developed countries such as the United States, Canada, Germany, Netherlands, Spain, Switzerland (Mirzaei, 2014), China (Deng et al., 2016), among others have successfully used BMSs for many decades. In contrast, some developing countries have focused mainly on the construction of new bridges and have only implemented BMS in the last decade (Tyvoniuk et al., 2024). However, other developing countries, like Ecuador, still lack a BMS and this situation is aggravated by the absence of comprehensive regulations that address all the necessary aspects to guarantee the safety, maintenance, and adequate planning of these structures (Cervantes et al., 2024).

To improve bridge management in a country, it is imperative that government agencies, engineering experts, and infrastructure planners collaborate effectively. This collaboration should focus on integrating existing BMS practices with emerging technologies and simplified methods of data collection, and optimization in maintenance strategies (Pregolato, 2019). Furthermore, through the joint efforts of these entities, it can be guaranteed that the resources allocated for the maintenance of the bridges are used appropriately, thus safeguarding both the structural integrity of the bridges and the safety of their users (Pregolato, 2019).

This research aims to address deficiencies in bridge management practices in Ecuador. To this end, the causes of bridge collapses and the implementations of BMSs in several countries are analyzed. Additionally, the current state of Ecuadorian bridges is evaluated, and a comprehensive analysis of national regulations is carried out to evaluate how they address and regulate critical aspects related to the causes of bridge collapses. The study seeks to identify the need for a robust BMS, and regulatory reforms adapted to local conditions, to improve the safety, durability, and functionality of bridge infrastructure in Ecuador.

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## 2. Literature Review

### 2.1. BMSs Around the World

Throughout history, studying the causes and mechanisms behind bridge collapses has been a priority for bridge engineers. Bridge collapses can be classified into two types: total collapse and partial collapse. Total collapse refers to the failure of all major components, resulting in the complete destruction of the bridge and requiring total reconstruction (Fu et al., 2012). Partial collapse, on the other hand, involves the failure of some major components, affecting traffic safety but allowing for possible repairs. However, repairing a partially collapsed bridge can be a challenge (Fu et al., 2012).

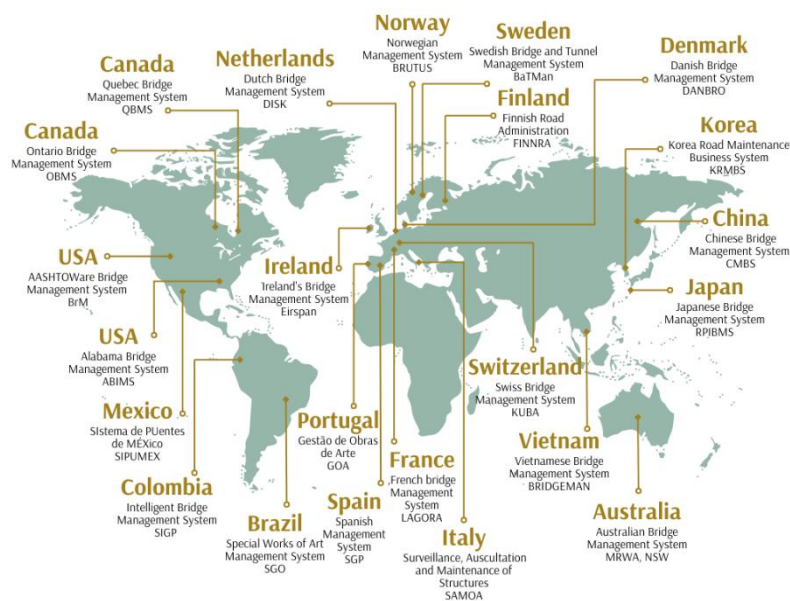
It has been found that the collapse of a bridge is usually the result of a complex process influenced by the combination of multiple factors, such as deficiencies in design or construction, poor maintenance practices, overload, use of defective and substandard materials, and inadequate consideration of external events (Wardhana & Hadipriono, 2003). However, the main causes of collapses can be classified into two groups: those caused by natural factors and those caused by human factors. Natural factors include events such as earthquakes, floods, scour, debris flows, hurricanes, and landslides. On the other hand, human factors include errors in design and construction, overloading of vehicles, lack of inspection and maintenance, and terrorist attacks (Deng et al., 2016).

To address these problems, numerous countries have implemented BMSs for the control, maintenance, and preservation of bridges, guaranteeing both safety and efficiency (Cervantes et al., 2024; Quirk et al., 2018), as shown in Figure 1. Some of these systems allow a comprehensive management that considers both natural and



human factors, ensuring that appropriate preventive and corrective maintenance strategies are taken to mitigate the risk of collapses and prolong the useful life of the bridges. Unlike the countries shown in Figure 1, Ecuador lacks a comprehensive BMS that addresses all aspects necessary to ensure proper bridge safety, maintenance, and planning. This deficiency is reflected in the poor condition of 45% of the country's road network (Telégrafo, 2023), and in the poor or fair condition of more than 70% of the bridges in provinces such as Bolívar, Carchi and Cotopaxi, thus evidencing the precarious state of roads and bridges nationwide (CONGOPE & Banco Interamericano de Desarrollo — BID, 2019b, 2019d, 2019f). Furthermore, bridge maintenance in Ecuador has been inconsistent and there is limited information available about them (Flores & Lantsoght, 2016).

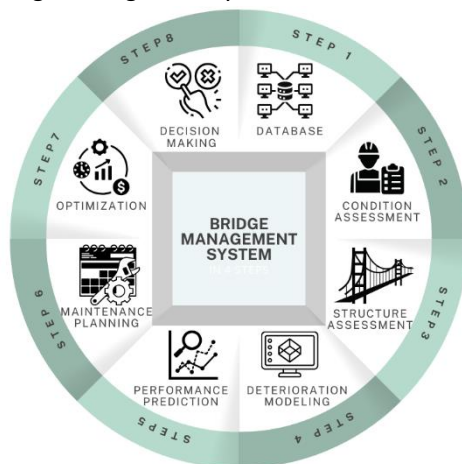
Figure 1: Bridge management systems around the world.



Source: Adapted from (Cervantes et al., 2024).

The fundamental elements of a BMS consist of database components, structural evaluation, deterioration prediction, life cycle cost and maintenance optimization (Omar & Nehdi, 2018) as explained in Figure 2. However, it is important to note that not all countries have systems that are this elaborate. The BMS database is used to store inventory. The condition evaluation and deterioration prediction components evaluate the current and future condition of the bridges, respectively. The life cycle cost component estimates the costs of different maintenance scenarios. Finally, the optimization component determines the most cost-effective maintenance strategies (Omar & Nehdi, 2018).

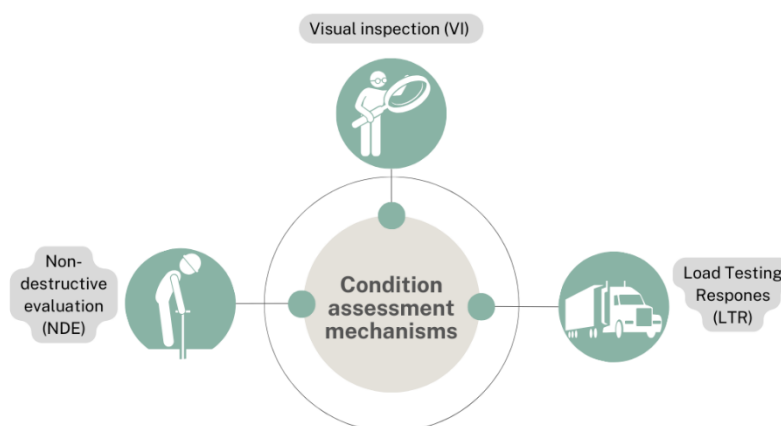
Figure 2: Basic components of a bridge management system.



Source: Adapted from (Messervey, 2009).

Given the importance of accurate assessment within a BMS, many countries have developed different bridge condition assessment methods to monitor the extent and severity of any existing defects or deterioration and identify the appropriate timing for repairs or maintenance necessary to maintain the condition of the structure within acceptable limits (Woodward et al., 2000). The purpose of the assessment of an existing bridge is to determine whether it can operate safely for a specified remaining useful life (Omar & Nehdi, 2018), and the ultimate goal of structural condition assessment will always be the prevention of bridge collapses (Figueiredo et al., 2013). In recent years, techniques for assessing the condition of bridges have evolved independently through two complementary approaches: Structural Health Monitoring (SHM) and BMSs (Figueiredo et al., 2013). Therefore, considering the BMS approach, the condition assessment methods can be classified into three categories, as detailed in Figure 3.

**Figure 3:** Condition assessment methods of reinforced concrete bridges.



**Source:** Adapted from (Omar & Nehdi, 2018).

## 2.2. Methodology in the USA and Ecuador

Visual inspection (VI) is the most conventional method for gathering information about the current condition of a bridge and the primary component of all existing BMSs. It is carried out by qualified inspectors, who prepare their assessments based on direct observation of the structure, and it is relatively inexpensive, as it does not require testing or cause traffic disruptions (Beltrami et al., 2021). The results of these bridge inspections are subjective and qualitative, influenced by several factors, such as the individual perspectives of the experts involved (Graybeal et al., 2002; Omar & Nehdi, 2018).

In the United States, the Federal Highway Act of 1968 established the National Bridge Inspection Program (NBIP), which requires states to inventory and inspect all highway bridges to ensure safety and compliance (Phares et al., 1999). In 1971, the National Bridge Inspection Standards (NBIS) were established as safety inspection standards for highway bridges on public roads throughout the United States. These standards require periodic inspections and specify the qualifications and training required for inspectors. It also includes a standardized condition rating system to prioritize maintenance and rehabilitation efforts, load capacity assessments to verify safe traffic support, and comprehensive documentation and data management for all bridges (Federal Highway Administration, 2022). These standards help identify potential problems early, allowing for timely repairs and reducing the risk of bridge failure.

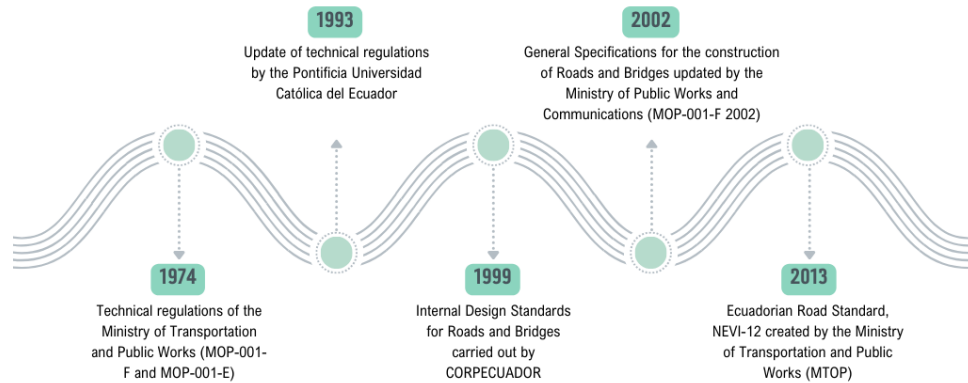
Highway bridge inspections generally fall into two categories: routine inspections and in-depth inspections. Routine inspections are scheduled periodically, at least every 24 months, to evaluate the physical and functional condition of bridges and ensure they meet serviceability requirements (Federal Highway Administration, 2022). These inspections must satisfy the requirements of the NBIP for frequency, inspector qualifications and documentation. On the other hand, in-depth inspections involve a practical and detailed examination of specific bridge elements using specialized equipment to identify less visible deficiencies (American Association of State



Highway and Transportation Officials Subcommittee on Bridges and Structures, 1994) and are less frequent than routine inspections but more thorough to detect specific defects (Graybeal et al., 2002).

Unlike the United States, where there is an established regulation that defines the recommended procedures and frequencies for bridge inspections and maintenance, Ecuador lacks such similar regulations (Cervantes et al., 2024). Figure 4 illustrates the evolution of the country's regulations from 1974 to the present.

Figure 4: Ecuadorian standards over time.



Source: Adapted from (Cervantes et al., 2024).

### 3. Methodology

This research compiled and analyzed previous studies on the analysis of bridge collapses in the United States, Colombia, China and Ecuador. The selected studies included the analysis of 503 bridge collapses in the United States between 1989 and 2000 (Deng et al., 2016; Wardhana & Hadipriono, 2003), 63 bridge collapses in Colombia between 1986 and 2001 (Diaz et al., 2009), 157 bridge collapses in China between 2000 and 2012 (Fu et al., 2012), and 72 bridge collapses in Ecuador between 2000 and 2022 (Guzmán & Noboa, 2022). Data from these studies were adapted and synthesized from (Cervantes et al., 2024) to ensure consistency and comparability across different regions and time periods. The analysis focused on identifying and analyzing the causes of bridge collapses due to natural and human factors. Additionally, the time periods during which the research was conducted were examined to contextualize differences in bridge collapse rates between countries.

Data from the 'Road Development Plan' were used to determine the total number of bridges in Ecuador and their condition. Additionally, the reliability of the results provided in these plans was discussed through a practical example of visual inspection of a bridge in Ibarra using international guidelines from Costa Rica due to the lack of specific local regulations. Furthermore, an in-depth review of the current Ecuadorian road standards was carried out to assess how they address and regulate critical aspects related to the causes of bridge collapses. This analysis covered all Ecuadorian Road Standard NEVI-12 volumes. The goal was to identify strengths, weaknesses, and gaps in the regulatory framework concerning bridge safety and maintenance practices in Ecuador.

### 4. Analysis and Results

#### 4.1. Causes of Bridge Collapse

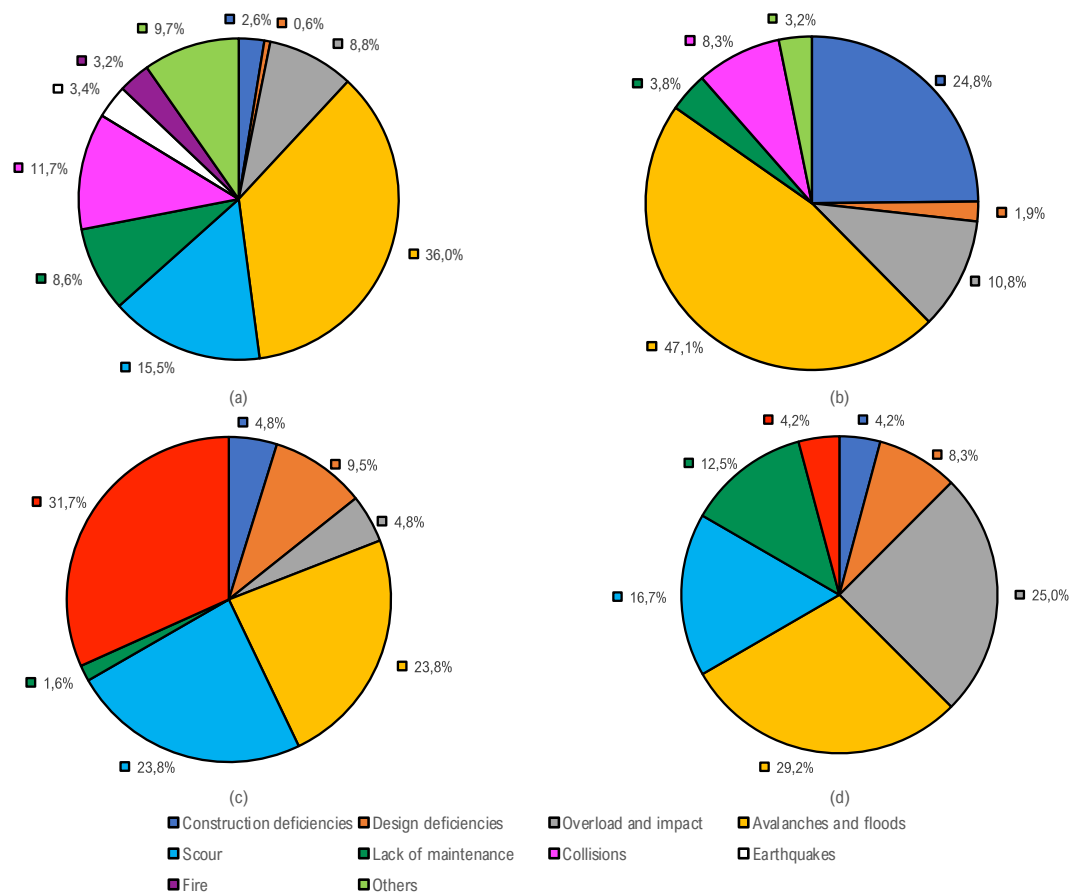
Several studies have been carried out in different countries to identify the causes of bridge collapses. The principal causes of bridge collapses were categorized as deficiencies in design and construction, overload and impact, lack of maintenance, collisions, avalanches and floods, scour, earthquakes, and fire. The first five causes of collapse are associated with human factors. The remaining causes are associated with natural factors. Figure 5 shows the distribution of the results of these studies.

It is important to recognize that these deficiencies may be interrelated, although such connections may not be immediately obvious (Wardhana & Hadipriono, 2003). An example of this interrelationship is the collapse of the I-35W bridge over the Mississippi River in Minneapolis, which was caused by multiple factors. The bridge's



original design included overly thin reinforcement plates, and subsequent renovations and additions significantly increased its weight without considering its structural impact (Salem & Helmy, 2014). At the time of the collapse, the bridge was carrying additional dynamic loads due to traffic and heavy machinery related to maintenance work. Additionally, corrosion and wear had weakened the structure, and inspections failed to detect all critical deficiencies, including undersized plates (Salem & Helmy, 2014). This combination of factors caused the bridge to collapse. In this study only the most probable primary cause in each case was considered.

Figure 5: Causes of bridge collapses in (a) the United States, (b) China, (c) Colombia, and (d) Ecuador.

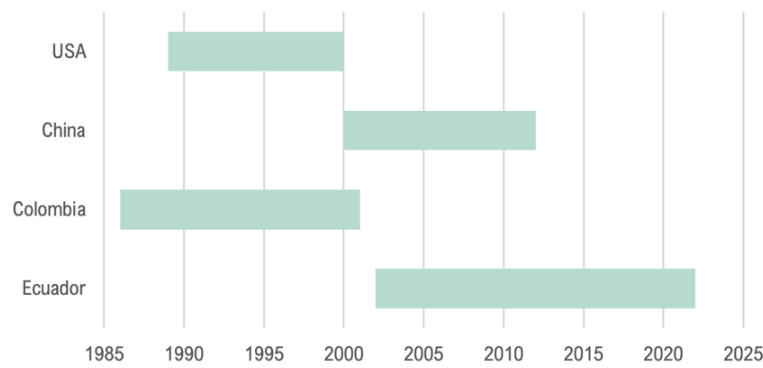


Source: Data from (Diaz et al., 2009; Fu et al., 2012; Guzmán & Noboa, 2022; Wardhana & Hadipriono, 2003). Adapted from (Cervantes et al., 2024).

The time periods in which each investigation was conducted, as shown in Figure 6, indicate that the data from the Ecuadorian study is more recent compared to two of the other countries. This temporal difference suggests that bridges in Ecuador were likely built with more up-to-date regulations and standards, as well as more advanced construction practices relative to the United States and Colombia (Cervantes et al., 2024). On the other hand, China and Ecuador carried out the studies in similar time periods. However, despite this similarity, collapses in China represent about 0.1% of all its bridges (Tang et al., 2022), while in Ecuador it is estimated that collapses represent approximately 1.5%, based on the total number of bridges identified in this study and the number of collapses presented in (Guzmán & Noboa, 2022). This large difference may be due to China having a BMS, as shown in Figure 1. However, it is also necessary to consider the age of the structures at the time of collapse to better understand these discrepancies. However, no information on the age of collapsed Ecuadorian bridges is available to make this comparison due to the lack of a BMS or national bridge inventory.



**Figure 6:** Time periods of investigations on causes of bridge collapses

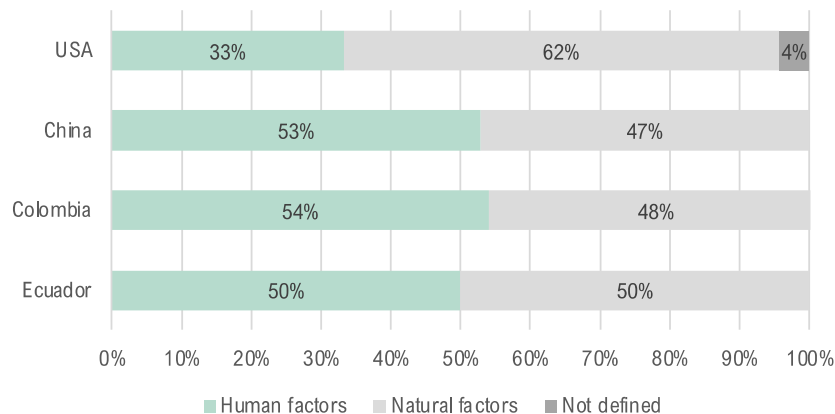


**Source:** Data from (Diaz et al., 2009; Fu et al., 2012; Guzmán & Noboa, 2022; Wardhana & Hadipriono, 2003).

#### 4.2. Natural and Human Factors of Collapses

Bridges are vulnerable to a variety of natural and human-induced factors that can cause serious damage or even collapse. Natural factors include phenomena such as floods, scour, earthquakes, landslides, debris flows and hurricanes. Human factors include improper design and construction methods, collisions, vehicle overloading, fires, terrorist attacks, and inadequate inspection and maintenance (Deng et al., 2016). It is observed that only in the USA the causes of natural collapses are considerably greater than those produced by human factors, as shown in Figure 7. Understanding these various threats is crucial to developing effective mitigation strategies that ensure the safety and durability of bridges.

**Figure 7:** Collapses due to natural factors vs. human factors.

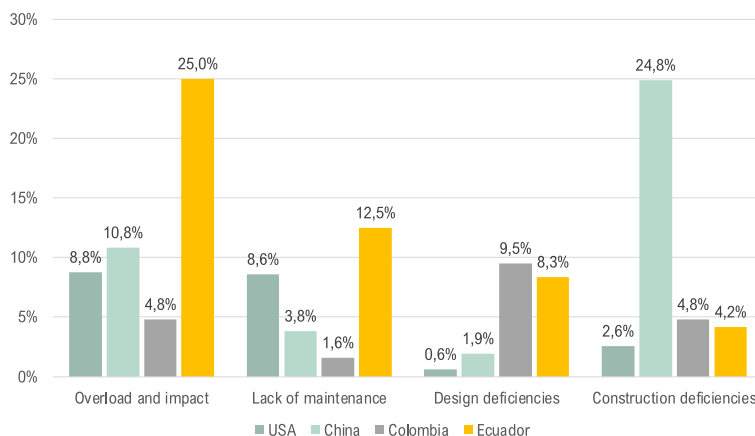


**Source:** Data from (Diaz et al., 2009; Fu et al., 2012; Guzmán & Noboa, 2022; Wardhana & Hadipriono, 2003).

Regarding collapses caused by human factors, in Ecuador there is a significantly higher incidence of causes such as overload, impact and lack of maintenance, as shown in the Figure 9. This suggests that it is necessary to strengthen regulatory measures regarding load limits that transit the road network. In addition, an analysis of the country's maintenance protocols is necessary, and a significant improvement is suggested. Furthermore, the highest percentage of collapses in all the countries analyzed occurs during the service stage of the bridge, as shown in the Figure 10 (Cervantes et al., 2024). This highlights the critical need for continuous maintenance, monitoring and timely repairs to ensure the structural integrity of bridges throughout their operational life.

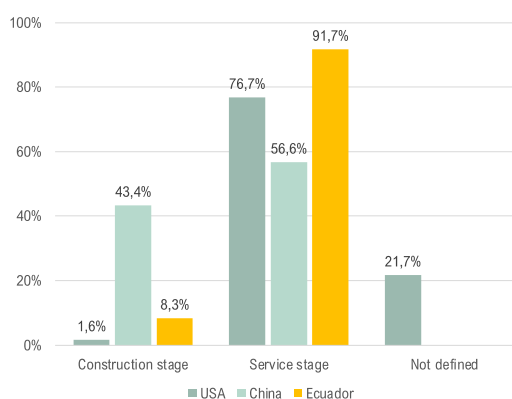


**Figure 9:** Causes of collapses due to human factors in bridges in the United States, Colombia, China and Ecuador.



**Source:** Data from (Diaz et al., 2009; Fu et al., 2012; Guzmán & Noboa, 2022; Wardhana & Hadipriono, 2003).

**Figure 10:** Phase of occurrence of collapses in bridges in the United States, Colombia, China and Ecuador.



**Source:** Data from (Diaz et al., 2009; Fu et al., 2012; Guzmán & Noboa, 2022; Wardhana & Hadipriono, 2003).

### 4.3. Ecuadorian Road Standard (NEVI-12) Content Analysis

The causes mentioned above are closely linked to codes, standards, and regulations that establish the framework and requirements for the design, construction, and maintenance of bridges and roads. Ensuring compliance with these regulations is crucial for maintaining the safety and structural integrity of bridges. For this reason, a detailed analysis of the current regulations in Ecuador was carried out, as shown in Table 1. This analysis aims to provide a comprehensive understanding of how current regulations address and regulate critical aspects related to the causes of bridge collapses.

**Table 1:** Ecuadorian Road Standard (NEVI-12) content analysis.

Standard	Scope	Content	Bridge references
Ecuadorian Road Standard (NEVI-12), Procedures for road projects	Approaches and methodology for the development of road projects	General information, introduction to road projects, general procedures, approaches to the development and methodology of road projects	Preliminary bridge design (section 1.304.3.5), topography for bridges (section 1.304.5.4), and hydraulic data (section 1.304.5.7)
Ecuadorian Road Standard (NEVI-12), Standard for road studies and designs	Regulatory principles for road studies	General information, geometric layouts, geodesy and topography studies, plans, reports, and study documents	Clear height (section 2a.204.6.3), and agricultural crossings (section 2a.204)



Ecuadorian Road Standard (NEVI-12), General specifications for construction of roads and bridges	Regulatory technical specifications for the construction of roads and bridges	General specifications, general specifications for environmental control, earthworks, pavement structure, structures, drainage, sewage and drinking water facilities, facilities for traffic control and use of the road area, sampling methods, testing and control	Piles (section 501), concrete structures (section 502), reinforcing steel (section 504), and steel structures (section 505)
Ecuadorian Road Standard (NEVI-12), Environmental studies and criteria for road projects	Specific regulatory legal framework for road environmental studies	Environmental and general legal framework applied to road projects, environmental considerations in studies of new layout projects	Environmental impact assessment (sections 4.404.4.1 and 4.404.4.2), environmental impact of bridges (section 4.403.5.3)
Ecuadorian Road Standard (NEVI-12), Operation procedure and road safety	Regulations and specifications for safety and road operation	Legal and institutional framework for road safety, road safety during the life cycle of a road project, traffic signage, traffic signage for road works, pedestrians on the road, speeds, advertising on road routes, use of the side area of the roadway, lighting	Bridges (section 5.904.4.1), marking of artwork and drainage (section 5.903.3), and containment barriers (section 5.903.2)
Ecuadorian Road Standard (NEVI-12), Road maintenance operations	Standards and specifications for road maintenance	Maintenance operations, study manual for scheduling road pavement conservation works	Bridge restoration and conservation techniques (section 6.108)

**Source:** Data from (Ministerio de Transporte y Obras Públicas del Ecuador, 2013a, 2013b, 2013c, 2013d, 2013e, 2013f).

Volume 1 of the Ecuadorian Road Standard (NEVI-12) contains information on the preliminary design of the bridge, specifying that a detailed hydrological and topographic study of the bridge site must be carried out. It also highlights the need to determine the frequency and duration of extraordinary floods and the times of year in which they occur. Based on this information, the bridge design will include a safety section to facilitate the passage of floating debris during flooding. Volume 2 specifies that the clear height of bridges must be at least 6 meters above the total width of the road, including auxiliary lanes and shoulders, and establishes that bridges will be constructed to maintain connectivity without compromising road safety in agricultural areas. Volume 3 describes the functions of piles, sheet piles, reinforced and pre-compressed concrete beams, and covers the use, installation requirements and specifications for steel and reinforced steel structures. Volume 4 addresses the environmental impacts of bridge construction, focusing on modifications to the natural landscape and potential disturbances to local ecosystems, and includes a detailed assessment of the environmental impacts caused by bridge structures. Volume 5 covers the aesthetic aspects of bridges, including specific signage for artwork and drainage, and the location and design of lighting units and highway containment barriers. Finally, Volume 6 details the methods and materials necessary to repair railings, pavements, load-bearing structural elements, wooden components, concrete surfaces, and cracks, as well as concrete compromised by reinforcement corrosion. It also describes the processes for replacing corner posts, drainage pipes, and wooden platforms, and

provides instructions for assembling modular bridges used temporarily during emergencies or for repairs to existing bridges.

The content of the Ecuadorian Road Standard (NEVI-12) reveals important deficiencies in several crucial guidelines for the preservation of bridges. First, this regulation lacks detailed specifications for inspections and maintenance, including the frequency with which these activities must be performed, resulting in inefficient management of the bridge infrastructure. Furthermore, the lack of a structured program for the training and certification of bridge inspectors in Ecuador shows a notable discrepancy compared to international programs, such as those adopted by the National Highway Institute in the United States (U.S. Department of Transportation, 2024). This deficiency prevents Ecuadorian professionals from acquiring the necessary skills to perform comprehensive and effective evaluations, essential to guarantee the integrity and safety of bridges.

Another important aspect to consider is that the standards do not adequately reflect country-specific vehicle loads but are adaptations of US standards. Vehicle overload can reduce the useful life of the structural components of a bridge due to the fatigue effect, accelerate pavement wear and, in extreme situations, cause the sudden collapse of the bridge (Deng et al., 2016). Imposing vehicle weight regulations and incorporating local vehicle loads aligned to the specific traffic conditions in each country has been shown to be an effective method to mitigate these problems (Diaz et al., 2009). In this context, it is crucial to develop more detailed regulations adapted to local conditions to ensure safety and structural integrity. These improvements should include regulations on which design vehicles should be used, as well as establishing overload controls. This will make it possible to comprehensively address everything related to vehicle loads on bridges.

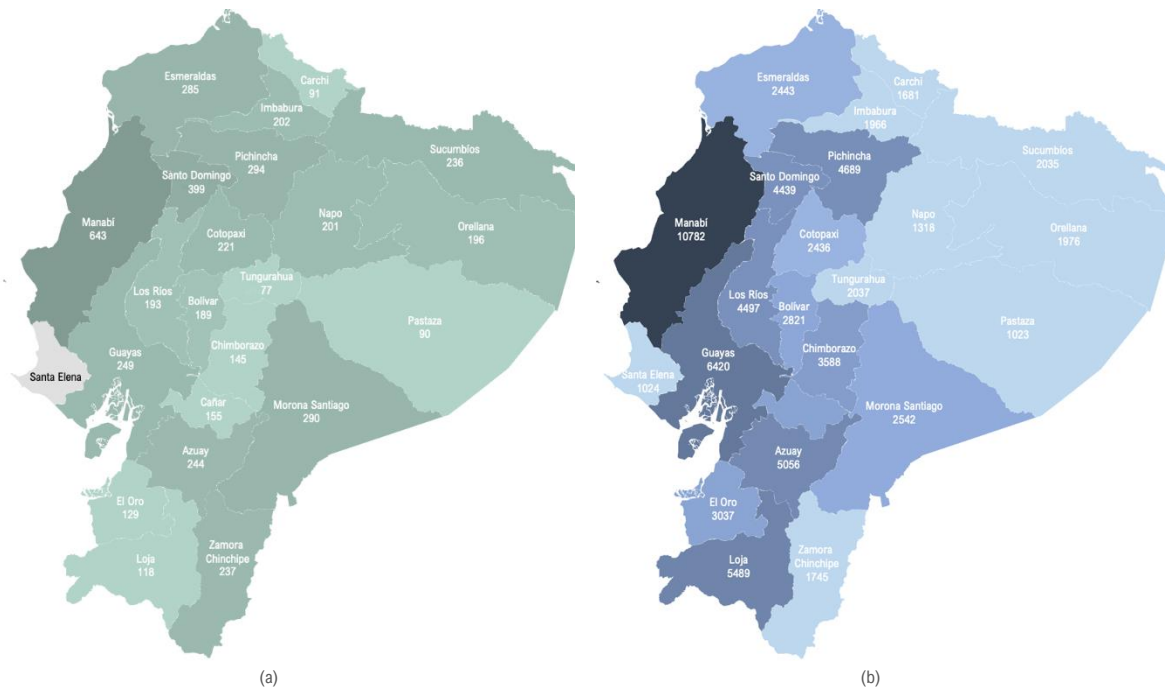
Finally, the absence of a structured system dedicated to the planning and management of these critical structures aggravates the situation. This lack of a proper management structure can lead to numerous operational and security issues, as well as significant economic costs. Among the most notable consequences are accelerated deterioration of bridge infrastructure, increased repair costs, and significantly increased risks to public safety. Frequent interruptions in communication routes are also observed, which can have a considerable negative economic impact, as evidenced by various studies (Cervantes et al., 2024; Vargas-Alas & Villalobos-Vega, 2019).

#### **4.4. Ecuadorian Bridges Analysis**

Everything mentioned above is reflected in the current state of the bridges in Ecuador. At the moment, the country does not have an inventory updated to 2024 that details the total number of bridges. However, the 'Road Development Plan' (CONGOPE & Banco Interamericano de Desarrollo — BID, 2019a) prepared by government entities of each province, provides information that has been processed to determine the total number of bridges in Ecuador, as shown in Figure 11a, and the kilometers of highway roads per province, as depicted in Figure 11b. It should be noted that there is no information available on the bridges of the provinces of Galapagos and Santa Elena. The absence of information highlights the need for an updated and detailed inventory to effectively manage and maintain the country's bridge infrastructure.

The data obtained allows a comparative analysis to be carried out between the different provinces. For example, Manabí is the province with the highest number of bridges, a total of 643, and has the most extensive road network in the country, with 10,781.54 kilometers of roads. On the other hand, Tungurahua, which is the province with the smallest number of bridges, has only 77 bridges distributed over 2,036.87 kilometers of roads. As for Pichincha and Guayas, these provinces have 294 and 249 bridges, and their road networks extend for 4,688.78 kilometers and 6,419.57 kilometers, respectively. These differences underscore the importance of adapting the 'Road Development Plan' to serve not only regions with high infrastructure density but also those with fewer assets but equally critical needs.

Figure 11: Inventory of Ecuadorian bridges and roads by 2019.



**Source:** Data from (CONGOPE & Banco Interamericano de Desarrollo — BID, 2019a, 2019b, 2019d, 2019e, 2019f, 2019g, 2019h, 2019i, 2019j, 2019k, 2019l, 2019m, 2019n, 2019o, 2019p, 2019q, 2019r, 2019s, 2019t, 2019u, 2019v, 2019w, 2019c).

The 'Road Planning Plans' of each province provide data on the state of their bridges, classifying them as good, bad, or fair (CONGOPE & Banco Interamericano de Desarrollo — BID, 2019a). However, some provinces such as Cotopaxi, Pichincha and Zamora Chinchipe carry out this classification considering only the state of the surface layer, while others such as Esmeraldas, Guayas and Napo consider the state of the superstructure. Therefore, the results presented in these plans do not necessarily reflect the true condition of the bridges. To illustrate this possible inaccuracy, data from a visual inspection of a reinforced concrete bridge located in Ibarra were used.

The elements of a bridge can have different degrees of damage and structural relevance, thus contributing independently to the damage condition of the structure (Muñoz Barrantes, 2017). For example, as shown in Figure 12, the wearing course has numerous cracks, potholes, and signs of deterioration, which compromises its functionality. Therefore, it is in poor condition. On the other hand, the bridge piers, represented in Figure 13, show significant damage, including cracks, holes, and poor-quality concrete, which may also represent a poor condition of the element. On the other hand, the vehicle barrier, represented in Figure 14, presents minor deterioration that does not affect its integrity, so it can be categorized as fair condition. This analysis demonstrates a lack of correlation between the state of the elements of the same bridge. Different elements can present different states of deterioration or damage, and relying on a single element as the sole indicator of the overall condition of the bridge would be incorrect. Therefore, a comprehensive evaluation of all components is essential for accurate assessment of its condition and correctly plan the necessary maintenance actions. This example also demonstrates the need to implement appropriate regulations for the evaluation, inspection, and maintenance of these structures.

**Figure 12:** Visual inspection of the wearing course of an Ecuadorian RC bridge.



**Figure 13:** Visual inspection of the piers of an Ecuadorian RC bridge



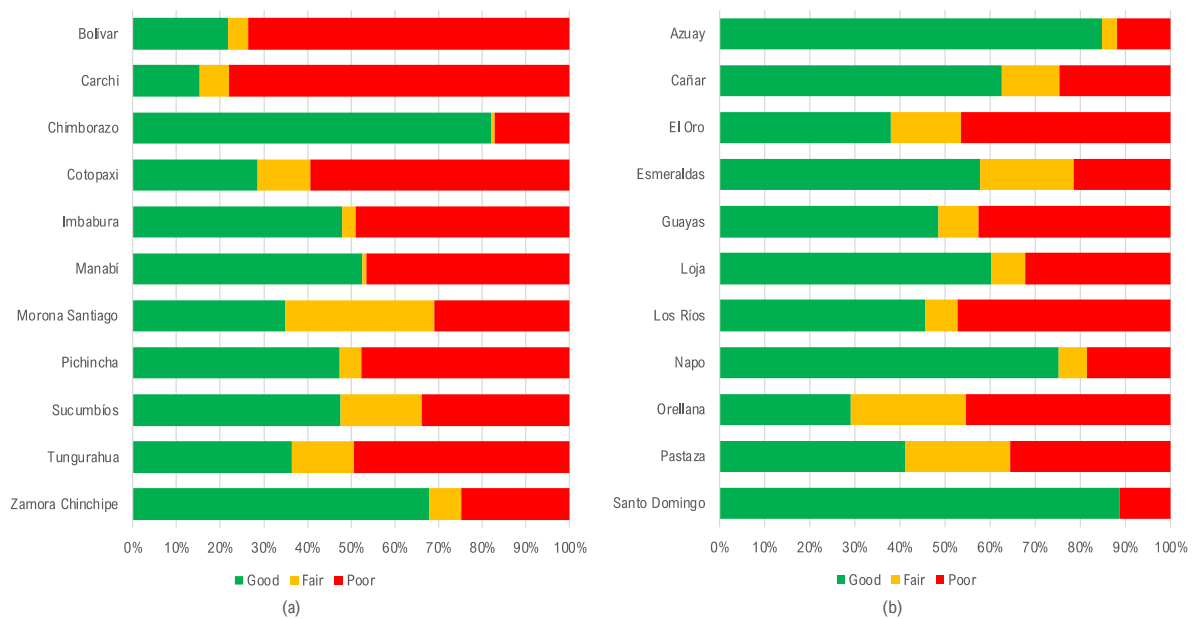
**Figure 14:** Visual inspection of the vehicle barriers of an Ecuadorian RC bridge



Figure 15 shows the evaluation of the state of reinforced concrete bridges in Ecuador. Figure 15a shows the results obtained considering only the condition of the bridge wearing course, while Figure 15b considers only the superstructure. From the analysis of these data, it is observed that approximately 54% of the country, or 13 of the 24 provinces, have more than 50% of their bridges in poor or fair condition, thus evidencing the precarious state of the roads nationwide. It is important to mention that, due to the way in which the results were obtained, it can be inferred that the budgets assigned by the entities of each province to these activities are probably lower than necessary.



Figure 15: Condition assessment of Ecuadorian reinforced concrete bridges.



Source: Data from (CONGOPE & Banco Interamericano de Desarrollo — BID, 2019a).

The results in Figure 15 are alarming and reveal that much of the national infrastructure is in fair or poor condition. This not only harms the reliability of road infrastructure, but also poses serious risks to public safety and economic stability. With more than half of provinces reporting that most of their bridges are rated in less than satisfactory condition, the problem appears to be systemic and extend beyond individual cases of neglect. Consequently, an immediate and comprehensive review and modification of the country's regulations is required to incorporate or improve aspects of the design, inspection and maintenance of bridges and thus extend their useful life and guarantee long-term safety and functionality. To achieve this, it is essential to develop international collaborations, which allow coordinating efforts and facilitating the exchange of ideas and best practices at a global level (Lantsoght, 2024). Furthermore, it is necessary to implement a more rigorous and systematic approach by integrating a bridge management system that allows continuous monitoring of structural integrity, early identification of structural damage, and effective planning of maintenance interventions. Additionally, it would be beneficial to implement network-level analysis to identify those bridges in poor condition that, if failed, would have the greatest negative impact. This strategic assessment would allow necessary interventions to be prioritized, ensuring that resources are allocated first to those structures whose deterioration could most significantly compromise road safety and have substantial impacts on public safety and the local economy.

## 5. Discussion

The results indicate that bridge collapses are influenced by a large number of factors broadly categorized into natural and human-induced causes. In Ecuador, collapses are generated mainly by human causes, which suggests a significant deficiency in the existing regulatory and management frameworks in the country. This is why the study establishes the need for a comprehensive reform in bridge management and maintenance practices in Ecuador. The absence of a robust BMS, as seen in more regulated environments such as USA, where National Bridge Inspection Standards govern inspection and maintenance schedules and practices, shows a clear path that Ecuador could consider replicating to reduce bridge collapses significantly.

While the study provides detailed information on the causes of bridge collapses, focusing primarily on Ecuador could limit the generalizability of the findings found. Future studies could expand to comparative analyzes with countries that have robust BMS implementations to further validate the effectiveness of such systems.

Additionally, the role of advanced technologies, such as drone inspections and real-time monitoring systems in other regions, could provide valuable information on innovative practices that could be adapted in Ecuador. Finally, it is imperative to analyze in greater depth the quantification of risks and vulnerabilities in regions prone to natural disasters, as well as the analysis of the economic impact derived from the collapse or interruption of these structures.

## 6. Conclusion

This study has exhaustively explored the causes of bridge collapses, with a particular focus on the effectiveness of BMSs in several countries, placing special emphasis on the situation in Ecuador. Results highlight that, in Ecuador, the predominant causes of bridge collapses are due to human factors, unlike countries with strong management systems such as the United States, where natural factors play a larger role.

The lack of a comprehensive BMS in Ecuador represents a critical vulnerability, which is reflected in the poor conditions of much of its bridge infrastructure. The implementation of a BMS is not only imperative to prevent future collapses, but also to establish a standard in infrastructure management that could serve as a model for other developing countries. This review is crucial to ensure the longevity, functionality and safety of the bridges, thus protecting economic interests and human lives.

The current regulatory framework, particularly the NEVI-12 standards, does not adequately meet the needs for regular and systematic inspections and maintenance. This study highlights the urgent need for corrective actions and regulatory updates to ensure the safety, integrity and efficiency of road infrastructure in Ecuador. These improvements are essential to achieve the safety and reliability criteria necessary for the country's infrastructure. Regarding vehicle overloading, the need to review and adapt current regulations is identified to more accurately reflect local vehicle loads, implementing more rigorous measures to control and sanction overloading.

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### Declaração Ética

**Conflito de Interesse:** Nada a declarar. **Financiamento:** Nada a declarar. **Revisão por Pares:** Dupla revisão anônima por pares.



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