Permit Checking of Vehicular Overloads: A New Methodology

(Revised Version, accepted for publication in the Journal of Bridge Engineering, ASCE)

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Abstract: Vehicular overloads are essential for economical activities but their circulation involves serious concerns regarding the structural safety of bridges. In most countries, the necessary permit process is time and cost consuming and the evaluation criteria sometimes do not lead to safe situations. This paper presents a new methodology for permit checking of vehicular overloads, based on an initial statistical study performed to characterize these vehicles. The method includes software which performs a simplified structural safety analysis of the bridges crossed by a vehicular overload, computing safety factors that compare the code design loads effects with those due to the vehicular overload. The software also includes a connection between the vehicular overloads database and a GIS representation of the highway network, allowing for the definition of several functionalities that support the permit decision. This new methodology

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allows for prompt, economical and safe decision-making on permit checking of vehicular overloads and is presently applied by the Portuguese national major expressway authority.

**CE database subject headings:** vehicles, overloads, bridges, safety analysis, geographic information systems.

**INTRODUCTION**

The circulation of very heavy trucks is essential for several economical activities, such as the construction and the electrical-mechanical industries. However, the circulation of these trucks, here referred as vehicular overloads or heavy trucks, causes serious constraints due to their large dimensions or the effect of their total weight on the safety of the existing bridges.

In most European countries, where the maximum dimensions and weight limits (maximum total weight of 40 ton) are legally regulated (European Commission 1996), the circulation of vehicular overloads implies a previous approval of the intended route by the road authorities. As a reference, in a small country like Portugal, annually there are presently about 200 to 300 permit requests, but the European Commission forecasts that the circulation of vehicular overloads will increase by 50% in 2010, relative to the 1998 level. Presently, the analysis of the permit requests is a significantly time and cost consuming process, as the authorities have to perform summary structural safety evaluations for most of the bridges involved. Further, in some cases where the permission is granted, several bridges have to be monitored or strengthened during truck passage.

In order to shorten the average permit decision period, and based on previous approval decisions experience, the main Portuguese Expressway Authority (*Brisa*) established in 2001 two
simplified criteria to authorize the circulation of heavy trucks: a) a maximum total weight of 106 ton; b) a maximum weight per axle of 12 ton. This permit procedure, based on the described experience criteria, proved to have some incorrections. In fact some licensing requests were incorrectly rejected (about 25% of the requests exceed those limits and therefore are immediately rejected) with negative direct consequences to the economical activities, and others were incorrectly accepted, as the structural safety depends not only on the loads values, but also on their relative positions, which were not analyzed.

In the U.S., the management of vehicular overloads regarding bridge’s structural safety uses an extension of the load rating concept of the American Association of State Highway and Transportation Officials (AASHTO 1983, 1994). However, the rating concept is supposed to cover normal traffic and not vehicular overloads, as it does not explicitly consider the low frequency of overloads.

Previous research on permit checking of vehicular overloads has been reported by Bakht and Jaeger (1984), Ghosn and Moses (1987), Fu and Moses (1991) and Ghosn (2000). Fu and Hag-Elsafi (2000) presented a method to develop live loads models including overload trucks and proposed associated reliability models for assessing structural safety of highway bridges and permit-load factors for overload checking. Phares et al. (2004) proposed a procedure for permit checking of vehicular overloads based on bridge load rating using experimental testing.

This paper presents a new method for permit checking of vehicular overloads referred in Correia and Branco (2004b). In order to understand and adequately characterize the vehicular overloads, a statistical study was initially performed, which led to the development of a database and to the definition of overload vehicle types. A software was then developed to evaluate bridge’s safety for each vehicular overload crossing (BIST, Bridge Investigation for Special
Trucks) and integrated in Brisa’s bridge management system (Branco and Correia 2004a). The software, which is applicable to the majority of Brisa’s expressway bridges, performs a simplified structural safety analysis of the bridges that are to be crossed by a particular vehicular overload, by determining, for each bridge, safety factors that compare the effects of the code design loads with those due to the vehicular overload (the analysis is performed for each overload as their frequency is quite low as compared with normal traffic). Simultaneously, a connection between the vehicular overloads database and the representation of the highway network in geographic information systems (GIS) was developed. Based on this connection, several functionalities were created, which allow for a better decision on the permit request. This methodology, which integrates simplified structural safety analysis software and involves the use of GIS functionalities, allows for prompt, economical and safe decision-making on permit checking of vehicular overloads. Although developed for the specific conditions of an expressway authority, the software can be easily adapted for other truck overloads and bridge structural types, more common in different authorities.

CHARACTERISATION OF VEHICULAR OVERLOADS

In order to define the characteristics of the vehicular overloads, to be considered in the software, a statistical study was performed on a sample of 400 licensed transports that traveled from 1996 to 2001 in Portugal (Branco and Correia 2002a,b). The characterization of the vehicular overloads included: (a) definition of typical vehicle types; (b) analysis of the transported materials; (c) analysis of their origins and destinations; (d) analysis of the transportation companies; (e) analysis of the loads; (f) and a tentative definition of “vehicular overload design loads”, for each vehicle type by ranges of total weight. The results of these
analysis, of course vary with the economy of each country, but in general, their main conclusions can be used as a reference for this characterization.

**Heavy Vehicle Types**

The vehicles were classified in 10 longitudinal types (figure 1), according to the number of tractors and trailers and the type of connections or gearings existing between the different elements composing the truck. The statistical distribution of the vehicles according to the longitudinal type (figure 2) shows that: the most usual vehicle type is 2.2, which together with vehicle types 1.1 and 2.3 are almost 90% of the number of transports carried out; vehicle types from 1.1 to 3.3 represent 99% of the totality of the transports.

The transversal geometry of the vehicles was also analyzed, regarding the number of wheels per axle and the transversal distance between wheels.

**Materials**

The study revealed that the materials transported by vehicular overloads can be classified in 3 different types: a) type 1 – construction materials (specially pre-cast structural elements); b) type 2 – electro-mechanical material (hydraulic equipment, engines, etc.); c) type 3 – construction machines (derricks, dumpers, digging machines, etc.). The statistical distribution of the number of transports according to the type of materials, shows that construction, either as materials (type 1 – 21.0%) or as equipments (type 3 – 29.7%), is about half of the transports carried out. The remaining half of the transports corresponds to electro-mechanical material (type 3 – 49.4%).

The correlation between the type of materials and the total weight of the heavy truck (figure 3) shows that: a) type 1 materials do not usually exceed 100 ton (only in 4% of the cases),
and in 82% of the cases total weight is within the 60-100 ton range; b) for type 2 materials, the range of the total weight is much wider (with a maximum value close to 500 ton), however 75% of the transports have a total weight below 100 ton; c) type 3 materials, similarly to type 1, do not normally exceed 100 ton (only in 2% of the cases).

**Origins and destinations**

The origins and destinations of the permit requests were also analyzed, concerning the following aspects: a) identification of the major origins and destination locations; b) distribution of major origins and destinations by types of materials; c) distribution of major origins and destinations according to the total weight.

This analysis showed that the main origins are associated with the land borders (27%), the industries locations (25%) and the major harbors (14%). Regarding the destinations, the geographical distribution is more disperse and the major locations correspond to harbors (19%), land borders (10%) and construction sites (9%).

The analysis of the origins and destinations showed that land borders usually correspond to type 1 and type 3 materials and the transports originated in the major harbours correspond to type 2 materials.

**Transportation companies**

The transportation companies were analyzed regarding the number of transports carried out, according to the types of vehicles and the total weight of the vehicular overloads. The statistical study revealed that although only 1 company carried more than 30% of the transports, a total of 81 companies was identified, showing that this market is rather disperse. The analysis
showed that transports with total weights above 100 ton were only carried out by 4 companies, a very small number.

**Loads**

The loads involved in these transports were analyzed regarding the total weights and the maximum axle loads. Table 1 summarizes the average, standard deviation and maximum values of the previous variables, for each vehicle type.

Concerning the maximum total weight, the following aspects should be emphasized: a) transports with the highest maximum total weight correspond to vehicle types 2.1, 3.1 and 4 (specially 3.1, with 474 ton); b) transports with the lowest maximum total weight are associated to vehicle types 1.1 and 1.2, with about 100 ton; c) the maximum total weight of the remaining vehicle types is about 150 ton.

Regarding the maximum axle load, which also depends on the load capacity of the tyres, a much more uniform distribution was found within the different vehicle types: a) transports with the highest maximum axle loads correspond to vehicle types 1.1, 2.2 and 3.1, with about 20 to 22 ton per axle; b) transports with the lowest maximum axle load correspond to vehicle type 1.2, with 8 ton per axle; c) the maximum axle loads of the remaining vehicle types are about 15 ton per axle.

**Tentative definition of “vehicular overload design loads”**

The statistical study investigated the possibility and significance of a correlation between the loads and the length of the groups of wheels or the distances between the groups of wheels of each vehicle type. The objective of this analysis would be the definition of “vehicular overload
design loads”, for each vehicle type, by ranges of total weight, to be used in design or to support the permit decision. However the statistical correlations obtained from regression analysis were not sufficiently accurate. As an example, figure 4 shows, for vehicle type 2.1, the correlation between the load and the length of the tractor.

Consequently, this approach was discarded and an alternative method was developed to evaluate the safety of the bridges when crossed by a particular vehicular overload, taking into consideration the actual vehicle geometry.

SIMPLIFIED EVALUATION OF BRIDGES STRUCTURAL SAFETY

The majority of Brisa’s expressway bridges were designed according to the Portuguese Loads Code (RSA 1983), which defines 2 different vehicular design loads: a vehicle with 3 axle loads of 200 kN, separated by 1.5 m; and the simultaneous effect of a linear distributed load of 50 kN/m and a uniform distributed load of 4 kN/m².

To implement the vehicular overload permit checking methodology, software was developed, BIST - Bridge Investigation for Special Trucks, which performs an evaluation of the structural safety of the bridges crossed by a particular heavy vehicle, by comparing the effects due to the loads defined in the Code with the effects due to the overloaded truck.

Based on this simplified safety concept, the software BIST, which was integrated in Brisa’s bridge management system, allows determining, for a particular bridge and a specific heavy vehicle, simplified safety factors evaluated in the most critical bridge sections.
**Transversal analysis**

The software *BIST* was developed considering 4 transversal bridge cross sections (figure 5) which represent more than 95% of *Brisa*’s expressway bridges: a) a 13.7 m wide 2-ribbed deck with 2x2 lanes (section 1); b) a 18.3 m wide 2-beamed deck with 2x3 lanes (section 2); c) a 19.6 m wide 4-ribbed deck with 2x4 lanes (section 3); d) a 10.0 m wide solid slab deck with 2x1 lanes (section 4). In future developments, further transversal sections can be easily analyzed and included in the software.

The transversal distribution load factors were computed for each section. As an example, figure 6 shows the transversal distribution load factors as a function of the span for section 1. Transversal analysis was then performed for each section, with the code loads being placed in unfavorable positions for the longitudinal structural elements, and the heavy truck being placed centered with the bridge’s axis.

This position of the overloaded truck is assumed, as the circulation of vehicular overloads is always escorted by traffic police that guarantees the observation of the following precautions: a) heavy vehicle passage is aligned with the bridge’s longitudinal structural axis; b) maximum circulation speed over the bridge is below 20 km/h.

**Longitudinal analysis**

For the longitudinal analysis, three longitudinal models were considered in *BIST*: a) a 3-span continuous beam (model 1), modeling 3-span bridges and simulating continuous bridges in general; b) a single span beam with rotation springs (model 2), modeling highway simple over and underpasses; c) a model to simulate pre-cast arch underpasses (model 3). Figure 7 shows the
geometry of the longitudinal models and the critical sections chosen to control the maximum bending moments and the supporting reactions.

To determine the maximum values of the bending moments and the supporting reactions in the critical sections due to the different actions, the expressions of the corresponding influence lines were computed for each longitudinal model. Longitudinal analysis was then performed with the code loads and those corresponding to the heavy truck being placed in each of the critical sections for each model. Regarding the heavy truck loads, a simplification was assumed that consisted in considering each group of wheels of the vehicle composed by 7 axles. All the possible combinations of relative positions between groups of wheels were then tested to determine the maximum bending moments and supporting reactions in each critical section due to the heavy truck.

**Definition of the simplified safety factor**

The bridge structural safety is then evaluated by comparison of the effects due to the factored code loads with the effects due to the non-factored heavy truck loads. Based on this simplified safety concept, the software *BIST* allows determining, for a particular bridge and a specific heavy vehicle, two simplified safety factors (SSF), one relative to bending moments in longitudinal structural elements, and the other relative to supporting reactions, both evaluated in the critical sections, according to the following expression:

\[
\text{SSF} = \frac{\gamma_S \times S_{\text{(Code loads)}}}{1.0 \times S_{\text{(Heavy truck loads)}}} \tag{1}
\]

where \(\gamma_S\) is the factor for the code loads (usually \(\gamma_S = 1.5\)) and \(S_{\text{(Code loads)}}\) and \(S_{\text{(Heavy truck loads)}}\) correspond to the loads effects.
The quotient between the effects due to the code loads and those corresponding to the heavy truck are expressed by the safety factor (SSF). If $SSF \geq 1.5$, the bridge structural safety for the heavy truck is similar or higher than the one defined in the design code, given that the bridge is well preserved. Whenever a bridge safety factor for a specific heavy truck is below 1.5, although the structural safety is lower than the standard code value, a lower safety factor for the heavy truck load may be adopted, as the exact value of the action is known. Considering the action as an accidental action, code allows the use of a factor up to $\gamma_S = 1.0$, applied to the load value. In the version being used at Brisa, a value up to $\gamma_S = 1.1$ leads to an automatic permit approval, and for bridges with $\gamma_S$ between 1.1 and 1.0, supervisor engineer must decide based on bridge conditions.

Regarding the material durability, the safety factor for the materials properties ($\gamma_m$ is usually 1.5) remains the same, unless bridge deterioration occurs. In these situations Brisa will define, for the deteriorated bridge, appropriate load ratings or capacity levels to be used in the definition of the minimum values of the SSF (Branco and de Brito 2004).

For arch underpasses, where the software BIST models the cover soil layer using Coulomb’s theory and the elasticity theory, the structural safety evaluation takes into consideration not only the bending moments, but also the axial force in the critical sections.

Integration in the bridge management system

BIST was integrated in Brisa’s bridge management system, in a software modulus, whose graphic interface is shown in figure 8.

The application of the new methodology to a permit decision is quite simple: BIST’s user has only to introduce as input the geometry and the loads of the heavy truck vehicle, according to
the vehicle types defined in the statistical study, and the origin and destination of the trip. This procedure allows identifying automatically all the bridges that are to be crossed throughout the transportation route, as well as their characteristics, as the BIST software is connected to the Brisa’s bridge management system. The BIST software, using that information as input, immediately returns as output the safety factors, for both bending moments and supporting reactions, corresponding to the bridges that will be crossed by the heavy truck which is being analyzed. Following this analysis, if all the bridges present safety factors above the limits defined by Brisa, the permit request is approved. If BIST identifies bridges presenting safety factors below the limits defined by Brisa, the permit request approval will depend on a route change or, in alternative, on an expert’s report based on detailed inspection and analysis of those specific bridges.

Additionally, the BIST software also returns, as output, a set of graphics that show the simplified safety factors as a function of the span, for all the possible combinations of transversal sections and longitudinal models, allowing to get a global overview of the structural safety of the existing bridges related to a particular heavy truck subjected to a permit checking analysis. As an example, figure 9 shows the safety factor relative to bending moments as a function of the span, for bridges with longitudinal model 1 and for all the transversal sections considered.

GEOGRAPHIC INFORMATION SYSTEMS

Simultaneously to the use of the BIST modulus developed to check the structural safety of bridges, another modulus that makes use of geographic information systems (GIS) is also used. The existing representation of the highway network in GIS is linked to the bridge management system and to the heavy trucks database (developed during the statistical study), and several
functionalities were created supporting the definition of the routes and allowing for the visualization of historic/statistical information.

During a permit request analysis, when the origin and destination highway interchanges are defined, an interactive map displaying the intended route and identifying the bridges that are to be crossed is generated (figure 10). After the running of safety modulus of BIST, the safety factors of the bridges are represented in the map, and the bridges with safety factors below the defined limits are clearly identified. These bridges can not be crossed and therefore, if the transport is to be approved, it must exit the highway in the corresponding previous interchange and re-enter it in the next interchange. In these particular circumstances, the GIS are very helpful in the redefinition of the routes.

The GIS functionalities also allow for the visualization of historic/statistical information, allowing the access to the heavy trucks database for each highway section (including information such as the vehicle types, the number of passages, the maximum total weights or the maximum axle loads). This information is displayed in maps, in a color based scale or in the form of graphics (figure 11), and allows knowing, for each highway subsection, the maximum total weight and vehicle type that already traveled on it. These GIS functionalities, along with the safety modulus of BIST, support the decision on the permit travel of vehicular overloads. The GIS software can be adapted to any other type of highway systems where a management system is implemented.

CONCLUSION

The circulation of vehicular overloads is very important for several economical activities but presently, the permit process is time and cost consuming and not necessarily safe related to
bridge crossing. This paper presents a new methodology for the licensing of vehicular overloads, which was developed based on the findings of a statistical study performed to characterize these particular vehicles. The proposed methodology includes the use of the software BIST – Bridge Investigation for Special Trucks, specifically developed to perform a simplified structural analysis of the bridges that are to be crossed by a particular vehicular overload. The safety modulus of BIST computes, for each bridge, a simplified safety factor that compares the effects due to the loads defined in the design codes with those due to the vehicular overload. The new methodology for permit checking also includes the use of geographic information systems, connected to the vehicular overloads database. Several functionalities were created helping on the definition of the routes and allowing for the visualization of historic/statistical information, therefore supporting the licensing decision. This new methodology allows for prompt, economical and safe decision-making on permit checking of vehicular overloads.

REFERENCES


TABLE 1. Average, standard deviation and maximum values of total weight and axle load for each vehicle type.

<table>
<thead>
<tr>
<th>Vehicle type (1)</th>
<th>Total weight (ton)</th>
<th>Axle load (ton)</th>
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<tr>
<td></td>
<td>Average (2)</td>
<td>Standard deviation (3)</td>
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<tr>
<td>1.1</td>
<td>78.1</td>
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<td>1.2</td>
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<td>10.6</td>
</tr>
<tr>
<td>5</td>
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</table>
FIG. 1. Longitudinal vehicle types of vehicular overloads.

FIG. 2. Distribution of the transports according to the longitudinal vehicle types.

FIG. 3. Distribution of the transports according to the total weight for the different types of materials.
y = 6.9478x - 7.2069

$R^2 = 0.4061$

FIG. 4. Correlation between the load and the length of the tractor for vehicle type 2.1.

FIG. 5. Transversal bridge cross sections considered by the software BIST.

FIG. 6. Transversal distribution load factors as a function of the span for section 1.
FIG. 7. Longitudinal models and respective critical sections considered by the software BIST.

FIG. 8. Graphic interface of Brisa’s bridge management system software modulus where BIST was integrated.
FIG. 9. Safety factor relative to bending moments as a function of the span, for bridges with longitudinal model 1, and for all the transversal sections considered.

FIG. 10. Map displaying the intended route and the bridges that are to be crossed.
FIG. 11. Graphics displaying the maximum loads and the number of passages on a highway subsection for the different longitudinal vehicle types.