LOAD AGGRESSIVENESS ON DIFFERENT PAVEMENT STRUCTURES DUE TO THE WEIGHT INCREASE OF HEAVY VEHICLES FROM 40 TONNES TO 44 TONNES

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Abstract. The load capacity of goods vehicles is a critical variable in calculating transport costs. In Europe, the *Council Directive 96/53/EC* establishes the maximum weight and dimensions of goods vehicles in international traffic but also allows that any Member State authorises the movement of vehicles that fail to comply with these weights and dimensions within its territory. For this reason, some countries have used this power to introduce internal regulations regarding the maximum transport capacity. A case of particular interest discussed in this article is the vehicle with five axles (two tractor axles and 3-axle semitrailer), which is only allowed a maximum weight of 40 t by the Directive above. While some countries allow a maximum weight of 44 t when circulating within their territories, the limitation in Spain has been established by the *Council Directive 96/53/EC* of 25 July 1996 40 t, although this restriction is often discussed by the different agents related to the transport of goods by road. Therefore, this paper analyses the effect of T2S3 vehicles loaded with 42 t and 44 t on sections of flexible and semi-rigid pavements of the Spanish road

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network, to provide information about the impacts of the modification of the regulations on capacity.

Keywords: flexible pavements, heavy vehicles, maximum permitted weight, pavement design, semi-rigid pavements.

Introduction

The load capacity of goods vehicles is a critical variable in calculating transport costs. In Europe, there is a *Council Directive 96/53/EC* of 25 July 1996 laying down for certain road vehicles circulating within the Community the maximum authorised dimensions in national and international traffic and the maximum authorised weights in international traffic. This Directive establishes the maximum weight and dimensions of goods vehicles in international traffic but also allows that any Member State authorises the movement of vehicles that fail to comply with these weights and dimensions within its territory, and for this reason, some countries have used this power to introduce internal regulations regarding the maximum transport capacity.

A case of particular interest, discussed in this article, is the vehicle with five axles (two tractor axles and 3-axle semitrailer – commonly called T2S3), which is only allowed a maximum weight of 40 t by the Directive above. Countries such as France, Italy, Belgium and Luxembourg, allow a maximum weight of 44 t when circulating within their territories, but others, such as Denmark, Czech Republic and Greece, allow no more than 42 t (International Transport Forum, 2016). In Spain, the limitation has been established by the European Directive 40 t (Dirección General de Tráfico,… 2013), although this restriction is often discussed by the different agents related to the transport of goods by road (Alianza por la competitividad…, 2013).

The internal transport of goods among member states of the EU represents approximately 75% of tonne-km, (European Commission Directorate-General…, 2014), and in Spain, according to the *Observatorio del Transporte de Mercancías por Carretera* (Gobierno de España, 2016), it accounted for almost 79% in 2014, and has exceeded 83% in previous years.

The advantages associated with a change in the capacity of these vehicles are reducing fuel consumption and emission of greenhouse gases. Although fuel consumption increases with vehicle weight, specific fuel consumption is reduced when the variable analysed is the amount of litters per ton-km of goods transported, since the amount of travel required is reduced, as has been demonstrated by Hedberg (2008). It is expected therefore to reduce CO_2 emissions by reducing

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fuel consumption, a fact commented on studies such as Leonardi & Baumgartner (2004).

The counterpart of these benefits is presented when the effect of this overload on the road infrastructure is evaluated. By increasing the axle load, the stress transmitted to the pavement also increases and therefore, it is necessary to determine the potential aggressiveness of maximum mass change. This topic has been the subject of studies focused on maximum vehicle mass 60 t, also known as mega truck, or officially as a vehicle for euro-modular configuration, (Díaz, Echaveguren, & Vargas-Tejeda, 2012; Leduc, 2009; Steer, Dionori, Casullo, Vollath, Frisoni, Carippo, & Ranghetti, 2013).

The effect caused by vehicles on the pavement depends on the configuration of vehicle load and also on other variables such as the volume of the moving vehicle, the pavement structure and climatic conditions. The load repetitions combined with all these features will damage the pavement, causing typical distresses as fatigue cracking, rutting, and lack of roughness. In order to assess the impact of repetition of different axle loads, it is frequently used the concept of Equivalent Axle Load (ESALs) as well as the law of the fourth power, derived from the American Association of State Highway and Transportation Officials (AASHO) Road Test in the USA (Highway Research Board, 1961).

For the previous reasons, this paper analyses the effect of T2S3 vehicles loaded with 42 t and 44 t on sections of flexible and semi-rigid pavements of the Spanish road network. The objective is to provide information about the impacts and benefits of the modification of the regulations on capacity.

2.   Methodology

The work methodology consisted of calculating the stress state of different pavement structures analysed when they are subjected to the axle loads of heavy vehicles type T2S3, considering different load configurations (15.5 t, 40 t, 42 t and 44 t).

The pavement structures analysed correspond to those defined as flexible and semi-rigid sections from the Spanish Guidelines *Norma 6.1-IC "Secciones de firme", aprobada por la Orden FOM 3460/2003.*

The elastic multilayer model developed by Burmister, Palmer, Barber, & Middlebrooks (1944), was used for the calculation of the stress-strain state of these structures. This model assumes that the pavement is composed of horizontal layers of constant thickness that extend infinitely in the horizontal direction and supported on a homogeneous semi-infinite space (subgrade). Each layer and the subgrade are assumed

to be linearly elastic, isotropic, continuous and homogeneous media, mechanically characterised by its Young modulus (E) and Poisson ratio (υ).

The determined parameters are the maximum horizontal strain in the lower fibre of the asphalt mixture layers, εh, and maximum horizontal stress in the lower fibre of the cement-treated layer σh. Both parameters have allowed assessing the aggressiveness of each of the heavy vehicles on the evaluated pavements.

To determine these parameters, Freeware BISAR 3.0 *Stress Analysis in Bitumen Roads*, developed by Shell, was used. The aggressiveness of each truck was calculated from the damage caused by the passage of their axles on a pavement, defined by Eqs (1) and (2) (Corté & Goux, 1996; Kerzreho, Hornych, Chabot, Trichet, Gouy, Coirier, & Deloffre, 2012).

$$A_i = \left(\frac{\varepsilon_i}{\varepsilon_0} \right)^\alpha - \text{for flexible pavements} \tag{1}$$

and

$$A_i = \left(\frac{\sigma_i}{\sigma_0} \right)^\alpha - \text{for cement-treated layers in semi-rigid pavements,} \tag{2}$$
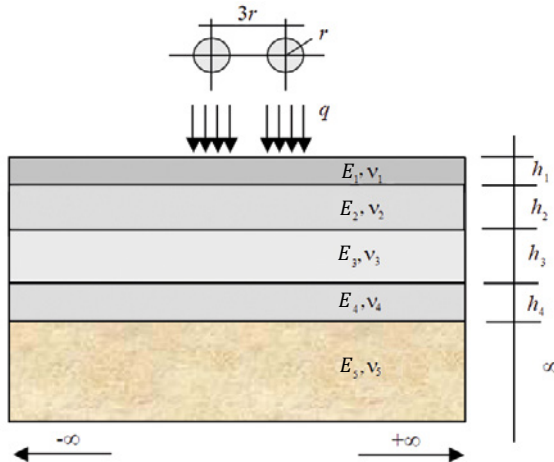
where A_i – the aggressiveness caused by one axle; ε_i – the horizontal strain in the lower fibre of the layers of asphalt mixture due to the analysed axle; ε_0 – the horizontal strain in the lower fibre of the layers of asphalt mixture due to the reference axle; σ_i – the horizontal stress in the lower fibre of the cement-treated layers due to the analysed axle; σ_0 – the horizontal stress in the lower fibre of the cement-treated layers due to the reference axle; α – the coefficient associated with the slope of the fatigue law of the materials.

The aggressiveness of a heavy vehicle, A_{VP} is the sum of the aggressiveness of each of its axles Eq. (3):

$$A_{VP} = \sum_{i=1}^{n} A_i. \tag{3}$$

Coefficient α for the calculation of the aggressiveness of each load configuration was selected based on two hypotheses:
- hypothesis A – proposed by the French SETRA (Dauzats, Kobisch, Leroux, Odeon, Maribas, & Delorme, 2003; Service d'Etudes Techniques…, 1994, 2009), of 5 for asphalt materials and 12 for cement-treated materials. These values were considered with the

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Note: r – radius of a circle with the same contact area of the tyre print,
r = 0.125 m; P – standard axle load with dual wheels of 13 t (used in Spain
and France for the pavement design). The axle has four wheels, P = 3.25 t;
q – contact pressure, resulting from the division between P and the contact area,
q = 0.662 MPa; E_i and υ_i – Young Modulus and the Poisson ratio of each layer
of pavement; h_i – the thickness of each pavement layer.

Figure 1. Configuration of tyres for the standard axle over a multi-layered
pavement characterised by Elastic modulus (E_i), Poisson ratio (υ_i) and layer
thickness (h_i)

aim of comparing the results with those usually taken as reference
in Spain, hypothesis B because these are more conservative;
  • hypothesis B – proposed by the *Normas de Secciones de Firmes
    de la Comunidad Valenciana* (Conselleria d'Infraestructures
    i Transport, 2009) and Kraemer, Pardillo, Rocci, Romana, Sánhez
    & del Val (2004), of 4 and 8, respectively. These values are usually
    considered in the Spanish pavement design procedure.

A single axle with dual tyres loaded with 13 t was considered as a
standard. Following the methodology developed by SETRA (Service
d'Etudes Techniques..., 2009), the data considered for the reference axle
is shown in Figure 1.

2.1. Pavement sections analysed

Flexible and semi-rigid pavement sections from the catalogue of the
Norma 6.1-IC were analysed, ranging from the highest traffic category
(called T00) to the lowest one (T42), supported on two subgrade

Table 1. Heavy traffic categories

Heavy vehicle traffic categories	T00	T0	T1	T2	T31	T32	T41	T42
$AADT_{hv}$ Annual Average Daily Traffic of Heavy Vehicles, first year	no less than 4000	from 399 to 2000	from 199 to 800	from 799 to 200	from 199 to 100	from 99 to 50	from 49 to 25	below 25

Table 2. Subgrade categories

Subgrade categories	S1	S2	S3
E_{v_2}, MPa	no less than 60	no less than 120	no less than 300

categories: S1 and S3, being the ones with the lowest and highest bearing capacity respectively. Traffic categories correspond to the volume of heavy vehicles considered in the projected lane, , in the first year of the road service and are defined in Table 1. The subgrade categories are discriminated by the deformation modulus in the second loading cycle, E_{v_2}, it is obtained from the load plate test, as it is shown in Table 2.

The 12 structural sections analysed correspond to equivalent solutions of flexible and semi-rigid pavements for the traffic categories T00, T1, T31 and T41, all supported on subgrades type S1 and S3; and are described in Table 3. In the case of semi-rigid pavements, only sections composed of asphalt mixture layers over soil-cement bases were studied because they are frequently used. Sections with gravel-cement bases (also admissible in the Spanish pavement catalogue) were discarded because of their lack of use.

Young modulus and the Poisson ratio for the characterisation of the different layers are presented in Table 4, selected from previous experience. In addition, full adhesion between the layers of the pavement was assumed in the definition of the sections.

2.2. Load configuration of T2S3 heavy vehicle

This heavy vehicle is the most frequent long-distance vehicle in Europe, the 2-axle tractor with a 3-axle semi-trailer, as shown in Figure 2.

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Table 3. Pavement sections studied

Pavement type	Traffic category	Subgrade	Thickness, cm		
			Asphalt mixture	Granular base	Soil-cement
Flexible	T00	S1	*	*	–
		S3	35	25	–
	T1	S1	*	*	–
		S3	25	25	–
	T31	S1	20	40	–
		S3	16	25	–
	T41	S1	10	40	–
		S3	10	20	–
Semi-rigid	T00	S1	*	–	*
		S3	25	–	30
	T1	S1	*	–	*
		S3	20	–	20
	T31	S1	15	–	20
		S3	12	–	22
	T41	S1	8	–	30
		S3	8	–	20

Note: *there are no pavement sections for the combination of traffic and subgrade T00-S1 and T1-S1 in the Spanish pavement catalogue.

Table 4. Young modulus and Poisson ratio of the layers considered in the analysis

Material	Young modulus, MPa	Poisson ratio
Asphalt mixture	5000	0.35
Granular base	200 over S1 500 over S3	0.30
Soil-cement	1500	0.25
Subgrade S1	50	0.40
Subgrade S3	260	0.40

Figure 2. Heavy vehicle T2S3 configuration (modified drawing from the Federal Highway Administration, 2016)

The vehicle consists of:
- a single axle with single tyres;
- a single axle with dual tyres;
- a tridem axle with single or twin tyres.

The impact of its axles was analysed, considering the tridem axles with single tyres as these are the most representative of the fleet, and they cause the most critical situation regarding the load distribution.

Four different maximum weights were considered – 15.5 t (simulating the empty vehicle to account for return trips) and 40 t, 42 t and 44 t (for the loaded scenarios). The particular characteristics of each axle and tyre are:

- wheelbase and load distribution – for a heavy vehicle with 40 t the wheelbase and load distribution used were those recommended by a similar study developed in France (Ministère de l'écologie,… 2011), keeping axle loads below the maximum values allowed in Spain, and the weight of front axle constant. For the empty vehicle, a weight of 15.5 t was estimated. The maximum loads per axle are regulated by Annex IX of the Spanish General Vehicle Regulations (Orden PRE/2788/2015,…, 2015), and are summarised below:
- the maximum permitted weight per drive axle – 11.5 t;
- the maximum permitted weight per tridem axle – 21 t (wheelbase shorter than 1.30 m), 24 t (wheelbase longer 1.30 m and shorter than 1.40 m);
- contact pressures – 0.662 MPa for single axles and 0.700 MPa for tridem axles with single tyres, by the recommendation of SETRA (Service d'Etudes Techniques, 2009);
- the radius of tyre contact – keeping the contact pressure of the tyre on the pavement, the radius of the circle with an equivalent area was calculated.

3. Results and discussion

3.1. Coefficient of aggressiveness – hypothesis A ($\alpha = 5$ – for layers of asphalt mixtures and $\alpha = 12$ – for the layers of soil-cement)

The results of aggressiveness calculated for the vehicle with different weights (15.5 t, 40 t, 42 t and 44 t), concerning the reference axle (13 t), calculated for the selected pavement sections, are presented below. Failure parameters considered were those related with fatigue cracking:

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the horizontal tensile strain at the bottom of the asphalt layer for flexible and semi-rigid pavements; and the horizontal tensile stress at the bottom of the soil-cement layer for semi-rigid pavements additionally.

The results of the aggressiveness of heavy vehicles on the pavement sections show rising trends as the layer thicknesses of each section are reduced, Figures 3 and 4. In traffic categories T31 and T41, it is also observed that sections of flexible pavements on the best subgrade (S3) have more aggressiveness, possibly because the high bearing capacity of S3 is unable to compensate the reduction of the thickness of the pavement layers. In the case of semi-rigid pavements, the same behaviour is observed for both failure criteria (asphalt mixture and soil-cement layers), except for the section of traffic T41 and the criterion of the asphalt mix layer, since here the aggressiveness increases when using subgrade S1.

Second, the ratio between the coefficients of aggressiveness of the empty vehicle with 15.5 t, and loaded with 42 t and 44 t, with respect to the vehicle loaded with 40 t, were calculated and the results are collected in Tables 5–7, to make a comparison to the reference considered truck (40 t).

It was impossible to calculate the stress state of some pavement sections corresponding to the lowest traffic category (T41) because of the limitations of the calculation method. Moreover, it is recommended to avoid analytical design methods for pavement sections of this traffic
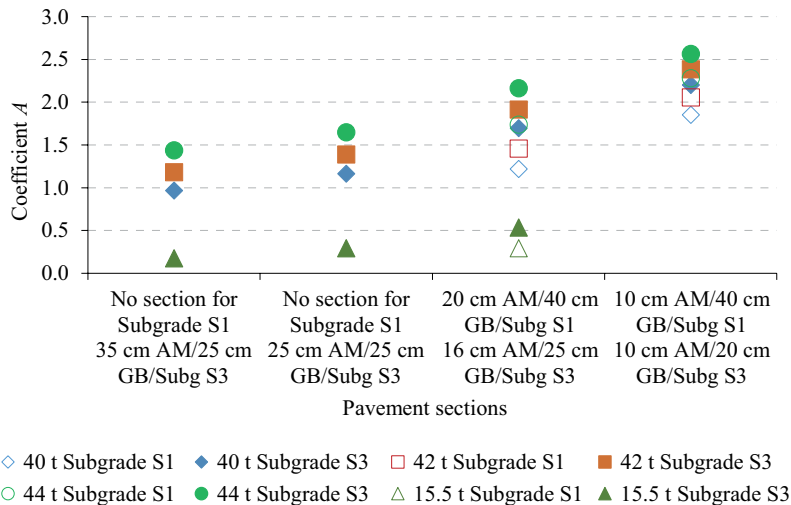
Note: failure criterion in the asphalt mixture layer. Hypothesis A.

Figure 3. Aggressiveness coefficient for a heavy vehicle on flexible pavements
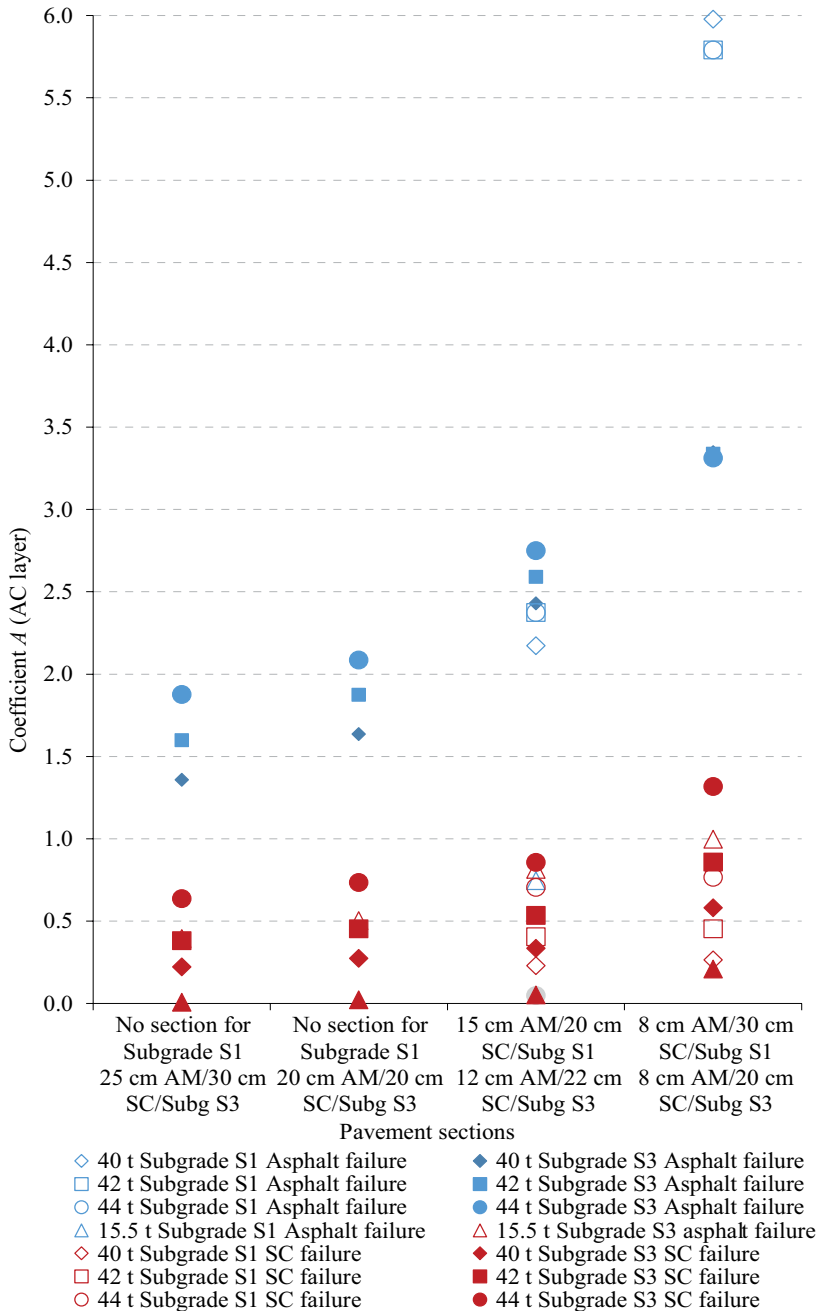
Note: failure criteria in both the asphalt mixture and the soil-cement. Hypothesis A.

Figure 4. Aggressiveness coefficient for a heavy vehicle on semi-rigid pavements

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Table 5. Aggressiveness coefficients ratio between a heavy vehicle with 15.5 t and 40 t. Hypothesis A

Pavement, traffic category, subgrade category	Flexible pavements			Semi-rigid pavements					
	Strain at the bottom								
	of the asphalt mixture layer						of soil-cement layer		
	A_iAC		RAC	A_iAC		RAC	A_iSC		RSC
	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t
T00 S3	1.19	0.18	0.15	1.59	0.39	0.25	0.44	0.01	0.02
T1 S3	1.40	0.29	0.21	1.85	0.50	0.27	0.53	0.02	0.04
T31 S3	1.90	0.54	0.28	2.54	0.82	0.32	0.65	0.05	0.08
T31 S1	1.45	0.29	0.20	2.32	0.75	0.32	0.49	0.05	0.10
T41 S3	2.34	–	–	3.27	1.00	0.31	1.00	0.21	0.21
T41 S1	2.04	–	–	5.15	–	–	0.54	–	–

Table 6. Aggressiveness coefficients ratio between a heavy vehicle with 42 t and 40 t. Hypothesis A

Pavement, traffic category, subgrade category	Flexible pavements			Semi-rigid pavements					
	Strain at the bottom								
	of the asphalt mixture layer						of soil-cement layer		
	A_iAC		RAC	A_iAC		RAC	A_iSC		RSC
	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t
T00 S3	0.97	1.18	1.22	1.36	1.60	1.18	0.22	0.38	1.71
T1 S3	1.17	1.39	1.19	1.64	1.87	1.15	0.27	0.45	1.66
T31 S3	1.70	1.92	1.13	2.43	2.59	1.07	0.34	0.53	1.60
T31 S1	1.22	1.46	1.20	2.17	2.37	1.09	0.23	0.41	1.76
T41 S3	2.20	2.38	1.08	3.35	3.34	1.00	0.58	0.86	1.48
T41 S1	1.85	2.06	1.11	5.98	5.79	0.97	0.26	0.45	1.72

category because it is known that these sections are not exhausted by fatigue phenomena but by the action of overloads (Kraemer & Albeda, 2004).

When trucks are loaded, the load aggressiveness on flexible pavements is similar to the load aggressiveness on semi-rigid pavements when strain under the asphalt layer is analysed, but when the stress under the soil-cement layer is studied, aggressiveness is much higher

Table 7. Aggressiveness coefficients ratio between a heavy vehicle with 44 t and 40 t. Hypothesis A
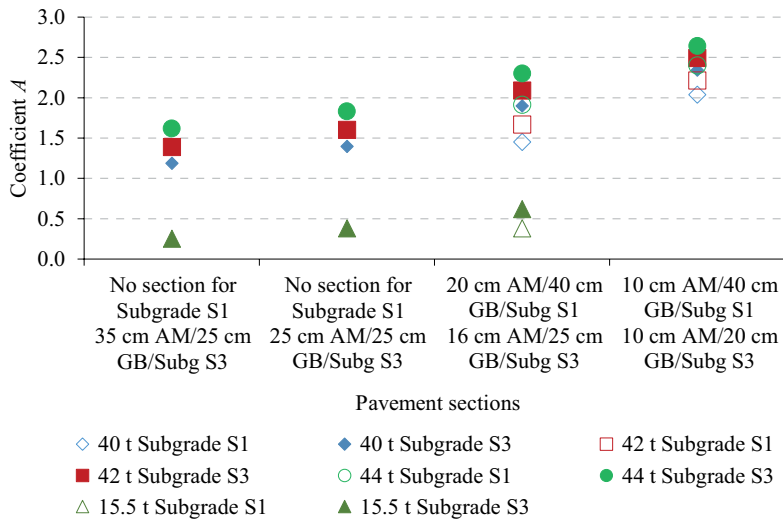
Pavement, traffic category, subgrade category	Flexible pavements			Semi-rigid pavements					
	Strain at the bottom								
	of the asphalt mixture layer						of soil-cement layer		
	A_iAC		RAC	A_iAC		RAC	A_iSC		RSC
	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t
T00 S3	0.97	1.44	1.49	1.36	1.88	1.38	0.22	0.64	2.86
T1 S3	1.17	1.65	1.42	1.64	2.09	1.28	0.27	0.74	2.68
T31 S3	1.70	2.16	1.28	2.43	2.75	1.13	0.34	0.86	2.56
T31 S1	1.22	1.74	1.43	2.17	2.58	1.19	0.23	0.71	3.06
T41 S3	2.20	2.57	1.16	3.35	3.31	0.99	0.58	1.32	2.27
T41 S1	1.85	2.28	1.23	5.98	5.58	0.93	0.26	0.77	2.90

than the previous conditions, for both cases, with 42 t and 44 t, as reflected in Tables 6 and 7.

The most critical sections are the 0032, 3112 and 4112 for vehicles loaded with 42 t and 44 t (indicated in red in Tables 6 and 7), where the highest ratio corresponds to the failure in the soil-cement layer. It is interesting to highlight that there are some pavement sections at which the ratio of aggressiveness of 42/40 is higher than that of 44/40. In these cases, the load increase at constant pressure (assumed hypothesis) requires increasing the tire-pavement contact area, causing a decrease in the evaluated parameter (ε_i), especially in pavements with the lowest thickness of asphalt mixture (semi-rigid pavements with T41).

3.2. Coefficient of aggressiveness – hypothesis B (α = 4 – for layers of asphalt mixtures and α = 8 – for the layers of soil-cement)

Following the same procedure used in the previous stage, the results of the coefficient of aggressiveness for the vehicle with different weights (15.5 t, 40 t, 42 t and 44 t) with respect to the reference axle (13 t), calculated for the selected structural sections, are presented below, Figures 5 and 6.
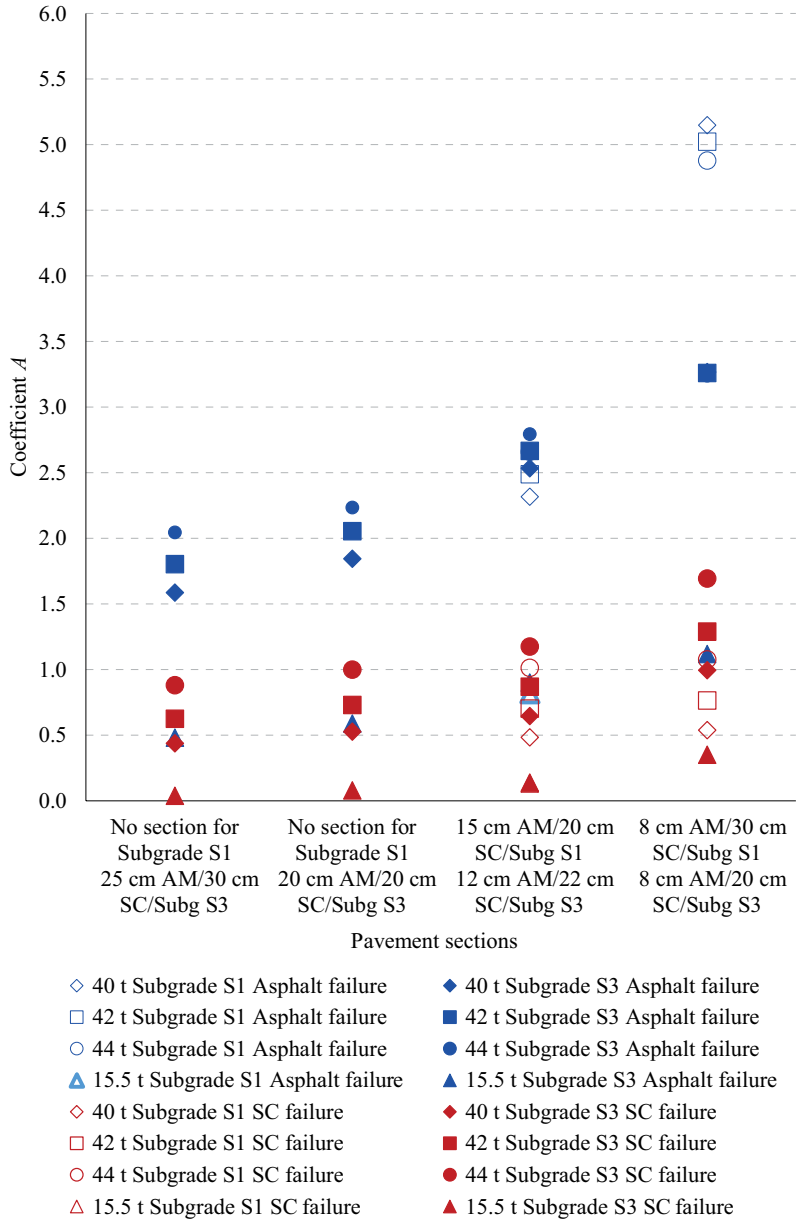
Note: Failure criterion in the asphalt mixture layer. Hypothesis B.

Figure 5. Aggressiveness coefficient for a heavy vehicle on flexible pavements.

Table 8. Aggressiveness coefficients ratio between a heavy vehicle with 15.5 t and 40 t. Hypothesis B

Pavement, traffic category, subgrade category	Flexible pavements			Semi-rigid pavements					
	Strain at the bottom								
	of the asphalt mixture layer						of soil-cement layer		
	A_iAC			RAC			A_iAC		RAC			A_iSC		RSC
	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t
T00 S3	1.19	0.25	0.21	1.59	0.48	0.30	0.44	0.04	0.09
T1 S3	1.40	0.38	0.27	1.85	0.59	0.32	0.53	0.08	0.15
T31 S3	1.90	0.62	0.33	2.54	0.90	0.36	0.65	0.14	0.22
T31 S1	1.45	0.38	0.26	2.32	0.82	0.35	0.49	0.13	0.27
T41 S3	2.34	–	–	3.27	1.12	0.34	1.00	0.35	0.35
T41 S1	2.04	–	–	5.15	–	–	0.54	–	–

Note: failure criteria in both the asphalt mixture layer and soil-cement layer. Hypothesis B.

Figure 6. Aggressiveness coefficient for a heavy vehicle on semi-rigid pavements

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Analogous to the analysis under the hypothesis A, the ratio between the coefficients of aggressiveness for empty vehicles with 15.5 t, loaded with 42 t and 44 t concerning the vehicle loaded with 40 t, was calculated for hypothesis B, Tables 8–10. Average, maximum and minimum values of all ratios for both hypotheses are collected in Figure 7 to have a global view of the results.

The coefficients for the empty vehicle with 15.5 t are shown in Table 8. As happened in the analysis of hypothesis A, it was impossible to

Table 9. Aggressiveness coefficients ratio between
a heavy vehicle with 42 t and 40 t. Hypothesis B

Pavement, traffic category, subgrade category	Flexible pavements			Semi-rigid pavements					
				Strain at the bottom					
	of the asphalt mixture layer						of soil-cement layer		
	A_iAC		RAC	A_iAC		RAC	A_iSC		RSC
	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t
T00 S3	1.19	1.39	1.17	1.59	1.81	1.14	0.44	0.63	1.42
T1 S3	1.40	1.60	1.15	1.85	2.05	1.11	0.53	0.73	1.38
T31 S3	1.90	2.09	1.10	2.54	2.67	1.05	0.65	0.87	1.35
T31 S1	1.45	1.67	1.15	2.32	2.49	1.07	0.49	0.70	1.45
T41 S3	2.34	2.49	1.06	3.27	3.26	1.00	1.00	1.29	1.30
T41 S1	2.04	2.22	1.09	5.15	5.02	0.98	0.54	0.76	1.42

Table 10. Aggressiveness coefficients ratio between
a heavy vehicle with 44 t and 40 t. Hypothesis B

| Pavement, traffic category, subgrade category	Flexible pavements			Semi-rigid pavements					
				Strain at the bottom					
	of the asphalt mixture layer						of soil-cement layer		
	A_iAC		RAC	A_iAC		RAC	A_iSC		RSC
	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t	40 t	44 t	$\frac{44}{40}$ t
T00 S3	1.19	1.62	1.36	1.59	2.05	1.29	0.44	0.88	2.00
T1 S3	1.40	1.83	1.31	1.85	2.23	1.21	0.53	1.00	1.89
T31 S3	1.90	2.30	1.21	2.54	2.80	1.10	0.65	1.18	1.82
T31 S1	1.45	1.91	1.32	2.32	2.66	1.15	0.49	1.01	2.09
T41 S3	2.34	2.64	1.13	3.27	3.24	0.99	1.00	1.69	1.70
T41 S1	2.04	2.40	1.18	5.15	4.88	0.95	0.54	1.08	2.00
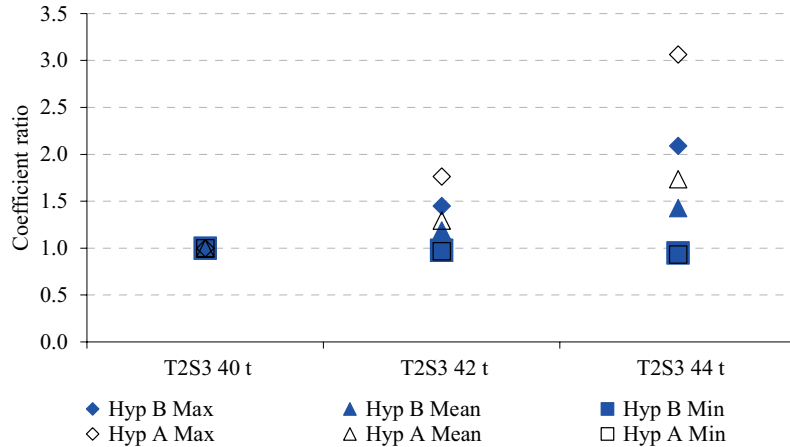
Figure 7. Maximum, minimum and mean values of the coefficient ratio

calculate the stress state of some structures corresponding to the lowest traffic category (T41) by the limitations of the method.
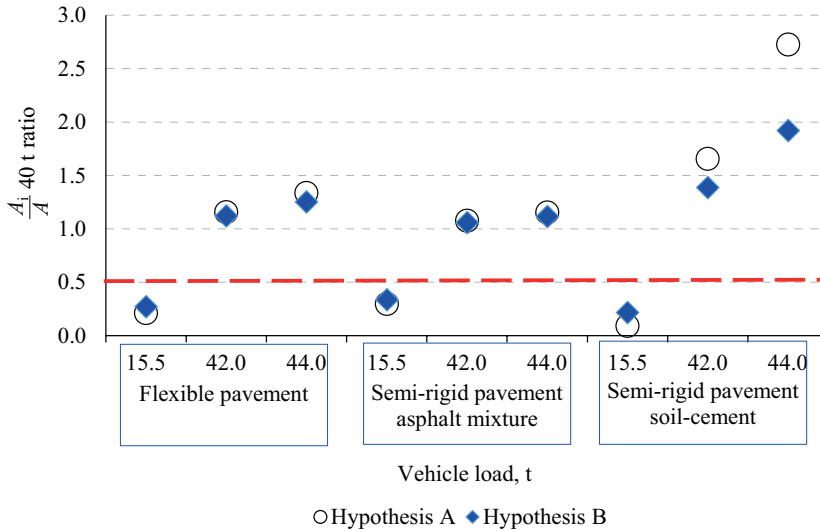
Following the same trend as the results obtained under the hypothesis A, the ratios calculated for the loaded vehicles show that the three most critical sections of semi-rigid pavements for vehicles with 42 t and 44 t, are those of sections 0032, 3112 and 4112, indicated in Tables 8 and 9 in red.

3.3. Comparison of the results with both hypotheses

Under hypothesis A, going from 42 t to 44 t means an increase of aggressiveness between 7% and 22% (depending on the section considered) in the case of flexible pavements. For semi-rigid pavements, the increase varies from 0% to 17% when the criterion of the asphalt layer is considered and from 53% and 73% when the stress under the soil-cement layer is analysed.

Under hypothesis B, the increase of aggressiveness when changing from 42 t to 44 t in flexible pavements ranges between 6% and 16%; and there is a similar variation for semi-rigid pavements, from 0% to 13%, when asphalt layers are analysed; and between 30% and 40% when soil-cement layers are evaluated. The notable difference among the results obtained with both hypotheses shows the sensitivity of the parameter analysed.

When the maximum coefficients obtained with respect to the truck loaded with 40 t are compared, it is clear that the aggressiveness of a vehicle loaded with 44 t is no more than three times the value of the

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Note: hypotheses A and B.

Figure 8. Mean values of the ratios between the coefficients
of aggressiveness of each load and 40 t

aggressiveness of a vehicle loaded with 40 t with the hypothesis A
(ratio 3.06), and no more than twice the value with the hypothesis B
(ratio 2.09).

To conclude this section, the mean values of the ratios presented in
the above tables for each vehicle weight analysed over each pavement
type and under the two hypotheses, are collected in Figure 8. From the
comparison of these results, it is clear that the soil-cement layer in semi-
rigid pavements is the critical factor.

Conclusions

The objective of this study was to evaluate the aggressiveness
caused by a heavy vehicle type T2S3 (two tractor axles and 3-axle
semitrailer) when its maximum weight increases from 40 t (maximum
value authorised in Spain) to 42 t and 44 t, considering that other
European countries admit these two limits. Different sectors of
society are currently discussing the possibility of increasing Spanish
restriction.
  1. The calculations of the stresses and strains caused by this heavy
     vehicle on the pavement were performed, taking into account two

different hypotheses (A and B). Hypothesis A is used in France, where there is extensive experience in this type of studies and where the circulation of vehicles with 44 t is allowed. Hypothesis B is usually recommended in Spanish literature. Both hypotheses differ from each other by the value of the factor-alpha (coefficient associated with the slope of the fatigue law of the materials) used in the calculation of aggressiveness.

2. The results obtained show that there are no significant differences under both hypotheses in the case of flexible pavements and the case of semi-rigid pavements when the failure criterion used is that of the asphalt mixture. However, the differences are significant when analysing the case of semi-rigid pavements, and the failure criterion is applied to the soil-cement layer. For these reasons, the authors consider that hypothesis A, proposed by the French Service d'Etudes Techniques des Routes et Autoroutes *Incidence des PL sur les coûts de construction des chaussées neuves*, with an alpha coefficient of 5 for asphalt mixtures and 12 for soil-cement must be used in the case of semi-rigid pavements to adopt a much more conservative position and ensure the good behaviour of the pavements.

3. From the study carried out, the results reveal that when the load of the heavy vehicle goes from 40 t to 44 t, the aggressiveness increases no more than 1.49 in flexible pavements and 3.06 in semi-rigid pavements.

4. The usefulness of the study conducted resides in potentially estimating the impact that a change in the legislation on the maximum permitted load in the vehicles studied will cause. On the one hand, the detrimental effect of the increased load on pavements must be evaluated, taking into account the proportion of heavy vehicles T2S3 type present in the vehicle fleet and the potential transfer of weight. On the other, advantages such as reducing the specific fuel consumption and greenhouse gas emissions, reduction of the vehicle density in circulation (improvement of the level of service) and optimisation of freight transport, must also be considered.

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