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Comparison of damage factors and unit damage of loaded trucks along a road corridor in Northern Colombia

Comparación de factores de daño y daño unitario de camiones cargados a lo largo de un corredor vial al Norte de Colombia

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Abstract
In the present study, a comparison could be established between the damage factors corresponding to the types of trucks that most frequently use Colombian roads. To this end, a mobile weighing operation carried out within the Riohacha - Maicao road sector, where trucks C2, C3, C3-S2 and C3-S3 were considered, was taken as a reference for which was established as a benchmark a parameter, called "unit damage", through which it could be shown that smaller trucks with a lower load capacity, generate more unfavorable conditions for the deterioration of the pavement, for the more they generate greater relative damage with respect to the mobilized payload.
key words: trucks, damage factor, payload, unit damage

Resumen
En el presente estudio, se pudo establecer una comparación entre los factores de daño correspondientes a los tipos de camiones que con mayor frecuencia hacen uso de las carreteras de Colombia. Para tal fin, se tomó como referente un operativo de pesaje móvil realizado dentro del sector vial Riohacha – Maicao, en donde se consideraron los camiones C2, C3, C3-S2 y C3-S3, para lo cual se estableció como referente un parámetro, denominado "daño unitario", a través del cual se pudo demostrar que los camiones más pequeños y de menor capacidad de carga, generan condiciones relativamente más desfavorables para el deterioro del pavimento, por cuanto generan mayor daño relativo con respecto a la carga útil movilizada.
Palabras clave: Camiones, factor de daño, carga útil, daño unitario

1. Introduction

In order to obtain the traffic variable for pavement design purposes, information related to the traffic volumes of the expected commercial vehicles must be available, as well as the distribution of the axle loads characteristic of the vehicles that make use of the road corridor under study (Jove, Feria, & Hernandez, 2019). For this purpose, traffic volumes can be estimated from historical series based on vehicle measurements made previously, over several years (Huang, 2004), or from specific vehicle counts carried out over several days, generally for a week

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in duration, in where all vehicles passing through the road section under study must be continuously classified and counted (Jove, 2011).

Regarding the effects generated by traffic loads, these can be characterized through the number of equivalent 80 KN standard axles expected in the design lane (Huang, 2004), or through the axle load spectra expected during the design period (Murgueitio, Benavides y Solano, 1997). In both cases, information is required related to the characteristic loads of commercial vehicles that make use of the road corridor, and in particular, the axle loads transmitted by the heaviest vehicles (buses and trucks), this information is It achieves in Colombia from the weighing of the axles of the vehicles through mobile weighing operations, which are carried out in some sites strategically located within the different road sectors of the country (Montejo, 2016).

One of the most traditional ways of representing the effect of vehicular traffic for a pavement project, is through the determination of the number of equivalent standard axles of 8.2 tons, expected in the design lane, during the design period (Jove, Feria, & Hernandez, 2019). In order to determine this parameter, knowledge of certain traffic characteristics is required, and in particular, that of heavy vehicles. Among the relevant information, the total number of buses and trucks expected in the design lane during the service life must be considered, as well as their relative distribution in the different types of vehicles and have information related to the distribution of the loads for each of the axle configurations considered as representative and the characteristic inflation pressures (Huang, 2004). To simplify the problem, the so-called damage factor for each type of commercial vehicle is usually determined through mobile weighing operations, a value that refers to the number of standard single axles to which the pitch of each class of vehicle is equivalent, depending on the configuration of the axes that comprise it (Jove, 2011). For this purpose, the information obtained in the mentioned operations (Jove, 2011), (Murgueitio et al., 1997) must be processed. In this sense, in developing countries such as Colombia, for a given project, previous information is usually used, taken from studies carried out at the regional or national level, where the representative damage factor for each class of vehicle is determined (Montejo, 2016), (Rondon, y Reyes, 2015), (Jove, Feria, & Hernandez, 2019), through the implementation of the fourth power law (Jove, Feria, & Hernandez, 2019); in such a way that, for a particular project, only the estimation of the total number of commercial vehicles during the service life and their relative distribution is required, which is possible, based on the information obtained from vehicle gauges executed by those responsible for the project, or of historical series (Montejo, 2016), (INVIAS, 2007) taken from government entities in charge of the Highway Administration, such as the National Highway Institute (INVIAS). By contrasting the information related to the number of commercial vehicles of each class, expected during the service life and the corresponding damage factors for each one, the design traffic can be obtained, for which the following expression is usually used (Jove, Feria, & Hernandez, 2019):

$$N_{8.2} = ADT_i \cdot \frac{A}{100} \cdot \frac{B}{100} \cdot 365 \cdot \frac{(1+r)^n - 1}{\ln(1+r)} \cdot T.F \quad (1)$$

Where:
N8.2: number of standard equivalent design axles
ADTi: initial average daily traffic
A: percentage of commercial vehicles of the capacity
B: factor per lane
n: design period (in years)
r: annual growth rate of transit
T.F.: truck factor representative of commercial vehicles

In equation (1), the truck factor corresponds to the number of standard single axles of 8.2 tons to which the pitch of any commercial vehicle is equivalent (Rondon, y Reyes, 2015), (Asphalt Institute, 1989). And its determination can be made, based on knowledge of the relative distribution of commercial vehicles along the road corridor under study and of the damage factors corresponding to each class of vehicle, including obtained through mobile weighing operations of other road corridors that can be considered as representative of the area of influence of the project (Jove, Feria, & Hernandez, 2019).

In this work, a comparison is established between the damage factors of the vehicles that most frequently circulate through Colombian roads, and their relative aggressiveness, determined from the relationship “equivalent standard axles generated / payload transported". To this end, use is made of a weighing operation carried out along the Riohacha - Maicao road corridor, located in northern Colombia.

2. Materials and methods

From the weighing operation carried out along the section in reference, the information related to the types of trucks that most frequently use the Colombian roads was used, for which reason we only worked with the named trucks, according to the configuration of its axles, such as C2 and C3, in the case of rigid units; and C3-S2 and C3-S3, in the case of articulated units. These four types of trucks represent about 95% of the cargo vehicles that transit the national road network (Macea, Fuentes, & Alvarez, 2013), (Jove, Cerpa, & Hernandez, 2019).

To obtain the damage factor of a particular vehicle, the axle load equivalence factors corresponding to each of the axles that make up the vehicle are made (Montejo, 2016), as shown in equation 2.

$$CVDF = \sum_{i=1}^{m} EALF \tag{2}$$

Where:
CVDF: Commercial vehicle damage factor
m: Number of axles of the vehicle configuration
EALF: Equivalent axle load factor

Now then, the Equivalent Axle Load Factor corresponds to the number of standard axles to which the pitch of a particular axles is equivalent, and for its determination, the fourth power law (Montejo, 2016), (Jove, Cerpa, & Hernandez, 2019) obtained at from the AASHTO road test, whose numerical value, in the case of flexible pavements, is obtained from equation 3.

$$EALF = \left(\frac{W1}{Wo}\right)^4 \tag{3}$$

Where:
EALF: Equivalent axle load factor, for flexible pavements.
W1: Load which equivalence with the standard is to be determined
Wo: Standard load

Regarding the standard load (Wo) to be used in equation 3, this takes different values, depending on the type of axles being evaluated (Murgueitio et al., 1997), as shown in Table 1.

Table 1
Reference axle load values

AXLE TYPE	**Wo (Ton.)**
Single steering axle	6.6
Single axle double wheel	8.2
Tandem Axle	15
Tridem Axle	23

3. Results and discussion

Table 2 shows the number of trucks analyzed for each class, as well as the corresponding damage factors, for two conditions: loaded and unloaded. It can be seen that around 75.5% of the heavy trucks in the mobile operation were registered as loaded and the remaining 24.5% as unloaded. This situation is characteristic of Colombian highways, where the vast majority of trucks transit through the different road sectors, with some type of load (Jove, 2011). Which is indicative that in a typical trip, the transporter union tries to return to its place of origin with some type of cargo, in order to maximize its income.

It can be seen from Table 2 that the smaller trucks (C2 and C3), which correspond to rigid units, present damage factors under loaded conditions, significantly less than the larger trucks (C3-S2 and C3-S3), which correspond to articulated units. This situation is not particularly rare, and rather it is common for it to happen, since articulated trucks have a greater load capacity than rigid units, and the comparison is being carried out precisely for the loaded condition. Thus, at first glance, it could be said that the C3-S2 and C3-S3 trucks generate more deterioration on the pavement, since they are the ones that present the greatest damage factors.

Table 2
List of trucks loaded, unloaded
and corresponding damage factors

TYPE OF TRUCK	LOADED		UNLOADED	
	NUMBER	DAMAGE FACTORS	NUMBER	DAMAGE FACTORS
C2	534	4.35	345	0.11
C3	39	4.41	18	0.23
C3-S2	218	6.73	42	0.23
C3-S3	998	5.71	175	0.23
TOTAL	1789		580	

Notwithstanding the foregoing, there is a detail worth reviewing, and refers to the damage generated by each type of truck, in relation to the transported payload. For this purpose, in Table 3, the useful load transported by each type of truck is presented; this information was obtained as the average of the difference between the total load registered for each truck in loaded condition and the average of the weights in unloaded condition corresponding to each type.

Table 3
Average weight of unloaded
trucks and transported payload

TYPE OF TRUCK	LOADED WEIGHT (TON.)	USEFUL LOAD (TON.)
C2	6.5	7.3
C3	10.5	14.7
C3-S2	14.9	25.3
C3-S3	16.9	29.6

In order to be able to compare the relative aggressiveness between the different classes of trucks, it is convenient to define a parameter that allows establishing the relative deterioration generated by each type of truck with respect to the transported payload. For the purposes of this work, the aforementioned parameter will be called "unit damage" and corresponds to the number of equivalent standard single axles of 8.2 tons generated, for each ton of cargo transported. For its determination, the implementation of equation 4 is proposed.

$$UD = \frac{DF}{UL} \quad (4)$$

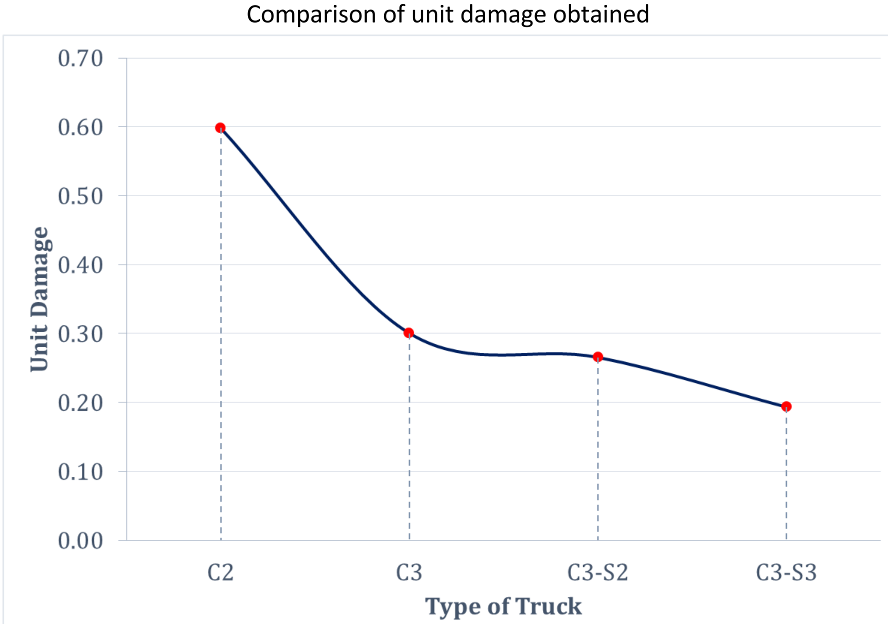
Where:
UD: Unit damage, given in "equivalent standard axles" per "ton of cargo transported"
DF: Damage factor
UL: Useful load, given in tons

As can be seen in Table 4 and Figure 1, the trucks that generate the greatest unit damage on the pavement correspond to rigid units C2 and C3, but in particular, truck C2 corresponds to the highest value of all, including doubling, the one that follows in aggressiveness. On the other hand, the articulated units C3-S2 and C3-S3, present the lowest values, corresponding to the C3-S3 truck, the significantly lower value of all. Therefore, if the intention is to protect the pavement from the aggressiveness of traffic, it would be advisable to try to mobilize as many road trucks as possible of C3-S3 class on the roads and try to limit the use of C2 trucks, to the minimum possible, unless the load to be transported for a given case is low and there is no justification for mobilizing a truck with a greater load capacity, which, on the other hand, would require higher vehicle operating costs.

Table 4
Unit damage by truck type

TYPE OF TRUCK	UNIT DAMAGE
C2	0.60
C3	0.30
C3-S2	0.27
C3-S3	0.19

Figure 1
Comparison of unit damage obtained



Now, when comparing C2 trucks with C3-S3 trucks (see Table 2 and 3), it can be seen that those of the C3-S3 type carry a payload of the order of four times that of C2 trucks; which can also be interpreted, saying that four trips of a C2 truck would be required, in order to transport the payload that can be mobilized in a single trip made by a C3-S3 type truck. Under this way of seeing things, it would be clear that while the pitch of a loaded C3-S3 truck generates damage equivalent to the pitch of 5.71 standard axles, the pitch of the four loaded C2 trucks would generate 17.4 standard axles; whence it results in this case, that the use of C2 trucks, under the stated condition, would generate damage of the order of 3 times greater than that generated by the C3-S3 truck.

In view of the foregoing, it is required from the authorities in charge of the control of the cargo transport sector, that the use of trucks with a greater load capacity be encouraged, in order to mitigate the accelerated deterioration observed throughout of the national highways of Colombia.

4. Conclusions

According to the results obtained in the present study, it was established that smaller trucks can generate greater relative damage to the pavement, if the comparison is made using the number of equivalent standard axles generated, per ton of cargo transported. Indeed, the C2 truck with 0.60 standard axles per ton, turned out to be the most aggressive, in contrast to the truck with the highest load capacity, C3-S3, which was the least aggressive of all, with only 0.19 standard axles per ton of payload transported. Therefore, the fact of transporting the greatest possible load through C3-S3 trucks, in addition to being beneficial for transport companies, due to the decrease in operating costs, is extremely favorable for the preservation of the stability of the pavement, since the damage generated on the structure could be reduced to about 70%.

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