Comparative study of bridge structural condition assessment methodologies

C.A.F. Souza, J.M.F Carvalho, A.C.P. Martins, F.G. Bellon, M.C.S. Alvarenga, D.S. Oliveira, K.M.L. Cesar & J.C.L. Ribeiro
Universidade Federal de Viçosa (UFV), Viçosa, Brasil

R.C. Verly & G.S. Santos
Departamento Nacional de Infraestrutura de Transporte (DNIT), Brasília, Brasil

ABSTRACT: Bridges, viaducts, and footbridges are essential elements in the country's transport network. Their proper functioning is critical for economic and social development; therefore, defining the performance of an existing bridge through an adequate assessment of its condition in an effective bridge management system is mandatory. In Brazil, the National Department of Transport Infrastructure – DNIT, classifies the bridges' conditions on a scale of 1 to 5. However, the perception of other methodologies and their critical analyses are valuable routes for proposing improvements and updating Brazil's current method. This article compares the current assessment method with two other methodologies in a set of bridges. They are the one adopted by the American Association of State Highway and Transportation Officials (AASHTO), and the GDE (degree of deterioration, from the acronym in Portuguese) method developed at the *Universidade de Brasília* (UnB). Three bridges in Brazil, were selected for inspection, evaluation and modelling.

1 INTRODUCTION

Cases of early deterioration are frequent and notorious in important structures of a country's road transport infrastructure, such as bridges, tunnels, viaducts and footbridges. In Brazil, such structures are known as Special Artworks (*Obras de Arte Especiais* - OAEs) and have great importance since a large part of the transport of goods and people goes by road. According to SENAT (2019), the road modal is the one that has the greatest participation in the Brazilian transport matrix, concentrating approximately 61% of the movement of goods and 95% of the passengers.

Brazil has continental dimensions and had 1,720,700 km of highways in 2019, with 213,453 km of paved highways and 1,349,938 km of unpaved roads (SENAT, 2019). The high number of roads led to the need for a high number of OAEs, and the Management Report indicates the existence of 8,037 OAEs in Brazil, 90% of which are bridges and viaducts, totaling 7,190 (DNIT (2017)). The same Management Report shows that 97.52% of the OAEs were built in reinforced and prestressed concrete.

For an adequate performance of such infrastructure, investments in maintenance, strengthening, and rehabilitation are necessary throughout the lifetime. In this sense, implementing OAE management systems are mandatory to optimize administrative decisions to manage these structures.

One of the main features of a Bridge Management System is its ability to assess the bridge's current level of performance, taking this as one of the main aspects in decision-making and planning. Re-evaluating and updating the conservation state analysis methods adopted by DNIT is a constant task, aiming to implement the advances provided by new studies, technologies and methodologies by defining new parameters, comparing results and evaluating the advantages and disadvantages.

The main objective of this investigation is to contribute to improvements in the DNIT management system by comparing the current assessment method with two others developed in Brazil and abroad, evaluating the main features of each one and providing comments and discussions aiming to point out opportunities for improvement.

2 ASSESSMENT OF THE STRUCTURAL CONDITION STATUS OF A BRIDGE

Assessments and inspections proved to be extremely important for the maintenance and durability of a bridge, with inspection practices being cited in several manuals and standards and various assessment methodologies implemented according to their level of detail and classifications obtained following the inspections.

Due to its importance for durability and maintenance, several agencies are concerned with the definition of inspection practices and their periodicity to obtain better results regarding management and

lifespan. In Brazil, two standards regulate and recommend the type and frequency of inspections: NBR 9452 (ABNT (2019)) and DNIT (DNIT, (2004b)).

From the records made in inspections, the evaluation of the reinforced concrete structure can be carried out element by element or globally.

According to Almeida (2013), the management systems can be differentiated at their level of assessment into three categories, defined according to the main type of performance indicator adopted, involving increasing levels of detail, respectively: Condition Status (CS), Structural Safety Index (SSI) and Risk Level (RL).

The Condition State is evaluated through visual observations, photographic records, and non-destructive tests in its main (routine) inspections. This performance indicator is structured on a simple quantitative scale related to the identified damages, making it an expeditious methodology and easy to implement (Almeida, 2013).

Several countries use the Condition State approach in their standards and manuals for the initial assessment of the state of repair of a bridge, each with its rating scale. In Brazil, DNIT assesses the conservation status of a bridge through a classification of technical grades varying from 1 (the worst) to 5 (the best) (Table 1).

Also in Brazil, a methodology was developed by Fonseca (2007) called GDE/UnB (an acronym for "Degree of Deterioration" from the Portuguese, developed by the University of Brasília) for the evaluation of building structures, which was later adapted for application in bridges by Verly (2015).

This methodology consists of calculating a degree of deterioration, using weighting factors to classify the damage, structural relevance and its intensity, in order to classify both the element and the structure in levels of deterioration as indicated in Table 2.

From the damage, the methodology reaches a Degree of deterioration of the element through the following formulation:

$$Gde = D_{\max}\left(1 + \frac{\left(\sum_{i=1}^{n} Di\right) - D_{max}}{\sum_{i=1}^{n} Di}\right) \quad (1)$$

Where the degree of deterioration D is calculated by:

$$D = 0{,}8\ x\ Fi\ x\ Fp \quad if \quad Fi \leq 2;$$
$$D = (12.Fi - 28)\ Fp \quad if \quad Fi > 2; \quad (2)$$

n: is the number of damages in the element; *Fi* is the damage intensity factor; *Fp* is the damage weighting factor; *Fi* and *Fp* are defined according to the element in which the damage is found and its intensity, pointed out in Verly (2015).

Fonseca (2007) calculates the degree of deterioration from the degree of deterioration of the element by the following formulation:

$$Gd = \frac{\left(\sum_{i=1}^{k} Gdf,i\ x\ Fr,i\right)}{\sum_{i=1}^{k} Fr,i} \quad , \quad (3)$$

where *Fr* is the structural relevance factor, defined according to the structural relevance of the element in the bridge as a whole, as pointed out in Verly (2015).

The degree of deterioration of the Gdf element family is calculated by:

$$Gdf = Gde_{max}\sqrt{1 + \frac{\left(\sum_{i=1}^{m} Gdeꞏi\right) - Gde_{max}}{\sum_{i=1}^{m} Gdeꞏi}} \quad , \quad (4)$$

where m is the number of elements; Gde_{max} is the major deterioration degree of the element.

Table 01 – Technical grades according to DNIT (2004b).

Technical grade (TG)	Element damage/ Structural failure	Stability condition	Bridge condition classification
5	No damage or structural failure.	Very good	No problems noted
4	There is some damage, but no signs of structural failure.	Good	Some minor problems
3	There are damages causing some structural deficiency, but no signs of structural failure.	Fair	Potentially problematic structure It is recommended to monitor the evolution of the damages through routine inspections, to detect, in a timely manner, any worsening of the structural health.
2	Thare are damages causing significant structural deficiency, but no apparent imminent risk of colapse.	Poor	Problematic structure Delaying the structure's intervention can lead it to a critical state, also implying a serious impact in the structure's lifespan.
1	There are damages causing serious structural deficiency; the element is in a critical state, with imminent risk of collapse.	Critical	Critical structure In some cases, it can be an emergency situation, and the recovery of the structure may be accompanied by special preventive measures, such as: load restriction, total or partial interdiction to traffic, temporary shoring, instrumentation with continuous monitoring of displacements and deformations.

Verly (2015) suggested adapting the formulation to calculate the degree of deterioration of the structure by the following formulation:

$$Gdmod = \frac{Kmax}{7{,}07}\sqrt{1 + \frac{(\sum_{i=1}^{k} Ki) - Kmax}{\sum_{i=1}^{k} Ki}} \quad (5)$$

Where *K* is the product of the degree of deterioration of the family of elements by the structural relevance factor of the element, and *kmax* is its highest value.

Table 2 – Deterioration levels and actions to be taken according to the GDE method (Verly (2015)).

Deterioration level	$\mathbf{G_{de}}$	Actions to be taken
Low	0 – 15	Acceptable state. Preventive maintenance.
Moderate	15 – 50	Define deadline/nature for a new inspection. Plan long-term intervention (maximum two years).
High	50 – 80	Define deadline/nature for detailed specialized inspection. Plan medium-term intervention (maximum 18 months).
Serious	80 – 100	Define deadline/nature for detailed specialized inspection. Plan short-term intervention (maximum one year).
Critical	> 100	Special emergency inspection. Plan immediate intervention.

The FHWA (2012) describes the alphanumeric codes that inspectors should use to classify the State of Condition on a scale from 0 to 9 of the items defined in the Coding Guide. These items are subdivided into three: Item 58 (Deck), Item 59 (Superstructure) and Item 60 (Substructure), as indicated in Table 3.

According to Table 3, the National Bridge Inventory (NBI) classifies the bridge in Rating Scales based on the classification shown in Table 4. The NBI uses this classification to measure the percentage of bridges in good or poor condition.

Although the FHWA Coding Guide is mandatory to classify the bridge by the condition status of the three items described before, for asset management purposes, it does not provide sufficient information about the cause of deterioration to predict future conditions or select appropriate maintenance actions (Boettger, 2018).

Bearing this challenge in mind, a complimentary assessment system at the element level was elaborated and implemented.

This element-level assessment was developed by the American Association of State Highway and Transportation Officials in its Bridge Element Inspection Guide Manual (AASHTO (2016)). This manual defines for each element, description, a set of four standard condition states (1-Good, 2-Fair, 3-Poor and 4-Severe) and feasibility actions (AASTHO, 2016, Boettger, 2018).

Table 3 – State of Condition scale according to FHWA (2012).

Condition State	General description of the condition
9	Excellent: a new bridge.
8	Very good condition: no problems detected.
7	Good condition: some minor problems.
6	Satisfactory condition: structural elements show some minor deterioration.
5	Sufficient Condition: Primary structural elements sound but may have minor section loss, deterioration, spalling or scour.
4	Insufficient condition: advanced section loss, deterioration, palling and scour.
3	Serious condition: loss of section, deterioration, spalling or scour with severe damage to primary structural elements.
2	Critical condition: advanced deterioration of primary structural elements. Cracks in steel or shear cracks in concrete may be present, or scour may have removed structural support. If not monitored, it may be necessary to close the bridge until rehabilitation is carried out.
1	Imminent failure: major deterioration or loss of section present in critical structural components or obvious vertical or horizontal movement affecting structural stability. The bridge is closed to traffic, but corrective actions may put back in light service.
0	Out of service, no possibility of rehabilitation.
N	Not applicable.

Table 4 – Bridge condition classification according to rating scales.

Condition	Grade
Good	9, 8 and 7
Fair	6 and 5
Poor	4, 3, 2 and 1

Taking the methodology developed by AASHTO, the New York State Department of Transport used the Bridge Inspection Manual (NYSDOT (2017)), with condition status classification parameters on a scale from 1 to 4 at the element level, as adopted in the Inspection Guide Manual (AASHTO (2016)), shown in Table 5.

Table 5 – Condition Status (NYSDOT (2017) aput AASHTO (2016)).

Condition Status	Condition Type
CS-1	Good
CS-2	Fair
CS-3	Poor
CS-4	Severe

3 METHOD

Two methods were defined to be compared with the one currently used by DNIT, which are GDE/UnB and AASTHO.

Bridges with different structural conditions and geographic feasibility were selected; they are the bridges with DNIT codes 140132, 140134 and 140136 located in the Rio Grande do Norte State, between kilometers 127 and 171 of the highway BR-405

Visual inspections, photographic and quantitative surveys of the three bridges were carried out following the inspection manuals indicated for each method. Subsequently, they were then modeled using the computer program Sketchup and evaluated according to the methods selected to compare results and point out improvement opportunities for the current assessment method used in Brazil.

4 RESULTS AND DISCUSSION

4.1 *Inspection and evaluation*

4.1.1 *Bridge code 140132*

Figure 1 shows the 22 meters long and 8 meters wide reinforced concrete "Km 127 bridge". According to the DNIT bridge management system, in the inspection carried out on July 2020, the bridge was in a good state of conservation, receiving a technical grade 4.

4.1.1.1 Inspection

In the inspection carried out on 05/29/2021, no structural damage was found in the slab, beams and transverse beams, only damp spots and biological degradation.

Also, there was no structural damage to the wall pillar or the abutments (Fig. 2a). All the elements showed dump spots, and in abutment 2, a slight disaggregation of the material was observed (Fig. 2b).



Figure 1 – km 127 bridge: (a) view of the pavement; (b) lateral view; (c) Sketchup 3D model.

On the asphalt pavement, cracks caused by the deficiency in the expansion joints were noted; on the New Jersey barrier, damp spots were observed; finally, the approach slab was the element with the most relevant damage, showing disaggregation and exposed rebars.



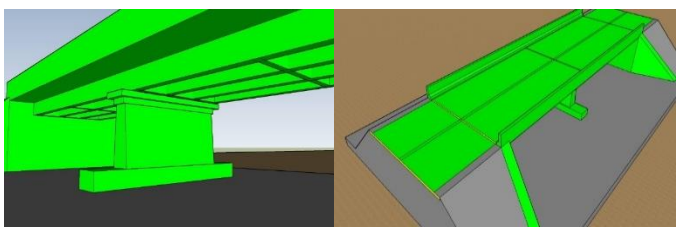
Figure 2 – Bridge 140132: (a) abutment 2; (b) dump spots and biological degradation.

4.1.1.2 Evaluation

Table 6 lists the structural condition states of bridge 140132 according to the three methods. Figures 3, 4 and 5 show the results in the 3D model using color scales.

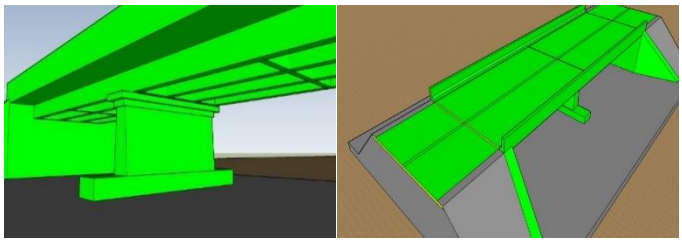
Table 6 – Results for bridge 140132.

Element	NT	Gde	CS
Reinforced concrete slab 01	4	8	1
Reinforced concrete slab 02		8	
Reinforced concrete beam 01	4	8	1
Reinforced concrete beam 02		4.8	
Reinforced concrete beam 03		4.8	
Reinforced concrete beam 04		8	
Reinforced concrete transverses 01	4	4.8	1
Reinforced concrete transverses 02		4.8	
Reinforced concrete transverses 03		4.8	
Reinforced concrete transverses 04		4.8	
Reinforced concrete transverses 05		4.8	
Reinforced concrete transverses 06		4.8	
Wall pillar in reinforced concrete	4	4.8	1
Abutment in stone wall 01	4	4.8	1
Abutment in stone wall 02		28	
Asphalt pavement	4	8	1
New Jersey barrier 01	4	4.8	2
New Jersey barrier 02		4.8	
Approach slab 01	3	40	2
Approach slab 02		40	
Expansion joint 01	3	40	2
Expansion joint 02		40	
Expansion joint 03		40	
Bridge Technical Note (DNIT)	4		
Bridge damage degree (Verly)	24.71		
Bridge damage degree (Fonseca)	18.82		



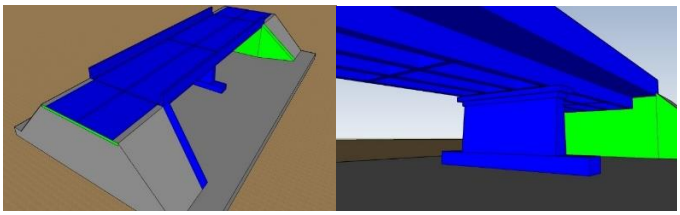
Green: GT 4; yellow: TG 3; orange: TG 2; red: TG 1

Figure 3 – Bridge 140132 by DNIT method.



Green: CS-1; yellow: CS-2; orange: CS-3; red: CS-4

Figure 4 – Bridge 140132 by AASHTO method.



Blue: Gde<15; green: 15<Gde<50; yellow: 50<Gde<80; orange:80<Gde<100; red:Gde>100.

Figure 5 – Bridge 140132 by GDE method.

4.1.2 *Bridge code 140134*

Figure 6 shows the "Cabelo bridge" in reinforced concrete, 32,7 meters long and 8 meters wide. According to the DNIT bridge management system, in the inspection carried out on July 2020, the bridge was in a fair state of conservation, receiving a technical grade 3.

4.1.2.1 Inspection

In the inspection on 05/29/2021, the beams and transverse beams showed similar pathological manifestations, such as biological degradation, dump spots, cracks, concrete reinforcement corrosion, and leaching. The slabs showed corrosion in an advanced state with broken steel rebars and concrete spalling (Fig. 7a).

No major damage was observed in pillars and abutments, with only a few dump spots (Fig. 7b).



Figure 6 – "Cabelo" bridge: (a) view of the pavement; (b) lateral view; (c) Sketchup 3D model.

In the asphalt pavement, cracks caused by the deficiency in the expansion joints and holes were noticed. In the New Jersey barrier, damp spots, cracking and exposed reinforcement were observed; Finally, no damage was observed in the access landfills.



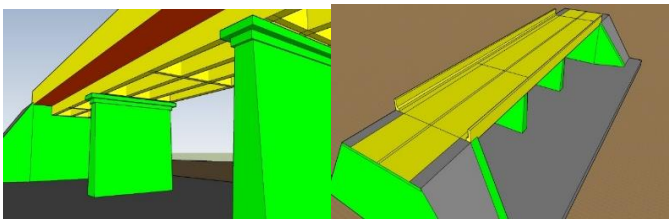
Figure 7 – Bridge 140134: (a) spalling and corrosion of rebars; (b) dump spots and biological degradation.

4.1.2.2 Evaluation

Table 7 lists the structural condition states of bridge 140134 according to the three methods. Figures 8, 9 and 10 show the results in the 3D model using color scales.

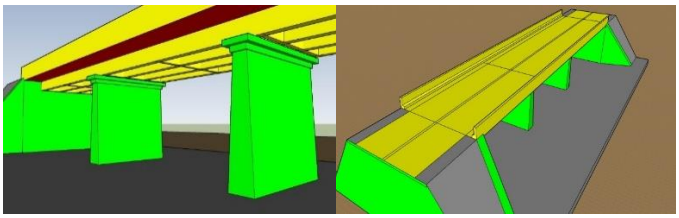
Table 7 – Results for bridge 140134.

Element	NT	Gde	CS
Reinforced concrete slab 01	2	130.17	4
Reinforced concrete slab 02		64.35	
Reinforced concrete slab 03		64.35	
Reinforced concrete beam 01	3	63.60	3
Reinforced concrete beam 02		39.62	
Reinforced concrete beam 03		52.97	
Reinforced concrete beam 04		59.59	
Reinforced concrete transverses 01	3	7.2	2
Reinforced concrete transverses 02		56.74	
Reinforced concrete transverses 03		56.74	
Reinforced concrete transverses 04		56.74	
Reinforced concrete transverses 05		32.34	
Reinforced concrete transverses 06		56.74	
Reinforced concrete transverses 07		56.74	
Reinforced concrete transverses 08		32.34	
Reinforced concrete transverses 09		7.2	
Wall pillar in reinforced concrete 01	4	4.8	1
Wall pillar in reinforced concrete 02		4.8	
Abutment in stone wall 01	4	4.8	1
Abutment in stone wall 02		4.8	
Asphalt pavement	3	60	2
New Jersey barrier 01	3	4.8	3
New Jersey barrier 02		47.15	
Access landfill 01	4	0	1
Access landfill 02		0	
Expansion joint 01	3	40	3
Expansion joint 02		100	
Expansion joint 03		40	
Bridge Technical Note (DNIT)	2		
Bridge damage degree (Verly)	140.78		
Bridge damage degree (Fonseca)	81.08		



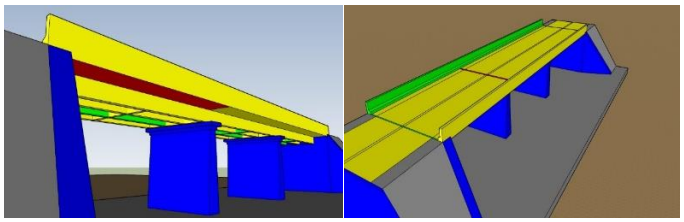
Green: GT 4; yellow: TG 3; orange: TG 2; red: TG 1

Figure 8 – Bridge 140134 by DNIT method.



Green: CS-1; yellow: CS-2; orange: CS-3; red: CS-4

Figure 9 – Bridge 140134 by AASHTO method.



Blue: Gde<15; green: 15<Gd<50; yellow: 50<Gde<80; orange:80<Gde<100; red:Gde>100.

Figure 10 – Bridge 140134 by GDE method.

4.1.3 *Bridge code 140136*

Figure 11 shows the "Catolezinho bridge" in reinforced concrete, 9,9 meters long and 10,8 meters wide. According to the DNIT bridge management system, in the inspection carried out on July 2020, the bridge was in a poor state of conservation, receiving a technical grade 2.

4.1.3.1 Inspection

In the inspection carried out on 05/29/2021 in the reinforced concrete slabs, damages were observed, but none indicated structural risk. The main damages were: leaching, concrete infiltration, superficial cracks, uncoated reinforcement, disaggregated concrete, concrete spalling and exposed and corroded reinforcement.

In the pillar wall, non-structural damage was observed, such as erosion of the pillar base, damp patches, leaching and carbonation, and a loss of pillar section causing structural damage.



Figure 11 - "Catolezinho" bridge: (a) view of the pavement; (b) lateral view; (c) Sketchup 3D model.

In addition to the damage observed in the pillar wall, significant structural damage was also observed in the abutments of the reinforced concrete walls, such as excessive deformation (Fig. 12b), deep cracks with openings greater than 0.03 mm, and a large diagonal slit in the abutment 01, cutting the entire element (Fig. 12a).



Figure 12 – Bridge 140136: (a) a large diagonal slit of abutment 01; (b) excessive deformation and deep cracks.

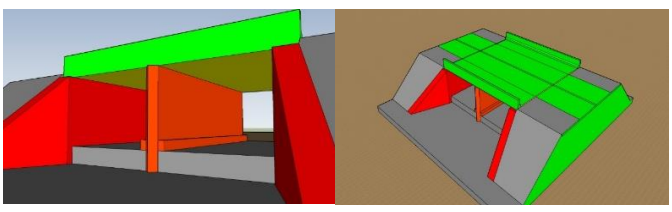
The asphalt pavement had cracks caused by the deficiency in the expansion joints; the New Jersey barrier showed damp spots, concrete spalling and cracks; finally, no damage to the access landfill was observed.

4.1.3.2 Evaluation

Table 8 lists the structural condition states of bridge 140136 according to the three methods. Figures 13, 14 and 15 show the results in the 3D model using color scales.

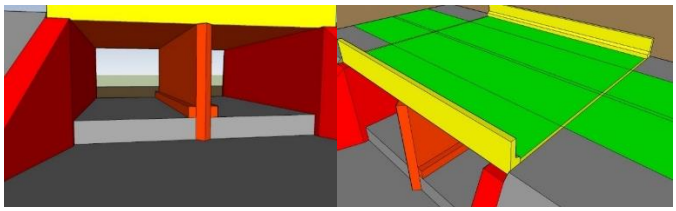
Table 8 – Results for bridge 140136.

Element	NT	Gde	CS
Reinforced concrete slab 01	3	34.15	3
Reinforced concrete slab 02		60.39	
Wall pillar in reinforced concrete 01	2	61.81	3
Abutment (wall pillar) in reinforced concrete 01	1	160.31	4
Abutment (wall pillar) in reinforced concrete 02		171.59	
Asphalt pavement	4	8	1
New Jersey barrier 01	4	28	2
New Jersey barrier 02		36.17	
Access landfill 01	4	0	1
Access landfill 02		0	
Expansion joint 01	3	40	2
Expansion joint 02		40	
Bridge Technical Note (DNIT)	1		
Bridge damage degree (Verly)	133		
Bridge damage degree (Fonseca)	104.88		



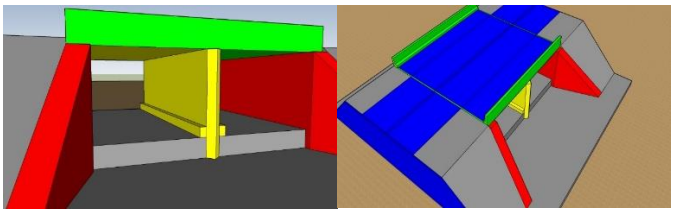
Green: GT 4; yellow: TG 3; orange: TG 2; red: TG 1

Figure 13 – Bridge 140136 by DNIT method.



Green: CS-1; yellow: CS-2; orange: CS-3; red: CS-4

Figure 14 – Bridge 140136 by AASHTO method.



Blue: 15<Gde; green: 15<Gde<50; yellow: 50<Gde<80; orange:80<Gde<100; red:Gde>100.

Figure 15 – Bridge 140136 by GDE method.

4.2 *Comparisons between methodologies*

The structural condition states of the bridges were compared using the DNIT and GDE methodologies, both in the Fonseca and Verly formulations. In contrast, the AASHTO methodology addressed in this article evaluates only element-by-element and not the bridge as a whole.

Figure 16 shows the difference in results for the Fonseca and Verly formulations. The highest damage weight is in the family of elements with the highest structural relevance factor by the first method. In contrast, by the second, the weight is the highest product between the relevance factor and the degree of deterioration of the element family (*Kmax)*.

Regarding the comparison of the two formulations with the DNIT technical note, the assessments agree for Bridges 140134 and 140132, since in the first case, the damages presented a critical situation and, in the second, the bridge shows minor damage, being in good condition.

The evaluation through Verly's formulation for the Bridge 140134 differs from the others since the weight of the highest product between the relevance factor and the degree of deterioration is considered for the family, as well as the weight of damage caused by corrosion of the steel rebars in slabs becomes similar to damage caused by the same pathology in elements with a higher relevance factor, such as columns and beams (although broken rebars into slabs do not have the same structural importance as broken rebars into a beam, for example). This same fact led to a higher DGE for bridge 140134 than for bridge 140136.

The element-by-element evaluations are shown in Figures 17 (slabs) and 18 (beams). There is a considerable discrepancy only in the classification of Slab 1 of bridge 140134, which was the only one to present broken steel rebars.

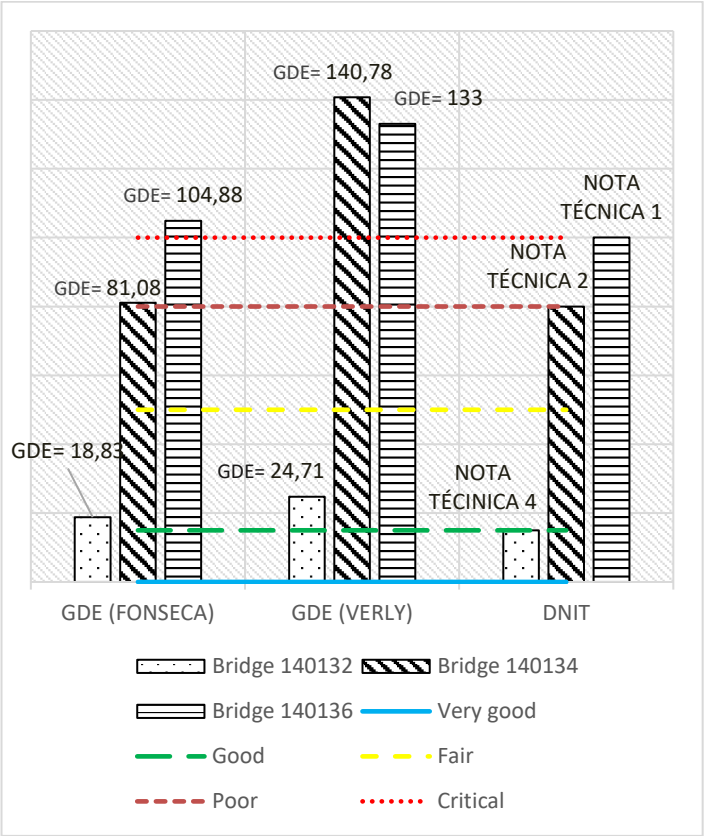


Figure 16 - Comparison of the assessment of the structural condition of bridges.

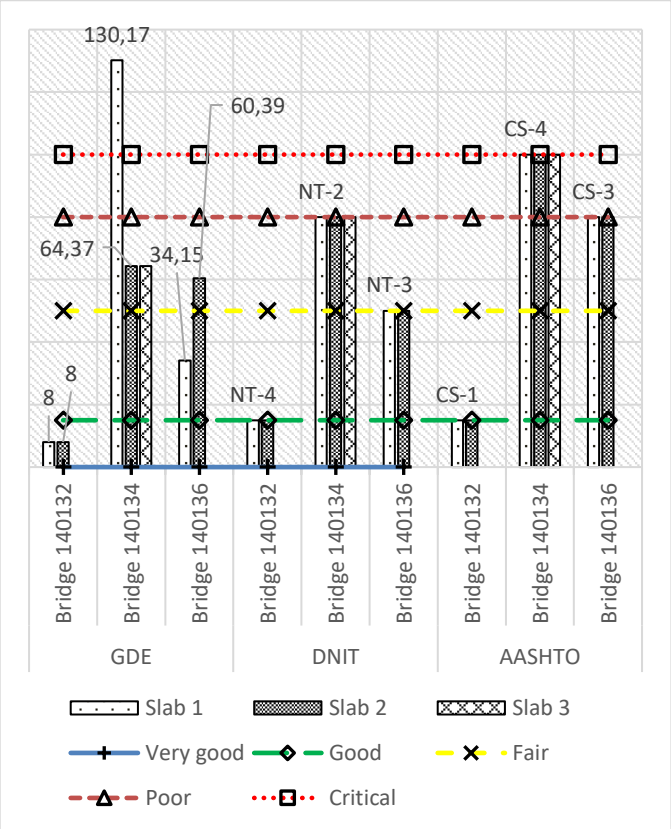


Figure 17 – Comparison of structural condition assessments at element level (Slab).

Figure 18 shows the importance of the element-level assessment. In this regard, the GDE methodology classifies the four beams independently, indicating in a specific way which beam has the greatest damage and the best way to intervene.

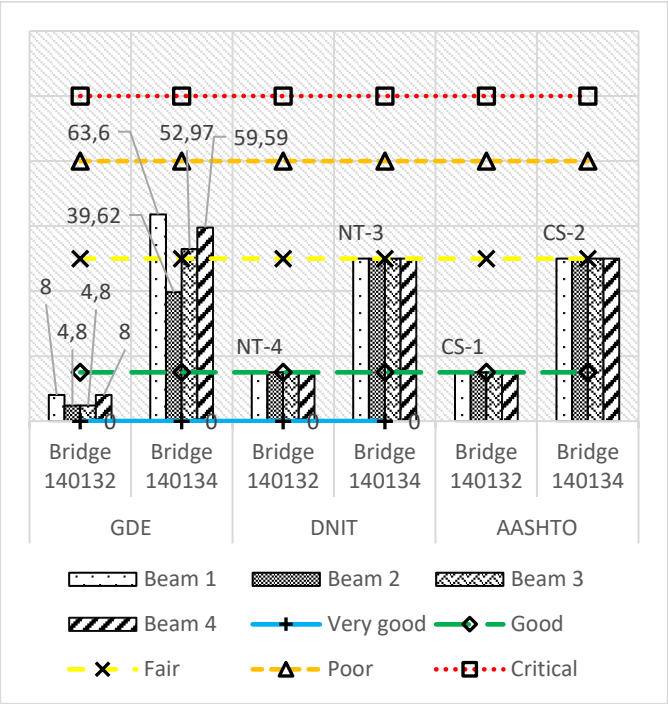


Figure 18 – Comparison of structural condition assessments at element level (Beams).

In the case of very specific damage, such an assessment at this level prevents an exaggerated classification of the bridge's structural condition, as well as the structural relevance factors adopted by the GDE. The methodology currently adopted by the DNIT, on the contrary, classifies the bridge only by the worst grade of the structural element.

Comparing the DNIT methodology with the AASHTO methodology, we noticed similarities regarding the classification of the condition status, with the main difference not being directly related to the classification but in how the damage assessment is carried out. While in the DNIT methodology, the classification is at the inspector's sole discretion, AASTHO links the damage classification to specific criteria in the manual.

4.3 *Improvement opportunities for DNIT methodologies in Brazil*

The element-by-element classification approach, numbering and evaluating separately, as proposed in the GDE method, proves to be quite effective in perceiving damage at a more detailed level, aiding in future interventions and decision support.

The modeling used in this study with color classification is a relevant visual tool in damage perception, in line with future BIM approaches, which supports high levels of detail at the element level in models, and even future modeling of the damage itself

Another point to be considered is the reduction in inspection subjectivity, as observed in the AASHTO methodology, which more objectively points out the classification of each damage in the definitions and the state of condition in its manuals.

AASHTO introduces element-level assessment into the NBI, making information processing more effective. Differently, the DNIT feeds the management system only with the condition state of the OAE as a whole. The conscious input of data at the element level must be taken into account, supported by computational tools. It can represent a more effective and economical management.

5 CONCLUSION

This article aimed to compare the methods of evaluating the structural condition state in a set of bridges to analyze, compare and improve the current DNIT methodology.

From the data obtained, it was possible to note and point out which improvements could be made, thus contributing to the methodology currently adopted in Brazil.

REFERENCES

AASHTO. (2016). *Manual for Bridge Element Inspection.* AASHTO.

Almeida, J. (2013). *Sistemas de gestão de pontes com base em custos de ciclo de vida.* Universidade do Porto, Porto.

Boettger, A. (2018). *Analise dos metodos de avaliação do Brasil, Estados Unidos e Japão aplicadas a um estudo de caso.* Florianopolis: UFSC.

CNT : SEST SENAT. (2019). *Pesquisa CNT de rodovias 2019.* Brasilia: CNT : SEST SENAT.

DNIT. (2004). *Manual de Inspeções em Pontes Rodoviarias.* DNIT, Rio de Janeiro.

DNIT. (2004b). *Norma DNIT 010/2004 - PRO.* DNIT, Rio de Janeiro .

DNIT. (2017). *Relátorio Gerencial | Atlas de manutenção rodoviaria.* Brasil: DNIT.

FHWA. (1995). *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges.* FHWA-PD-96-001, Bridge Division, Office of Engineering, Federal Highway Administration, Washington.

FHWA. (2012). *Bridge Inspector's Reference Manual.* Virgina: Federal Highway Administration.

FLORIDA DEPARTMENT OF TRANSPORTATION. (2016). *Implementation of the 2013 AASHTO Manual for Bridge Element Inspection.*

Fonseca, R. (2007). *A estrutura do instituto central de ciências: aspectos historicos, cientificos e tecnologico do projeto, execução, intervenção e proposta de manutenção* . Universidade de Brasilia , Brasilia .

NBR 9452. (2019). *Inspeção de pontes, viadutos e passaleras de concreto - Procedimento.* Associação Brasileira de Normas tecnicas, Rio de janeiro.

NYSDOT. (2017). *Bridge Inspection Manual.* New York: NYSDOT.

Verly, R. (2015). *Avaliação de metodologias de inspeção como instrumento de priorização de intervenções em obras de arte espaciais* . Universidade de Brasilia , Brasilia .