Identification and analysis of pathologies in bridges of urban and rural roads

Identificación y análisis de patologías en puentes de carreteras urbanas y rurales

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Abstract

A concern with a great number of bridges with significant pathological problems was the motivating factor to carry out this research. Small and medium size bridges have significant relevance for the economic and social development of the country, because they must ensure the transit of people, vehicles with raw material and local produce. However, the precarious conditions of bridges in the urban and rural areas make the displacement difficult, causing discomfort and unsafety for users. Furthermore, the transportation costs for producers and the maintenance for the local government continue to increase. This article intends to show the conservation conditions of small and medium sized bridges in the urban and rural region of Campinas (SP)-Brazil. Thus, this study is based on the analysis of four bridges of this region, in which is presented several examples in situ of the pathological manifestations in concrete, steel and wood bridges. This article also focuses on the design of bridges and its relationship with the pathological condition establishing concepts that could be applied to the corrective method and the pathology identification in concrete, steel and wood bridges. Finally, it aims to conclude that the most appropriate way to avoid a pathological state is preventive maintenance.

Keywords: Bridges, pathology, concrete, steel, wood

Resumen

La preocupación con un gran número de puentes con importantes problemas patológicos fue el factor de motivación para llevar a cabo esta investigación. Puentes de tamaños mediano y pequeño tienen relevancia significativa en el desarrollo económico y social del país, pues deben garantizar el tránsito de personas, vehículos, materias primas y productos locales. Sin embargo, las precarias condiciones de los puentes en las zonas urbanas y rurales hacen difícil el desplazamiento, causando incomodidad e inseguridad para los usuarios. Por otro lado, los costos de transporte para los productores y el mantenimiento para los gobiernos locales continúan aumentando. Este artículo tiene la intención de evaluar las condiciones de conservación de puentes pequeños y medianos en la región urbana y rural de Campinas (SP)-Brasil. Así, este estudio se basa en el análisis de cuatro puentes de esta región, en los que se presentan varios ejemplos sobre el terreno de las manifestaciones patológicas en puentes de concreto, acero y madera. Este artículo también se centra en el diseño de puentes y la relación con su estado patológico estableciendo conceptos que podrían aplicarse al método correctivo y a la identificación de la patología en puentes de concreto, acero y madera. Por último, el objetivo es concluir que la forma más adecuada para evitar un estado patológico es el mantenimiento preventivo.

Palabras Clave: Puentes, patología, concreto, acero, madera

1. Introduction

The importance of bridges for the development and human relationship has been the main reason for the advance impulse in knowledge of construction and maintenance of these structures.

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In general the initial purpose of a bridge is to transpose an obstacle and then the continuation of the road. Nevertheless, taking into account technical literature on bridge classifications, it is necessary to consider several design aspects, such as transposed obstacles, side view, number of clear span, bearing area constituent material, traffic nature, etc.

In general, it is acknowledged, technically, that there is an emphasis on large bridges with complex structural systems, without a proper consideration to the small and medium sized bridges. However, thousands of small bridges connect many people, offering them an access opportunity to necessary resources and a flow of production.

Unfortunately, it is possible to notice that a majority of rural and urban bridges presents critical pathological conditions, offering risks to society's safety and producing financial losses.

This article aims to collaborate on the pathology identification task in small and medium sized bridges. For this purpose, it is necessary to review the issues related to bridge designs and pathologies in wood, steel and concrete structures. The exemplification work on bridge pathology identification is presented along with a case study of four bridges in Campinas (SP) region in southeastern of Brazil.

2. Bridge design preparation

Bridge designs are characterized by complexity and information that should be synthesized by the designer. Thus, in great and special designs, a multidisciplinary team is required. The quality of a bridge can be measured with respect to its functional, structural, economic and esthetic success. Therefore, a professional need for transportation, architecture, structure, geotechnical engineering, topography, hydraulics and other specialists are necessary for each project.

When observing the structural aspect, it is noticed that the adequate bridge structural design is of major importance, as this will interfere with its feasibility, cost, functionality and aesthetics. However, structural efficiency is not always considered as a quality, but as a prerequisite for a correct design compared with other characteristics such as functionality, hydraulics, geotechnical engineering and aesthetics.

In the design of a road bridge, design values of actions, ultimate and serviceability limit states should follow in accordance with the Brazilian code ABNT: NBR 8681 (2003) in which, for instance, the classification of actions is made for exceptional, variable and permanent ones. According to ABNT: NBR 7187 (2003) on reinforced and pre-stressed concrete bridge design and execution, the active actions within bridges are presented with these three action groups with features related to the design of bridges.

When active actions are determined by calculating routines, internal forces and resistant section are verified in the design procedure taking into account local and global effects.

The determination of internal forces in bridge structures is not an easy task and demands experience and skill of the engineer. The knowledge of structural static in conjunction with action combinations allows the designer to determine loading distribution.

Liebenberg (1993) also states that even with data processing and computing updates, structural analysis interactive processes such as finite element method enabled designs of bridges to become more realistic and substituted numerable and difficult calculations.

Hambly (1990) described sizing calculations such as checking the set of equilibrium equations, in total or part of structure, checking each section resistance and checking serviceability condition and second-order effects.

After sizing and detailing each step, the constructive method selection should be the main concern.

Bridge building and assembly require very careful studies. In this particular study, all step-by-step actions to be performed must be considered in order to guarantee the safety aspects of the construction, according to Pinho and Bellei (2007). Another concern is the resource allocation on the construction method, as Liebenberg (1993) highlighted, because the construction method is a very important factor on bridge structural solution choices. There are several construction methods for superstructures such as in situ concrete, precast concrete elements and successive spans.

3. Structural pathologies

According to Ripper and Souza (1998), what is designated for Structural Pathology is the Building Engineering field that studies origins,

manifest forms, consequences and mechanisms of failure occurrence and structure damage systems. Also, the Engineering area which leads with pathologies is a part of it that studies systems, mechanisms, causes and origins of civil construction failures, i.e., that studies the parts which compose the problem diagnosis.

Structural pathologies presented with bridges vary in intensity and incidence, may times causing high costs for their correction, as commented by Raina (2003). Under a similar aspect, there will always be aesthetics committal and often, resistance capacity reduction, sometimes leading to a partial or total structure failure.

With the constant increase in the structural pathological problems, Structure Pathology has been searched, not only for the pathology systematization but also the promotion of new technical conceptions. New concepts, not so widespread until recently, are the performance, durability, environment, conformity, service life cycle and maintenance.

It is possible to define material life cycle as the period when its chemical and physical characteristics remain above the minimal limits specified for its function. Its life cycle may be extended significantly with a correct program of structural maintenance.

Structural pathology study envelops a detailed problem analysis, describing its causes, manifest forms, occurrence mechanisms and structural maintenance and prophylaxis. With a correct case estimate, it is possible for the involved professional to define one of the four common therapeutic measures in case of a pathological condition. According to Sartorti and Mascia (2010) therapeutic is responsible for studying these problem corrections and solutions. It is agreed that, for a correct choice and therapy appliance, there should be a detailed study showing the real diagnosis for the pathology origin. In Table 1, therapies are shown to be adopted, according to the case. Maldonado et al. (2009) also argued that a correct evaluation of the events occurring in the structure leads to an intervention that will depend, among other factors, the materials available, cost of labor and time limit.

Tratamiento/Treatment	Característica/Characteristic
Recuperación Recovery	Se entiende como recuperación la ejecución de procedimientos necesarios para la recobrar la capacidad resistente y soporte de la estructura As a recovery, it is understood as the necessary procedures for the bearing and strength capacity recovery of structure
Restauración Restoration	Es una intervención que sólo restablece las condiciones estéticas de la estructura An intervention that only reestablishes the esthetical conditions of the structure
Reforzamiento Reinforcement	Corresponde a las actividades para aumentar la resistencia de la estructura o su capacidad de soporte It is the promoted activities for the structure resistance increase or bearing capacity
Limitación de vida útil Serviceability Limitation	Esta opción debe ser adoptada cuando el tratamiento de recuperación no es económicamente viable That option must be chosen when the recovering therapy is not economically viable
Demolición Demolition	Es el tratamiento extremo, puede variar desde la demolición parcial de la estructura hasta su completa demolición The extreme therapy can vary from a partial to a complete structure demolition

Tabla 1. Tratamientos comunes para estructuras de concreto reforzado
Table 1. Common treatments for reinforced concrete structures

3.1 Reinforced and pre-stressed concrete pathologies

Concrete, the way it is used, has an unstable nature over time, occurring some chemical and physical alterations in its characteristics due to its component properties and their reactions to impositions created by the environment where the structure performs its functions.

There are several factors that influence the final concrete behavior, the most relevant for the pathology study within pre-stressed and reinforced concrete structures are: material quality; water/cement ratio (w/c); environment; actions and the quality in the civil construction process.

3.1.1 Pathology causes in concrete structures

In the damaged structure analysis, the pathological cause acknowledge has constituted of indispensable importance with a correct treatment, necessary to guarantee the post-recovering pathology minimization. The causes of deterioration of structures can be divided into two large groups, as discussed in Ripper and Souza (1998). Those are intrinsic and extrinsic causes.

The intrinsic causes are those that reside in the structure itself. They have their origin into the structure components and materials. These causes are generated by human error at the execution and/or use phase, and by external and natural agents like chemical attacks and even accidents. Yet the extrinsic causes are those that are independent of the structure itself, as well as of its composition or failures due to the execution. They can be understood as factors attacking the structures, “from the outside-in”, during its whole conception process, execution or design service life.

3.1.2 Formation and manifest mechanisms of pathologies in pre-stressed and reinforced concrete

a) Cracks

Cracks are due to a deformation caused by the mechanical or environmental loading in a pre-stressed or reinforced concrete piece, may have its origin from various factors, such as: tension and compression cracks by bending (a critical state of fragile collapse); cracks caused by shear came from a shear or twist (according to Fusco (2008), it is a critical state of fragile collapse); cracks caused by the concrete creep; cracks caused by shrinkage; cracks caused by thermal and hygroscopic strains; cracks caused by deficiencies in support equipment positioning and teeth joint details.

The openings can present different dimensions and designations according to Raine (2003). Through their magnitudes, they can be listed and shown in Table 2. Some comments are described as follows:

corrosion of concrete

The concrete corrosion particularity is the deterioration where reactions are only chemical and not electrochemical, being able to occur in three ways: leaching, ionic reaction, and expansion. Lourenço et al. (2009) draws attention to microbiological corrosion as an important corrosion cause in bridges and viaducts. The genetic and physiological existing variability among micro-organisms, especially bacteria, allows determined groups to be installed into special structures, causing damages.

corrosion of steel reinforcement

Aggressive environments, high porosity, high capillarity, deficiency in cover thickness, construction materials with problems and severe cracking are, according to Perdrix (1992), predominant factors of corrosion of steel reinforcement.

The steel corrosion, according to its manifest form, can be classified as shown in Figure 1.

As concrete presents a high calcium hydroxide concentration, a considerable alkalinity occurs, being its $\text{pH} \geq 12.5$. Carbon dioxide, which is responsible for carbonation reaction, reduces concrete pH, depassivating steel and facilitating an attack of deleterious substances. The penetration speed of carbonation front is a direct function of material permeability and cracking. The relation w/c that determines the concrete specific permeability and the cover thickness can have an influence in the carbonation speed, which is verified by Table 3. (Helene and Pereira, 2007).

Tipos de abertura/Opening Types	Tamaño/Size
Fisura capilar/Capillary Cracks	menor a 0.2 mm/Less than 0.2 mm
Fisura/Cracks	desde 0.2 mm a 0.5 mm/from 0.2 mm to 0.5 mm
Surco/Split	desde 0.5 mm a 1.5 mm/from 0.5 mm to 1.5 mm
Ranuras/Slit	desde 1.5 mm a 5 mm/from 1.5 mm to 5 mm
Fracturas/Fracture	desde 5 mm a 10 mm/from 5 mm to 10 mm
Brechas/Breach	mayor a 10 mm/more than 10 mm

Tabla 2. Dimensiones de las aberturas de grietas, surcos, ranuras, fracturas y brechas
Table 2. Opening dimensions of crack openings, splits, slits, fractures and breaches

Penetración en el tiempo, años /Penetration time in years						
Cubierta/Cover (mm)	5	10	15	20	25	30
Relación/Relation w/c						
0.45	19	75	>100	>100	>100	>100
0.50	6	25	56	99	>100	>100
0.55	3	12	27	49	76	>100
0.60	1.8	7	16	29	45	65
0.65	1.5	6	13	23	36	52
0.70	1.2	5	11	19	30	43

Tabla 3. Penetración del frente de carbonatación en el hormigón de cemento Portland
Table 3. Carbonation front penetration in Portland cement concrete

Yoris et al. (2010) also commented that the carbonation is significant in structures located in industrial environments and are subject to cycles of wetting and drying.

One of the preventive and corrective measures is the cathode protection with sacrificial anodes; however, Pereira (2009) point out that an adequate conception and sizing of the cathode protection systems as well as the appropriate anode periodic inspection, own a great importance for protection system efficiency and performance. This inspection should take into consideration the design life system because, with the system working, the anodes will wear out until total consumption, allowing the emergence of a corrosive processes.

b) Chemical reactions

In addition to the chemical reactions necessary for the hydration of cement compounds hydration, which induce shrinkage strains, there can be deleterious reactions such as expansive reactions. Mehta and Monteiro (2008) noted that the most common ones of that kind are: alkali-aggregate reaction; alkali-dolomite reaction; calc-sodic feldspars, sulphate attack.

c) Damage provoked by vehicle collisions and fire

Vehicle collision against bridge structures produce very high and extreme loadings of difficult sizing, causing sharp deformation and damages such as cover thickness detachment and steel reinforcement bar exposition, demands a maintenance program for such repairs (El Debs and Takeya, 2003).

Yet fire study is more common, having a good material quantity referring to the subject. At the reinforced and pre-stressed concrete structures, fire produces a great deleterious action. Material heating provokes a volume increase generating strong internal stresses, causing concrete deformation, cracking and breakdown of the concrete.

Helene and Pereira (2007) noted that the degree of change that can be produced in a concrete and its components when the action of fire, will depend mainly on the level of temperature reached, exposure time and composition of the concrete. Mehta and Monteiro (2008) also highlighted that a more permeable concrete will provide a level of deterioration less than a concrete more compact because it allows the steam of water retained in the capillaries and voids of the matrix.

d) Pre-stressed concrete deterioration

Pre-stressed concrete elements can still suffer deleterious action of some well-known and quantified factors according to Cauduro (2003): adherence loss between tensioned steel and concrete; pre-stressing steel relaxation; concrete retraction; concrete creep corrosion under pre-stressing steel tension; passive steel reinforcement bar deficiency at anchoring.

3.2 Wood Bridges

According to Wood Handbook (1999), at the beginning of the twentieth century, most of the North American bridges were made of wood. In the 1990s, there was a national campaign to restore and enable them to elevate their loading capacity.

Calil et al. (2003) highlight that the wood durability – once it is performed correctly the processes of drying and preservation – along with modern techniques of use, can produce structures in Brazil that last for 50 years or more of use. Indeed, the construction market requires products of good performance, low cost, esthetic value and “green” from an environmental point of view.

3.2.1 Interference factor in the structural performance of wood

According to Porteous and Kermani (2008), the essential factors which influence wood properties are anatomical factors (density, fiber angles, nodes, wood natural failure, presence of pitch and parenchyma bend); environmental and use factors (moisture and failures caused by biological attacks, drying and processing defects).

3.2.2 Mechanisms of pathological formation and manifestation in the wood structures

The manifestation of wood pathologies is closely related to the environment where the wood is situated and the drying process that has occurred. Although it is susceptible to deterioration, its durability is proved through proper techniques of prevention and can be mentioned examples of wood pieces with more than 2000 years in Egyptian monuments, according to Dinwoodie (2000).

The process of drying wood, accordance with the Montana handbook (2000), is of relevant significance because it presents the following advantages: decrease of its self weight; increase of mechanical resistance; wood contractions occur before its use; a rise of resistance against fungi, bacteria and insects; improved bond resistance; greater bonding ability; warping and splits generally occur when drying; paintings, varnishes and lacquers can only be applied after drying. In addition, a wood characteristic which deserves to be highlighted is its own anisotropy, responsible for different elastic and resistant properties according to the direction of load application related to the fibers, according to Stalnaker and Harris (1997). Wood deterioration is a process that changes significantly its properties. According to Calil et al. (2008), in a simple way, the causative agents of pathology can be classified in biotic agents and abiotic agents.

a) Biotic agents

Represented specially by microorganisms as fungi and bacteria; Coleopteran (Beetles and borers) and Isopteran (termites) insects; and marine borers (mollusks and crustaceans). Biotic agents need some conditions in order to survive, such as temperature, oxygen, moisture and proper source of food that is wood (Montana handbook, 2000).

The essential pathological effects of these agents are rot and insect infestation that, depending on the ability of each organism, may occur isolated attacks by only a single type or by a group of terminates (organisms which have wood as food).

ABNT: NBR 7190 (1997) establishes risk situations for wood biodeterioration. Designers must indicate a proper procedure for each situation. According to Calil et al. (2003), four preservatives are responsible, in general, for about 80% of treated wood, which are: creosote, pentachlorophenol, CCA (chromium salt – copper – arsenic) and CCB (chromium salt – copper – boron).

b) Abiotic agents

According to Calil et al. (2003) abiotic agents include physical, mechanical, chemical and climatic agents. The essential pathological mechanism of wood considering the abiotic agents are: warping and splits provoked by moisture variations; mechanical abrasion; corrosion of metal parts; photochemical degradation; deterioration due to higher temperatures; pathologies caused by excessive deformity and instability; wood removal; initial fractures and damages caused by fire.

3.3 Steel bridges

Davison and Owens (2003) observed that the structural steel as a metallic alloy composed mainly of iron and small amounts of carbon (from 0.002% to 2.0%) with resistance and ductility properties. Additives and special alloys are widely used and are steel engineering specialties. In addition to the types of pathologies present in steel structures, described as follows, Pinho and Bellei (2007) observe that composite structures (beams and plates), made by steel and concrete, used widely in construction of small and medium bridges, also have to verify the integration between concrete and steel, i.e., the connections.

3.3.1 Mechanism of pathological formation and manifestation in steel structures

a) Steel corrosion

Pannoni (2004) states that the steel corrosion phenomena involve a great variety of generating mechanisms that can be combined in four groups: corrosion in aqueous environment (90%); oxidation and hot corrosion (8%); corrosion in organic environments (1.8%); corrosion by liquid metals (0.2%). The most frequent cause of deterioration in metal structures is the steel oxidation. The corrosion of steel structures is shown by Figure 1.

Figura 1. Tipología de la corrosión del acero. (A) vista superior, (B) vista lateral
Figure 1. Steel corrosion typology. (A) superior view, (B) side view

The means commonly applied to avoid steel oxidation is painting, which should be applied at maximum intervals of 5 and 10 years, depending on the environment. The criteria for the application of paintings are presented by Pfeil and Pfeil (2009). In addition to painting, it is essential to provide with an adequate drainage, preventing water accumulation in any part of the structure.

The oxidation level can be classified in three categories:

- ✓ superficial – only superficial oxidation, with no reduction of the section area;
- ✓ medium – definitive corrosion areas appear, creating small layers;
- ✓ severe – advanced corrosion, penetrating into steel that may lead to the perforation of the part.

In marine areas, pieces located in part of tide fluctuation, or subjected to irregular wetting are more attacked. The heads of bolts and welded parts are more prone to corrosion.

b) Deterioration caused by overload

Parts subjected to very high stresses can reach their limits of yielding, producing visible permanent deteriorations that are named of plastic deteriorations according DNIT (2004).

c) Deteriorations caused by lack of bracing

Lack of bracing in steel structures can lead to transverse displacement of extreme severity, leading to collapse by buckling. Another phenomenon related to lack of bracing is excessive vibration (Rodrigues, 2008).

d) Deteriorations caused by thermal effects

According Pfeil (1983) temperature variations act on the structures causing movements of stretching and shortening. When these movements are stopped by the support, there are high stresses in the material that may exceed the yielding limit, especially in hyperstatic structures, resulting in plastic strains. This effect is reduced by gaps between supports and connections, and also using support equipments in adequate condition.

e) Damage caused by the effect of fire

High temperatures above 100°C, according to Pfeil and Pfeil (2009) tend to eliminate the yielding limit of the material making the diagram stress-strain curve, also occurring a great variation of elastic modulus. Temperatures above 250 and 300°C, according to Silva (2001), cause creep in steels, therefore a thermal treatment is the best way of increasing the resistance time of an element in a fire situation.

f) Cracks caused by fatigue and/or stress concentration

Some inadequate details produce large stress concentration in metallic parts, which may create cracks in the metal. Some examples are: re-entrant corners in acute angle; sharp changes in plate's width or thickness; welds concentration.

Fissures or cracks of fatigue occur in structures subjected to cyclic loading as in case of bridges. These variations in loading cause strong oscillations in stress that cause fissures and cracks. At stress concentration points, the effects of fatigue are more acute. Ruptures caused by fatigue are dangerous and fragile and some factors that may cause cracks and fissures by fatigue are: high frequency heavy truck traffic; large-scale in stress variation; material quality; weld quality; age and history of loads on the bridge.

g) Failures in welding

The failing in welding, either by poor performance or by inadequate material, can provoke severe damages to structure that can cause fragile rupture.

h) Damages caused by excessive vibrations

The use of floor structures with large span and reduced damping can result in vibrations that cause discomfort. ABNT: NBR 8800 (2009) indicates that the vibration problem must be considered in the structural design through dynamic analysis. The deleterious effects of vibration can be turned into discomfort to users and a risk of structure rupture by cyclic effect generating fatigue.

3.4 Other sources of pathologies in bridges

In bridges, there still can be observed pathological situations in their elements or in the structural set as a whole independent from the material in which their structure is made. The more common pathologies are: problems in foundations and joints; vertical movement of the structure as a whole; rotational movement of the structure as a whole; wear and defects on the roadway; joints with insufficient space or in inappropriate conditions; changes in water courses leading to erosion and outbreak of the foundations; problems with maintenance of the support equipments. (DNIT, 2004).

3.5 Structural maintenance and inspections of bridges

Maintenance and inspection of bridges have been the concern of public and private agencies as is common consent that these measures minimize losses with major reforms and also with accidents. Commenting on ABNT:NBR 9452 (1986), code on inspections of bridges and concrete viaducts, Sartorti and Mascia (2010) state that the current form does not meet the completeness which is required when carrying a satisfactory inspection. It does not cover items considered relevant and frequent in bridges and viaducts, because of this restrains and undermines the inspection, hiding valuable information relevant to the stability of the structure. In light of this reality, it is possible to appeal using this as an alternative source in addition to the DNIT code (2004). There are at least five classifications for inspection in conformity with the DNIT (2004) which include registration, routine, special, extraordinary and intermediary inspections. Based on the data collected, there must be adopted a structural maintenance program which aims at increasing useful service life and cost reduction as a possible intervention to correct said pathologies.

4. Identification of bridge structural pathologies in the region of Campinas - SP

The correct pathology diagnosis will reveal not only the causes but also the responsible individuals whose identification will be necessary for legal purposes. The diagnosis of any kind of pathologies must be based on a deep structure analysis and an adequate knowledge of mechanisms of formation and manifestation of pathologies.

This research attempts to carry out visual inspections on nine bridges of urban and rural road collectors in Campinas-SP, Brazil. This article presents the collected data on four of those bridges. Table 4 highlights the main characteristics of each bridge analyzed.

Puente Bridge	Sistema estructural de la súper-estructura Structural system of the superstructure	Geometría Geometry	Ancho (m) Width(m)	Longitud (m) Length (m)	Material
1	Vigas/Beams	Línea recta ortogonal Straight Line Orthogonal	5.00	13.00	Acero/madera/suelo Steel/wood/soil
2	Losa/Slab	Línea recta ortogonal Straight Line Orthogonal	8.00	7.50	Hormigón reforzado Reinforced Concrete
3	Vigas/Beams	Línea recta ortogonal Straight Line Orthogonal	6.20	38.20	Hormigón reforzado Reinforced Concrete
4	Vigas/Beams	Línea recta ortogonal Straight Line Orthogonal	4.50	16.00	Madera Wood

Table 4. Datos generales de los puentes investigados

Table 4. General data of researched bridges

4.1 Bridge 1

This bridge is located adjacent to the Joaquim Egídio road, and is a connection for the district environmental station as well as for regional agricultural farms. Its main traffic is constituted by cars and small trucks. The bridge was built with steel girders and timber logs, transversally, forming a grid for the slab (see Figure 2), composed of a layer of soil. The joints are constituted of stone blocks and mortar.

Figura 2. Vista general del puente

Figure 2. Bridge overview

Figure 3 indicates the bridge with the steel beams in extreme corrosion condition, which has already lost a considerable part of its transversal section on the tension region. The transversal timber logs are also in a precarious condition, with great signs of decay because of the continuous presence of moisture that is kept in the soil layer and serves as a slab. Additional problems are related to the joints which present visible cracks, indicating excessive overloading than the design allows for. The joints are partially unblocked due to erosion and poor performance and also it is noted that the wooden guard rails are in a precarious condition and may even fail with small loads.

As a suggestion to improve or maintain the structural function of the bridge is to replace the superstructure of this bridge by a composite structure of concrete and steel or wood. Thus, the concrete slab contributes to the resistance would be beneficial as higher load capacity and eliminate problems as vegetation on the bridge and moisture retention, which causes the rotting of logs.

Figura 3. Corrosión del acero

Figure 3. Steel corrosion

Figura 4. Deterioro del pavimento

Figure 4. Deck deterioration

4.2 Bridge 2

Located on Antônio Zaine Street, in the district of Barão Geraldo, the bridge in Figure 4 is next to Rio Branco School, presenting traffic with all kinds of vehicles and at of the day the flow of traffic is very intense due to the school. The entire structure is of reinforced concrete with a structural system, a slab-bridge, supported at the joints with reinforced concrete. The span is small measuring only 7.5 m, but its total width is 14.0 m including two crosswalks of 3.0 m each.

The joint structure presents large splits in many parts, indicating that the lateral earth pressure is greater than its strength capacity. Besides the pathological deficiency, the conservation state of the bridge guard rails and pavement are precarious. It is noticed that the drainage of the bridge is not efficient.

The advanced degree of cracking indicates an excessive effort. This type of pathology can cause danger to society, especially students from nearby school. It is urgent an intervention to strengthen the supports.

The other pathologies such as corrosion of the reinforcement of the guard bodies and advanced deterioration of the pavement are also of concern requiring treatment. Note a state of relative neglect in the inspection and maintenance of the bridge structure.

4.3 Bridge 3

Built over the Atibaia River, in the district of Sousas, the bridge is the main connection between the two district, without mentioning that this is the optimized route to arrive the district of Joaquim Egídio. The bridge serves as a constant pathway of cars, buses and trucks according to Figure 5.

Figura 5. Vista del tráfico
Figure 5. Traffic view

The structure is of reinforced concrete, divided into two parts. The slab covers a span of 38.2 m, and is supported by the joints and a central pillar positioned in the middle of the river. The traffic lane presents a 6.2 m width, in which steel beams are fixed to support the pedestrian sidewalks with an approximated width of 2.0 m and built with wooden board.

An inferior bridge part, the longitudinal members are noted with a crescent variation in section along the restraints (variation due to the greater shear in this region) and transversal members that are connected monolithically with a board slab.

Among the pathological problems found, it is the excessive vibration noted when inspecting the bridge. It is observed that some possible concrete leaching derive mainly from the concrete permeability and drainage deficiency. It is also noticeable that there is detachment due to corrosion of steel reinforcement.

The steel members that support the walkway are corroded, but not at an advance stage, and the concrete slab is worn. The wood parts from the walkway are deteriorated by a fungi action and presents significantly risks for the pedestrians (see Figure 6).

This bridge is part of the heritage of the city of Campinas and a risk to the population needing an urgent maintenance. Corrosion of metal profiles requires treatment of the substrate for removal of corrosion products and impurities as well as applying anti-corrosive paints in sections where it is necessary to replace material. The replacement of much of the board of pieces of treated wood also is required.

Figura 6. Estado de desintegración de la acera

Figure 6. State of decay of walkway

4.4 Bridge 4

Located in a lane of the road from Rhodia in Barão Geraldo this bridge serves to connect the agricultural areas, making it a place of constant passage of trucks. Its board is made of longitudinal wood boards and its wood logs and transverse members are used for the timber logs as according to Figure 7. The bridge presents a span with an extension of 16.0 m and width of the roadway 4.5 m long.

Due to the precarious state of conservation of the wooden logs, a steel transverse beam is positioned in the middle of the span, supported by two steel cables at each end and anchored in blocks of concrete in the bridge headwater. It is noted in the visual inspection that the cables present insufficient tension, therefore, it is able to move them manually.

The logs are in a critical state of rot fungi and the presence of moisture allowed for the appearance of moss as shown in Figure 8.

The joints, built in reinforced concrete, have regions with clusters of concrete caused by deficiencies during construction. The bridge still has a lot of dirty, especially in its transversal member indicating that the water level rises to the slab increasing the risk of collapse in time of floods.

The wood that provides the slab is still in a reasonable state of conservation, but there are some points of decay and repairs carried out in a poor manner, making the bridge dangerous to local drivers and pedestrians. The guard rails are also in a poor condition with a low resistance capacity.

It is recommend for the maintenance of this bridge that the cables to be properly protected from corrosion and tensioned as well. In addition, the logs of the guardrail should be replaced quickly.

Figura 7. Vista de la losa
Figure 7. View of the slab

Figura 8. Desintegración de la madera de la estructura principal

Figure 8. Decay of wood of the main structure

5. Conclusions

This research provides important information that is extremely relevant for the civil engineering, specifically to the maintenance of the highway infrastructure in an emerging country that should improve the means of transport to increase its exports and its economy. This fact could contribute to the human well-being of its population.

This article highlights the conditions of the several bridges which are mostly inadequate for traffic vehicular use. This fact is confirmed due to the expressive number of serious pathologies found, providing evidence of inefficiencies in planning, design and maintenance.

The literature review in which the paper was based on expresses the importance of the design based on solid principles, involving a multidisciplinary team in order to evaluate all points by giving the design of the bridges a functional, economical, aesthetic and environmental character. It is also observed need for technical knowledge concerning the study of structural pathologies before carrying out an inspection. In the aspect of durability, it is noted that the mapped pathologies affect significantly the structure, as through them there can arise another pathology which will reduce the service life of a structure.

It is suggested for each present bridges that in the most severe cases public agencies present viable solutions such as the replacement of damaged structures by new bridges acting in a rapid manner and with efficiency in the implementation of such structures.

Finally, it was concluded that the best way to avoid a pathological state is prevention. Preventive maintenance is generated not only by a correct design or by an implementation according to the quality parameters, but also by a structural maintenance program.

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