BRIDGE WEIGH-IN-MOTION (B-WIM) AS THE MAIN TOOL FOR ISSUING SPECIAL TRAFFIC AUTHORIZATIONS (AETs) IN BRAZIL





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Abstract

In Brazil, according to the National Department of Transport Infrastructure (DNIT), special vehicles transporting indivisible loads and overweight and/or oversize vehicles need a Special Traffic Authorization (AET) for use federal highways. This requires a structure feasibility study (geometry and load capacity) for the bridges along the highway. The methodology used in this research is based on the bridge weigh-in-motion (B-WIM) system widely used in Europe. Along two years, bridges were instrumented for collecting data and analyzing their safety. Sixty sensors were installed to obtain signals produced by vehicles crossing the bridges, giving as results the Gross Vehicle Weight (GVW), weight per axis, type of vehicle and speed. By monitoring the bridges, it was possible to obtain the relationship between the GVW and the Dynamic Amplification Factor (DAF), that allow to assess the safety level for each structure (RF). If RF > 1.0 then an AET may be issued. In the present study, two special vehicles required an AET, and the RF values obtained were 3.44 and 3.30. Therefore, in both cases, the structures were shown to be safe, allowing the crossing of vehicles with special loads.

Keywords: B-WIM, weight sensor, data collecting, indivisible loads, AET.

Resumen

En Brasil, de acuerdo con el Departamento Nacional de Infraestructura de Transporte (DNIT), los vehículos especiales que transportan cargas indivisibles y vehículos con sobrepeso y / o de gran tamaño, necesitan una Autorización Especial de Tránsito (AET) para el uso de carreteras nacionales. Esto requiere un estudio de factibilidad de la estructura (geometría y capacidad de carga) de los puentes a lo largo de la carretera. La metodología utilizada en esta investigación se basa en el sistema bridge weigh-in-motion (B-WIM) ampliamente utilizado en Europa. Durante dos años, los puentes fueron instrumentados para recolectar datos y analizar su seguridad. Sesenta sensores fueron instalados para obtener señales producidas por los vehículos que cruzan los puentes, dando como resultado el peso bruto dos vehículos (GVW), el peso por eje, el tipo de vehículo y la velocidad. Al monitorear los puentes, fue posible obtener la relación entre el GVW y el Factor de Amplificación Dinámica (DAF), que permite evaluar el nivel de seguridad para cada estructura (RF). Si RF > 1.0 entonces se puede emitir una AET. En el presente estudio, dos vehículos especiales requirieron una AET, y los valores de RF obtenidos fueron 3.44 y 3.30. Por lo tanto, en ambos casos, las estructuras se mostraron seguras, permitiendo el cruce de vehículos con cargas especiales.

Mots-clés: B-WIM, sensor de peso, recolección de datos, cargas indivisibles, AET.

1. Introduction

The bridge weigh-in-motion (B-WIM) concept was introduced by Moses (1979) in the late 1970s by means of an algorithm named after him. Studies only gained international visibility in the early 1990s, when researchers from Slovenia and Ireland developed prototypes using Moses's methodology. By the end of the decade, several European research projects on the B-WIM system were released (Žnidarič and Kulauzović, 2018).

The Moses (1979) algorithm has been modified in the commercial systems, but it presents the basic theoretical principle of the Line of Influence (IL) concept to obtain the weight of vehicles crossing a bridge. In Brazil, the B-WIM system was first used in 2008 and the first installation in the Santa Catarina state of data collecting devices on a bridge, happened in 2012.

One of the technical responsibilities of the National Infrastructure and Transport Department (Departamento Nacional de Infraestrutura de Transportes - DNIT) of Brazil is to evaluate the safety conditions of infrastructures such as bridges, which require the issuing of Special Transit Authorization (Autorizações Especiais de Trânsito – AET) documents. These are issued to special load or indivisible load vehicles that do not follow dimensions and weight limits established in the National norms (Conselho Nacional de Trânsito - CONTRAN).

The majority of Brazilian bridges were built in the 1960s, thus constant monitoring and deep analysis of structural conditions are required to guarantee the safety of users and of the structure itself. In this scenario, B-WIM technology can be an important ally, as it can measure the impact of dynamic forces over the structure in a nondestructive way and retrieve relevant data for the analysis of infrastructure constructions. The installation of strain sensors and data collectors on the bridge can provide information such as speed, distance between axes, weight per axes, vehicle category and Gross Vehicle Weight (GVW).

The B-WIM system presents advantages for use and dissemination as per the studies of Žnidarič & Lavrič (2010) qtd. in Žnidarič et al. (2016), pioneers in this type of technology. These systems include high precision data retrieved from uniform surfaces and reasonably accurate information from non-uniform surfaces. Ease of installation of devices with no obstruction to the road, access to structural information of the bridges and portability of equipment without reducing accuracy, are positive aspects of the system. The authors describe the cases for the use of this type of technology, such as the choice of a bridge that allows for the proper calibration to be installed. However, it is important knowledge of how bridges work to evaluate if the system is properly configured.

This paper presents the Brazilian methodology of bridge inspection and safety assessment that will contribute to the issuing of AET using B-WIM technology.

2. B-WIM in Brazil

With the advance of WIM technologies for road networks, the first test of Weigh-in-Motion on bridges took place in 2012 in Palhoça city, in Santa Catarina state. The bridge in this study has a seven prefabricated prestressed concrete longitudinal beam structure with a concrete deck. The bridge was instrumented with sixteen strains sensors, including a weighing sensor applied on each of the seven longitudinal beam spans (WM), four Free-of-df detectors (FAD), and five sensors for shear stress distribution detection near the beam's support (WC), as shown on Figure 1. The system was calibrated using two vehicles: a rigid three-axle truck and a six-axle articulated truck (semi-trailer), with thirteen crossings on each lane carried out for each truck (ZAG, 2012).

Figure 1 - General view of the installation (left) and weight sensors (WM), shear stress (WC) and Free-of-Axle Detectors (FAD) sensors (right).

Shortly after, three bridges were instrumented in the state of Goiás, center west region of Brazil, with a research focus, of which the collected data is now used in this paper.

3. Instrumentation and Data Collection with B-WIM

This study aims to present the installations and data retrieved from the application of B-WIM methodology to inspect and evaluate three bridges during a two-year research period. The instrumentations and readings took place on the bridges that cross the Passa Três River, the Itinguijada River, and the Lambari River along the federal highway BR-153 at the 197th km, 147th km, and 135th km, respectively.

A visual inspection was completed prior to the installation of the weighing sensors, to evaluate the general conditions of the bridges and to identify any pathologies present. For this initial analysis, non-destructive tests such as pacometry, corrosion potential, sclerometer test, and ultrasound were used. A rating from very good to satisfactory was established, based on the deterioration factor that determines the bridge conditions to receive the instrumentation. Table 1 presents the technical data and evaluation of each bridge.

As for service conditions and structural load capacity, all bridges were in a normal state even though a few signs of pathology, like corrosions, were identified. The geral conditions were considered acceptable because the bridges receive regular maintenance and there is capacity of load redistribution.

Table 1 - Bridge data and rating

Bridge	Superstructure and Total Length (TL)	General Conditions	Rating
Passa Três River	3 spans simply supported, 5 longitudinal beams, No transversal beams. TL of 105 m	Does not present serious degradation.	Very good
Itinguijada River	1 simply supported span with cantilevers, 2 longitudinal beams, With transversal beams. TL of 29 m	Satisfactory condition (steel corrosion in transversal beams).	Satisfactory
Lambari River	1 span, 4 longitudinal beams, With transversal beams. TL of 22 m	Generalized presence of moisture (spots of steel corrosion).	Good

3.1 B-WIM Instrumentation

The instrumentation consists of implementing a fixed number of extensometers underneath the bridge's deck. These collect the reactions and deflexions generated by vehicles movements, allowing to determine the Gross Vehicle Weight (GVW, weight per wheel axis, and the type of vehicle. The positioning of the sensors should be carefully defined to obtain the most clear and representative signals. Figure 2 shows a typical installation for this method, while the number of sensors of each type varies according to the bridge.

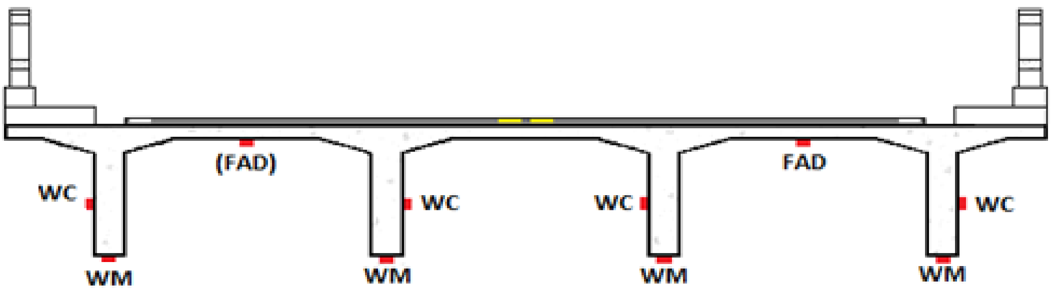

Figure 2 - B-WIM typical sensor positioning

Various types of sensors are used in the process of weighing vehicles in bridges. For the three bridges in study, as well as the bridge instrumented in Palhoça city in 2012, the WC, WM and FAD sensors were used. Table 2 summarizes the number of sensors used in each bridge being analyzed.

Table 2 - Number of sensors used in the bridges

Bridge	WC Sensors	WM Sensors	FAD Sensors
Passa Três River	10	10	4
Itinguijada River	4	4	4
Lambari River	8	8	4

3.2 System Calibration

The calibration process is the most important and sensitive stage during the installation of the monitoring system, since it is during this phase that the actual Influence Line (IL) of the bridge is obtained. This information is vital to guarantee the accuracy of the vehicle's weighing, and for the future evaluation of the bridge's safety.

For the purpose of this study, the Slovenian software SiWIM was used. According COST 323 (1999), this system uses two trucks with previously known weights in the calibration process. The calibration process consists in driving these vehicles several times over the bridge and obtaining at least ten significant readings for each type of vehicle at different speeds. As per COST 323 (1999), the recommendation for the calibration of WIM systems is that the higher the number of readings, the more precise the system will be in terms of the collected data.

The calibration of the system took into account the configuration of the structure in question, and the trucks chosen for the calibration process are amongst the most popular models on a National scale. Typically, a three-axle rigid truck and a five-axle articulated truck are chosen for the calibration. The system's calibration process was completed for all the three bridges in analysis.

3.3 B-WIM Data Collection

The B-WIM data is presented in histograms representing the quantity of vehicles weighed by the SiWIM system in relation to the GVW in tons and organized by truck type. The characterization of the traffic and the forces on each bridge varied in different stages of the analysis, the first stage being measured in 2013 and the second stage in 2017. The volume of traffic considered in the analysis refers to the majority of vehicles monitored between the two years, and the values shown on the histograms refer to each one of the bridge's lanes.

Small variations were noticed in the monitored traffic volume of each lane. The histograms on Figure 3 present the traffic characterization of analyzed bridges where (a) refers to the Passa Três River bridge, (b) Itinguijada River bridge, and (c) Lambari River bridge.

These histograms of GVW of the bridge's traffic analysis are used alongside the Influence Line (IL) to obtain the forces impacting the structure.

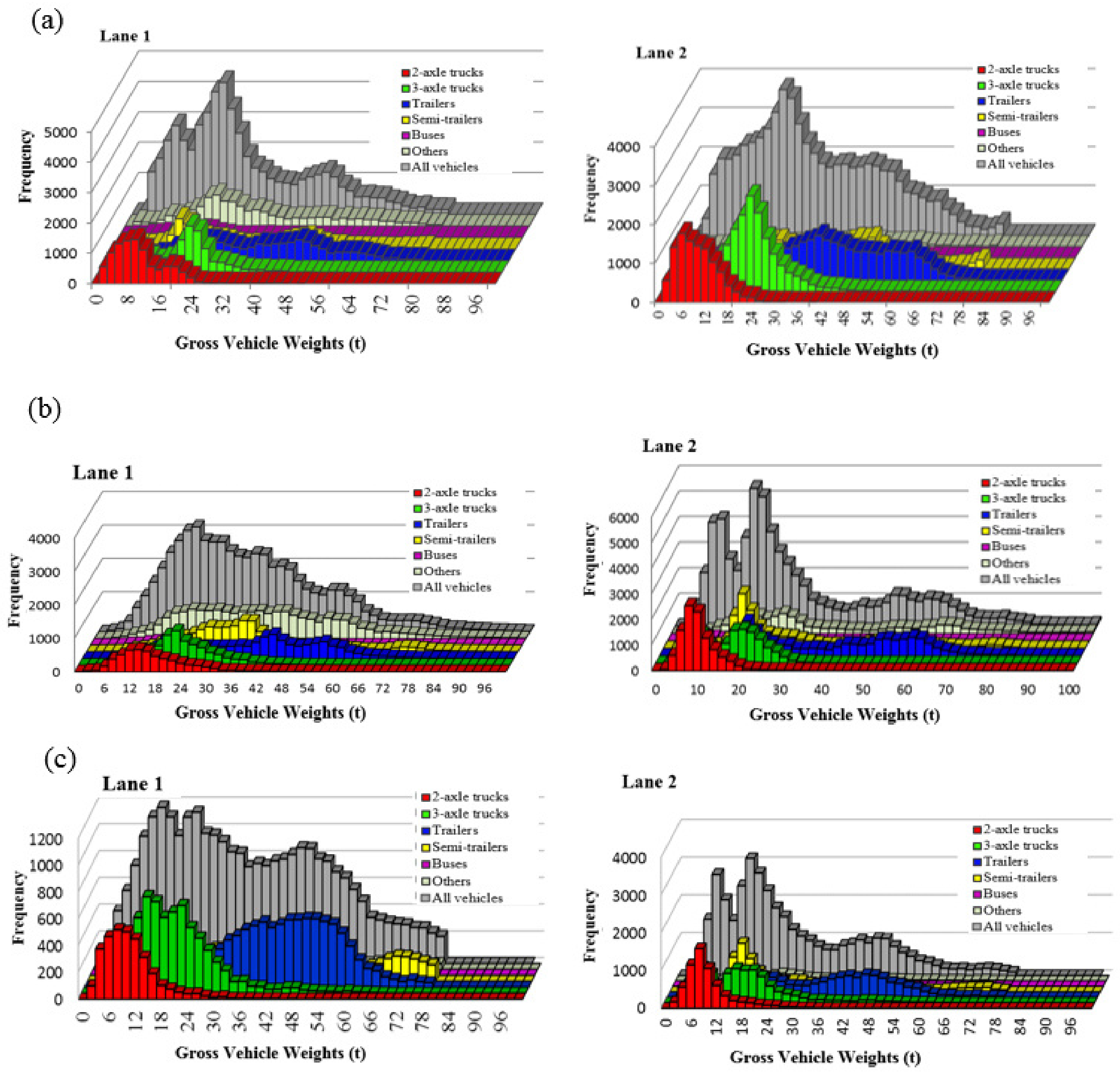

Figure 3 - Gross Vehicle Weight (GVW) histograms of the bridges

4. Safety Evaluation of the Bridges

The purpose of safety evaluation of bridge is for verify the structure's capacity to resist the loading levels that it will be subjected. In this case, the proposed methodology focuses on identifying the bridges which show levels of resistance that are close to their levels of demanding forces, thus informing the decision-making process regarding to the deployment of resources for necessary interventions (maintenance and recovery), and the confident issuing of AET permits to special vehicles that will frequently cross the bridge.

The collected data is then used in a numeric model that generates important structural characteristics such as Influence Lines (IL), traffic load distribution in different structural components, and experimental evaluation of Dynamic Amplification Factor (DAF). The B-WIM Slovenian software, which uses Eurocode or DIN 1072, was used to determine the safety levels of the bridge, that are represented by the RF factor and were obtained by Equation 1.

$$RF = \frac{\Phi \times R_d - \gamma_G \times G_n}{\gamma_Q \times G_Q \times DAF} \quad (1)$$

Where:

Φ	Resistant capacity reduction factor obtained during the initial inspection;
Rd	Loading capacity of the beam section obtained from the structural project and site inspection;
γG, γQ	Safety factors to augment normatized forces respectively;
Gn, G_Q	Forces due to permanent loads and traffic loads, respectively, obtained from collected B-WIM data;
DAF	Dynamic Amplification Factor, obtained from collected B-WIM data.

For a bridge to be considered safe, the RF factor must be 1.0 or higher. However, special attention is advised in the consideration of values between 1.0 and 1.5.

5. Adaptation of the Methodology for Special Transport Authorization (AET)

The safety evaluation methodology can be adapted to aid in the issuing of Special Transport Authorization (AET) permits. The requirement for an AET can be seen in the structural safety evaluation context as an exceptional load of known characteristics. Effectively, when an application for an AET is filled, the necessary information of the load such as the number of wheel axes and its respective weights must be delineated. Based on the provided information, the system was adapted accordingly.

To correctly adapt the system, it is necessary to analyze the bridge's safety evaluation data from Equation 1. Through the monitoring of the bridge using the SiWIM system, it is possible to obtain the DAF of each vehicle that crosses it. The DAF values of a specific bridge are inversely proportional to the GVW of the vehicles. Therefore, the higher the GVW of the vehicle, the smaller the impact of dynamic amplification.

Figure 4 illustrates the monitoring of a bridge during a sufficient period of time to delineate a confidence curve that relates the GVW and the DAF. Thus, to identify the DAF of a special vehicle it is necessary to apply the GVW value to the equation on Figure 4. If the RF ≥ 1.0 then the AET can be issued as mentioned previously. If the value is lower than 1.0, then either the truck's silhouette or the transit route must be changed.

The DAF equation *DAF = 1.40 - 0.008 x L*, where L refers to the bridge's length, were used in the bridge design code used in Slovenia before the Eurocode. Other studies developed by Žnidarič and Kulauzović (2018) presented the DAF as 1.146 in a 27 meters long bridge with six steel beams and concrete deck.

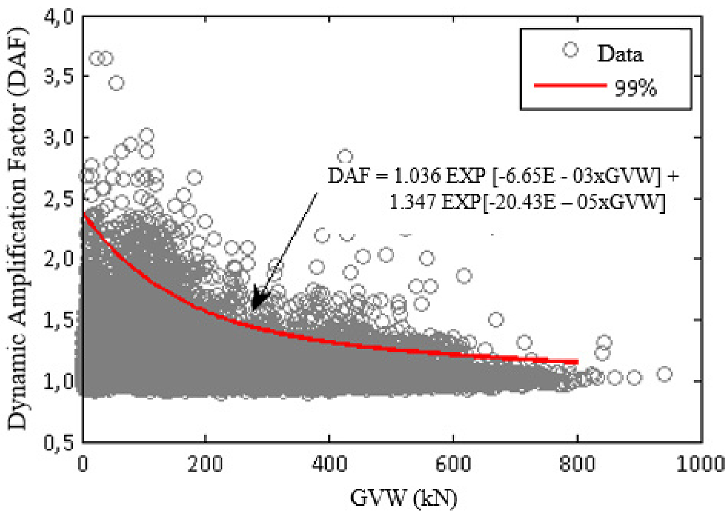

Figure 4 - DAF confidence interval for the Lambari River bridge

Using the equacion showed in Figure 4, the result values of DAF equation for the Lambari River bridge for AET release of 2 combined GVW (truck + cargo) were 1.13 and 1.10 in a 22 meters long bridge. The values, are similar with studies developed by Peaglite *et al* (2015) and says that the effects of DAF decrease as a function of increase in lenght bridge, until stability. Based on this information, this numeric model will be used to evaluate whether the bridge is able or not able to support an AET applicant vehicle.

6. Case Study

Two trucks that required a AET to drive on the highway BR-153 and that would cross the bridge over the Lambari River were verified. The bridge was monitored with the SiWIM system and the real Influence Line (IL) is illustrated in Figure 5. The relation between the DAF and the GVW was generated from the confidence curve from Figure 4 that presents values with 99% confidence that they will not be surpassed.

The first truck to pass over the bridge has a combined GVW (truck + cargo) of 69.5 tons and is distributed in 7 axles. For the issuing of an AET for trucks with a GVW less than 288 tons, the combined effect between the actual vehicle and a standard vehicle must be considered, as per the Brazilian norm NBR 7188 (2013).

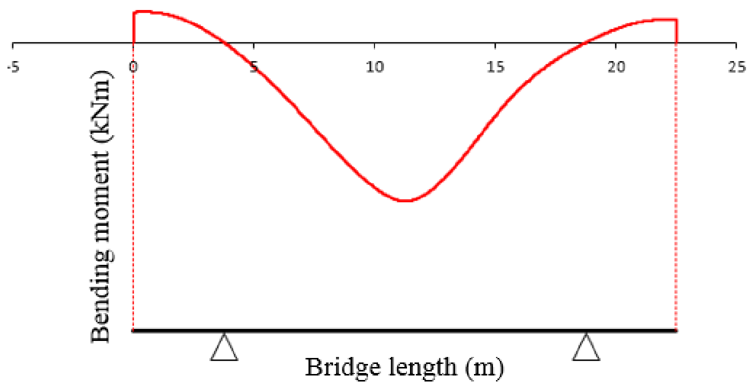

Figure 5 - Influence Line (IL) of the Lambari River bridge

The bending moment is obtained when the centre of the truck's axes is in the middle of the bridge's central span, on the LI peak, which is equal to 862.5 kNm. The normalized standard truck, when positioned in the central span, introduces a bending moment of 1,024.0 kN. Therefore, the maximum variable force (G_Q) is 1,886.5 kNm. These values are applied to the confidence interval that results in a DAF of 1.13. A summary of the calculation parameters of RF are presented in Table 3.

Table 3 - Safety parameters for the Lambari River - Truck 1

Φ	γ_G	γ_Q	G_n (kNm)	G_Q (kNm)	DAF	R_d (kNm)
0.85	1.2	1.3	1,326.3	1,886.5	1.13	4 x 3,273.0

As per Equation 1, the safety Rating Factor (RF) is 3.44, thus the AET for this truck can be issued for the GVW presented and in reference to the Lambari River bridge.

The second truck to drive through the Lambari River bridge has a combined GVW (truck + cargo) of 111.5 tons distributed along nine axles. The bending moment of this truck occurs when the centre of the axles is over the central span of the bridge, where the Influence Line peak is at 996.3 kNm. In this case, it is also necessary to combine a normalized standard truck. The maximum force G_Q is equal to 2,020.3 kNm. With this combined GVW, the DAF results in 1.10, and the parameters used can be seen in Table 4.

Table 4 - Safety Parameters for the Lambari River - Truck 2

Φ	γ_G	γ_Q	G_n (kNm)	G_Q (kNm)	DAF	R_d (kNm)
0.85	1.2	1.3	1,326.3	2,020.3	1.10	4 x 3,273.0

Since the rating factor (RF) in this case results in 3.30, this truck can also receive the AET for the presented GVW and for the Lambari River bridge.

7. Final Considerations

The road network operated by the National Department of Transport Infrastructure (DNIT) contains a significant number of bridges that require constant evaluation of the structural conditions of safety. This article summarizes the Brazilian methodology of bridge inspection and safety assessment. Considering also the load capacity of critical sections, capacity reduction factors, factor of increase of forces and permanent loads and of traffic.

In this first moment, the goal was to analyze the support capacity of the bridges and in this way the analyzes were developed according to the obtained safety factor (RF). The RF values serve as a reference for the release or not of the Special Traffic Authorization (ETA) on these bridges. During the process three bridges of the state of Goias/BR were selected. The results concerning the bridge over the Lambari River were presented and analyzed as a model.

The final considerations include the instrumentalization of these bridges, the system calibration process and the characterization of traffic and forces.
For the load, two large vehicles were used and after the requests the RF safety values were 3.44 and 3.30. Under these values, it is determined that the bridge over the Lambari River is safe and that the AET can be emitted in this stretch.

8. Acknowledments

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