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Study on the current conditions of a bridge exposed to an aggressive environment on highway BR-101 / PE

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ABSTRACT

Significant amount of Special Engineering Structures (SES) of Brazilian highways are currently in advanced state of degradation due the presence of pathological manifestations and damage structures. These problems, when associated with the lack of routine inspections and preventive maintenance, can compromise both the functionality and stability of these bridges, viaducts and footbridges that make up the country's road system. On the federal highways of Pernambuco, there are approximately 600 registered bridges and viaducts by the National Department of Transport Infrastructure (DNIT); Of this total, 120 SES are located in the BR-101 / PE, built in the 60's and whose northern section stands out as one of the main traffic corridors, including for the transportation of heavy loads destined to the industrial pole of the city of Goiana and to the States of the Northeast Region. The high intensity of traffic, associated to the strong environmental aggressiveness, characteristics of the industrial zone and coastal area, contribute a lot to the structural deterioration of the SES of this highway. It is in this context that this work aims to study the situation of the Igarassu River's Bridge, in BR-101 / PE, considering its current structural conditions, especially those of the board, characterized by concrete degradation, corroded by the absence of the covering layer and by the lack of adhesion between concrete and reinforcements; there are still serious damage to the bearings. The study consisted of visual inspection, survey of existing geometry, and a preliminary structural analysis to better assess the performance and safety of the structure under the effects of existing damages. Recommendations are also showed for immediate and final actions to increase the safety, functionality and durability of the bridge that is the object of this work.

Keywords: Environmental aggressiveness, Deterioration, Inspection, Damage, Recovery.

1 INTRODUCTION

Since the construction of the first Brazilian federal roads (1940s), bridges, viaducts and pedestrian walkways have been undergoing a significant aging process, whose main consequence is a progressive deterioration of these structures that can take them to the ultimate limit state.

In addition to project design flaws, other aspects contribute to shortening service life, such as the early emergence of structural anomalies and damages that are most often caused by the absence of periodic inspections and preventive maintenance, especially when these structures are exposed conditions.

One of the major damages that affect the structures of the SES is the corrosion of rebar. The presence of this anomaly to a high degree may impose limits of use, such as the restriction of loads, or even partial or total interdictions.

It is in this context that this paper shows the study of the Igarassu River's Bridge, on highway BR 101 / PE, km 41.7 subject to severe environmental conditions, heavy traffic and no maintenance.

2 CASE STUDY

The study of the Igarassu River's bridge was done using information from the DNIT's Special Engineering Structures Management System (SGO) database, as well as through observations made during inspections carried out in the structure, which included surveying the existing geometry, and also data from a provisional reinforcement project prepared by one of the authors of this text. This methodology also included the procedures of Standard DNIT 010/2004 - PRO [1], which defines stability conditions by assigning a grade that can vary from 1 (critical structure) to 5 (structure without problems).

Based on the observations and the verification of structural damages and other damages in the structure, the analyzes were carried out corresponding to the conditions of conservation and a preliminary evaluation of the structural safety, considering the current state of degradation in which the bridge is located.

2.1 Description of the analyzed structure

The Igarassu River's Bridge was built in 1958 with bridge deck a reinforced concrete poured on-site, with two spans of 13.55 m, totaling 27.10 m in length and width of 8.30 m. The bridge deck is formed by a grid of four longitudinal beams with variable inertia and five transversal ones, three in the supports and two in the middle of the spans. The mesostructure is composed of abutments at the extremities of the bridges and a column-central wall, all in concrete. The transmission of the forces of the bridge deck to the abutments and columns is made by pendulum type bearings at one end and by metal bearings at the other supports, a solution widely used at the time the bridge was built. The live loads are of the class 240 kN standard truck, according to the standard that was in force at the time.

Regarding the functional protection devices, the bridge deck has on one side a "New Jersey" barrier and on the other a guard-rail with wheels of 0,95 m. The Figures (1) and (2) show a top view and side view of the bridge.

Fig. 1: Top view of the bridge

Source: Authors (2018)

Fig. 2: Partial side view of the bridge

Source: DNIT (2017)

2.2 Main pathological manifestations and the structural damages on the bridge

For many years this bridge is in advanced state of structural deterioration, partly caused by the aging process of the structure, aggravated by the fact that it is located in an area of high environmental aggressiveness and receives under its structure polluting waste from a factory, resulting from the process of manufacturing toilet paper, napkins, paper towels and cartons, as shown in Figure (3).

Combined to these aspects, the structure is still subject to heavy traffic of heavy vehicles and does not receive preventive and corrective maintenance for many years. This combination of unfavorable factors is amplified by the fact that the bridge was built at a time when Brazilian standards did not provide sufficient cover of concrete or reinforcement with suitable resistance to resist environmental aggression and to guarantee a greater durability to the structures.

This degree of degradation was confirmed by means of the inspections carried out, the consultation of the DNIT files and other studies that supported the elaboration of this paper, in order to identify in detail, the main pathological manifestations and damages in the various components of the structure, as described below.

Fig. 3: Waste pollutants that flow into the river under the bridge

Source: Authors (2018)

2.2.1 Damages to the superstructure

The problems identified in the superstructure are those that represent a higher risk and are related to the advanced state of degradation of concrete and reinforcements of girders, especially those located at both edge of the abutments. The two internal beams also have concrete and rebar damaged, but with less severe deterioration.

The structural insufficiency of the external beams is characterized by significant losses of the sections of the bending and shear reinforcement, associated to the loss of adhesion between these reinforcements and the concrete. The concrete in turn shows itself in an advanced state of deterioration, as shown in Figures (4) and (5).

Fig. 4: Loss of concrete sections and bending rebar in external girders

Source: Authors (2017)

Fig. 5: Severe corrosion and destruction of shear reinforcement in regions of the external beams support

Source: Authors (2017)

The cross beams and the lower surface of the slab of the bridge also show a constantly evolving degree of deterioration, characterized by exposed and oxidized reinforcement, efflorescence from the leaching process and cracks in the concrete. It is possible to observe large infiltrations of water by the edge joints, by the porous concrete itself of the bridge deck and also by the absence of drains and drippings at the ends of the lateral balances of the slab of the bridge deck. Another issue observed was the undue fixing of pipes on the sides of the deck, which also contributed to aggravate the damages and infiltration of water in the concrete. These problems are illustrated in Figures (6) and (7).

Fig. 6: Inadequate mounting of pipes on deck, increasing the damages on the concrete

Source: Authors (2017)

Fig. 7: Infiltrations, efflorescence and generalized staining on the lower surfaces of the deck

Source: Authors (2017)

2.2.2 Damages to the infrastructure and mesostructure

The mesostructure, consisting of two abutments and a concrete pillar-wall, receives the loads from the bridge deck through pendulum type bearings at one end and metal bearings at the opposite end and at the central support. The observations made during the inspections showed that there are major failures in the concrete pendulums and a destruction of the metal bearings. This means that these elements are no longer conveying the forces nor allowing the movements of the structure as predicted in the original design of the bridge. In general, both abutments and the central pillar, although showing some deterioration, have no significant damages; however, the bearings are no longer fulfilling their functions, especially in the case of the pendulums, where it is observed the possibility of at least one of them reaching the rupture. As for the metal bearings, it is possible to observe the crushing of the concrete of the beams in the region of compression on the supports. These situations can be seen in Figures (8) and (9).

It was not possible to inspect the foundations buried beneath the bed of river. There is also no information available on which solution was originally adopted, because the structural design was not available. Given the lack of this information, it was only possible to presume the type of foundation existing by means of the analysis of two holes of geotechnical drilling at the ends of the bridge in 2014. The reports of these surveys indicate that the soil layer with good resistance is situated between six and ten meters deep below the river bed. This means that the existing foundation was probably carried out by means of pipes, a solution widely used at the time, or in stakes, since the soil characteristics are not suitable for the use of direct foundations. This hypothesis has a great possibility of being the most correct because it has not been observed cracks and / or displacements related to the occurrence of differential pressures, a recurrent phenomenon in direct foundations of bridges based on layers of soft soil or low resistance. However, it will only be possible to accurately identify the type of foundation existing after conducting appropriate surveys and studies at the location where the bridge is located.

Fig. 8: Collapse of one of the pendulums type bearings one of the girders.

Source: Authors (2017)

Fig. 9: Crushing of the concrete and bearings of one of the beams

Source: Authors (2017)

2.3 Evaluation of the stability conditions and study of a temporary reinforcement

It was evidenced that the precarious conditions of conservation of the bridge conditions have directly resulted in the compromising of safety conditions, that may cause the partial or total collapse of the structure, if no definitive measures or at least immediate mitigation measures are adopted, aiming at reducing the evolution of the agents responsible for the degradation. As this work adopted the DNIT 010/2004-PRO standard [1] to evaluate the conditions of the bridge, the criteria in Table (1) were used which assign a score varying from 5 to 1 to characterize the damages and relate them to the conditions of stability.

In view of these criteria, note 1 was assigned to the structure, which ranks it from the point of view of stability conditions as a precarious work that urgently needs structural reinforcement or be replaced; under the view of the general conditions was classified as a critical structure that could have the structure compromised and whose recovery must be accompanied by special preventive measures.

Vitório [2] studied and elaborated a special preventive measure to avoid the collapse of the bridge until the definitive measures for the rehabilitation, widening and reinforcement were adopted. This is a project, which means a mixed shoring solution with temporary reinforcement, to be used for a certain period of time until definitive interventions are carried out; then it can be completely dismantled and its parts reused. This solution, which has not yet been carried out, provides that, in the event of the rupture of one or both of the external girders of bridge deck, the actuating forces are transferred to beams made of metal profiles positioned on both sides of the longitudinal members. The metal profiles in turn are supported on the existing abutments and the central wall pillar and were also dimensioned to guarantee the stability of the deck in case of rupture of the damaged pendulum. The system is designed so that a possible failure of the external beams is ductile, absorbed by the metal profiles and with little transfer of load to the internal girders. It was planned to apply self-compacting concrete between the top of the profiles and the bottom of the bridge deck to ensure a more monolithic condition of support on the metal elements in case of rupture of the external beams.

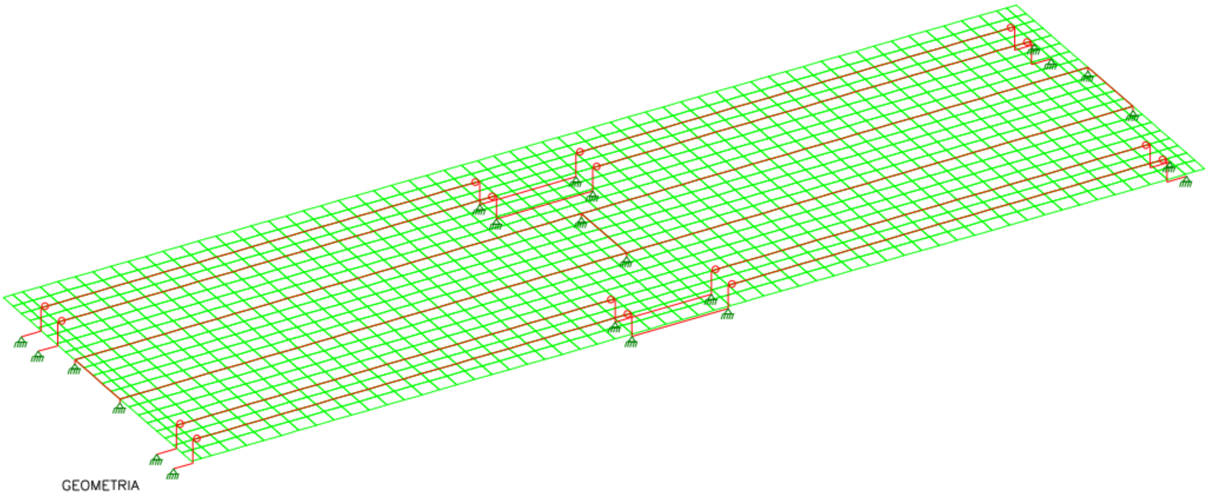
With this solution there is no need for vertical shoring under the bridge, so that all the forces coming from the structure, both in use situation and in case of failure, are transmitted to the abutments and to the central pillar. The dimensioning of the temporary reinforcement / propping was done by means of bridge deck modeling with a finite element software, considering the live and permanent loads acting on the structure and the presumed properties for the existing materials. This made it possible to make every force in the bridge deck components for the combinations provided and the loads that would have to be absorbed by the metal profiles and internal girders in the event of rupture of the external beams. The Figure (10) shows the discretization model adopted for the bridge deck and Figures (11) and (12) illustrate some details of the shoring / reinforcement system.

Table 1: Imputed notes and structural damages observed in SES inspections

GRADE	DAMAGE / STRUCTURAL INSUFFICIENCY	CORRECTIVE ACTION	STABILITY CONDITIONS	CLASSIFICATION OF BRIDGE CONDITIONS
5	No damage or structural deficiency	Nothing to do	**Good**	**Structure without problems**
4	Some damage, but no sign that it is causing any structural deficiency	Nothing to do beyond regular maintenance service	**Good**	**Structure without significant problems**
3	There is some damage generating structural insufficiency, but no signs of compromised stability	The recuperation of the structure can be postponed, but the problem must be systematically monitored	**Apparently good**	**Potentially problematic structure** Following the evolution of the problems through routine inspections is recommended, in order to detect any worsening of the deficiency in a timely manner
2	There is damage generating significant structural insufficiency in the bridge, but there is still no apparent tangible risk of structural collapse	Recuperation (usually with structural reinforcement) of the structure must be performed in the short term	**Tolerable**	**Problematic structure** Too much delay in performing recuperation could leave the structure in a critical state, possibly seriously compromising its useful life. Intermediate inspections to monitor the problems are recommended
1	There is damage causing severe structural insufficiency of the bridge; the element in question is in critical condition, with a tangible risk of structural collapse	Recuperation (usually with structural reinforcement) or in some cases, replacement, must be done without delay	**Precarious**	**Critical Structure** In some cases, it may constitute an emergency situation, and recuperation of the structure may be accompanied by special preventive measures, such as: bridge load restriction, total or partial traffic interdiction, provisional shoring, instrumentation with continuous displacement, deformation readings, etc.

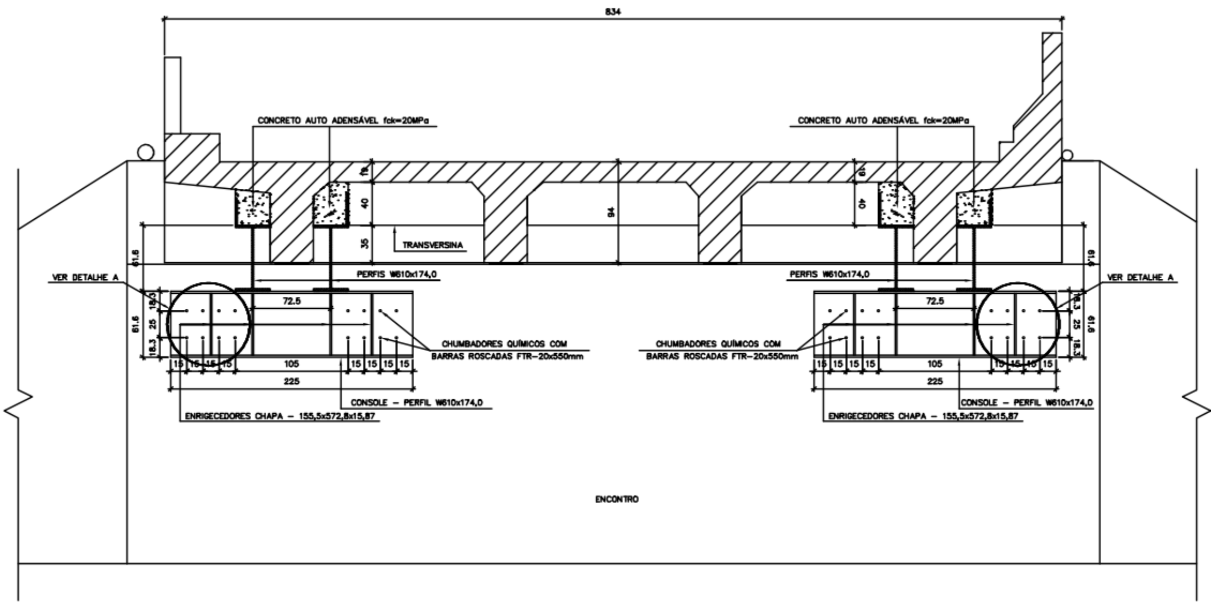
Source: DNIT (2004)

Fig. 10: Discretization model of the bridge deck to obtain the acting forces



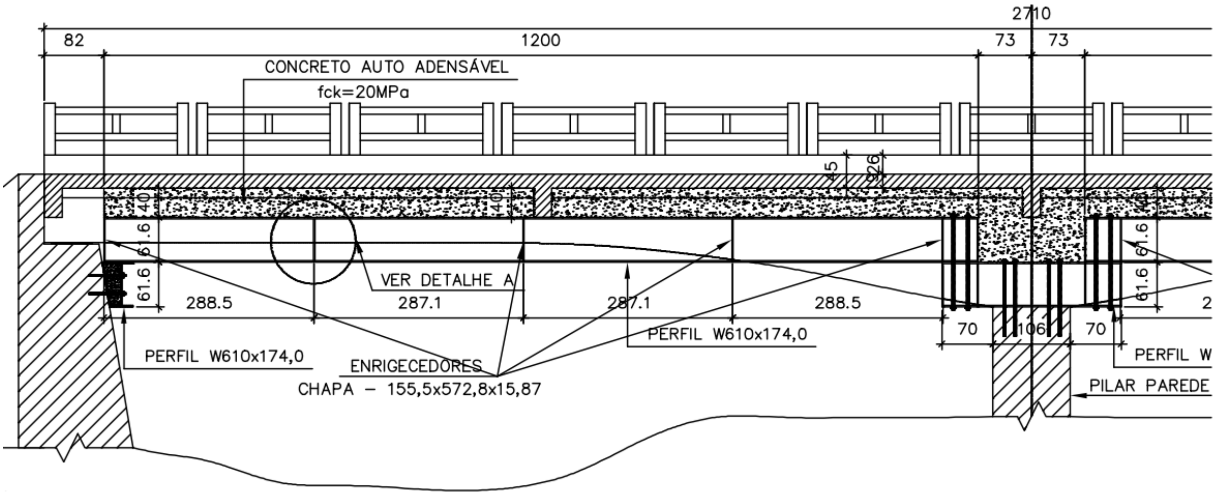
Source: Vitório (2014)

Fig. 11: Temporary reinforcement cross-section



Source: Vitório (2014)

Fig. 12: Temporary reinforcement longitudinal section



Source: Vitório (2014)

3 RESULTS

The results obtained from the inspections and analyzes carried out on the bridge structure showed an advanced degradation level of the concrete and the reinforcement of the slabs, cross beams and girders of the bridge deck; the most serious situation corresponds to the two ends beams, whose resistant sections in the snatchs of bending moments and maximum shear stresses are compromised by the high degree of corrosion of the bending and shear reinforcement, as well as the lack of adhesion between the rebars and the concrete. The concrete in turn shows fissures, displacement and efflorescence in a generalized way, which contributes to further stress the loss of resistance.

Several functional aspects, which also contribute to the deterioration of the structure and reduction of durability, were also observed as: the absence of drippings at the lateral ends of the bridge deck; the obstruction and / or destruction of the drains responsible for the drainage of the rainwater on the deck; cracks and wear on the asphalt pavement of carriageways over the bridge and damages to the barriers guardrails.

It has also been observed that the bearings show a worrying situation because of the importance of these elements in the transmission of the forces of the bridge deck for the abutments and pillars, especially the pendulum that acts as support of one of the external girders, badly damaged and in a pre-collapse state. The other bearings, probably in lead plates, are completely crushed and no longer fulfill their functions.

The analysis of the conditions of the two abutments and the central pillar-wall showed that these components, although they have wears, some cracks and stains related to water infiltration, do not appear to have malfunctions that could compromise the structural safety of the bridge, so much so they will be the elements responsible for absorbing the stresses transmitted by the temporary reinforcement in the event of the collapse of the beams that have malfunctioning.

The results of the two geotechnical prospecting conducted at the ends of the bridge found no soft clay layers under the foundations, which explains the absence of symptoms related to differential stresses in the foundations of the abutments and the central pillar.

4 CONCLUSIONS

The analyzes carried out and commented on in the previous item allow to conclude that the Igarassu River's bridge shows serious problems that can compromise its structural safety conditions and its functionality, if short-term corrective measures are not adopted, considering the tangible risk of structural collapse, confirmed by note 1 which was attributed to its stability conditions according to DNIT 010/2004-PRO [1]. It is also possible to conclude that the bridge has not yet collapsed due to the fact that its reinforced concrete grid bridge deck, consisting of slab, four hyper-static girders with variable inertia and great robustness, besides intermediate cross beams and in the supports, have a great redundancy which has been guaranteeing resistance to the actions in severe conditions up to now, even with the lack of sections in maximum requests.

The corrective measures should be carried out in the shortest possible time and comprehend structural reinforcement and recovery, accompanied by the widening of the deck, considering that this bridge is subject to a large flow of heavy traffic and has a strategic location for the transit of vehicles that arrive in the Metropolitan Region of Recife on the Northern side of BR 101 / PE.

Structural, geotechnical, hydrological and material studies should be carried out for definitive interventions to provide sufficient elements for the elaboration of the executive projects of reinforcement, recovery and widening, thus guaranteeing a longer durability and a residual useful life. However, it is recommended to carry out the temporary reinforcement described in this text to ensure that the bridge does not collapse before the definitive services are carried out. It should be clarified that restoration, reinforcement and widening interventions will only be technically and economically feasible if, after completion of the services, the bridge receives appropriate and systematic maintenance. If this does not happen, the residual service life, resulting from the interventions carried out, will not correspond to a favorable benefit / cost ratio, including from the social point of view.

ACKNOWLEDGMENTS

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