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## **Effect of different platoon configurations on strains and fatigue performance of flexible pavements**

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# Effect of different platoon configurations on strains and fatigue performance of flexible pavements

This paper presents part of the studies developed in the European project ENSEMBLE. ENSEMBLE main objective is to pave the way for adopting multi-brand truck platooning in Europe to improve fuel economy, traffic safety, and throughput. The first part of the paper describes the validation of a numerical model, using the software ViscoRoute 2.0, based on comparisons with experimental results obtained from a test section subjected to the pass of 3 human-driven trucks simulating a platoon configuration. The numerical model is then used to predict the maximum and accumulated strains produced by the passage of each truck on the same test section at two different temperatures, 15°C and 35°C, when the following platoon parameters are varied: (1) inter-truck time gap, (2) truck speed and (3) lateral deviation (wandering). The results confirm that the proper control of these parameters can help to keep the same level of fatigue damage as with trucks in individual configurations. In this way, the environmental, social and economic benefits of platooning can be attained without compromising the existing pavement structures.

Keywords: truck platooning; numerical simulation; traffic wander pattern; inter-truck distance.

## Introduction

The deployment of truck platooning is one of the strategies supported by the European Union Horizon 2020 programme, regarding sustainable development. The benefits associated with platooning include better road safety, optimisation of road capacity and asset utilisation, and reduction of emissions, fuel consumption and labour costs (Alam et al., 2015; Bhoopalam et al., 2018; Bonnet & Fritz, 2000; Eilers et al., 2015; Gungor et al., 2020; Gungor & Al-Qadi, 2020a; Hoque et al., 2021; Humphreys et al., 2016; Janssen et al., 2015; Konstantinopoulou et al., 2019; Ladino et al., 2021; Lammert et al., 2014; Noorvand et al., 2017a; Robinson et al., 2010; Suzuki, 2011; Thunberg et al., 2019; Tsugawa, 2014; Tsugawa et al., 2016).

From the point of view of vehicle manufacturers and transport companies, the best results in terms of fuel consumption reduction, aerodynamic improvements, road safety benefits and reduction of traffic congestion are obtained with reduced wander patterns between trucks, reduced inter-truck distances and improved control of the reduced reaction times (Bhoopalam et al., 2018).

In these conditions, trucks in platoon configuration lead to new loading conditions for pavement structures, characterised by (1) multiple loads passing in a reduced time over the pavement, (2) reduced lateral wandering of the vehicles forming the platoon and therefore load channelization (Chen et al., 2019, 2020; Gungor et al., 2020; Gungor & Al-Qadi, 2020b, 2020a; Marsac et al., 2020; Noorvand et al., 2017b; Rana & Hossain, 2021; Song et al., 2021; Zhou et al., 2019) and (3) reduced inter-truck distances between the trucks in the platoon, which may hinder the self-healing capacity of asphalt concrete materials (Gungor et al., 2017, 2020; Gungor & Al-Qadi, 2020b, 2020a).

In this context, the European Commission launched in 2018 a 3-year H2020 research project called ENSEMBLE. The objective of ENSEMBLE is the integral

deployment of multi-brand, cross-border and ad hoc platooning technology around Europe. This project is led by the Netherlands Organisation for Applied Scientific Research (TNO) and involves six European truck manufacturers (DAF, DAIMLER, IVECO, MAN, SCANIA and VOLVO Group), the European Association of Automotive Suppliers (CLEPA), original equipment manufacturers (NXP, ZF, Bosch, Continental, Brembo), ERTICO-ITS Europe (link to the European Truck Platooning Community), and knowledge partners (IDIADA Applus, Gustave Eiffel University, Royal Institute of Technology and VU Brussel).

As a partner of the project, Gustave Eiffel University (UGE), previously known as the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR) is in charge of various studies (Leiva-Padilla, Blanc, Salgado, et al., 2022; Leiva-Padilla, Blanc, Trichet, Salgado, et al., 2022; Marsac et al., 2020) focused on the evaluation of the effect of platooning trucks on pavements. The research efforts of UGE have for objectives: (1) to analyse the impact of platooning configurations on pavement structures, (2) to define a valid model to predict the structural response of pavement structures subjected to trucks in convoy formation and (3) to develop a tool for carrying parametric studies of the effect of platooning trucks on the performance of pavement structures. The present document presents some main results of this study, which can be used to help transport policymakers understand the impact of platoons on pavement structures and propose solutions to limit it.

## **Research Plan**

### ***Phase 1: Experimental Campaign***

The first phase of the study consisted in performing full scale tests on an instrumented pavement section, to measure its response under the passage of trucks in individual and platoon configurations. The experimental section was built on the test track facilities of Applus IDIADA in Tarragona, Spain, commonly used to provide design, testing, engineering and homologation services to the world's leading vehicle manufacturers.

As shown in Figure 1, the test section has a pavement structure composed of 25 cm of asphalt layers (4 cm thick wearing course, 6 cm thick binder course and 15 cm thick base course), placed over an unbound granular layer. According to European standard UNE-EN 13108-1 for asphalt mixture classification, the types of asphalt mixtures are respectively: AC 22 G (G-20), AC 22 S (S-20), and AC11 surf (D12). The mixtures were manufactured with a polymer-modified binder type PMB 45-80/65 according to UNE-EN 14023, reaching densities of 2.38 to 2.39 g/cm<sup>3</sup> and air void contents of 4.7% to 6.8%.

The instrumentation installed in the test section comprises 24 strain gauges, placed at 10 cm and 25 cm depth below the pavement surface. These depths correspond to the bottom of the binder course and of the base course, and represent critical levels for the evaluation of the fatigue damage of the asphalt pavement layers. The strain gauges are placed transversally (6 at each depth) and longitudinally (6 at each depth) relative to the direction of traffic, to evaluate the transversal and longitudinal strains at both depths.

Since the tests were done at the beginning of the ENSEMBLE project, the platooning truck configuration used during testing consisted of three 5-axle human-driven semitrailer trucks, separated by an inter-truck time gap of 0,8 s. The truck's lateral deviation was monitored during testing by measuring the distance between a reference line along the safe guard of the test section and the right tire of the steer axle

of each truck. The corresponding measurements were done using a laser distance measurement system installed in the right side of the road lane and reflective discs attached to the right steer axle of each truck. All the vehicles were loaded to the maximum loads allowed in Europe (40 to 48 ton) (European Commission Directorate General Transport, 2001).

The results and main findings obtained in the experimental were used for the validation of a pavement response model (Leiva-Padilla, Blanc, Hammoum, et al., 2022; Leiva-Padilla, Blanc, Trichet, Baudru, et al., 2022; Leiva-Padilla, Blanc, Trichet, Salgado, et al., 2022; Leiva-Padilla, Schmidt, et al., 2022) which was then used as base for the development of the parametric analysis described in the present paper.

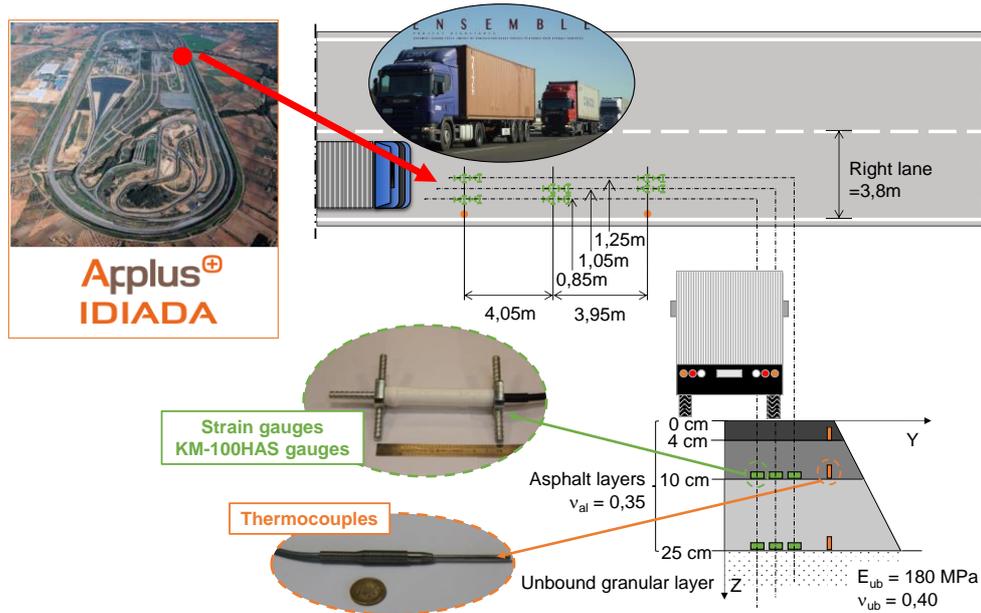


Figure 1. Test section: Pavement structure and instrumentation. Sketch based on the studies: (Leiva-Padilla, Blanc, Hammoum, et al., 2022; Leiva-Padilla, Blanc, Trichet, Baudru, et al., 2022).

### *Phase 2: Modelling of platoon loading and parametric analysis*

The modelling of the pavement response, under platoon loading, was performed using a visco-elastic model, based on the software ViscoRoute 2.0, developed by Université Gustave Eiffel (Chabot et al., 2010). This model was presented in detail in previous studies done by the authors (Leiva-Padilla, Blanc, Hammoum, et al., 2022; Leiva-Padilla, Blanc, Trichet, Baudru, et al., 2022).

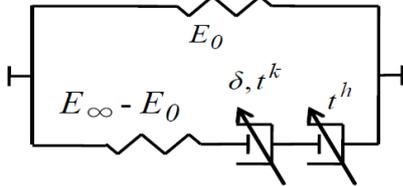
ViscoRoute 2.0 is a semi-analytical software, developed to simulate the 3D mechanical response of multilayer pavements under loads moving at constant speed (Chabot et al., 2010). To say it in a simple way, the solving method in this software consist in deriving the equations of elastodynamics in the moving frame attached to the loads, expressing and solving the problem in the wave number domain prior to computing the solution in the spatial domain by inverse Fast Fourier Transform (FFT) and paying special attention to the integrable singularities. The effect of any loading configuration on a pavement, including single and dual wheels, tandem or tridem axles or even a whole truck can be analysed by using ViscoRoute 2.0. In this software, an elementary load pattern is defined as a force (horizontal or vertical) distributed over a circular or rectangular area resulting in a uniform pressure distribution at surface of the

pavement, under this area. A tire imprint can thus be represented considering a single elementary load or several of them of different magnitude put side by side for a closer representation of a nonuniform tire/pavement contact pressure. Then, depending on the actual loading configuration to be applied on the pavement (axles tandem, tridem, etc.), several tire imprints can be added to compose the input load data to the computation.

In this program, each layer is assumed isotropic homogeneous and has a behaviour that can be either linear elastic (usually the case for subgrade and unbound layer) or thermo-viscoelastic (case for asphalt concrete materials). The latter is represented in ViscoRoute 2.0 according to the Huet-Sayegh model (Huet, 1965, 1999; Sayegh, 1965) which is well adapted and extensively used for modelling bituminous materials.

As shown in Table 1, the schematic representation of this rheological model is composed by two branches. The first branch is composed by one spring and two parabolic dampers settling the viscous properties of the model, which depend on the load frequency ( $\omega$ ) and temperature ( $\theta$ ). The second branch is composed by a spring and represents the long-term static behaviour of the model response. These model components are described by the five viscoelastic and the three thermal coefficients shown in the same Table. For a given asphalt material, these coefficients are usually calibrated in the frequency domain by fitting the Black and Cole-Cole representation of the Huet-Sayegh model with that stemming from complex modulus tests performed at several frequency and temperature conditions.

**Table 1. Thermo-viscoelastic characterisation of the asphalt layers used in ViscoRoute 2.0**

Model	Coefficient	Definition
Schematic representation:  Huet-Sayegh rheological model (Visco-elastic characterisation): * $E(\omega, \theta) = E_0 + \frac{E_\infty - E_0}{1 + \delta(j\omega\tau(\theta))^{-k} + \delta(j\omega\tau(\theta))^{-h}}$	$E_\infty$	Instantaneous elastic modulus.
	$E_0$	Static elastic modulus.
	$k$ and $h$	Exponents of the parabolic dampers ( $1 > h > k > 0$ ).
	$\delta$	Positive adimensional coefficient balancing the contribution of the first damper.
Function of temperature (Thermal characterisation) $\tau(\theta) = \exp(A_0 + A_1\theta + A_2\theta)$	$A_0, A_1, A_2$	Scalar parameters describing a lateral adjustment factor in the Huet-Sayegh model as a function of temperature.

\*  $j$  for the representation of the complex components for  $j^2 = -1$ .

Finally, ViscoRoute 2.0 can be run for full-bonded or slip interface conditions (Chupin et al., 2010) between the pavement layers. These are the basic conditions usually considered in pavement modelling. However, as reported in recent research (Attia et al., 2021; Duong et al., 2018), the interface behaviour between asphalt layers can be more complex and depend on temperature for instance. Particularly for the purpose of this study, it was necessary to represent an intermediate condition between

full-bonding and slipping. This was achieved by modelling the contact behaviour between asphalt layers through a thin viscoelastic layer of finite thickness (2 mm) that was assigned the mechanical properties of a tack coat emulsion (Huet-Sayegh constitutive law).

Figure 2 shows the loading case used in ViscoRoute 2.0 to validate the model. This loading corresponds to a platoon passage with a lateral deviation close to 0 cm (-0,09 m for truck 1, -0,05 m for truck 2 and -0,06 m for truck 3 at 40 km/h and -0,06 m for truck 1, -0,04 m for truck 2 and -0,05 m for truck 3 at 80 km/h). The square load areas used in the model characterize the loads measured during testing for each tire and the corresponding area width, function of the type of tire. The distances between axles were measured for each vehicle and the inter-truck distances were calculated by converting the 0,8 s inter-truck time gap into equivalent distances, function of vehicle speeds.

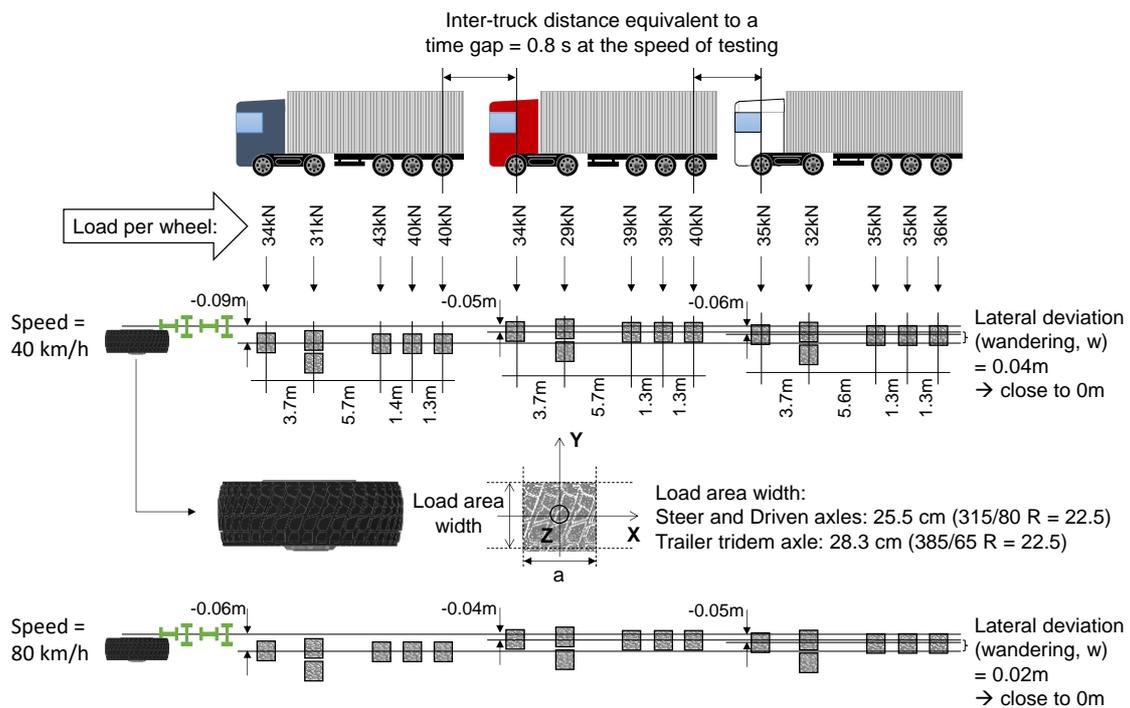


Figure 2. Load case used during the validation of the model for the summer campaign (the images are not to scale). Sketch based on the studies: (Leiva-Padilla, Blanc, Hammoum, et al., 2022; Leiva-Padilla, Blanc, Trichet, Baudru, et al., 2022).

The development of the visco-elastic model, and the comparisons with in-situ measurements are described in detail in previous papers (Leiva-Padilla, Blanc, Hammoum, et al., 2022; Leiva-Padilla, Blanc, Trichet, Baudru, et al., 2022). The ViscoRoute 2.0 calculations were performed with asphalt layer viscoelastic parameters determined from laboratory complex modulus tests. For modelling of pavement interlayers, different assumptions were made: fully bonded, sliding, or interlayers described by thin viscoelastic layers). The comparisons with the experimental strains indicated that the best predictions were obtained using 2 mm thin viscoelastic fully-bonded interlayers, characterised by typical Huet-Sayegh parameters of a tack coat emulsion. Figure 3 below presents one example of comparison of experimental and predicted transverse strains, obtained for the full scale experiment, with the model with

visco-elastic interlayers. The results show that the model predicts well the maximum transverse strains, and also the strain recovery after each truck passage.

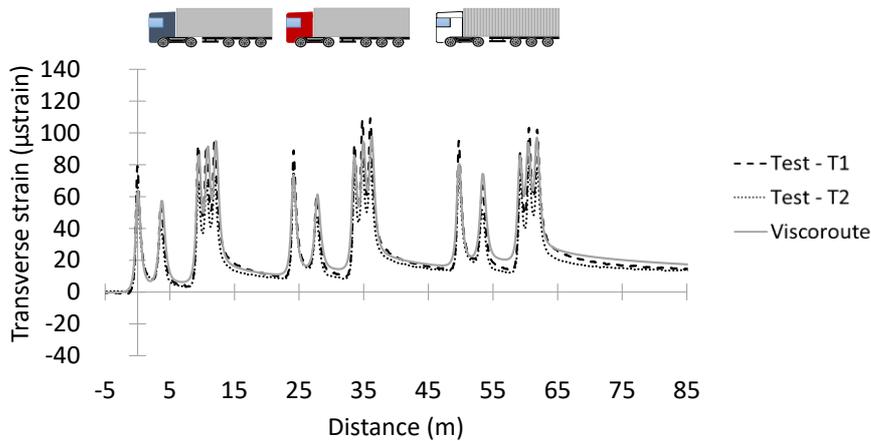


Figure 3. Predictions obtained with the model with viscoelastic interfaces (Summer campaign, temperatures of 27°C and 34°C for the asphalt layers, 40 km/h speed, strains at the bottom of the base course, Wandering = 4 cm). Sketch based on the studies: (Leiva-Padilla, Blanc, Hammoum, et al., 2022; Leiva-Padilla, Blanc, Trichet, Baudru, et al., 2022).

## Data analysis

### *Effect of inter-truck time gaps*

After validation, the model was used to simulate the effects of different inter-truck time gaps, truck speeds and the introduction of 30 cm of wandering (0 cm of lateral deviation for truck 1, -15 cm for truck 2 and +15 cm for truck 3). The calculations were performed for two pavement temperatures, 15°C and 35°C. Figure 4 shows an example of the transverse strain values calculated when a 3-truck platoon is traveling at 80 km/h and the inter-truck time gaps are 0.5 s, 2.0 s and 3.5 s, for the conditions with and without a lateral deviation of  $\pm 15$  cm (a wandering of 30 cm). The results indicate that increasing the inter-truck time gaps and for a wider wandering, could be an option to reduce the transverse strains generated by fully-loaded trucks in platoon formation at the bottom of the asphalt layers. They also indicate that the effects of platoon loading (strain increase under multiple trucks, effect of inter-truck time gaps) are much more important at high temperature (35 °C).

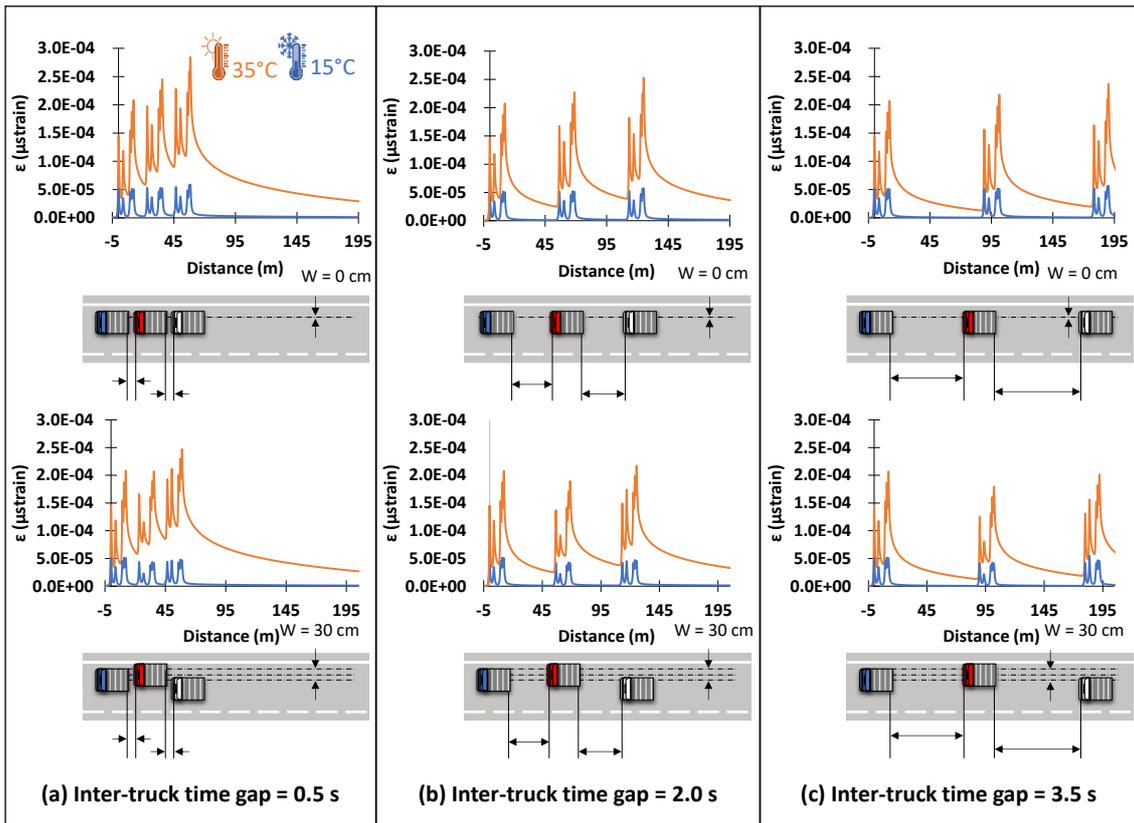


Figure 4. Example of transverse strain values calculated with the variation in the inter-truck time gaps and wandering for a truck speed = 80 km/h.

Figure 5 and Figure 6 show the maximum transversal tensile strains and the accumulated transversal strains calculated at the bottom of the asphalt layers during and after the passage of the platoon. The results are presented for two truck speeds, 40 km/h and 80 km/h and indicate that:

- The effect of pavement temperatures on the maximum and accumulated strains is very important. The maximum transverse strain values obtained at 35°C are 4 to 6 times higher than those obtained at 15°C, depending on the truck speeds and wandering values. This is explained by the sensitivity of the behaviour of the asphalt material to temperature.
- The impact of platoons is also more important at high temperature. At a temperature of 15 °C, the maximum strains under the second and third trucks are very close to those under the first truck. At 35 °C, on the contrary, maximum strains increase under the second and third truck, indicating an accumulation of strains under the successive truck passages, due to viscoelastic behaviour.
- Increasing the inter-truck time gaps in the platoon leads to a notable reduction of the accumulated transversal strains. This means that a longer recovery time is beneficial for the asphalt materials. The maximum transverse strain are reduced only at 35°C. For example, for the results presented:
  - At 35°C and 40km/h the accumulated strain values are reduced by 62% to 73% when the inter-truck time gaps are increased from 0.5 s to 3.5 s.
  - At 35°C and 40km/h, the maximum strains for truck 3 decrease by about 14% when the time gap passes from 0.5 s to 3.5 s. At 15°C for the same speed, passing from 0.5 s to 3.5 reduces the maximum strain values. By only 1 to 2%

- The introduction of a lateral deviation (wandering patterns) appears as an efficient solution to reduce the damaging effect of platoons. The inclusion of a lateral deviation increases the loaded area, optimizing the use of the pavement surface. For example, for the results presented:
  - A lateral deviation of -15 cm for truck 2 and +15 cm for truck 3, which means a total wandering pattern of 30 cm width in the convoy passing at 80 km/h, leads to a reduction of about 16% of the maximum strain values for truck 2 and 14% for truck 3 at 35°C. The accumulated strains are reduced by about 5% for truck 2 and 2% for truck 3 at 35°C.

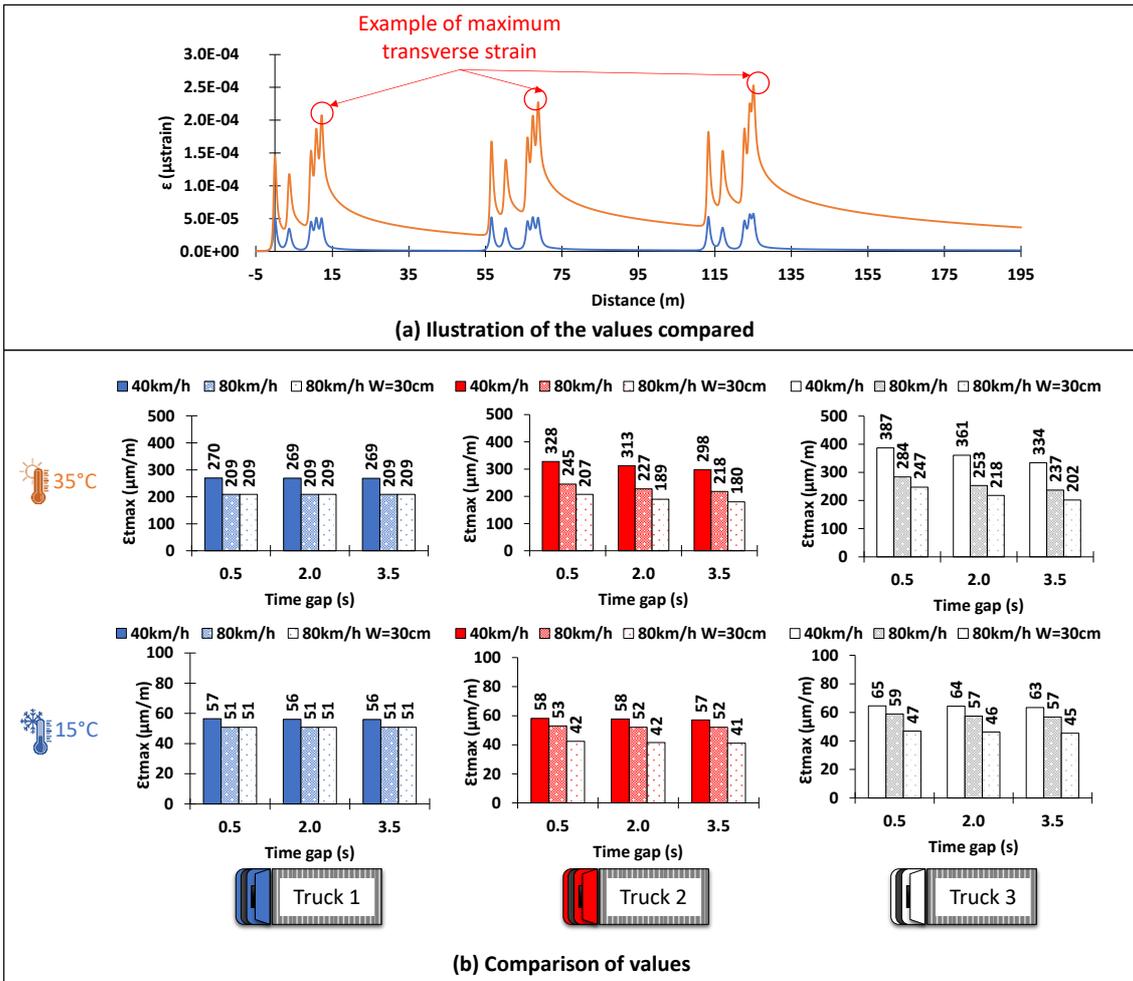


Figure 5. Maximum transverse strains obtained under the passage of the tridem trailer axle.

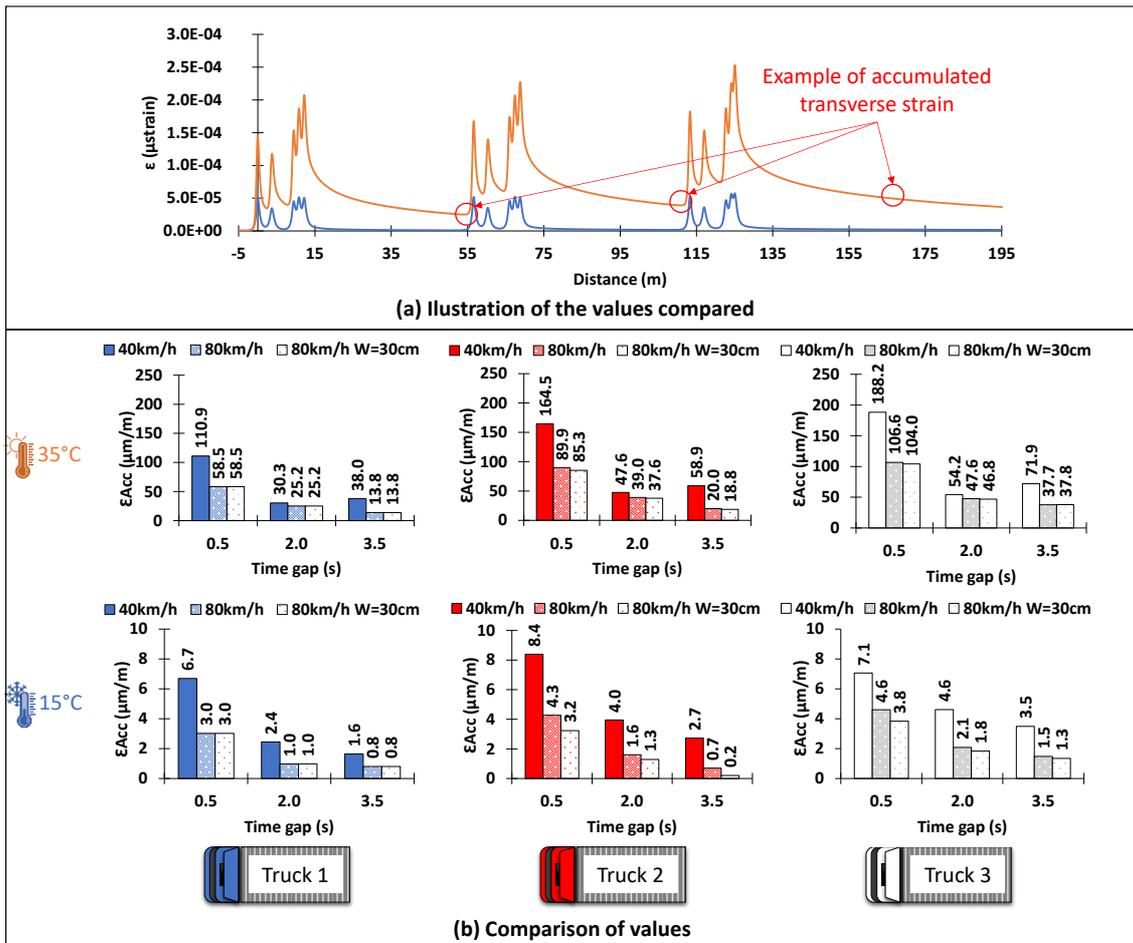


Figure 6. Accumulated transversal strains obtained after the passage of the tridem trailer axle.

The percentage of strain recovery achieved after the passage of each truck forming the platoon was calculated using Equation 2. The corresponding values are shown in Figure 7. For all the cases, the strain recovery was calculated using the strain levels already presented in Figure 5 and Figure 6. The results in this case indicate that:

- (1) Higher percentages of recovery are obtained at 15°C. This can be explained by the thermoviscoelastic behaviour of the asphalt materials, which leads to higher irrecoverable strains at high temperatures. For example, in this case when the temperature increases from 15°C to 35°C, for zero wandering and 80 km/h, the percentage of recovery is reduced by about 5% to 30% (depending on the time gap).
- The percentages of recovery at 80 km/h are slightly higher than the ones obtained at 40 km/h (about 1% to 6% higher at 15°C and 1% to 13% higher at 35°C). This is due again to the visco-elastic behaviour.
- As expected, higher percentages of recovery are achieved when the inter-truck time gaps increase. For example, passing from a time gap of 0.5 s to 3.5 s at 35°C for a zero wandering and 80 km/h can increase the percentage of recovery by about 21% to 28%.
- At 35°C, the percentages of recovery at 80 km/h, with the inclusion of 30 cm of wandering, seem to be slightly reduced in comparison to the condition without wandering. This effect could be due to the fact that the maximum transverse

strain values are significantly reduced by the wandering, whereas the accumulated transverse strains remain of the same level as without wandering.

$$Recovery = \frac{\varepsilon_{max} - \varepsilon_{Acc}}{\varepsilon_{max}} * 100 \quad (2)$$

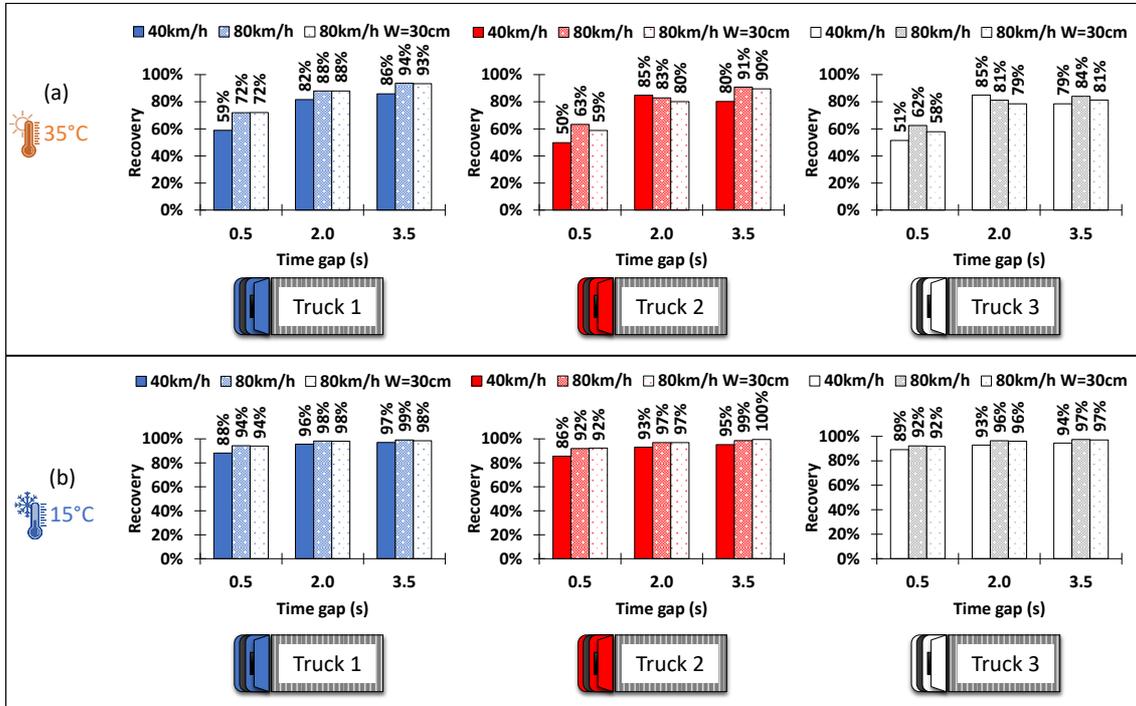


Figure 7. Percentage of recovery of the accumulated transverse strain.

### Number of equivalent axles

The different simulations presented in the previous section consisted in predicting the maximum tensile strains at the bottom of the pavement base layer (and also the accumulated strains). These maximum tensile strains can be used to estimate the fatigue life of the pavement, for the different platoon loading conditions.

According to the French Pavement design method (SETRA-LCPC, 1997), the fatigue life of an asphalt pavement can be predicted using the fatigue model defined by (Equation 3) .

$$\varepsilon(NE, \theta_{eq}) = \varepsilon_6(10^\circ C, 25 Hz) [E(10^\circ C, 10Hz) / E(\theta_{eq}, 10Hz)]^{0.5} (NE/10^6)^b \quad (3)$$

With:

$\varepsilon(NE, \theta_{eq})$ : tensile strain leading to fatigue failure after  $NE$  load cycles, for an equivalent temperature  $\theta_{eq}$ .

$\varepsilon_6(10^\circ C, 25 Hz)$ : parameter of the fatigue law corresponding to the tensile strain leading to failure for  $10^6$  cycles, at a temperature  $\theta = 10^\circ C$  and a frequency  $f = 25Hz$ .

$b$ : exponent of the fatigue law.

$E(10^\circ C, 10 Hz)$ : norm of the complex modulus of the material at  $10^\circ C$  and a frequency of 10 Hz.

$E(\theta_{eq}, 10 Hz)$ : norm of the complex modulus of the material at a temperature  $\theta_{eq}$  and a frequency of 10 Hz.

The parameters of the fatigue law,  $\varepsilon_6(10^\circ\text{C}, 25\text{ Hz})$  and  $b$  are determined by strain-controlled two point bending fatigue tests, generally performed at  $10^\circ\text{C}$  and  $25\text{ Hz}$ . For the calculations presented in this paper, typical recommended values of these parameters, corresponding to a French base course asphalt material have been used. These values are  $\varepsilon_6 = 90\ \mu\text{strains}$  and  $b = -0.2$ .

Equation 3 can be used to calculate the number of equivalent axle loads  $NE$  leading to fatigue failure, for a tensile strain level  $\varepsilon(NE, \theta_{eq})$ .

Here, calculations of the number of equivalent axle loads  $NE$  leading to failure were performed for a truck speed of  $80\text{ km/h}$  and a lateral deviation of zero or  $\pm 15\text{ cm}$ . Furthermore, Equation 3 was adapted in order to calculate the number of equivalent axle loads corresponding to the loading of individual trucks (Equation 4) and to the loading of platoons (Equation 5).

$$NE = \frac{\sum_{Ax=1}^{Ax=5} \left( \frac{\varepsilon_{Ax}(NE, \theta_{eq}, f)}{\varepsilon_6(\theta_{eq}, f) [E(10^\circ\text{C})/E(\theta_{eq})]^{0.5}} \right)^{1/b} * 10^6}{N_{Ax}} \quad (4)$$

Individual trucks

$$NE = \frac{\sum_{Truck=1}^{Truck=3} \sum_{Ax=1}^{Ax=5} \left( \frac{\varepsilon_{Truck,Ax}(NE, \theta_{eq}, f)}{\varepsilon_6(\theta_{eq}, f) [E(10^\circ\text{C})/E(\theta_{eq})]^{0.5}} \right)^{1/b} * 10^6}{N_{Trucks} * N_{Ax}} \quad (5)$$

Platoons

In these equations:

$\varepsilon_{Ax}(NE, \theta_{eq}, f)$  and  $\varepsilon_{Truck,Ax}(NE, \theta_{eq}, f)$ : maximum tensile strains for each axle of each truck in individual and platoon configuration,

$N_{Trucks}$ : number of trucks in the platoon,

$N_{Ax}$  is the number of axles of each truck (here  $N_{Ax} = 5$ ).

Figure 8 presents the results of the fatigue calculations, considering a platoon of 3 trucks, a speed of  $80\text{ km/h}$ , two temperatures ( $15^\circ\text{C}$  and  $35^\circ\text{C}$ ), and 3 inter-truck time gaps (0.5, 2 and 3.5 s). The results are presented in terms of fatigue life (number of equivalent axle loads to failure  $NE$ ). They indicate that:

- Truck platooning generally reduces the fatigue life of the pavement (number of equivalent axle loads to failure  $NE$ ) in comparison with trucks circulating in individual configuration. The fatigue life reduction is less important at low temperature, and decreases when the inter-truck time gap increases. For example, at  $15^\circ\text{C}$ , with an inter-truck time gap of 3.5 s and zero wandering the reduction of  $NE$  is only of 5% for the platoon configuration. In comparison, at  $35^\circ\text{C}$ , and with a smaller time gap of 0.5 s, the fatigue life reduction can be as high as 54 % for the platoon configuration.
- Including 30 cm of wandering in this case can increase the  $NE$  for both trucks in platoon and individual configuration.
- Comparing only the platooning situation, including a lateral wandering can reduce significantly the impact of the platoon. For example, including a wandering of 30 cm in a 3-trucks platoon for a pavement temperature of  $15^\circ\text{C}$ , can increase the  $NE$  from  $5.25\text{E}+07$  to  $1.63\text{E}+08$ , which represents an increase by approximately a factor of 3.

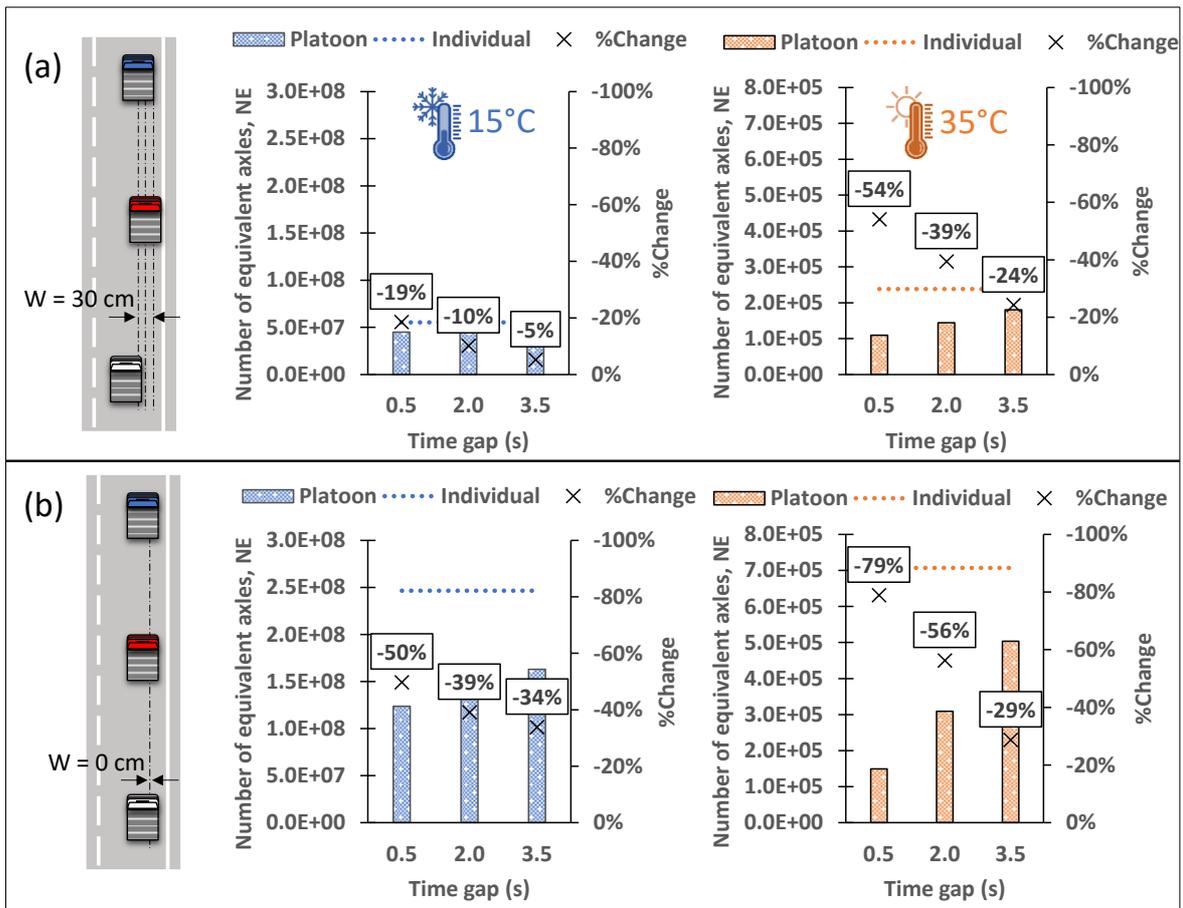


Figure 8. Pavement service lives expressed in number of equivalent axles (NE) for 3-trucks platoons at 80 km/h.

## Conclusions

This paper presents part of the results of the ENSEMBLE project, dealing with the evaluation of the impacts of platooning trucks on pavement structures. The parametric study presented in this paper is mainly focused on the characterisation of the transverse strains and fatigue performance of a pavement structure when varying the inter-truck time gaps and the lateral wandering of a specific truck platoon configuration. The parametric study was based on a viscoelastic model, validated by a full-scale experiment designed to evaluate the fatigue strains of a pavement structure under truck platoon loading.

The parametric study mainly analysed the influence of inter-truck time gaps and lateral wander on the impact of platoons on pavement strains and pavement fatigue. The first result of the study is that without special precautions (with short inter-truck time gaps of 0.5 s and no lateral wandering), platoon loading can increase pavement fatigue. At maximum, in the parametric study, a reduction in fatigue life of 79 % was obtained with the 0.5 s time gap, and at 35 °C. The second important result is that the impact of platoons on pavement strains and pavement fatigue depends on pavement temperature. At low to intermediate temperatures (15 °C in the study), the strain increase due to platoons is very small, because the strain accumulation under multiple loads, due to viscoelasticity, is very limited. At high pavement temperatures (35 °C in the study), the visco-elastic effects become much more important, and the multiple loads, with short rest periods, due to platoons increase asphalt strains (and therefore pavement fatigue), compared with single trucks.

The parametric study also showed that the impact of platoons decreases when the inter-truck time gaps increase. Longer time gaps (meaning longer rest periods between loads) allow significantly higher strain recovery of the transverse strains produced at bottom of the asphalt layers. Allowing a better strain recovery in this critical region of the pavement, can increase the fatigue service life of the pavement structure. Similarly, adding a lateral wander of the vehicles in the platoon allows to distribute the loads on a larger area, and further reduces the impact of platoons.

For example, at 35°C and using the simple fatigue model of the French pavement design method, for the **platoon configuration and asphalt pavement structure** analysed in this study, with zero wandering, the reduction in the number of standard axle loads NE to fatigue can pass from 79% to 29% by increasing inter-truck time gaps by 3 s (changing from 0.5 s to 3.5 s). For the same conditions, including a relatively small lateral wander of 30 cm further limits the reduction in the number of loads NE to fatigue (For example from 79 % to 54 % for the time gap of 0.5 s).

In conclusion, the study shows that the impact of platoons on pavement fatigue can be limited by optimising inter-truck time gaps, and lateral wander of the trucks. As the impact of platoons also depends largely on temperature, their impact could be further reduced by limiting their traffic at certain hours of the day or certain seasons, avoiding the hottest periods.

This paper presents only part of the results obtained in ENSEMBLE. In the project, more detailed parametric studies have been performed and will be continued, to evaluate the impact of platoon configurations on different types of pavements, distress modes (rutting, top-down cracking, reduction of skid resistance) and contexts (types of trucks and axles, types of pavement structures, different climates).

Finally, it should be reminded that the predictions of pavement fatigue life have been performed using the calculated maximum tensile strains, and the simple fatigue model of the French pavement design method, which parameters are determined using standard fatigue tests performed under continuous loading at 25 Hz, and at a constant temperature of 10 °C. Additional laboratory fatigue studies are planned, to improve the current fatigue model, by taking into account the effects of additional parameters such as multiple loads, different temperatures, and variable rest periods, in order to predict more accurately the fatigue damage under platoon loading.

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