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Assessment of the remaining service life of Curado walkway and the bridge over the River Tanque, Pernambuco, Brazil

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ABSTRACT: This study addresses the assessment of the Curado walkway and bridge over the River Tanque, both situated on the federal highway BR-232/PE, using the service life concept of standard ISO 15686 (2011) and the performance precepts of standard ABNT NBR 15575-1 (2013). The existing guidelines for inspection procedures and to assess the stability conditions of these structures in standard DNIT 010/2004-PRO were adopted. The results highlight the use of this methodology to estimate service life in case studies where there is no background of regular inspections.

Keywords: bridges and viaducts, deterioration, inspection, durability, service life

1 INTRODUCTION

Brazilian highway bridges and viaducts have been undergoing a severe process of deterioration, endangering their durability and service life. The following are useful in identifying the level of degradation of such structures: visual inspection, monitoring and bridge management systems. These tools help obtain relevant information to make better use of public resources, in order to minimize high costs of their rehabilitation, and to avoid unsuitable preventive maintenance.

Another key point refers to the safety assessment of existing bridges. On this matter, several countries have been doing extremely important studies. Gode (2014) and Krakhmal'ny et al. (2016) suggested new procedures to estimate the remaining service life of concrete bridges.

In light of this, this study adopted standards ISO 15686 (2011) and ABNT NBR 15575-1 (2013) for the service life estimation of two structures located on the Brazilian federal highway BR-232/PE. The methodology adopted in this study involves a more comprehensive study in development regarding the remaining service life of Brazilian highway bridges and viaducts.

2 MATERIALS AND METHODS

The Curado walkway and bridge over the River Tanque were selected for this study, both located on the federal highway BR-232-PE, at km 8.2 and km 342.440, respectively.

2.1 *Curado Walkway – km 8.2*

The walkway under study was built in the 1980s. It is 5.50m in height from the pavement of highway BR-232/PE, and consists of one (1) central span 57.4 m in length and 4.0 m in width. This span is supported on two pillars in the central reservation between two local roads and two main roads, as well as the two small spans of approximately 9.20 m and 11.90 m in length.

The structure also consists of four (4) ramps 60.40 m long, two of them at each end of the central sidewalk. Each ramp segment is underpinned by three intermediary pillars.

The central sidewalk and ramps are protected laterally by a guardrail consisting of three pipes with different diameters, attached to small concrete bollards

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approximately 1.00 m in height. Figures 1 and 2 show the longitudinal and top views of the Curado walkway.

2.2 *Bridge over the River Tanque – km 342.440*

This is a reinforced concrete bridge built in 1939, 9.95 m in width and 22.05 m length, with two spans where there are three dilation joints, two of which are at the ends and the other in the deck on the central support. The abutments are mortar stone wall-pillar types. Figure 3 illustrates the top view of the structure.

On the shoulders, the carriageway is protected by wheelguards and walkways with guardrails specified by the Highway Department (DER).

Figure 1. Longitudinal view of Curado walkway.

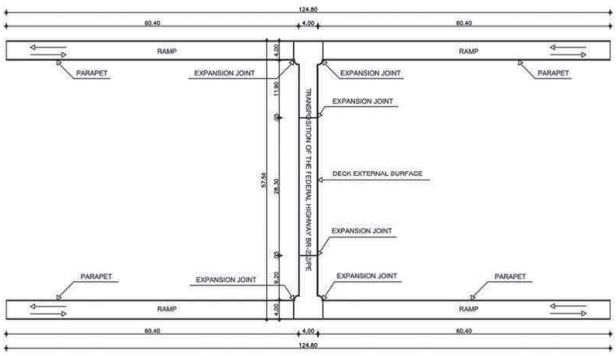

Figure 2. Top view of Curado walkway.

Figure 3. Top view of the bridge over the River Tanque.

The cross-section of the deck consists of six beams underpinned by the abutments, and in the middle by a reinforced concrete wall-pillar. Figure 4 highlights the cross-section of the bridge over the River Tanque.

2.3 *Methodology*

2.3.1 *Inspection and assessment of stability conditions of the analyzed structures*

The guidelines for inspecting the analyzed structures in standard DNIT 010/2004-PRO were adopted by adding a technical note to the analyzed structure based on the notes attributed to their structural elements, which may vary from 1 to 5, the lowest figure for the worst stability condition and the highest for the best condition (Figure 5).

2.3.2 *Service life Estimation according to ISO 15686-1 (2011) and ABNT NBR 15575-1 (2013) guidelines*

ISO 15686-1 (2011) allows the identification and determination of general criteria for useful life planning, using a systematization of a structure to carry out or planning the service life of a building planned or executed over a long (total or residual) life cycle for new or existing buildings and constructions such as bridges, tunnels and walkways.

Thus, the guidelines of standard ISO 15686 (2011) were adopted to help obtain the Estimated Service Life (ESL) of the analyzed structures.

To obtain the ESL, the Reference Service Life (RSL) was first adopted, as provided in ABNT NBR 15575-1 (2013), to estimate its service life. The ELS of a certain element or structure can be obtained by multiplying the RSL by the seven factors according to Equation 1 below:

$$ESL = RSL \times A \times B \times C \times D \times E \times F \times G \quad (1)$$

where:

- RSL – Reference service life
- ESL – Estimated service life

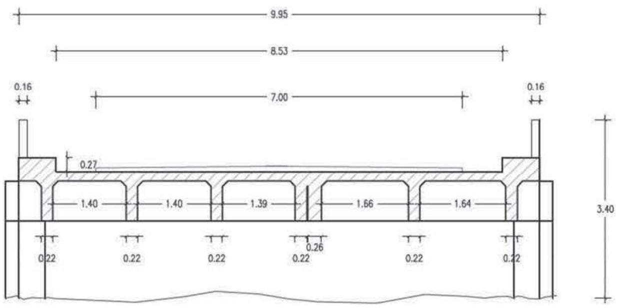

Figure 4. Bridge cross-section over the River Tanque.

Note	Damage to element / Structural insufficiency	Corrective action	Stability conditions	Classification of bridge conditions
5	No damage or structural insufficiency	Nothing to do	Good	Structure without problems
4	Some damage, but no signs that they are creating structural insufficiency	Nothing to do, only repair services	Good	Structure without significant problems
3	Some damage causing insufficiency but no detrimental signs for structure stability	The recuperation of the structure can be postponed, but the problem must be systematically monitored	Apparently Good	Potentially problematic structure Recommended to follow up future problems by routine inspections, to detect in time any worsening of the insufficiency
2	Damage causing significant structural insufficiency of the bridge, but so far no tangible risk of structural collapse	Rehabilitation (generally with structural reinforcement) must be done in the short term	Tolerable	Problematic structure To delay the recovery of the structure too much may lead it to a critical state, also entailing serious impairment of working life of structure. Intermediary instructions recommended to monitor the problems
1	Some damage causing severe structural insufficiency of bridge: the element in question is in a critical state, with a tangible risk of structural collapse	Rehabilitation (generally with structural reinforcement) - or in some cases, substituting the job, must be done with no delay	Precarious	Critical structure In some cases, an emergency may arise and the structure's rehabilitation may be accompanied by special preventive measures, such as load restriction on bridge, total or partial traffic closure, temporary shoring, instrumentation with constant displacement / deformation readings, etc.

Figure 5. Note attributed to stability status in inspections of the analyzed structures (Standard DNIT 010/2004-PRO).

- Factor A – Quality of construction materials
- Factor B – Design quality level
- Factor C – Level of executive quality
- Factor D – Internal environment characteristics
- Factor E - External environment characteristics
- Factor F – Characteristics of use
- Factor G – Maintenance level

Also in light of the above, each factor has variables that may affect the deterioration process. A weight was allocated to each of these variables as follows:

- 0.80 – For very unfavorable situations for structure or element in study
- 1.20 – For very favorable situations for structure or element in study
- 1.00 – For attributes in standard conditions, e.g., which merely comply with the regulations

2.4 *Pathological evidence and deteriorations identified in the studied structures*

The pathological signs and structural damage identified in the studied structures are presented below.

2.4.1 *Curado walkway – km 8.2*

With regard to the walkway's stability, special should shall be given to the deck, considering that two stringers of the central walkway have reinforcement bars (Figure 6) and shearing partly destroyed by impact of vehicles traveling along the highway with a vertical clearance beyond the standard recommendation (5.5 m).

Different corrosion processes were identified in the reinforcement bars at the base of some of the structure's pillars (Figure 7).

Also regarding the walkway, some fair-sized plants were seen in the deck joints and concrete showing efflorescence and moisture (Figure 8).

2.4.2 *Bridge over the River Tanque – km 342.440*

Concerning the River Tanque, the stability of the structure is passable, in addition to the intense vibration level of the deck when vehicles pass by.

In this respect, major deterioration was found in the lower part of the deck. Figure 9 shows holes in the concreting and efflorescence.

With regard to the stringers, Figure 10 portrays the severe corrosion of reinforcement bars in one of these structural elements.

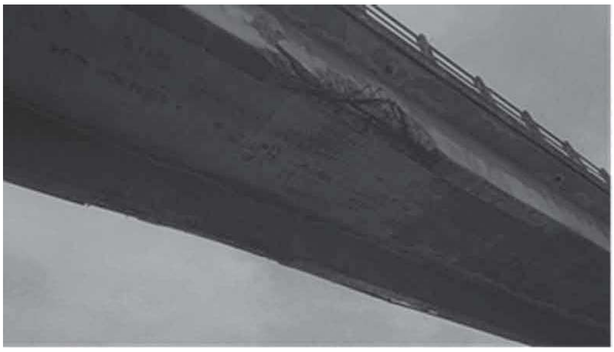

Figure 6. Stringers in the central walkway containing reinforcement bars and shearing partly destroyed by vehicle impact.

Figure 7. Corrosion of reinforcements at the bottom of one lateral pillar surface of the structure.

Figure 8. Presence of sparse vegetation, general seepage, efflorescence and corrosion of reinforcement on one side of the walkway's pillar.

Figure 9. Severe deterioration of the bottom part of the deck due to the presence of holes in the concrete and efflorescence.

Figure 10. Severely corroded reinforcement bars in one of the bridge stringers.

Subsidence was also observed in one of the traffic lanes as a result of widening without consolidation (fixed support) in the old structure. Figures 11 and 12 highlight the aforementioned widening and subsidence.

Figure 11. Widening without consolidating the old structure.

Figure 12. Subsidence in a traffic lane on the bridge.

3 RESULTS AND DISCUSSIONS

Presented below are the results of the assessment of the stability status provided by standard DNIT 010/ 2004-PRO and the service life estimation of the structures according to ISO 15686 (2011) standard.

3.1 *Assessment of the stability status of the analyzed structures (DNIT 010/2004-PRO)*

To allocate the final rating for each structure, the technical inspections were performed that helped identify major pathological evidence and structural damage. Table 1 below highlights the ratings allocated to the structures in the study herein.

3.2 *Service life estimation according to ISO 15686 (2011) criteria*

Tables 2 and 3 stress the average value applied to each variable for the Curado walkway and the bridge of over the River Tanque, respectively.

Table 1. Ratings given to the analyzed structures (Standard 010 DNIT/PRO-2004.

Highway	Structure	Year of construction	Train type	Rating 1	2	3	4	5	Stability status
BR-232/ PE	Curado walkway Km 8.2	1980	——- —	X					Critical structure
	Bridge over on River Tanque Km 342.440	1939	240 kN		X				Problematic structure

Table 2. Variables allocated to each walkway factor.

Curado walkway - km 8.2

Factor	Variable: Infrastructure	Mesostructure	Super-structure	Average (End value of factor)
A	1.0	1.0	1.0	1.0
B	0.8	0.8	0.8	0.8
C	1.0	1.0	1.0	1.0
D	1.0	1.0	1.0	1.0
E	0.8	0.8	0.8	0.8
F	0.8	0.8	0.8	0.8
G	0.8	0.8	0.8	0.8

Table 3. Variables attributed to each bridge factor.

Bridge over the River Tanque - km 342.440

Factor	Variable: Infrastructure	Mesostructure	Super-structure	Average (End value of factor)
A	1.0	1.0	0.8	0.9
B	0.8	0.8	0.8	0.8
C	1.0	1.0	0.8	0.9
D	1.0	1.0	1.0	1.0
E	1.0	1.0	1.0	1.0
F	1.0	0.8	0.8	0.9
G	0.8	0.8	0.8	0.8

3.3 *Determining the service life estimation of the analyzed structures*

Tables 4 to 6 provide the ELS of each structure analyzed for a RSL of 50, 63 and 75 years, respectively.

Table 4. Result of service life estimation of analyzed structures – RSL (50 years).

Structure	RSL (Years)	ELS (Years)
Walkway km 8.2	50	20.48
Bridge over River Tanque km 342.440	50	24.16

Table 5. Result of service life estimation of analyzed structures– RSL (63 years).

Structure	RSL (Years)	ELS (Years)
Walkway km 8.2	63	25.80
Bridge over River Tanque km 342.440	63	30.44

Table 6. Result of service life estimation of analyzed structures– RSL (75 years).

Structure	RSL (Years)	ELS (Years)
Walkway km 8.2	75	30.72
Bridge over River Tanque km 342.440	75	36.24

3.4 *Determining the remaining service life of the studied structures*

Tables 7 to 9 below display the remaining service life of each structure of the present study with its RSL reductions.

Table 7. Summary of assessment of structures for 50-year RSL.

Highway	Structure	RSL	ESL	Reduction of RSL (%)	Construction Period	Remaining Service Life	Current Situation	Decision to adopt
BR-232/ PE	Curado Footbridge Km 8.2	50	20.48	59.04	1980	2000	Survival Period	Immediate intervention
	Bridge overTanque River Km. 342.440	50	24.16	51.68	1939	1963	Survival Period	Immediate intervention

Table 8. Summary of assessment of structures for 63-year RSL.

Highway	Structure	RSL	ESL	Reduction of RSL (%)	Construction Period	Remaining Service Life	Current Situation	Decision to adopt
BR-232/ PE	Curado Footbridge Km 8.2	63	25.80	59.04	1980	2006	Survival Period	Immediate intervention
	Bridge overTanque River Km. 342.440	63	30.44	51.68	1939	1969	Survival Period	Immediate intervention

Table 9. Summary of assessment of structures for 75-year RSL.

Highway	Structure	RSL	ESL	Reduction of RSL (%)	Construction Period	Remaining Service Life	Current Situation	Decision to adopt
BR-232/ PE	Curado Footbridge Km 8.2	75	30.72	59.04	1980	2011	Survival Period	Immediate intervention
	Bridge overTanque River Km. 342.440	75	36.24	51.68	1939	1975	Survival Period	Immediate intervention

4 CONCLUSIONS

The article herein presents a methodology in progress, which assessed the stability status and proceeded to estimate the remaining service life of the Curado walkway and bridge over the River Tanque, both situated on the federal highway BR-232/PE.

With regard to the stability status, the structures were classified according to the existing criteria in DNIT 010/2004-PRO as Critical Structure (Note 1) and Problematic Structure (Note 2), thereby requiring rehabilitation of both in the short term. In this respect, the DER/PE recently signed a contract to begin rehabilitation services of the Curado walkway.

The 50, 63 and 75-year periods of Reference Service Life (RSL) were adopted in order to determine the remaining service life. This analysis demonstrated that for those periods the Curado walkway had around a 59% drop in its RSL. The bridge over the River Tanque showed a RSL drop of around 52%, which are within the survival period and require immediate intervention.

The results from the analysis show that the methodology applied to the structures in the study for service life estimation can be used in situations where there is no regular inspection background, considering that there are more suitable tools for this purpose, such as stochastic methods, neural networks and Petri-Net, hidden Markov model algorithms, and so on.

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