PAVEMENT AND BRIDGE IMPACT ASSESSMENT OF VEHICLES WITHIN PROJECT FALCON

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Abstract

Traffic has a damaging effect on infrastructures. Concerning pavements and bridges, this damage is linked to the weights and dimensions of heavy truck traffic. Therefore, assessing and comparing the effect of various types of trucks on infrastructure is important.

In this article, the article presents the work done within CEDR project FALCON: representative European infrastructure has been selected, with its design criteria. Then the truck fleet developed within the project has been assessed on these infrastructure elements. For both pavements and bridges, the underlying assumptions for assessment are given, the structures to be assessed are given and some conclusions are drawn.

It is shown that a given truck may be damaging for one type of infrastructure, but not for another. Therefore, it is important to assess the vehicles on a representative road network.

Keywords: Traffic, impact on pavements, impact on bridges, damage.

1. Introduction

Project FALCON has been devoted to "Freight And Logistics in a Multimodal Context". Work Package C has created a well-described fleet of existing vehicles all around the world (Deliverable 3.1), a notional infrastructure catalogue and their design criteria (Deliverable 3.2 and 3.4) and the assessment of the damage and the behavior of this fleet on this infrastructure (Deliverable 3.5).
The FALCON fleet is described in Deliverable 3.1 or the FALCON project: it consists of 27 trucks, divided in 6 groups. It only contains high-capacity vehicles and group 1, for example, gathers vehicles currently in use on the roads in Europe.
For the damage on infrastructure, the impact on pavements and on bridges has been assessed. In Section 2, we present the assumptions leading to our methodology and our calculations, the pavements that have been assessed and the conclusions that have been drawn. Section 3 presents the same elements for bridges. Afterwards a conclusion gives some general ideas on the impact on infrastructure of this FALCON fleet.

2. Impact assessment on pavements

Prior to road construction, the road pavement is designed with a lifetime expectancy limited to a few decades, usually 20 to 40 years. It is expected that during this period the pavement will be subject to various weather conditions and to a whole spectrum of traffic loads. These are the main factors influencing pavement wear. In the design phase, the road structure is usually represented by a multi-layer model and the expected traffic loads are usually expressed in a number of standard axle loads. The effect of an axle load on the multi-layer model is expressed in strains or stresses at different depths. Fatigue laws for the materials in the road structure are used to determine the expected lifetime. The limitation of a maximal allowed axle load for vehicles limits the strains and stresses imposed to the pavement by the vehicles.
However, existing roads were designed for truck combinations that existed or that could be imagined at the time when the design was done. Hence, for a road manager the assessment of the impact of newly developed truck combinations on existing pavements is important.

2.1 Hypotheses, Approach and Limitations

Materials and layer thicknesses in pavements are very different throughout Europe. For the computations in the FALCON project only 4 road structures were considered. Amongst the 27 truck combinations under investigation in FALCON, 6 were selected for assessment.
The software Alizé-LCPC for pavement structures analysis and design (see Balay (2013)) was used. A linear elastic multi-layer model represented the road structures and their behavior. The truck combinations were completely modelled in the software. In addition, a single standard axle of 100 kN was modelled and was used as reference load. Theoretical strains and stresses generated by the truck loads at different depths in the road structure were computed with this software.
The use of a linear elastic multi-layer model is quite common for the design of new pavements and for the evaluation of existing pavements. By doing so, we do not take into account the viscosity properties of some of the pavements. However, in most countries the use of software that can model the viscosity is not common practice.
Variations in temperature between different seasons are not taken into account. The computations are based upon elasticity moduli of the materials at 15°C, assumed here as the average temperature over the year. The climate conditions throughout Europe are very different and this disparity could not be taken fully into account in these computations. The particular case of frost actions including thaw cycles would need additional computations.

Since the objective of the computations presented here was to compare different axle loads and trucks under the same conditions (and not their overall performance all over Europe under all possible conditions) these simplifications are acceptable.

2.2 Chosen Truck Combinations and Infrastructures

Table 1, Table 2 and Table 3 show the 6 chosen truck combinations. Trucks 1.3 and 2.1 are currently in use on European roads and are here considered as reference trucks. Trucks 3.1, 4.5, 5.1 and 6.1 are designs for LHVs. Two series of computations have been made: one series with all 6 truck combinations on all 4 pavements and one series with 3 of the truck combinations carrying more load (expressed as different Gross Vehicle Combination Mass – GCM) on the "thick bituminous" pavement only.

Table 1: Chosen truck combinations and their GCM for the first series of computations.

		Vehicle configuration															
Vehicle	Vehicle description	Unit 1	Unit 2	Unit 3	Unit 4	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	Axle 8	Axle 9	Axle 10	Axle 11	GCM
1,3	TR4x2-ST3 (13.6m)	TR4x2	ST3 13.6			steer LD	drive	trailer	trailer	trailer							
	Distance behind axle 1 (m)					0	3,6	9,335	10,645	11,955							
	Axle load (kg)					6.301	7.511	5.289	5.289	5.289							29.678
2,1	TK6x2-CT2 (2x7.8m)	TK6x2	CT2			steer LD	drive	tag	trailer	trailer							
	Distance behind axle 1 (m)					0	4,8	6,15	12,976	14,786							
	Axle load (kg)					5.973	9.665	5.203	7.285	7.285							35.412
3,1	TR6x4-ST3-CT3(45ft+20ft)	TR6x4	ST3 45ft	CT3		steer HD	drive	drive	trailer	trailer	trailer	trailer	trailer	trailer			
	Distance behind axle 1 (m)					0	3,3	4,65	9,595	11,005	12,315	17,92	19,22	20,52			
	Axle load (kg)					6.174	5.326	5.326	6.345	6.345	6.345	3.806	3.806	3.806			47.280
4,5	TK6x4-CT2-CT2 (3x7.8m)	TK6x4	CT2	CT2		steer HD	drive	drive	trailer	trailer	trailer	trailer					
	Distance behind axle 1 (m)					0	4,8	6,15	13,03	14,84	21,62	23,43					
	Axle load (kg)					6.627	7.519	7.519	7.638	7.638	7.232	7.232					51.405
5,1	TR6x4-ST3-DY2-ST3 (2x45ft)	TR6x4	ST3 45ft	DY2	ST3 45ft	steer HD	drive	drive	trailer	trailer	trailer	dolly	dolly	trailer	trailer	trailer	
	Distance behind axle 1 (m)					0	3,3	4,65	9,595	11,005	12,315	17,225	18,625	23,995	25,405	26,715	
	Axle load (kg)					6.208	5.547	5.547	5.735	5.735	5.735	5.359	5.548	5.723	5.723	5.723	62.581
6,1	TK6x4-DY2-LT2-ST3 (4x7.8m)	TK6x4	DY2/s1	LT2	ST3/s3 2x7.8	steer HD	drive	drive	dolly	dolly	dolly	dolly	trailer	trailer	trailer		
	Distance behind axle 1 (m)					0	4,8	6,15	10,55	11,95	18,255	20,065	28,32	29,63	30,94		
	Axle load (kg)					6.767	7.248	7.248	6.007	6.007	9.225	9.225	6.422	6.422	6.422		70.993

Table 2: Chosen truck combinations and their GCM for the second series of computations.

		Vehicle configuration															Iter 2
Vehicle	Vehicle description	Unit 1	Unit 2	Unit 3	Unit 4	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	Axle 8	Axle 9	Axle 10	Axle 11	GCM (kg)
2,1	TK6x2-CT2 (2x7.8m)	TK6x2	CT2			steer LD	drive	tag	trailer	trailer							
	Distance behind axle 1 (m)					0	4,8	6,15	12,976	14,786							
	Axle load (kg)					6.439	12.052	6.731	9.526	9.526							44.273
3,1	TR6x4-ST3-CT3(45ft+20ft)	TR6x4	ST3 45ft	CT3		steer HD	drive	drive	trailer	trailer	trailer	trailer	trailer	trailer			
	Distance behind axle 1 (m)					0	3,3	4,65	9,595	11,005	12,315	17,92	19,22	20,52			
	Axle load (kg)					6.499	6.620	6.620	7.990	7.990	7.990	4.808	4.808	4.808			58.132
6,1	TK6x4-DY2-LT2-ST3 (4x7.8m)	TK6x4	DY2/s1	LT2	ST3/s3 2x7.8	steer HD	drive	drive	dolly	dolly	dolly	dolly	trailer	trailer	trailer		
	Distance behind axle 1 (m)					0	4,8	6,15	10,55	11,95	18,255	20,065	28,32	29,63	30,94		
	Axle load (kg)					7.300	9.190	9.190	7.398	7.398	11.662	11.662	8.304	8.304	8.304		88.714

Table 3: Cargo volume and cargo masses considered in both series of computations.

Truck	Internal Volume *V* (usable for transport) [m^3]	Cargo mass [kg] First series of computations	Cargo mass [kg] Second series of computations
1.3	87.0	16317.720	-
2.1	95.8	17968.248	26829.720
3.1	117.5	22038.300	32890.300
4.5	143.7	26952.372	-
5.1	168.6	31622.616	-
6.1	191.6	35936.496	53657.496

Trucks are considered as a sequence of consecutive axle groups. An axle group can consist of one single axle, or can be a tandem axle group or a tridem axle group.

A concrete, a semi-rigid and a thick bituminous structure designed for French traffic class T1, and a fully flexible road structure designed for the lower French traffic class T5 were used.

Table 4 gives the multi-layer models (type of material, layer thickness H, elasticity modulus E and Poisson coefficient ν) for each of the considered road structures.

Table 4: The multi-layer models for "thick bituminous", "semi-rigid", "concrete" and "fully flexible" road structures.

Material (" semi-rigid ")	H (cm)	E (MPa)	ν
BBSG (bituminous concrete)	8.5	5400	0,35
GC3 (cement treated gravel)	22	23000	0,25
GC3 (cement treated gravel)	20	23000	0,25
PF2 (subgrade)	-	50	0,35

Material ("concrete")	H (cm)	E (MPa)	ν
BC5 (concrete)	20	35000	0,25
BC2 (concrete)	18	20000	0,25
PF2 (subgrade)	-	50	0,35

Material ("fully flexible")	H (cm)	E (MPa)	ν
BBSG (bituminous concrete)	5	5400	0,35
GNT3 (untreated granular material)	25	200	0,35
PF2 (subgrade)	-	50	0,35

Material ("thick bituminous")	H (cm)	E (MPa)	ν
BBSG (bituminous concrete)	8.5	5400	0,35
GB3 (base course asphalt material)	10	9300	0,35
GB3 (base course asphalt material)	11	9300	0,35
PF2 (subgrade)	-	50	0,35

Fatigue laws of materials describe the relationship between strains ε_i or stresses σ_i, and the maximum number of repetitions of axle loads before failing of the pavement. In the computations we only consider one criterion of failure: the stress or the strain at one particular depth in the road structure. Hence, for the concrete and semi-rigid pavements only the fatigue law for hydraulically bound materials is used in the computations; for the thick bituminous and flexible pavements only the fatigue law for bituminous materials is used in the computations. The following choices have been made for the four road structures under consideration:

- For the concrete pavement, we considered tensile stress σ_i at a depth of 0,200 m at the bottom of the concrete layer.
- For the semi-rigid pavement, we considered tensile stress σ_i at a depth of 0,305 m under the first layer of "GC3".
- For the thick bituminous pavement, we considered the strain ε_i in the direction of the movement of the truck at a depth of 0,185 m at the bottom of the first layer of "GB3".
- For the flexible pavement, we considered the strain ε_i in the direction of the movement of the truck at a depth of 0,050 m at the bottom of the bituminous layer.

From the strains ε_i or stresses σ_i obtained with the Alizé-LCPC software, we determined the number of repetitions $N_{gr,i}$ of the loads applied by the axle groups before failing of the pavement. For the load applied by the reference axle (a 50kN single wheel of a 100kN single axle) the strains or stresses computed with Alizé-LCPC give rise to the number of repetitions N_{ref} of the load applied by the reference axle before failing of the pavement. For single axles, the fatigue laws can be applied directly. However, tandem and tridem axle groups consist of two or three consecutive axles positioned close to each other so that the strains and stresses imposed by the load of first axle are not relaxed before the next axle applies its load. Therefore, for tandem and tridem axle groups, stresses or strains are taken into consideration under each axle of the axle group and in the middle between two consecutive axles of the axle group. For instance, for a tridem axle group, the stresses or strains give rise to values N_d, N_b and N_f for each of the individual axles in the tridem axle group and then these are combined with Equation (1) to NTR for the axle group as a whole:

$$3\,N_{TR} = \frac{1}{\frac{1}{3}\frac{1}{N_b} + \frac{1}{3}\frac{1}{N_d} + \frac{1}{3}\frac{1}{N_f}} \qquad (1)$$

This approach was presented briefly in Stet, M., Briessinck, M. and Rens, L. (2006), but full details on the approach can be found in Cocu and Pilate (2007).

2.3 Results of Computations and Perspectives

We define the aggressiveness $A_{gr,i}$ of the i-th axle group as the ratio between N_{ref} and $N_{gr,i}$, as in Equation (2):

$$A_{gr,i} = \frac{N_{ref}}{N_{gr,i}} \qquad (2)$$

We then define the aggressiveness A of a truck as the sum of the aggressiveness's Agr,i of all m axle groups of the truck (Equation 3):

$$A = \sum_{i=1}^{m} A_{gr,i} \qquad (3)$$

The values for $N_{gr,i}$ (and N_{ref}) are computed with the formulas given in Cocu and Pilate (2007), and these use only the strain ε_i or stress σ_i at one particular depth in the pavement structure computed with the Alizé-LCPC software. The results for aggressiveness A are presented in Table 5:

Table 5: Aggressiveness A and rankings (R1, R2, R3 and R4) for the trucks on each of the pavements.

	Thick bituminous (first series)		Thick bituminous (second series)		Semi rigid		Concrete		Fully flexible	
	A	R1	A		A	R2	A	R3	A	R4
Truck 1.3	0.68	1			0.09	1	0.39	2	2.45	1
Truck 2.1	1.93	4	3.85		0.55	5	1.00	4	3.20	2
Truck 3.1	1.12	2	1.99		0.10	3	0.37	1	3.44	3
Truck 4.5	2.31	5			0.09	1	1.00	4	4.34	4
Truck 5.1	1.60	3			0.12	4	0.67	3	4.94	5
Truck 6.1	3.03	6	5.76		0.83	6	1.65	6	5.85	6

Since the absolute value of the aggressiveness A also depends on the road structure, these absolute values cannot be compared between different road structures. We therefore propose to look at the rankings between the trucks on the same road structure instead. Adding up the rankings (R = R1+R2+R3+R4) for each truck, we can get an idea about the aggressiveness of each of the considered trucks.

Also, the LHVs can be compared to the most aggressive truck currently on the road: clearly truck 2.1 always has higher values for A than truck 1.3.

We still propose two other ways of ranking. In order to take the internal volume V for cargo for each of the vehicles into account, we propose to compute A/V and proceed again as above. In addition, the ratio between A and V can be divided by the ratio between cargo mass and GCM for each of the trucks and pavements, and then new rankings can be determined. Each of these comparisons can be interpreted individually or combined. For instance, we could compute the average of the rankings in each of the 3 individual interpretations and then rank the trucks accordingly. The latter combined ranking is given in Table 6. For details on these computations we refer to deliverable 3.5 of the FALCON project.

Table 6: Combined rankings of the trucks over all pavement structures.

	Average of the rankings	Combined ranking
Truck 1.3	2.000	1
Truck 2.1	5.250	6
Truck 3.1	2.583	3
Truck 4.5	3.333	4
Truck 5.1	2.667	2
Truck 6.1	5.167	5

The second series of computations do not show a difference in the relative ranking between the trucks: only the absolute value for A increases with higher freight loads.
Since we dispose of the aggressiveness of each axle group, the vehicle constructor can consider this information and slightly modify the design. Since a heavier freight load and its distribution over the truck combination induces other absolute values for the aggressiveness, the transporter can consider these effects when deciding on how to load the to be transported freights in one or more trucks.

3. Impact assessment on bridges

As for the pavements, we present here the assumptions made during the work, the bridges that have been selected for assessment and some elements of conclusion.

3.1 Assumptions, approach, limitations

Design loads and design physical values

This work deals with the design of new infrastructure, and not with the assessment of existing infrastructure. This means that all the information available on the infrastructure is theoretical; indeed, there is no a-posteriori information, obtained on the infrastructure by monitoring or diagnosis. This is the case for the material properties (resistance), the dimensions and design of the infrastructure and for the characteristics of the traffic (volume, loads, etc.). Therefore, the structural behavior of the bridge is the ideal one, not one which would be modified due to cracks, instability of bearings, alkaline-aggregate reaction…
A corollary of this is that models of vehicles obtained from truck manufacturers are used, and not WIM data (or badly loaded trucks) as this might have been done for existing infrastructure assessment against current or longer and heavier trucks.

Design structural behavior

An assumption resulting from the previous one is that the considered infrastructure elements are in nominal shape. Therefore, mathematical equations and physical assumptions used in this report to describe their mechanical behavior are valid. For example, the bridge bearing capacity and structural behavior comply with the physical theories (Saint-Venant principle, material resistances…) used to design them.

It is also assumed that infrastructure is correctly designed against the other actions (than traffic loads), and thus considering the traffic loads as the design loads is relevant.
Therefore, this report only considers structures designed according to the in-service rules with behavior in accordance with the design principles.

Linear elastic behavior of the structure
Another assumption is that the behavior of the structure is linear elastic, meaning that the structure experiences some stresses/strains during the passage of the vehicles, but comes back to a no stress/no strain state when no vehicle is present.
More particularly, this means that extreme loads as high as abnormal loads (for example 400-tonne vehicles) are not treated. These could lead to deformation who would stay in the -some-bridge(s) (residual deformation).
It also means that no dynamic behavior of the bridge is investigated, as for example the combination of vehicle loads and wind loading.

Absence of dynamic amplification
To calculate the effect on the vehicles on the structures, the convolution between the influence lines of the chosen effects with the vehicles (succession of vertical loads with distances between them) is done.
No dynamical amplification is considered, with dynamical amplification factor or complete vehicle-bridge interaction modelling. Indeed, as the main goal in his work is to compare the effect between "theoretical" vehicles, this methodology is valid.
Moreover, complete bridge-vehicle interaction models are time-consuming, therefore not adapted for regulation design, and they integrate many parameters/coefficients that have to be chosen.

Load distributed uniformly on the loading surface
Partners of the project have provided the FALCON representative fleet used for the calculations here, by supposing that the load is well distributed within the truck.
However, it should be noted that damaging vehicles often correspond to vehicles that have been loaded by putting too much load on some parts of the truck. One can cite as example:

- For a semi-trailer (5 axles, 1 steer + 1 drive + 1 tridem), when the load has been put in the front of the trailer, the second axle (driving axle) is often heavily loaded; in this case, it can be higher than 15 tons which damages a lot pavements and short span bridges.
- In a similar way, semi-trailers may be loaded heavily to the back of the trailer, putting much load on the tridem in the back. In this case, the load can be above 35 tons on 3 meters (single axle load above 10 tons and distances between axles of the group below 1.35 m), which is really damaging.

That is why controlling the distribution of the load within the vehicle is very important (ITF 2011).

3.2 Chosen Truck Combinations and Infrastructures

As explained before, we will focus on the static assessment of bridges. Two damage phenomena must be considered: extreme effects and fatigue. To do that, the static effects of vehicles on a bridge must be calculated.
As stated before, European bridges are designed according to load models defined in the Eurocode 1991-2. These load models integrate safety margins and are supposed to represent the whole traffic being at a same time on a bridge.
This means that bridges are designed and assessed according to standards that are applied Europe-wide. Differences from one country to another are due to some National α-factors

applied to the load intensity of the load models to adjust them to the national traffic conditions. The design criteria have been listed in deliverable D3.4 of FALCON project.
When creating a catalogue of bridge structure, one would want an exhaustive list of theoretical structures to which these loads models are applied. However, all these theoretical structures are represented by influence lines for the various load effects to be considered. Therefore, working with influence lines is sufficient for this study, as it has already been done in the calibration works of Eurocode 1 (EN1), PBS studies in South Africa (Nordengen 2016) or American Bridge-Formula assessments. The influence lines chosen here are shown in Table 7.

Table 7: Catalogue of bridge structures to be assessed.

	Bridge structure	Effect	Span length	Damage model
1	Simply supported, single span	Bending moment at midspan 1, shear at support 0	10m, 20m, 35m, 50m, 100m	Extreme effects & Fatigue
2	Two-span, continuous bridge	Bending at midspan 1 and support 1, shear at support 0	10m, 20m, 35m, 50m, 100m	Extreme effects & Fatigue

For these bridge structures, the effects of the various vehicle configurations of the FALCON fleet will be calculated. The outer envelope of these effects can then be searched as it provides the upper limit for design criteria of a PBS.
These calculations are numerous (25*N calculations, where N is the number of vehicles in the fleet). Indeed, the bridge calculations have been done for all 27 vehicles from the FALCON fleet, see Deliverable 3.1 from FALCON project

3.3 Results of Computations and Perspectives

When comparing the effects and contrary to what is the case for pavements, the vehicle with the maximum effect is not always the same, see Table 8. More precisely, even within a given group of vehicles, the vehicle with the maximum effect is not always the same.

Table 8: Vehicle with maximum effect, for a sample of the calculated effects.

Effect	Truck with maximum effect
1	4.6
2	1.4
3	1.3
4	1.3
5	1.3
6	3.3
7	6.4

So for example, if for each effect, we divide the effect of each vehicle by the maximum effect for the whole fleet, a general tendency can be found for the vehicles, but it may be false to keep only a few vehicles from this fleet, see Figure 1.
For example, by comparing the first 4 columns of dots of this figure, it can be seen that from group 1 (vehicles 1.1, 1.2, 1.3, 1.4), vehicle 1.2 is generally the most aggressive. Similarly, by comparing all the columns, it can be seen that the first 2 groups of vehicles (from 1.1 to 2.3) are generally less aggressive than the others. Moreover, within these two groups, vehicle 3 (column 3, vehicle 1.3) and vehicle 7 (column 7, vehicle 2.3) are the least aggressive.

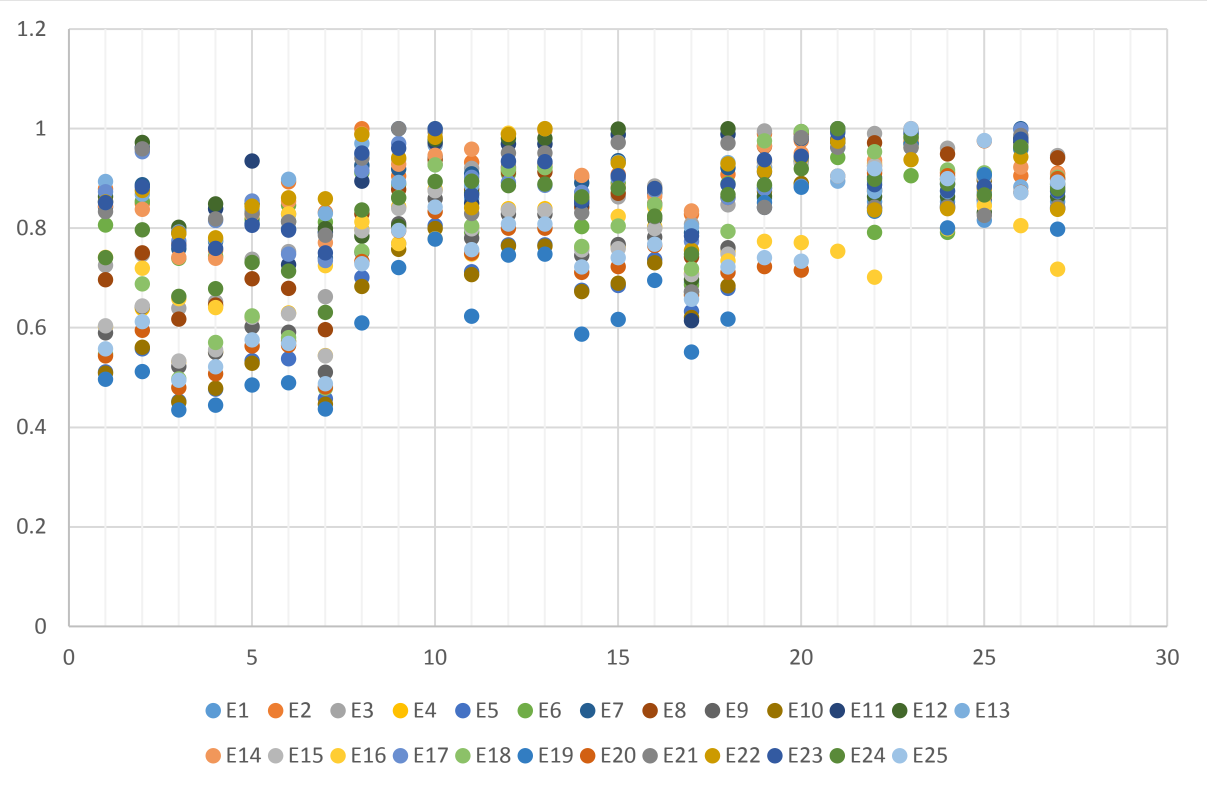

Figure 1: Ratio of effect of vehicle to maximum effect within the fleet (on the x-axis the various vehicles of the Falcon fleet are given).

Several types of normalization can be proposed, in order to compare in a rational way, the effects of the various vehicles. We investigated several types of normalizations:

- Normalization with the total length between the first and last axle,
- Normalization with the volume,
- Normalization with the cargo mass (payload),
- Normalization with the total mass (GCM).

The normalized effects seem quite similar for all these cases, therefore the solution to be taken might be more complex than that.

Some effects make it possible to discriminate clearly the vehicles, e.g. separating vehicles with high effect (damage) from those with low effect (damage). These are the effects of long bridge spans.

This is not really a surprise, as smaller spans only encounter parts of the vehicle, which means that the effect of the vehicle is the effect of axles or group of axles.

On the other side, for longer spans, the load model to design the structure would be a queue of vehicles (traffic jam), which is the case in the Eurocodes (uniformly distributed load of LM1 of Eurocode 1). Therefore, the most important structural models might be spans between 25 and 50 meters.

If vehicle 2.1 (conventional European semi-trailer) is considered as the reference vehicle, we can classify the vehicles depending on their effects: if all their effects are higher than those of vehicle 2.1, they will be considered as aggressive (marked as grey, see Table 9). In the opposite case, they will be classified as non-damaging vehicles (marked as green). When all the effects are of similar value, the vehicle will be marked in yellow.

Two comments are necessary here:

- It should be noted here that we used a 10% rule to decide what value is "similar", "higher", "lower". This is also a threshold, which can be studied and fixed in an adapted way.
- Moreover, the various effects of a given structure may not give the same classification (for a given vehicle, one effect may be higher than the effect of vehicle 2.1, whereas another will be lower). In this case, we classified this vehicle as more aggressive than the reference vehicle (in grey). But here, also one could decide to classify it in the lowest category (in any case), or decide a hierarchy between the effects (the result of one effect would decide on the classification, over the result over another effect.

We will do that for the structures that have been studied, namely:

- Structure 1: single-span structure, span length equal to 10m, structure verified through bending moment at midspan and shear on support
- Structure 2: single-span structure, span length equal to 20m, structure verified through bending moment at midspan and shear on support
- Structure 3: single-span structure, span length equal to 35m, structure verified through bending moment at midspan and shear on support
- Structure 4: single-span structure, span length equal to 50m, structure verified through bending moment at midspan and shear on support

Table 9: Damaging effect of vehicles compared to the reference vehicle 2.1.

Structure	Normalization with length	Normalization with mass
1	4.5, 5.1, 6.1 2.1, 3.1 1.3	4.5, 5.1, 6.1 2.1, 3.1 1.3
2	4.5, 5.1, 6.1 1.3, 2.1, 3.1	4.5, 5.1, 6.1 3.1 1.3, 2.1
3	4.5, 5.1, 6.1 1.3, 2.1, 3.1	4.5, 5.1, 6.1 1.3, 2.1, 3.1
4	4.5, 5.1, 6.1 1.3, 2.1 3.1	4.5, 5.1, 6.1 1.3, 2.1, 3.1

We can conclude on the following points:

- High-capacity vehicles are -generally- less aggressive than the reference vehicle (or already allowed vehicles, like 1.3 and 2.1),
- A finer classification between the damaging effect of the various vehicles can be done, but decisions should be made (type of normalization, threshold of the meaning of higher/similar/lower, type of structures and effects to be analysed, …).

In the following, we will focus on short- and medium-span bridges, for several reasons:

- These are the main issue for bridges (ITF 2011).
- Moreover, for long span bridges, the governing case is congestion (meaning a queue of vehicles covering the whole bridge), and not just one vehicle.

3.4 Conclusions on bridge calculations

For these calculations, several points can be noted:

- In a strict case, it cannot be said that one vehicle is more/less aggressive than another, because it depends on the structure that are studied. Indeed, vehicle A may be more aggressive than vehicle B for structure 1 but less aggressive for structure 2.
- But in generally, when normalized by loading capacity both in terms of volume (or loading length) or mass (total mass or cargo mass), high capacity vehicles are not more aggressive than more conventional vehicles. Indeed, the European semi-trailer is generally more aggressive when compared to the loading possibilities.
- The development of a bridge formula involves several assumptions which are of regulatory/political nature and which have to answered, the most important being: what vehicle or fraction of load model should be supported by the structures, during their lifetime?

4. Conclusions

This article presented some work done with CEDR project FALCON where representative infrastructure has been selected and for which the impact of various vehicles has been assessed. This work has been based on several assumptions, under which the conclusions are valid.
One point that can be noted is that one vehicle, which is damaging for one type of infrastructure, may not be damaging for another one, therefore the development of the infrastructure catalogue on which the vehicles have to be assessed is an important step.

5. References

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