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Analysis of pathological manifestations of concrete in urban overpasses

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ABSTRACT
The paper presents the case study of pathological manifestations in concrete structures, located in the Northern Road Hub of Brasília, using the GDE / UnB methodology, which qualifies and quantifies the degradation of structural damages. The general state of the structure was characterized in order to serve as a subsidy for decision making regarding routine interventions, in order to extend the useful life of the structure. The methodological routine consists of conducting field inspections, catalog of structural pathologies with photographic survey, characterization of pathologies and classification according to the weighting factors and damage intensity factors of the structure according to the GDE / UnB methodology for special works of art, calculation and overall classification of the structure damage.
Keywords: pathologies; concrete structure; overpass.

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Análise de manifestações patológicas do concreto em viadutos urbanos

RESUMEN

O trabalho apresenta o estudo de caso de manifestações patológicas em estruturas de concreto, localizadas no Eixo Rodoviário Norte de Brasília, por meio da metodologia GDE/UnB, que qualifica e quantifica a degradação de danos estruturais. Foi realizada a caracterização do estado geral da estrutura com a finalidade de servir de subsidio para tomadas de decisões quanto a intervenções rotineiras, de forma a ampliar a vida útil da estrutura. A rotina metodológica consiste na realização de inspeções em campo, catálogo das manifestações patológicas estruturais com levantamento fotográfico, caracterização dos fenômenos patológicos e classificação segundo os fatores de ponderação e fatores de intensidade de danos da estrutura conforme a metodologia GDE/UnB para obras de arte especiais, cálculo e classificação global dos danos da estrutura.

Palabras clave: manifestações patológicas; estrutura de concreto; viadutos.

Análisis de manifestaciones patológicas del concreto en viaductos urbanos

RESUMEN

El trabajo presenta el estudio de casos de manifestaciones patológicas en estructuras de hormigón, ubicadas en el Eje Rodoviario Norte de Brasilia, por medio de la metodología GDE / UnB, que califica y cuantifica la degradación de daños estructurales. Se realizó la caracterización del estado general de la estructura con la finalidad de servir de subsidio para tomas de decisiones en cuanto a intervenciones rutinarias, para ampliar la vida útil de la estructura. La rutina metodológica consiste en la realización de inspecciones en campo, catálogo de las manifestaciones patológicas estructurales con levantamiento fotográfico, caracterización de las manifestaciones patológicas y clasificación según los factores de ponderación y factores de intensidad de daños de la estructura conforme a la metodología GDE / UnB para obras de arte especiales, calculo y clasificación global de los daños de la estructura.

Palabras clave: manifestaciones patológicas; estructura de hormigón; viaductos.

1. INTRODUCTION

The correct identification of the beginning of the pathological problems allows the researcher to establish in which moment of the management of the construction they occurred. Thus, it is possible to know if they were originated in the project phase, in the specification of the material, because of unskilled workers in the execution stage of the construction, lack of supervision, or yet if the failures were due to improper operation and poor maintenance.

This analysis of identification and proposal to attack the pathological manifestations is appropriate and it is confirmed when they are compared with the cost of late changes when the manifestations have already occurred, as defined in the management of works by Mattos (2010) and PMBOK (2014). In this approach, when evaluating the cost of avoiding a pathological problem in different phases of construction, it is observed that the later the possibility of problems or pathological manifestations due to lack of planning is identified, the greater is the cost of the repair and the possibility of structural collapse.

According to Helene (1997), the intervention costs increase exponentially the later the intervention occurs, and, in summary, they can be avoided in the following phases:

a. Project phase - represents the reference cost among the measures that can be verified to avoid future problems. Some mitigating measures can be highlighted as follows:

- Additives and additions to improve concrete durability and decrease permeability;
- Increase the thickness of the concrete cover as a measure of protection against corrosion;
- Reduce the water–cement (w/c) ratios of the concrete in order to reduce the porosity of the concrete and consequently decrease the permeability;
- Increased characteristic strength of the concrete.

b. Execution phase - its delayed intervention implies a cost five (5) times higher than the cost of an intervention if the project phase is taken as the reference.

c. Preventive maintenance phase - can cost up to 25 times more than correct measurements taken in the structural design phase. Usual measures that could avoid cost increases:
   - Periodic paints;
   - Waterproofing.

d. Corrective maintenance phase - corresponds to the repair of structures that already have visible pathological manifestations. These activities can be associated with a cost 125 times higher than the cost of the measures that could and should have been taken in the design phase. It should be noted that the high cost is not only associated with labor costs and costs of the materials for the maintenance itself, but also with the indirect costs related to its intervention, such as the time and disturbances of the interdiction of the structure during the repair period.

2. LITERATURE REVIEW

2.1 Pathological manifestations found in reinforced concrete

According to Metha (2008) and Ribeiro (2014), the pathological causes in reinforced concrete can be divided into three groups: physical, chemical and biological.

The physical causes of the reinforced concrete deterioration can be subdivided into two categories: surface wear (or loss of mass) due to abrasion, erosion, and cavitation; cracking due to temperature and humidity normal gradients, salt crystallization pressures in the pores, structural loading and exposure to extremes temperatures such as freezing or fire.

The chemical causes of concrete deterioration are usually due to the presence of chemical substances, which can occur due to: hydrolysis and leaching of the cement paste components by pure water; ionic exchanges between the aggressive fluids and the cement paste; causative reactions of expandable products such as sulfate expansion, alkali-aggregate reaction and corrosion of the reinforcement in the concrete.

The biological causes are mainly related to the presence of microorganisms, which provide aggressive corrosive environments to concrete and steel, by means of sulfur or sulfide-oxidizing bacteria, which accelerate the deterioration of these structures.

2.2 Non-destructive testing

Often, in addition to the visual analysis, it is necessary to perform experiments to provide information related to the conditions of strength and rupture of components of the surveyed structure, as well as to obtain greater knowledge about the foundation soil.

The decision to whether carry out additional tests on visual inspection shall be taken by the engineer responsible for drawing up the technical report. The most well-known tests on concrete and masonry structures are classified as non-destructive and destructive tests according to Table 1.

Table 1. Destructive and non-destructive tests

Non destructive	Destructive
Sclerometry; Carbonation; Control of the expansion joint cracks with plaster or glass seals; Ultrasonography; Gammagraphy; Load test; Measurements of deformations and settlements.	Axial compression strength in specimens removed from the structure; Tensile strength in specimens removed from the structure; Modulus of deformation of concrete and mortars; Reconstitution of concrete and mortar trace; Specific mass, permeability and water absorption; Chloride content; Determination of tensile flow in reinforcement samples taken from the structure; Determination of the corrosion potential of reinforcement samples taken from the structure; Compressive strength of individual bricks and blocks; Compressive strength of brick and block prisms.

3. STATE OF THE ART OF THE GDE/UNB METHODOLOGY

The use of the GDE/UnB methodology is pertinent for the analysis of pathological manifestations since it makes possible to compare, in a fast and objective way, the degree of deterioration of different concrete structures through data collected in field visual inspections.

Several authors developed the methodology and adapted it over time for different applications.

Klein et.al. (1991) was the pioneer of the improved methodology at the University of Brasília. The objective of this study was to create and implement a systematic survey of concrete structures with the aim of prioritizing actions to repair structures in the city of Porto Alegre. The methodology classifies the structures according to the variety and severity of the presented problems, through the definition of a degree of risk. The study resulted from an agreement signed between the Federal University of Rio Grande do Sul and the City Hall of Porto Alegre where eleven constructions were classified according to the degree of deterioration of the damages imposed by the pathological manifestations.

Castro et al. (1995) developed a systemic methodology based on the observations made by Klein et.al. (1991). The Castro's methodology, also called the GDE/UnB methodology, aims to adjust the specific evaluations of bridges and overpasses to any conventional concrete structure. For the model, optimized formulations of the Tuutti's (1982) model of concrete reinforcement corrosion evolution were implemented. By analogy, the author was able to quantify the degree of deterioration in the structures for other degradation processes. Subsequently, it was implemented in the methodology the Inspection Book, which was an essential document of data collection, which contained the concept of the highest incidence damages and references to the values of Intensity of damage factors.

Lopes (1998), used the methodology to develop the study of improvement of the building maintenance system of a commercial edifice. Through the quantification of physical degradation, it was possible to reliably predict the best time for preventive maintenance interventions in buildings. In this study, the degree of deterioration of the individual structure was analyzed, associating it with the other components, which allowed, as a result, a unique degradation index for the building. However, there was a need to make some changes in the methodology proposed by Castro et al. (1995) in order to improve its applicability. In this study, the following changes were made in the element families, in the damage relationship, in the definition of new damage weighting factors and in the calculation of the deterioration degree of an element (G_{de}). The research was carried out in six ‘Banco do Brasil’ buildings and, in general, proved to be effective for use in building applications.

Boldo (2002) reports the results of evaluations performed in forty buildings of concrete structures of the Brazilian Army, regarding the application of the methodology, which allowed quantify the degree of deterioration of concrete structures, using parameters that evaluate the manifestations of damages and their evolution. With the efficiency of the GDE/UnB methodology for use in buildings proven, it has enabled the establishment of systematic and more effective maintenance programs at Army facilities.

Fonseca (2007) applied the GDE/UnB methodology in building structures at the UnB Central Institute of Sciences - ICC and proposed changes in the formulation to calculate the degree of deterioration of a family (G_{df}) and degree of damage (D).

Euqueres (2011) carried out a study with eleven inspections in bridge structures in order to validate proposals for a reformulation of the methodology to calculate the structure deterioration according to the GDE/UnB methodology. As a basis for the decisions regarding the rehabilitation of the inspected work, visual inspections were carried out in all structures. The author emphasized the sampling of incidences of relevant pathological manifestations in the structures, among which we can report the corrosion of the reinforcement, cracks by crushing, crushing of the support apparatus, efflorescence with the formation of stalactites, concreting mistakes, and stains of moisture.

Medeiros (2015) evaluated the durability conditions of the Carmo River Bridge in a region of aggressive environmental. In the study, the following tests were performed: sclerometry non-destructive tests, ultrasound, carbonation depth, and the presence of chlorides. The pathological manifestations were estimated using the methodologies of inspections: standard DNIT 010/2004 and GDE/UnB. According to Medeiros, by the analysis of the results, comparatively the GDE/UnB methodology, they lead to a greater accuracy due to the richness of details in its analysis.

Verly (2015), as well as Medeiros (2015), studied two methodologies for inspecting structures regarding the evaluation of the following special engineering structures: National Department of Transport Infrastructure (DNIT) and the GDE/UnB methodology. Verly carried out visual inspections in 22 overpasses located in Brasília/DF. Initially, changes were proposed in the formulation of the GDE/UnB methodology for a better application to special engineering structures. Due to the incidence of different damages in the inspected structures, it is again possible to conclude that the GDE/UnB methodology presented results with a better scale of values that simplified the arranging of the structures regarding decision making for interventions.

3.1 GDE/Unb Methodology

A series of inspections are carried out on the element to be analyzed. Sequentially, a photographic report of the pathological manifestations presented is carried out which are compared with the reference frame for the assignment of damage values. With this data, it is possible to develop the routines of the GDE/UNB methodology.

Figure 2 shows the block diagram. It presents the analysis sequence of the element deterioration identification model and the other parameters used in the methodology.

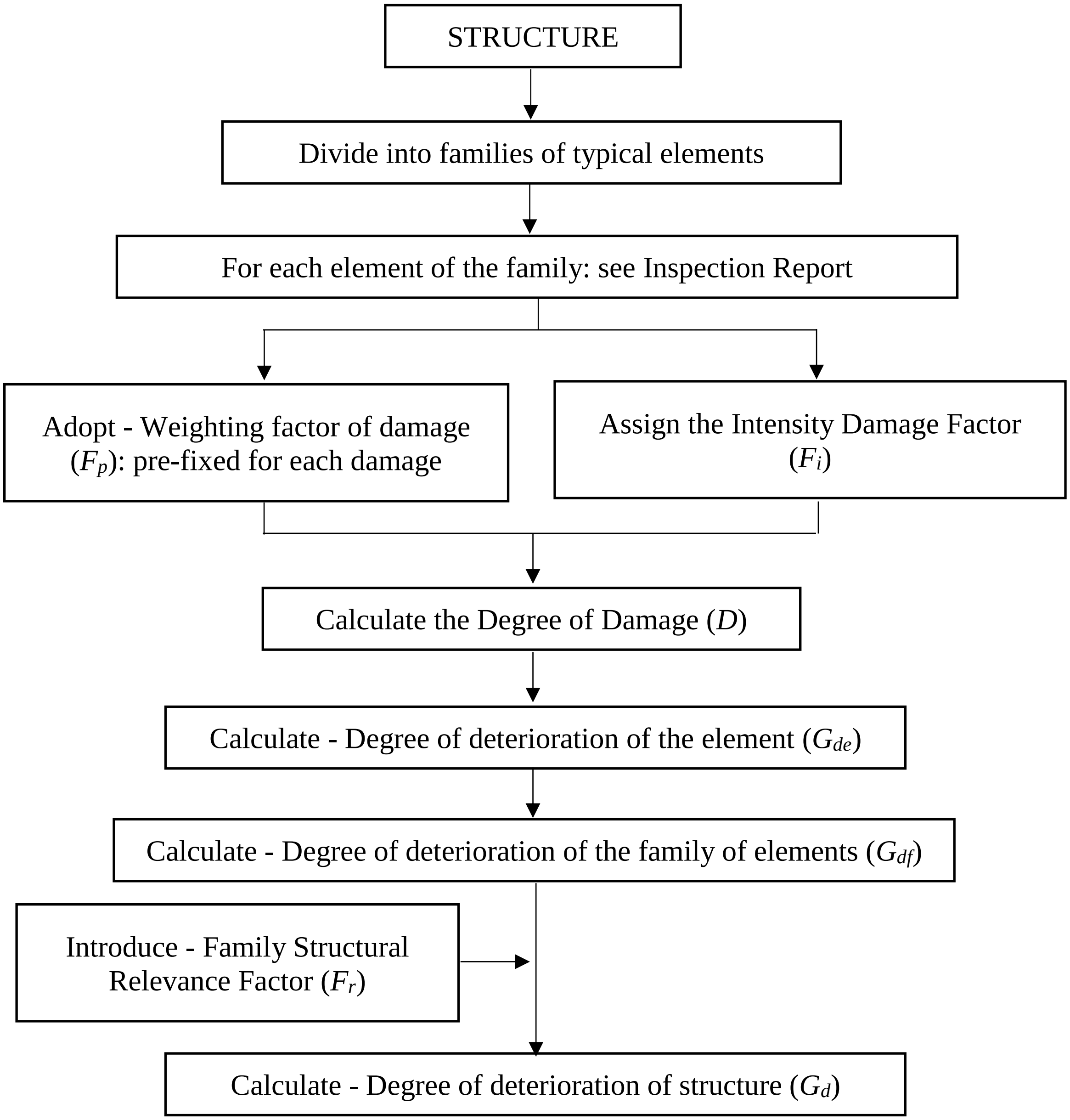

Figure 2. Structure of the GDE/UNB Methodology.

Initially, the conceptualization of damages and typical degradations is performed. With the help of the Reference tables, the values of the damage weighting factors (F_p) according to the family of elements and the damage intensity factors (F_i) of the elements are assigned. Then, with the use of the formulations, the calculation is performed to determine the degree of damage in each element, the element families, and the degree of overall deterioration of the structure.
It is worth mentioning that the Brazilian Standard regarding the inspection of special engineering structures is ABNT NBT 9452 (2016) - Inspection of bridges, overpasses and concrete footbridges - Procedure.

4. ANALYSIS OF RESULTS

For the analysis of the methodology and results, inspections were carried out on 03 overpasses. They are located on Avenida Eixo L, Eixo W, and Eixão Norte. The 03 are positioned perpendicular to the avenues, between the superquadras 103/104 and 203/204 North, as it is shown in Figure 3.

Figure 3. Location of the 03 overpasses of superquadras 103/104 and 203/204 North.

Only the visible structural elements of the overpasses were analyzed. In addition, they are composed of curtains, slab, bodyguard and bearing track. Since the span length of the overpass is relatively short, no structure had intermediate columns. The methodology was applied and used to quantify the structural damages. Thus, it served as a subsidy for decision making for interventions. Since several maintenances have been made on the bearing track over the years, it was not possible to check the state of the expansion joints.

The data collected from each analyzed structure are presented below.

4.1 Overpass 01

The overpass 01 is in Eixo L near to the superquadras 103/104 North.

Stains were identified in the structural elements of reinforced concrete in the soil as presented in Figure 4. They can be caused mainly by the infiltration of rainwater from the soil adjacent to the structure, and by infiltration of water from the flexible pavement of the bearing track to the slab. This situation could be mitigated if there was a drip tray on the side of the support floor of the bodyguard that is on the slab. Another measure that should be adopted is the waterproofing of the concrete layer on the slab before the layer of H.M.A. of the pavement. These poor waterproofing phenomena were also seen in the curtains.

Figura 4. Manchas na estrutura da Laje

By the analysis of Figure 5, it was observed, in the slab region, large areas with insufficient concrete cover to protect the steel reinforcement. As a result of this insufficient cover, there is a high level of deterioration on the rebars. Because it was exposed to moisture, a reduction of steel section was observed. Thus, the durability of the reinforcement was significantly affected.

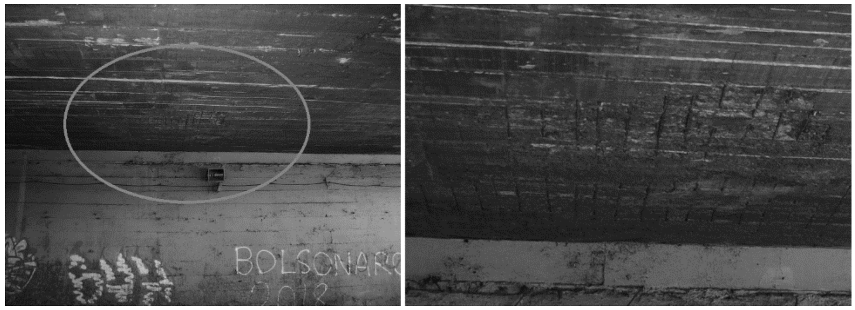

Figura 5. Cobrimento insuficiente e deterioração da Armadura

Failures were observed in the concreting at the surface of the slab as well as segregation of the aggregate, due to a bad concrete launching and vibration. It was also possible to observe the phenomenon of deterioration of the rebars; mainly on some longitudinal reinforcements.

Another damaging factor was verified and it is the impact of vehicles on the structure. Although it interferes in the integrity of the structure, it is not included in the GDE/UnB Methodology. In this specific case, the large number of trailing marks, due to hit from the top of load trucks, can be observed in the slab.

The bearing track, regarding the methodology, presented very good maintenance and conservation results. Apparently, it did not show excessive surface wear and the presence of cracks and holes.

4.1.1 Analysis of the Degree of Deterioration of the Structure (GD)

From the inspection, the Degree of Deterioration of the Structure was calculated. The final result of the global deterioration of the structure is defined as the weighted average of the degrees of deterioration of the elements families (G_{df}), taking as their weights the respective relevance factors (F_r) from Table 2. Considering the degree of deterioration for the curtain 7.8, for the bodyguard 6.0, for the slab deck 34, 67.

$$G_d = \left(\frac{\sum_{i=1}^{n} F_{ri} \cdot G_{df}}{\sum_{i=1}^{n} F_{ri}} \right) \tag{01}$$

$$G_d = \left[\frac{(7{,}8 \cdot 3) + (6{,}0 \cdot 1) + (34{,}67 \cdot 4)}{3+1+4} \right] = \frac{168{,}08}{8} = 21{,}01 \tag{02}$$

Degree of deterioration of the structure (G_d) of the Overpass 01 = 21.01

Table 2. Structural Relevance Factor of the Element Families (Fr)

Family	**Fr**
Barriers, bodyguard, wheel guard, bearing track	1
Expansion joints	2
Transversal, curtains, wings	3
Slabs, foundations, secondary beams, supports	4
Main beams and columns	5

The structure obtained a final G_d of 21.01 which according to the level of deterioration is considered average for values in the range of 15-50. Hence, for Overpass 01, it is recommended to define the term and nature of new inspection and to plan a long-term intervention at a maximum of 2 years.

It is worth noting that this inspection/intervention period is in accordance to the method of analysis adopted. For other authors, for example, they consider that the interventions should be immediate and the inspections should be periodic.

4.2 Overpass 02

The overpass 02 is located at the Eixão between the superquadras 103/104 and 203/204 North.
It presented a great number of stains in several parts of the structure; most of them in the part that is exposed to rain without a concrete cover as seen in Figure 6.

Figure 6. Stains scattered on the structure

Different types of damage to the bodyguard such as failure on the concreting, displacement of the concrete covering on the columns that resulted in the exposure of the rebars to the rains, and corrosive agents in the reinforcement can be observed in Figure 7.

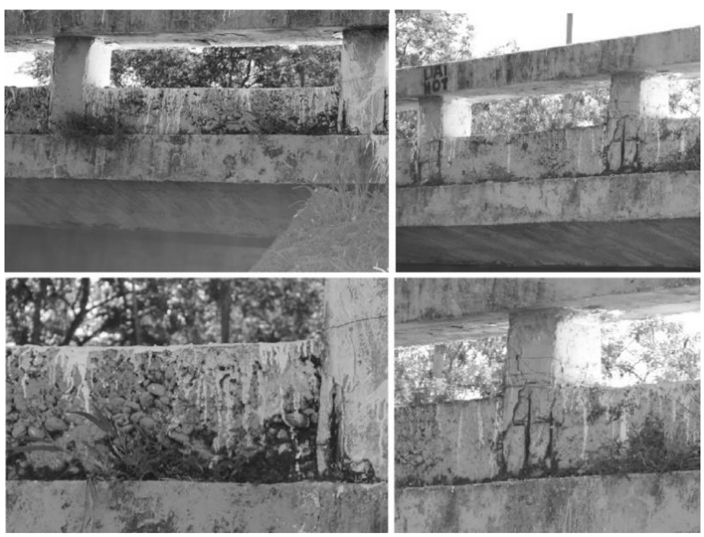

Figure 7. Failure in concreting, displacement of concrete, and pathological manifestations on the rebars (Bodyguard)

In the slabs deck, several damages were also observed: concrete failure due to lack of vibration after the launch, pathological manifestations of the reinforcement and, in some parts, it is possible to notice a deficient concrete covering by the visualization of exposed stretches of the rebars in small extensions. In the edges of the slab, where is the most susceptible part to the action of the rain, it can be perceived strong stains of great extension. Also, it can be verified that this phenomenon has compromised the reinforcement by the deterioration of the steel. In addition, in some parts it is possible to clearly notice the loss of section.

Damage was observed such as insufficient concrete covering, failure on the concreting, staining and attacking to the reinforcement. In the lower part of the bodyguard beam, it was seen signs of concrete failure, cracking, concrete displacing and pathological manifestations of reinforcement in its exposed regions.

In Figure 8, it is possible to visualize a vertical crack and wooden formwork left in the region of the curtain. In addition, the condition of the flexible pavement was analyzed. On the slab of the overpass, by the figure, it is noticeable the presence of a small hole and a crack perpendicular to the flow. Analyzing the crack, there is evidence that it has caused by the wear of the expansion joint material of the deck.

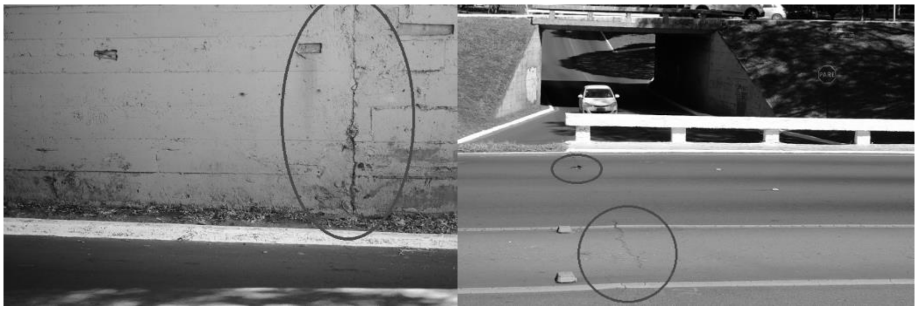

Figure 8. Crack in the curtain and pathological incidences in the bearing track.

4.2.1 Analysis of the Degree of Deterioration of the Structure (GD)

The final result of the global deterioration of the structure (G_{df}), weighted by the respective relevance factors (F_r), was 37.25. This result, according to the level of deterioration, is considered average for values in the range of 15-50. Hence, for the Overpass 01, it is recommended to define the term and nature of new inspection and to plan a long-term intervention at a maximum of 2 years. It is worth noting that this inspection/intervention period is in accordance to the method of analysis adopted. There are authors who consider that the interventions should be immediate, and the inspections should be periodic.

4.3 Overpass 03

Overpass 03 is located at Eixo W near the superquadras 203/204 North.

Figure 9 shows two types of frequent damage caused by the impact of vehicles on this type of overpasses. They are both related to the impact of a vehicle on the bodyguard and the dragging of the truck body that travels in the track with a higher height to the height of the overpass. Those impacts cause damage to the concrete covering of the slab and, in some occasions, to the own reinforcement of the structure.

Figure 9. Damage to the bodyguard structure and overview - Damage to the slab due to vehicle tallest than the height of the overpass.

4.3.1 Analysis of the Degree of Deterioration of the Structure (GD)

Applying the methodology, it was found a final G_d of 19.48. According to the level of deterioration, it is considered average for values in the range of 15-50. Hence, for Overpass 03, it is recommended to define the term and nature of new inspection and to plan a long-term intervention of no more than 2 years. It is worth observing that this inspection/intervention period is in accordance to the method of analysis adopted. There are other authors who consider that the interventions should be immediate, and the inspections should be periodic.

5. CONCLUSIONS

From the information obtained in the technical literature, field inspections, and the use of the GDE/UNB methodology, the following conclusions are presented. They have the purpose of serving as a subsidy for decision-making regarding the prioritization of routine interventions, so the lifetime of the elements and of the overall structure may be extended.

- In overpass 01, the element that presented the highest degree of deterioration was the slab with the value of 34,67. It is recommended for it to define the term and nature of new inspection and to plan a long-term intervention at a maximum of 2 years due to their degree of average damage.
- In overpass 01, the G_d presented a final value of 21.01 which according to the level of deterioration is considered average. Hence, it is recommended to define the term and nature of new inspection and to plan a long-term intervention at a maximum of 2 years.
- In overpass 02, the element that presented the highest degree of deterioration was the slab with the value of 62.46. This result is considered high, being recommended to define a term for specialized inspection and to plan a medium-term intervention in a period of maximum 1 year.
- In overpass 02, the G_d presented a final value of 37.25, which according to the level of deterioration is considered average. Hence, it is recommended to define the term and nature of new inspection and to plan a long-term intervention at a maximum of 2 years.
- In Overpass 03, the element that presented the highest degree of deterioration was the bodyguard with a value of 84.53, which is considered a poor level. Therefore, it is recommended to define a period for rigorous specialized inspection and to plan a short-term intervention at a maximum of 6 months.
- In Viaduct 03, the G_d presented a final value of 19.48 which according to the level of deterioration is considered average. Hence, it is recommended to define the term and nature of new inspection and to plan a long-term intervention at a maximum of 2 years.
- Therefore, Overpass 02 presented the highest deterioration value of 37.25. Since all the three overpasses are very close to each other, a plausible justification for this difference of values would be the flow of vehicle that in this overpass is much more intense than in the other two, causing its durability to decrease and the structure life as well.
- The elements that also suffered the highest incidence of damages were the slabs. Both can be verified visually by the field photographic records and by the results of the methodology.

In view of the above, it is considered that the methodology meets its assumptions of assisting the responsible engineer to make a fast decision on inspections of overpasses and other special engineering structures. It is suggested that inspections should be made periodically, and the maintenance should also be periodic, in order to ensure the structural safety and durability of the elements analyzed.

The repair and reinforcement of the elements that need intervention must come from projects elaborated by expert professionals and executed by companies with the technical capacity to act in recovery and reinforcement of bridges structure. One point to be considered is that a management system should be in place to manage constructions, inspections, monitoring, and interventions. Traffic is constantly increasing, evidencing the need to control the road system.

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7. REFERENCES

ABNT - Associação Brasileira de Normas Técnicas (2014), *ABNT NBR 6118:2014 - Projeto de estruturas de concreto — Procedimento*, Rio de Janeiro.
ABNT - Associação Brasileira de Normas Técnicas (2016), *ABNT NBR 9452:2016 - Inspeção de pontes, viadutos e passarelas de concreto – Procedimento*. Rio de Janeiro.
Boldo, P. (2002), *Avaliação quantitativa de estruturas de concreto armado de edificações no âmbito do Exército Brasileiro*. Dissertação de Mestrado, Departamento de Engenharia Civil e Ambiental, Universidade de Brasília, Brasília, DF. 295p.
Castro, E. K. (1994), *Desenvolvimento de metodologia para manutenção de estruturas de concreto armado*, Dissertação de Mestrado, Departamento de Engenharia Civil, Universidade de Brasília, Brasília, DF. 185 p.
Castro, E. K., Clímaco, J. C. T. S., Nepomuceno, A. A. (1995), "*Desenvolvimento de uma metodologia de manutenção de estruturas de concreto armado*", 37º. Congresso Brasileiro do Concreto, Instituto Brasileiro do Concreto - Ibracon, Anais, v.1, pp. 293-307, Goiânia.
Euqueres, P. (2011), *Metodologia de inspeção em estruturas de pontes de concreto armado*. Dissertação (Mestrado), Universidade Federal de Goiás, Goiânia, 168 p.
Fonseca, R. P. (2007), *A estrutura do Instituto Central de Ciências: Aspectos históricos, científicos e tecnológicos de projeto, execução, intervenções e propostas de manutenção*. Dissertação de Mestrado em Estruturas e Construção Civil, Departamento de Engenharia Civil e Ambiental, Universidade de Brasília, Brasília, DF. 213 p.
Helene, P. R. L. (1997), *Introdução da durabilidade no projeto das estruturas deconcreto*. In: WORKSHOP DURABILIDADE DAS CONSTRUÇÕES. São Leopoldo. Anais, São Leopoldo: ANTAC, 1997. p. 31-42.
Klein, D. L., Gastal, F. P. S. L., Campagnolo, J. L. (1998), *Critérios adotados na vistoria e avaliação de obras de arte*. In: XXV Jornadas Sul-Americanas de Engenharia Estrutural, 1991, Porto Alegre. Anais... Porto Alegre: UFRGS, 1991, p. 185-197
Lopes, B. A. R. (1998), "*Sistema de manutenção predial para grades estoques de edifícios: Estudo para inclusão do componente "Estrutura de Concreto"*. Dissertação de Mestrado, Departamento de Engenharia Civil, Universidade de Brasília, Brasília, DF,1998. 308 p.
Mattos, Aldo Dórea (2010), *Planejamento e controle de obras*. Pini.
Medeiros, A. G. (2015), *Análise de durabilidade da ponte do Rio do Carmo utilizando ensaios não destrutivos, norma DNIT e a metodologia GDE/UNB*. 165 f. Dissertação (Mestrado em Engenharia Civil) – Programa de Pós-Graduação em Engenharia Civil. Universidade Federal do Rio Grande do Norte. URI: http://repositorio.ufrn.br/handle/123456789/20496
Mehta, P. K; Monteiro, P. J. M. (2008), *Concreto: microestrutura, propriedades e materiais*. 3° ed., IBRACON, São Paulo, p. 674.

Ribeiro, D. V. et al. (2014), *Corrosão em estruturas de concreto armado: teoria, controle e métodos de análise*. 1° ed., Campus / Elsevier, Rio de Janeiro, 2014. p. 272. ISBN:978-85-352-7547-6

Tuutti, K. (1982). *Corrosion of steel in concrete*. Stockholm - Swedish Cement and Concrete Research Institute.

Verly, R. C. (2015), *Avaliação de metodologias de inspeção como instrumento de priorização de intervenções em obras de arte especiais*. Dissertação (Mestrado em Estruturas e Construção Civil)—Universidade de Brasília, Brasília.