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The Influence of the Technical Standards Revisions on Old Bridges in Brazil

Fabio Santos Cerbino
UFRJ - Federal University of Rio de Janeiro
(fscerbino@yahoo.com.br)

Abstract- This article assesses the conditions of the old bridges in Brazil, built about 50 years ago, before the current Technical Standards criteria of structural analysis. It presents a historical research of the Brazilian situation in order to provide an overview of the main geographic, political and technical aspects. It is exposed the relevance of this issue in the national scenario concerning bridge's projects in Brazil. The methodology used was the study of a hypothetical case of an old bridge, with characteristics commonly found in the Brazilian Roadway Infrastructure. It was possible to quantify the influence of the revisions of the normative criteria on the girders of an old bridge through the simulation of loading conditions set in the current Technical Standards. Then, the safety conditions were verified by comparing the structural analysis results of the girders according to the old and current Technical Standards criteria. By presenting the results of this research, it is expected to contribute to the public policies concerning the management of public civil works in Brazil.

Keywords – *Brazilian Roadways, Old Bridges, Technical Standards, Roadway Transportation*

I. INTRODUCTION

The economic progress of a country is heavily influenced by the conditions of its transportation's infrastructure. In Brazil, there is an infrastructure, predominantly composed by roads and with extensive stretches in inadequate conditions of efficiency and safety. The situations are more serious in parts where there are bridges commonly designed under obsolete criteria of road geometry and structural capacity.

The intensification of the investments in Roadway Transportation started in the 1950s. It aimed at strengthening the processes of the market integration, the industrial development and the regional urbanization development in Brazil. Thereby, the current panorama is composed by many bridges designed according to overtaken traffic characteristics and overtaken load requests.

Moreover, the Technical Standard recommendations were revised due to the increase of traffic and load carrying capacity of the vehicles. This resulted in changes in the cross-section geometry criteria and in the structural analysis criteria in the bridge's projects.

In a special way, the bridge is an important element of the transportation system and must achieve the conditions of efficiency, safety, comfort and road traffic capacity. Otherwise, the traffic flow would be restricted or would be redirected to other routes not projected to receive it.

The first Brazilian Technical Standards for design and execution of reinforced concrete structures were published in the 1940s, such as NB-1:1946 and NB-2:1946. The current Brazilian Technical Standards are NBR-6118:2014, NBR-7187:2003 and NBR-7188:2013, which set the procedures for bridge's projects, for reinforced concrete structures and for moving loads criteria on roadway bridges.

Regarding the geometry of the cross-section, the National Department of Transportation's Infrastructure (DNIT) released the Manual of Special Constructions, in 1996, which classifies the projects of roadways and provides guidelines for the geometric design. Thereby, it is possible do identify that some old bridges do not fulfill the current geometrical requirements.

As considered for other structures, the life span of the bridges consists of the period in which they are able to present functional and structural performance as previously defined in project, with no need for unexpected maintenance interventions. On the other hand, it has to be considered their technical-operational life span that is related to the warranty of bridge's functionality facing the evolution of the future demands of traffic capacity and cargo transportation.

Therefore, the structure of a bridge, even in a good condition, might be adapted to fulfill the current Technical Standards requirements or it will cause an inefficiency of the roadway transportation system.

II. THE BRAZILIAN PANORAMA

The interior of Brazil is very extensive and the country is a great exporter of raw material. Firstly, most of the cargo that arrives to the ports needs to be transported through the roadways. In few cases, the railways are used to complement logistics, but the use of roadways is still the most expressive.

From the 1990s, the works of duplication and/or extension of important federal and state roadways have been intensified, which led to the need for further studies about engineering interventions in old bridges and viaducts.

The extension of Brazilian roadways can be observed in the Brazilian Federal Roadway Map, developed by the Ministry of Transportation and presented in Figure 1.

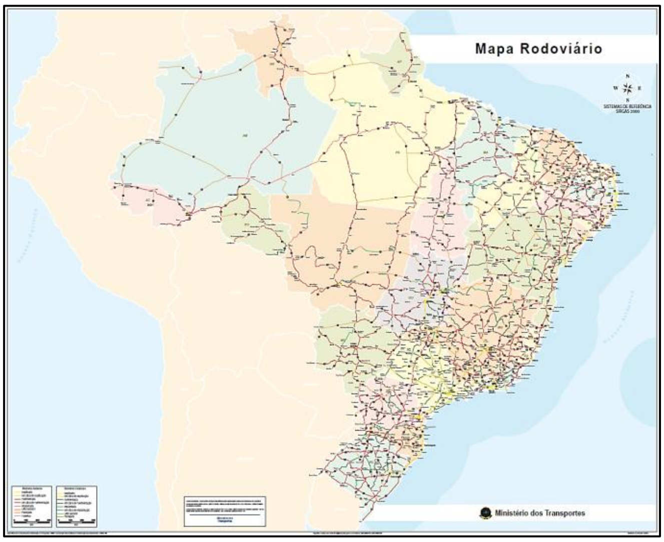

Figure 1. Brazilian Federal Roadway Map. (Ministry of Transportation)

According to data from 2013 of the Confederation of National Transportation (CNT), 61.1 % of all cargo in Brazil is transported by roadways, as shown in Figure 2. When transportation of iron ore is excluded, that percentage becomes greater than 70 %.

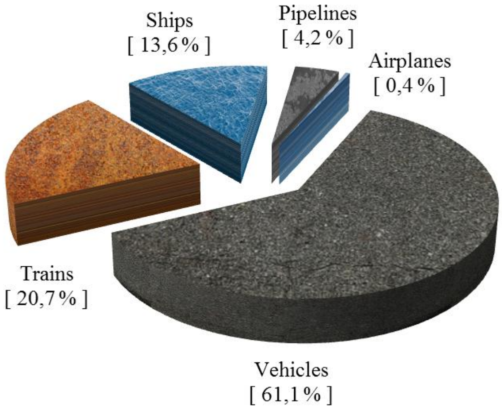

Figure 2. Distribution of cargo transportation. (CNT)

Nevertheless, there are many cases of accidents in bridges that present an inadequate traffic condition and low maintenance, expressed by structural, geometric and signaling deficiencies, as presented in Figure 3. As a consequence there is a limitation to traffic flow or even a total blockage of the roadway for a long time period.

Figure 3. Traffic of heavy truck over an old-narrow bridge.

Mendes (2009) mentions a survey carried out by the National Department of Transportation's Infrastructure (DNIT) which describes some characteristics of the Brazilian bridges, as summarized and presented in Table I.

TABLE I. CHARACTERISTICS OF THE BRAZILIAN ROADWAY BRIDGES

Description	Percentage
Structural system based on reinforced concrete or prestressed concrete.	94 %
Up to 40.00 m of maximum span's length.	93 %
Projected to 240 kN or 360 kN "Standard Vehicles".	90 %
Up to 12.00 m of deck's total width, considered as a narrow measure to the current Standard.	79 %
Built over 30 years ago.	70 %
Up to 50.00 m total length.	63 %
Conceived in a single span and two extreme cantilevers.	50 %

Due to their geometric and structural characteristics, the need for adequacy of Brazilian roads and bridges becomes even more evident when we analyze the scenario under the current Technical Standard criteria.

In 2004, the National Department of Transportation's Infrastructure (DNIT) summarized the concepts used in bridges designs according to their year of construction, as presented in Table III.

TABLE II. ROADWAY BRIDGE'S PROJECTS CRITERIA

Year of Construction	Cross-Section Width (m)	Standard Moving Loads	
		Point Load (kN)	Uniform Load (kN/m²)
Up to 1950	8.30	90 and 240	450
From 1950 to 1960	8.30	120 and 240	500
From 1960 to 1975	10.00	360	300 and 500
From 1975 to 1985	10.80	360	300 and 500
After 1985	12.80	450	500

In some situations, for the adequacy of the whole bridge, it is necessary so many adjustments. In such cases, the best choices are either the construction of a parallel bridge or the demolition of the existing structure in order to build a new one. However, these solutions are too much expensive and not often well accepted by the people who pay their taxes.

Then, several researches related to the use of materials for structural reinforcement have been carried out in order to prolong the life span of the structures and to fulfill the technical-operational requirements.

III. Methodology

This work consists on the simulation of a hypothetical case of an old bridge, built in the 1960s and designed according to the Technical Standards at the time of its construction. Nowadays, this bridge would be subject to different Technical Standard applications concerning the moving load characteristics and the value of the impact factor.

The purpose is to highlight the situation of old bridges currently subjected to the influences of the changes in moving load characteristics and in structural analysis criteria, defined by the current Technical Standards.

In order to show the influence of the Technical Standards revisions on the structure of an old bridge, this work evaluates the increases of the internal efforts in the girders due to the current moving load criteria. It was developed a computational analysis based on the principle of the Finite Element Method (FEM) with the use of structural analysis software.

Thereafter, it is shown the safety conditions of the girders through the comparison between the results of the old and the current Technical Standards criteria and considering the rheological characteristics of the concrete.

The CASE 01 represents the simulation of the old bridge projected according to the Technical Standard criteria at the year of its construction, as following:

- NB-1:1960 – Calculation and Execution of Reinforced Concrete Constructions;
- NB-2:1961 – Calculation and Execution of Reinforced Concrete Bridges;
- NB-6:1960 – Moving Loads on Roadway Bridges;
- EB-3:1967 – Conditions to the Use of the Steel Bars as Rebars in Reinforced Concrete Elements.

The CASE 02 represents the simulation of the old bridge projected according to the current Technical Standard criteria, as following:

- NBR-6118:2014 – Project of Reinforced Concrete Structures – Proceedings;
- NBR-7187:2003 – Project of Bridges in Reinforced Concrete and Prestressed Concrete – Proceedings;
- NBR-7188:2013 – Roadway and Pedestrian Moving Loads on Bridges, Viaducts, Footbridges and Other Structures;
- NBR-7480:2007 – Steel Used as Bars in Reinforced Concrete Structures – Technical Specification

IV. Application and Results

The model used for the cross-section of the bridge's deck corresponds to a typical old bridge, built between the years of 1960 and 1975, as presented in Figure 4.

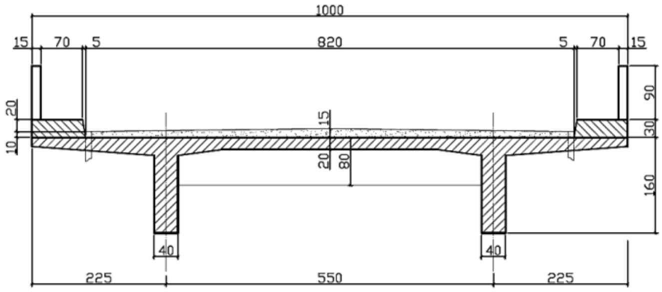

Figure 4. Cross-section of the bridge's deck (dimensions in centimeters).

The bridge's longitudinal section considered has 58.00 meters in total length. It has four support pillars, one 20.00 meters in length central span, two 15.00 meters in length intermediate spans and two 4.00 meters in length extreme cantilevers, as presented in Figure 5.

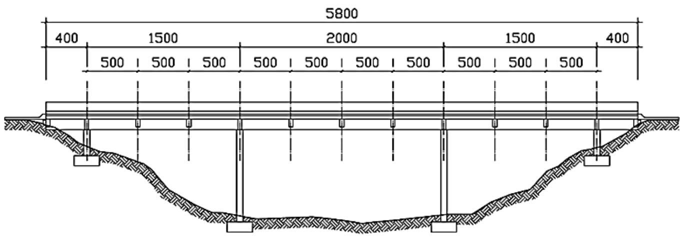

Figure 5. Longitudinal section of the bridge (dimensions in centimeters).

From the geometric characteristics of the bridge, the structural model was designed in software based on the Finite Element Method (FEM), as presented in the Figures 6 and 7.

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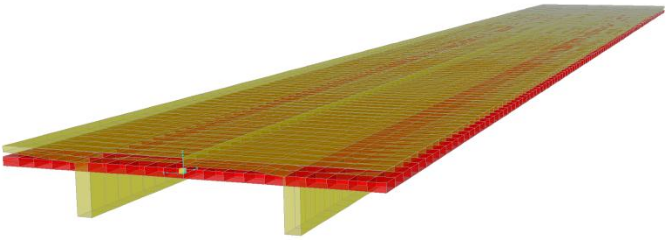

Figure 6. Computational model based on the Finite Element Method (FEM).

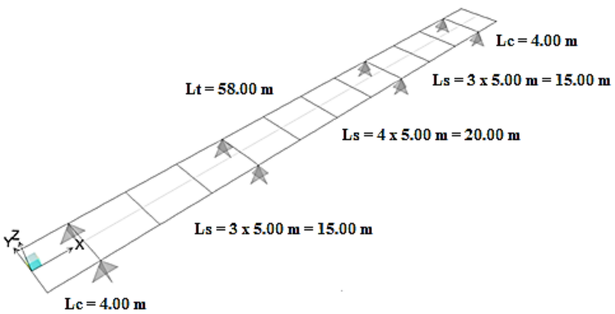

Figure 7. Unifilar diagram of the bridge's structure.

After finishing the computational model, it was simulated the CASE 01. It was used the moving load criteria set by the Technical Standard NB-6:1960, as presented in Figure 8.

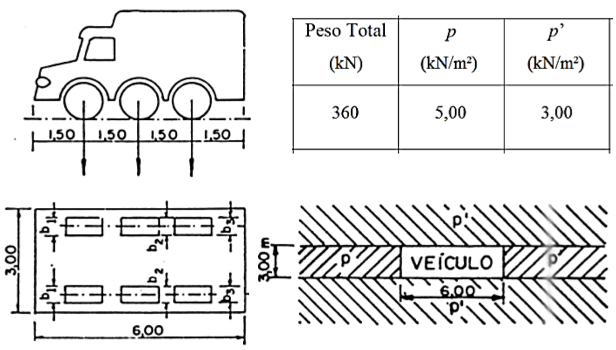

Figure 8. Characteristics of the moving load (NB-6:1960).

The Technical Standard NB-2:1961 sets the incidence of an impact factor, in order to simulate the increase of the traffic effects on the bridge's spans and extreme cantilevers. The impact factor is not a safety factor as the other factors used for increase the load values and its calculation is defined by the following equations:

$$\varphi_v = 1.4 - (0.007 \cdot L_v) \geq 1 \quad (1)$$

$$\varphi_b = 1.4 - (2 \cdot 0.007 \cdot L_b) \geq 1 \quad (2)$$

φ_v : impact factor on span;

φ_b : impact factor on cantilever;

L_v : span length;

L_b : cantilever length.

As the ratio between the length of the central span and the length of the intermediate spans is greater than 70 %, it was possible to set a single length value to the spans. It corresponds to the arithmetic average of the spans lengths, resulting in values as 1.283 for the spans and as 1.344 for the cantilevers.

After simulating the CASE 01, it was started the simulation of the CASE 02. It was used the moving load criteria set by the Technical Standard NBR-7188:2013, as presented in Figure 9.

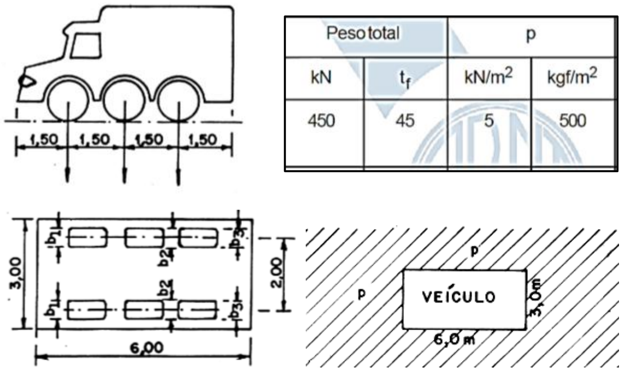

Figure 9. Characteristics of the moving load (NBR-7188:2013).

The NBR-7188:2013 sets the new parameters for the calculation of the impact factor, as defined by the following equations:

$$\varphi = CIV \cdot CNF \cdot CIA \quad (3)$$

$$CIV = 1 + 1.06 \cdot \left(\frac{20}{Liv + 50} \right) \quad (4)$$

$$CNF = 1 - 0.05 \cdot (n - 2) > 0.9 \quad (5)$$

$$CIA = 1.25$$

φ : total impact factor;

CIV : vertical impact factor;

Liv : spans average length or cantilever's total length;

CNF : impact factor related to the number of lanes;

n : number of lanes;

CIA : additional impact factor.

Likewise the CASE 01, as the ratio between the length of the central span and the length of the intermediate spans is greater than 70 %, it was possible to set a single length value to the spans. It corresponds to the arithmetic average of the spans lengths, resulting in values as 1.318 for the spans and 1.741 for the cantilevers.

It is possible to observe the influence of different Technical Standards criteria by comparing the results due only to the action of the moving loads on the bridge's deck, with no application of the safety factor to increase the load values.

The diagrams of bending moments and shear forces in the girders are presented in Figures 10 and 12, to the CASE 01, and in Figures 11 and 13, to the CASE 02.

The calculation sections analyzed for the comparisons between the internal forces results are identified by the letters A to F in the diagrams.

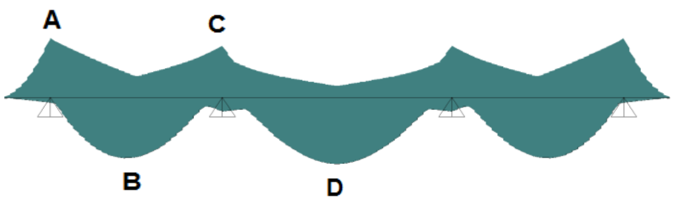

Figure 10. CASE 01 – Bending moment envelop diagram.

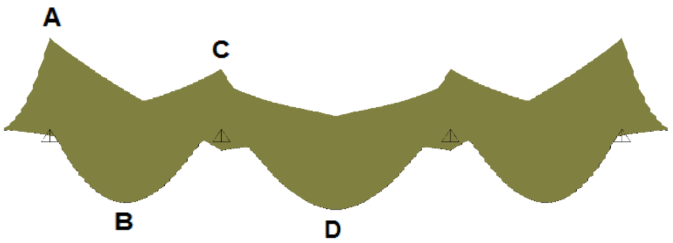

Figure 11. CASE 02 – Bending moment envelop diagram.

Figure 12. CASE 01 – Shear force envelop diagram.

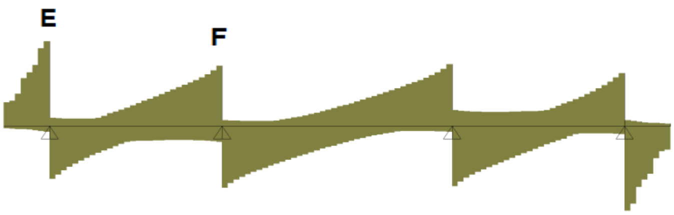

Figure 13. CASE 02 – Shear force envelop diagram.

The Table III presents the comparative analysis between the CASE 01 and CASE 02 results, concerning the bending moment values and the shear forces values in the calculation sections of the girders, just due to the moving load effects.

TABLE III. COMPARATIVE ANALYSIS OF THE INTERNAL EFFORTS

Section	Internal Efforts		Increase
	CASE 01	CASE 02	
A	- 1043 kN*m	- 1592 kN*m	52.64 %
B	+ 1060 kN*m	+ 1278 kN*m	20.57 %
C	- 909 kN*m	- 1050 kN*m	15.52 %
D	+ 1162 kN*m	+ 1395 kN*m	20.06 %
E	323 kN	492 kN	52.33 %
F	305 kN	359 kN	17.71 %

There were increases of the internal forces about 15 % to 53 %, what quantifies the influence of the current Technical Standard criteria, established in 2013, comparing it to the old criteria, established in 1960.

However, it is noteworthy that these results do not mean that the structure does not have structural capacity to support the current moving loads. For this question, it was necessary to perform a comparison between the results of the reinforced concrete analysis obtained according to the different Technical Standards calculation criteria.

The Technical Standard NB-1:1960 is based on criteria such as Stage II reinforced concrete's structural analysis, concrete's compressive strength up to 22 MPa and 500 MPa steel's tensile strength (steel bars CA-T50).

The Stage II is based on the Permissible Stresses criteria in which the material stresses are set in a pre-defined value and it is not applied the safety factor to increase the permanent load values. In these criteria, the safety factor is used on moving load values due to the uncertainty of its real effects. The Stage II reinforced concrete's diagrams are presented in Figure 14.

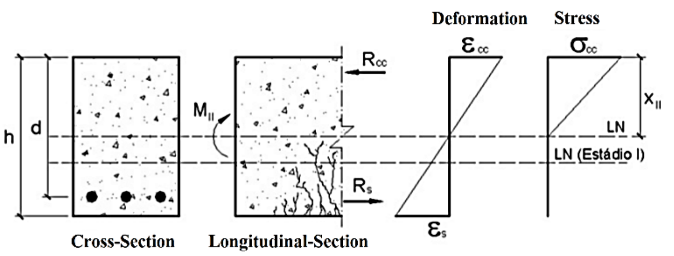

Figure 14. Stage II reinforced concrete's diagrams.

Therefore, the parameters set for the structural analysis of the girders, for the CASE 01 and using the NB-1:1960 Stage II criteria are presented in Table IV.

TABLE IV. CASE 01 PARAMETERS – NB-1:1960 – STAGE II

Material Strength		Permissible Stress		Safety Factor	
Concrete (MPa)	Steel (MPa)	Concrete (MPa)	Steel (MPa)	Permanent Load	Moving Load
22	500	8.8	300	1.0	1.2

Moreover, the steel bars fatigue criteria was introduced by the Technical Standard EB-3:1967. It means that there are real cases of old bridges designed without considering the steel fatigue criteria.

In contrast, the Technical Standard NBR-6118:2014 is based on criteria such as Stage III reinforced concrete's structural analysis, concrete's compressive strength up to 90 MPa and 500 MPa steel's tensile strength (steel bars CA-50)

The Stage III is based on the Ultimate Limit State (ELS) criteria, in which the concrete's ultimate stress and the steel's yield stress are considered. In these criteria, the safety factors are used to increase the permanent and moving load values and to decrease the materials strength values. The Stage III diagrams are presented in Figure 15.

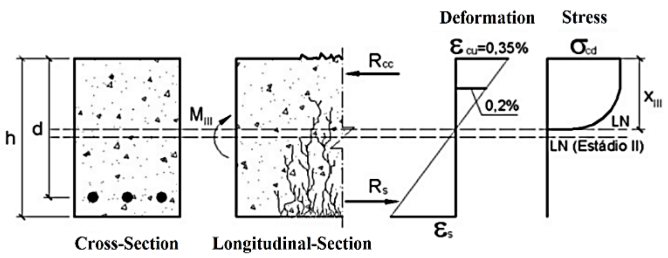

Figure 15. Stage III reinforced concrete's diagrams.

For the CASE 02 structural analysis, it was considered that the concrete's strength have been increased over the years from the moment that the original structure was built.

This is usually obtained by extracting concrete's samples or by empirical calculation, using the equations expressed in the Technical Standard NBR-6118:2014, as following:

$$f_{cd} = \frac{f_{ckj}}{\gamma_c} \cong \beta_1 \frac{f_{ck}}{\gamma_c} \quad (6)$$

$$\beta_1 = \exp\{s[1-(28/t)^{1/2}]\} \quad (7)$$

s = 0.38, when used the Portland cement types CP III e IV.

s = 0.25, when used the Portland cement types CP I e II.

s = 0.20, when used the Portland cement types CP V-ARI.

t = effective concrete's age, in days.

Therefore, the parameters set for the structural analysis of the girders, for the CASE 02 and using the NBR-6118:2014 Stage III criteria, are presented in Table V.

TABLE V. CASE 02 PARAMETERS – NBR-6118:2014 – STAGE III

Material Strength		Calculation Strength		Safety Factor	
Concrete (MPa)	Steel (MPa)	Concrete (MPa)	Steel (MPa)	Permanent Load	Moving Load
27.4	500	19.6	435	1.35	1.5

In these criteria, it was considered the effect of steel bars fatigue, due to the cyclic action of the traffic passing on the bridge's deck.

The Tables VI and VII present the comparative analysis between the CASE 01 and CASE 02 results, concerning the necessary steel bars areas in each calculation section indicated in the Figures 10 to 13 due to the permanent load and moving load effects.

TABLE VI. COMPARATIVE ANALYSIS OF THE STEEL BARS AREAS TO BENDING MOMENTS

Section	CASE 01		CASE 02		Deficit (cm²)
	Bending Moment (kN*m)	Steel Bars Area (cm²)	Bending Moment (kN*m)	Steel Bars Area (cm²)	
A	-1757	42.37	- 3070	48.19	5.82
B	+ 1842	40.86	+ 2686	39.88	-
C	- 3000	80.64	- 4153	67.07	-
D	+ 2555	57.25	+ 3660	54.61	-

TABLE VII. COMPARATIVE ANALYSIS OF THE STEEL BARS AREAS TO SHEAR FORCES

Section	CASE 01		CASE 02		Deficit (cm²)
	Shear Force (kN)	Steel Bars Area (cm²)	Shear Force (kN)	Steel Bars Area (cm²)	
E	610	13.46	1032	13.18	-
F	874	19.29	1224	18.82	-

Additional steel bars would be required due to the bending moments in the calculation section A, mainly caused by the influence of the increase of the impact factor on the extreme cantilevers. Even though the structure remains steady, it means that there was a reduction of the safety factor's level in the calculation section A.

V. CONCLUSION

The current panorama of the bridges in Brazil is a consequence of the public management history concerning its roadway infrastructure. It consists of several old bridges, often under poor maintenance conditions and designed according to old Technical Standards criteria which are no longer accepted.

When comparing this situation with the perspective of evolution of the current traffic load characteristics, it becomes evident the need for a deep analysis concerning the old bridges conditions in Brazil.

It was simulated the situation in which an old bridge, designed according to the old moving load and Stage II reinforced concrete's criteria, set by the NB-6:1960 and the NB-1:1960, was submitted to the current moving load and Stage III reinforced concrete's criteria, set by the NBR-7188:2013 and the NBR-6118:2014.

The comparative analysis presented in the Tables VI and VII shown that the NB-1:1960 Stage II reinforced concrete's criteria are generally more conservative than the NBR-6118:2014 Stage III reinforced concrete's criteria.

Although the structure of the old bridges remains stable, it was observed that structural reinforcements in some parts of the old bridges would be necessary, especially in the calculation section A, situated on the cantilevers and which internal efforts are heavily influenced by the current impact factor criteria.

Concerning the quick evolution of the freight vehicles characteristics, it may result in new revisions of the current Technical Standards, related to the moving load characteristics to be considered in the future structural analysis. Thus, the structural safety of the old bridges should be reviewed even more carefully.

In order to extend the life span of the old bridges, structural reinforcement techniques can be used instead of expensive solutions, such as their demolitions to build a new one or building another parallel bridge due to their insufficient traffic flow and load support capacities.

Therefore, the objective of this work was to highlight the importance of the studies concerning the traffic conditions and structural safety of the old bridges in Brazil. It was based on an historical review, computational simulations and structural analysis, in order to quantify the influence of the Technical Standard revisions and to overview the old bridge's status facing the next revisions.

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F. S. Cerbino has a Barchelor degree in Civil Engineering from Fluminense Federal University (UFF – 2010) and a Master degree in Projects of Concrete and Steel Structures from Federal University of Rio de Janeiro (UFRJ – 2015).