Journal of Traffic and Transportation Engineering 12 (2024) 207-213
doi: 10.17265/2328-2142/2024.05.001

# Quantification of the Vertical Load Applied to the Pavement during Cornering Maneuver of a Battery Electric Commercial Vehicle

Pablo Kubo[1], Ney Siqueira[1], Gilberto Grossl[1], Luis Welin[2], Mairon Dobicz[2] and Marcio Andrade[2]

*1. Department of Complete Vehicle, Volvo Group North America, Greensboro 27409, USA*

*2. Department of Complete Vehicle, Volvo Trucks Brazil, Curitiba 81260-900, Brazil*

**Abstract:** The wheel loads of heavy trucks are the major source of pavement damage, given the repeated loadings imposed by them due to transient events and surface irregularities. While related studies focus on steady-state context regarding simplified vehicle's parameters and ideal pavement conditions, this paper aims to analyze the vertical load applied to the pavement by considering cornering maneuver as a transient event, on a battery electric vehicle truck. In this concern, measurements were performed on a rigid truck, with two steering front axles, in a closed course proving ground. The relationship has been presented between vehicle's speed, lateral acceleration and transferred vertical load for a given curve radius of 85.6 m and 3.7 ° of transversal slope. The measurements results indicated that for every 10 km/h increasing on the vehicle's speed, additional 110 kgf will be transferred to the pavement on the outer side of the cornering radius. This value itself could not be considered high, but it will be also added to the static load, or overload in some truck applications.

**Key words:** Load transfer, durability, vehicle dynamics.

## 1. Introduction

Besides impacting directly on the vehicle behavior (rolling resistance, ride & handling, fuel economy, noise/vibration/harshness), the tire-road interaction is also a factor that compromises the pavement integrity. As larger loads and vehicles appear in the road transportation system, pavement damage concerns are becoming an increasingly relevant issue in road construction and maintenance activities [1-4].

Wu, Liang and Adhikari [5] emphasizes that, static uniform load is most commonly used on pavement structure for the mechanical analysis and calculation, which is reasonable for conditions such as low speed and small number of loads.

According to Taheri, Obrien and Collop [6], the traditional approach of pavement life assessment considers all axle weights and calculates the number of equivalent axles of standard weight (8.2 tons). Those authors add that it does not explicitly calculate/quantify the local effect of dynamic oscillation of axle forces about static weight.

In the vehicle perspective, some maneuvers would directly affect the load applied to the pavement, such as rolling.

According to Gillespie [7], the mechanics of the roll moment applied to an axle are shown in Fig. 1 and characterized by Eq. (1).

$$F_{Z0} - F_{Zi} = 2 \times F_y \text{ x } h_r/t + 2K_\varphi \times \varphi/t = 2 \times \Delta F_Z \quad (1)$$

where:

$F_{Z0}$: load on the outside wheel in the turn
$F_{Zi}$: load on the inside wheel in the turn
$F_y$: lateral force
$h_r$: roll center height
$t$: track width
$K_\varphi$: roll stiffness of the suspension
$\varphi$: roll angle of the body

**Corresponding author:** Pablo Kubo, Ph.D., Ph.D. in Mechanical Engineering and Ph.D. in Civil Engineering, research fields: Interaction between vehicle suspension and pavement.

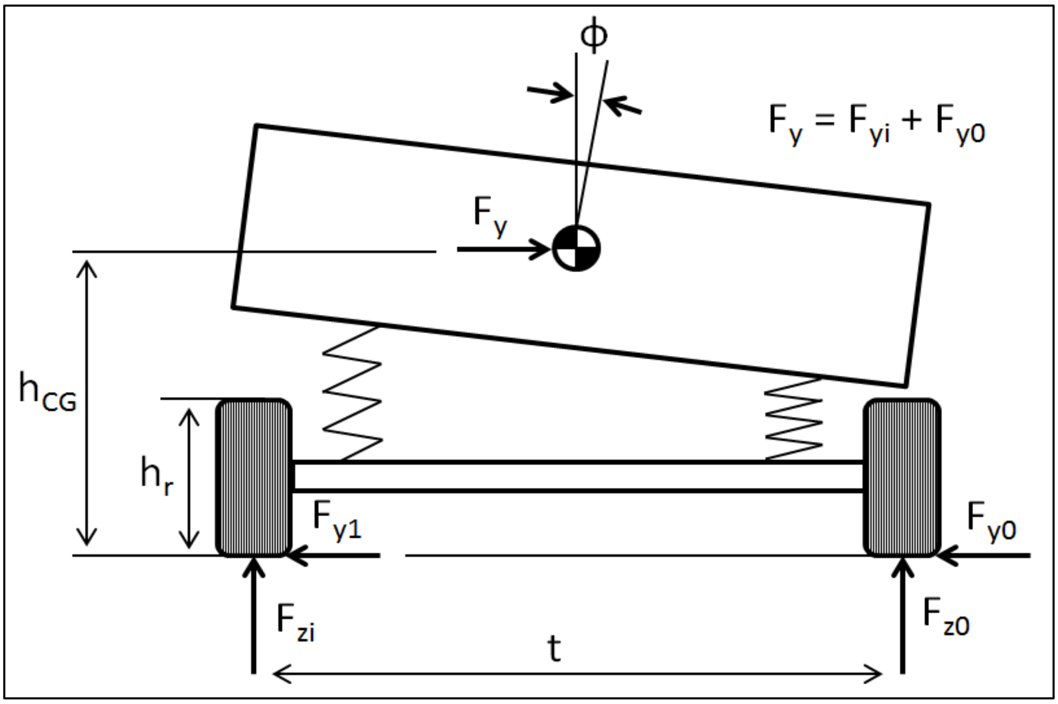


**Fig. 1 Forces analysis of a simple vehicle in cornering.**
Source: Adapted from Gillespie [7].

In summary this, Gillespie [7] states that the difference between the vertical load from the outside/inside wheels will be equal to the sum of the lateral load transfer due to cornering forces and the lateral load transfer due to vehicle roll.

In this way, the objective of this paper is to quantify the load transfer during cornering events on a flexible pavement.

## 2. Methodology

### *2.1 Vehicle Instrumentation*

A 6×2 battery electric tractor truck (Fig. 2) with the following specifications has been used for the measurements: 6 tons per axle on the front suspension; 295/80 R22.5 tire size and 110 psi (approx. 7.6 bar) of tire pressure.

Uniaxial strain gauges with a full bridge setup were placed on the main leaf spring of the 1st steering axle, on both LHS (left hand side) and RHS (right hand side) of the vehicle, as illustrated in Fig. 3.

The recorded values given by aforementioned instrumentation were in $\mu_e$ (micro-strain). Therefore, calibration of the system was necessary to estimate the force applied to the pavement.

Utilizing known weights and a calibrated vehicle scale, calibration curves can be derived for applied load (in tons) versus $\mu_e$ (in other words, each leaf spring is used as a load cell). The coefficients of theses calibration curves (Fig. 4) are used during the data post-processing, to convert the measured values, microstrain ($\mu_e$), to applied load (tons) to the pavement contact patch [8].

In addition to the strain gauge instrumentation, an accelerometer was installed on the front axle of the test truck to quantify the vehicle lateral acceleration during the cornering maneuver. Fig. 5 illustrates the complete instrumentation, data acquisition and post-processing steps.

### *2.2 Measurements*

Measurements were performed at a closed course proving ground to minimize safety issues.

The vehicle speed, during cornering was set according up to safety margin, to avoid accidents (70 km/h).

For each vehicle speed (30, 40, 50, 60 and 70 km/h) the measurements were repeated three times. All measurements were performed on the same day to minimize the risk of variation of the adhesion coefficient of the test track ($\mu$ = 0.854). Also, it is important to highlight that the curve radius was 85.6 m and 3.7 °of transversal slope.

**Fig. 2 6×2 tractor truck used for the measurements.**

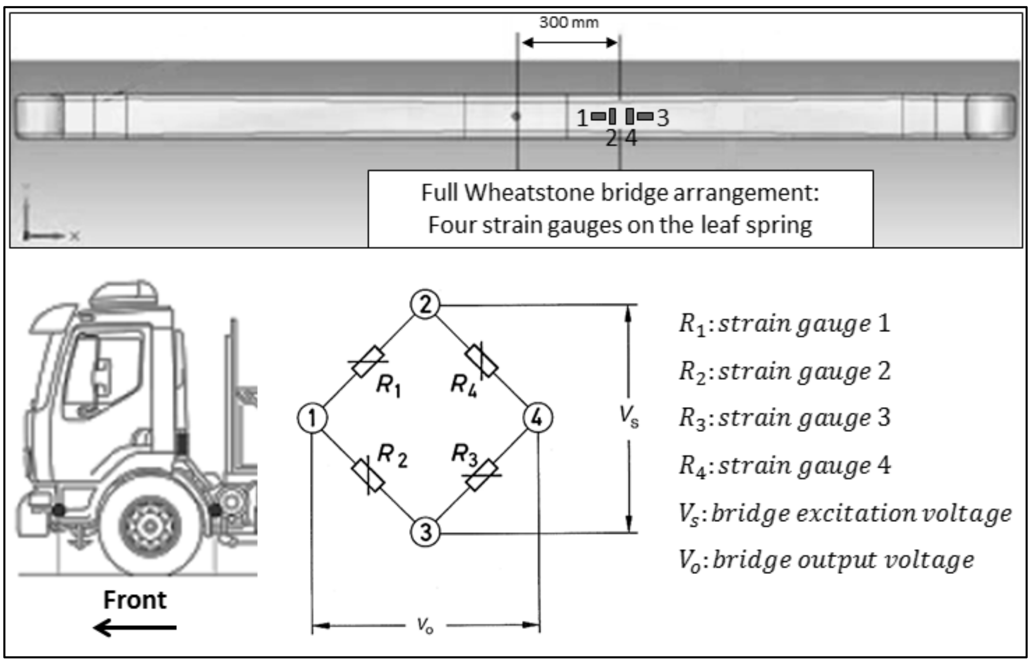


**Fig. 3 Illustration of the strain gauge instrumentation on the leaf spring.**

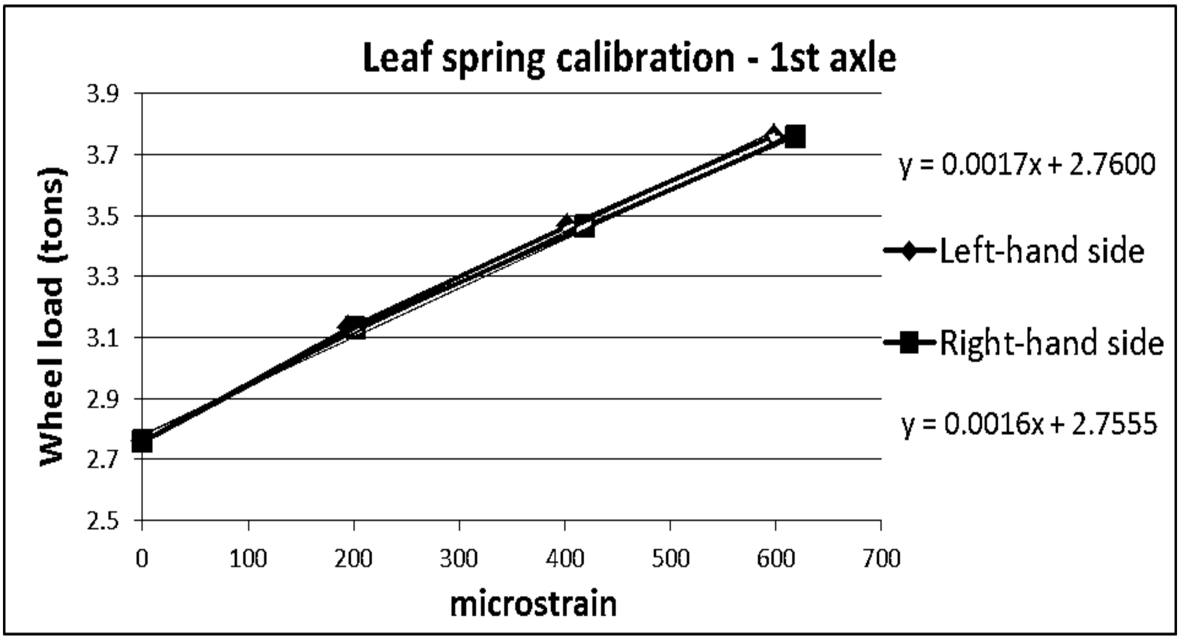


**Fig. 4 Calibration of 1st axle's springs.**

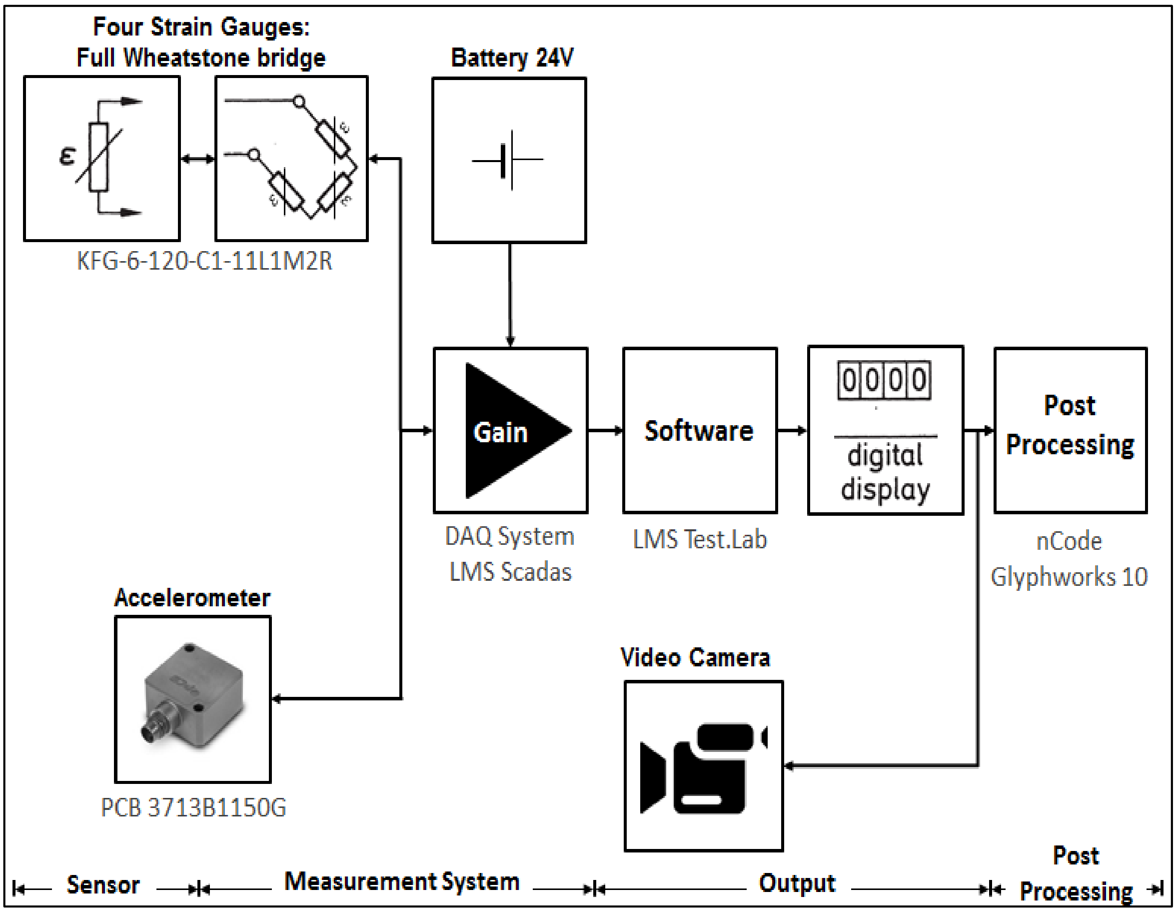


**Fig. 5 Summary of instrumentation, data acquisition and data post-processing.**

## 3. Results and Discussion

Table 1 presents the collected data from the performed measurements, in terms of vertical load applied to the pavement, and lateral acceleration, by considering static values and the variation with the vehicle speed.

By plotting the results on a chart of vehicle speed versus lateral acceleration, it is possible to check the linearity of those two parameters through the $R^2$ index of 0.9914 in Fig. 6.

As mentioned before, for safety issues, the maximum vehicle speed was 70 km/h, which generated lateral acceleration of 0.34*g*, but virtual analysis with similar vehicle specification [9] suggested lateral acceleration of 0.7*g* before vehicle rollover.

In this way, it is possible to plot the vertical load applied to the pavement with the vehicle speed (Fig. 7).

In summary, the vertical load applied to the pavement could be translated by Eq. (2).

$$\text{Vertical load during cornering} = 0.011 \times \text{vehicle speed} + \text{static load} \quad (2)$$

**Table 1 Results summary.**

| Vehicle speed (km/h) | 1st axle (ton) | | Acceleration (*g*) |
|---|---|---|---|
| | 1st axle LHS | 1st axle RHS | |
| Static | 2.76 | 2.755 | - |
| | 2.827 | 2.76 | 0.01 |
| 30 | 2.841 | 2.749 | 0.02 |
| | 2.846 | 2.743 | 0.02 |
| Average | 2.84 | 2.75 | 0.02 |
| | 2.934 | 2652 | 0.08 |
| 40 | 2.923 | 2.662 | 0.07 |
| | 2.925 | 2.657 | 0.07 |
| Average | 2.93 | 2.66 | 0.07 |
| | 3.127 | 2.509 | 0.16 |
| 50 | 3.132 | 2.497 | 0.17 |
| | 3.132 | 2.494 | 0.16 |
| Average | 3.13 | 2.50 | 0.16 |
| | 3.318 | 2 368 | 0.26 |
| 60 | 3.335 | 2.36 | 0.26 |
| | 3.33 | 2353 | 0.26 |
| Average | 3.33 | 2.36 | 0.26 |
| | 3. 489 | 2.24 | 0.33 |
| 70 | 3.483 | 2.24 | 0.33 |
| | 3.508 | 2.194 | 0.35 |
| Average | 3.49 | 2.22 | 0.34 |

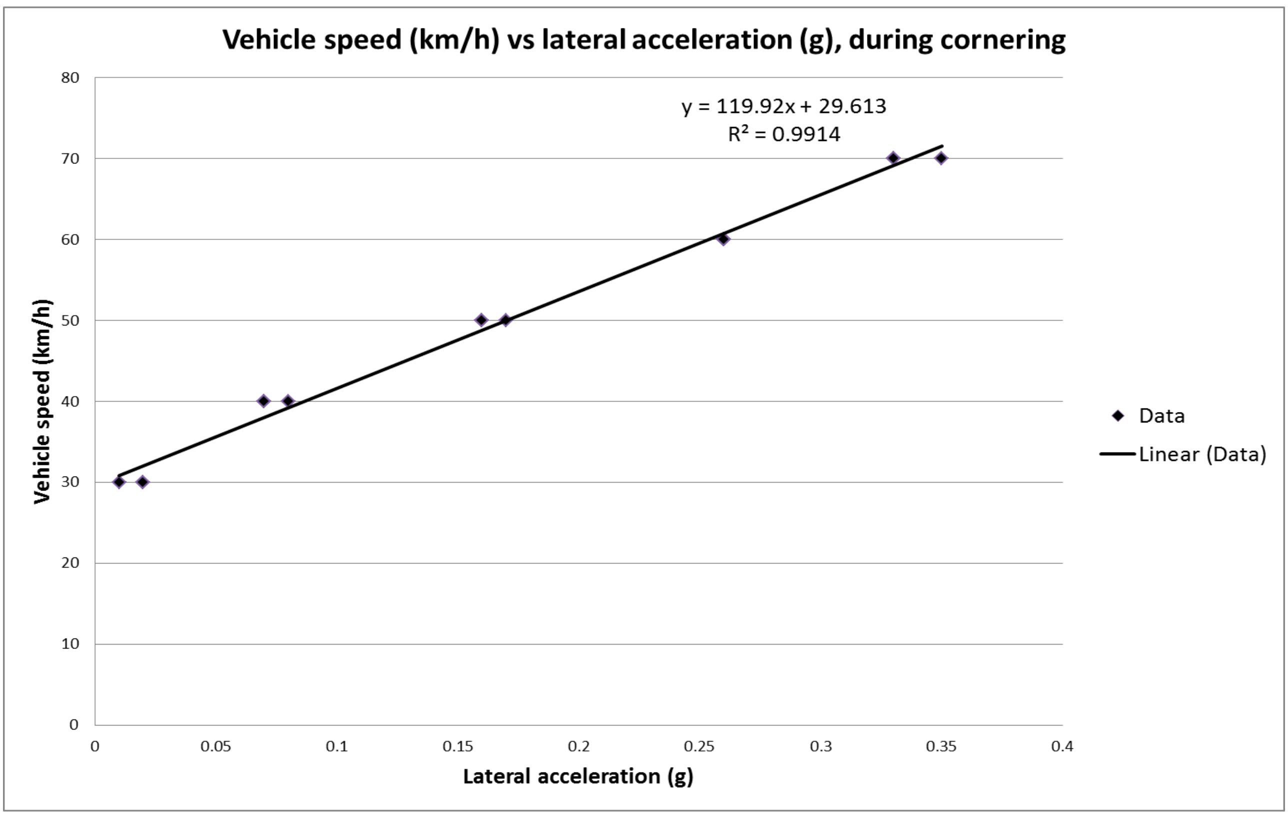


**Fig. 6 Vehicle speed vs. lateral acceleration.**

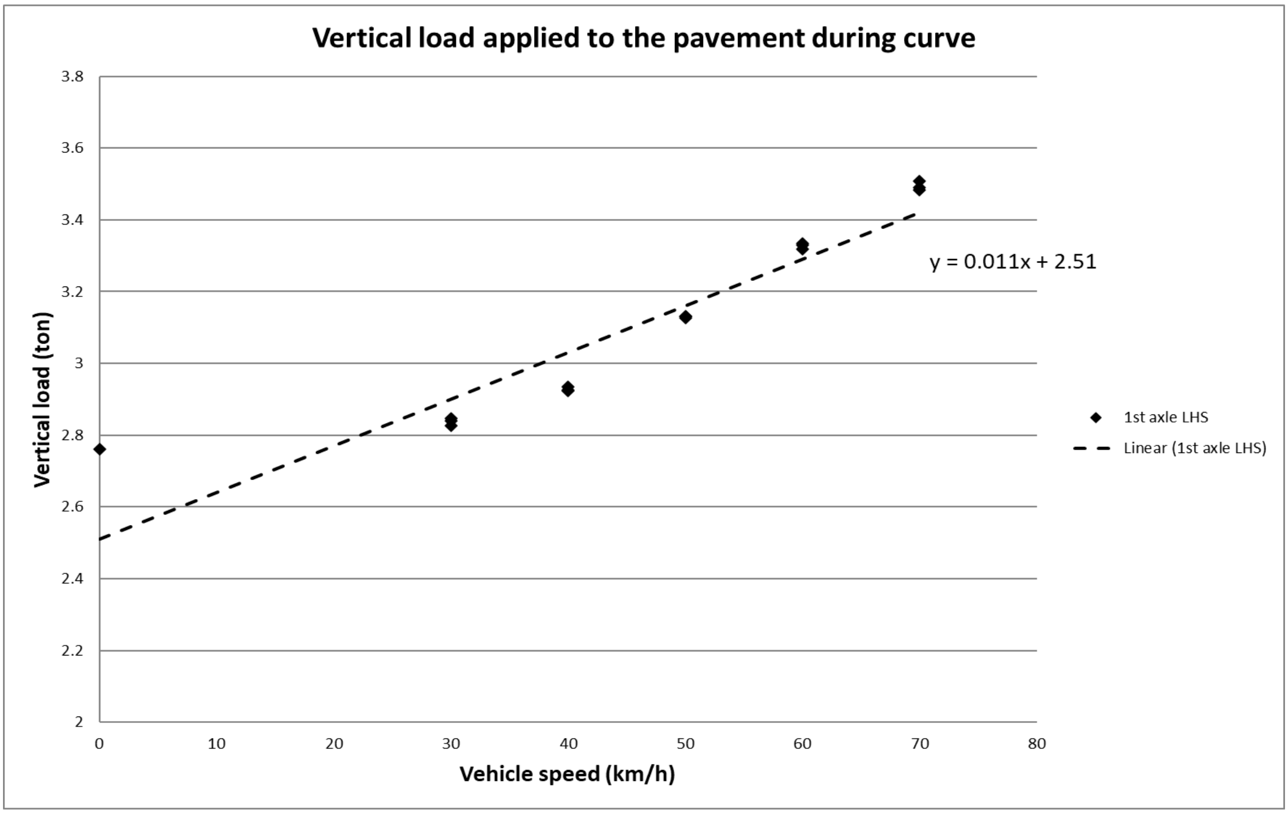


**Fig. 7 Vehicle load applied to the pavement vs. vehicle speed.**

## 4. Conclusions

During high-speed curve, it is possible to predict the load applied to the pavement with Eq. (2). For a given center of gravity, the trend lines are added to the static load.

The measurements results indicated that for every 10 km/h increasing on the vehicle's speed, additional 110 kgf will be transferred to the pavement on the outer side of the cornering radius. This value itself could not be considered high, but it will be also added to the static load, or overload in some truck applications.

If it is considered a vehicle is traveling at 70 km/h with a static load of 6 tons on the front axle (maximum allowed load for front axle by Brazilian legislation), it will apply 25% more load to the pavement, if compared to the static load—if considering the tolerance of 5% of the Brazilian legislation, this value will increase to 31%.

Despite the fact that the hypothesis is that the load transfer is related to the lateral acceleration of the vehicle, for future studies, it is recommended to repeat the same procedure on curves with different radius and slopes.

## References

[1] Gallegos, M., Hernandez, R., Vega, D., and Flores-Centeno, O. 2010. "Evaluation of Contact Force and Pressure of Heavy Vehicle's Supersingle Tire versus Dual Tires." SAE Technical Paper 2010-01-1900, Society of Automotive Engineers. doi: 10.4271/2010-01-1900.

[2] Oliveira, A., Valentim, C., Duarte, M., et al. 2008. "Tire Pressure Impact on Structural Durability Tests Results." SAE Technical Paper 2008-36-0041, Society of Automotive Engineers. doi: 10.4271/2008-36-0041.

[3] Kubo, P. *et al*. 2014. "Vertical Load Effects Applied on the Pavement Considering the Variation of Tire Pressure". Journal of Traffic and Transportation Engineering 2: 107-115.

[4] Kubo, P. *et al*. 2015. "Influence of Shock Absorber Condition on Pavement Fatigue using Relative Damage Concept". Journal of Traffic and Transportation Engineering. https://doi.org/10.1016/j.jtte.2015.10.001.

[5] Wu, J., and Liang, J., and Adhikari, S. 2014. "Dynamic Response of Concrete Pavement Structure with Asphalt Isolating Layer under Moving Loads." *Journal of Traffic and Transportation Engineering* 1 (6): 439-47.

[6] Taheri, A., Obrien, E. J., and Collop, A. C. 2012. "Pavement Damage Model Incorporating Vehicle Dynamics and a 3D Pavement Surface." *International Journal of Pavement Engineering* 13 (4): 374-83.

[7] Gillespie, T. 1992. *Fundamentals of Vehicle Dynamics*. Warrandale, USA: Society of Automotive Engineers.

[8] Kubo, P. *et al*. 2019. "Methodology to Quantify the Real Vertical Load Applied to the Pavement". International Journal of Pavement Research and Technology. https://doi.org/10.1007/s42947-019-0084-2.

[9] Lima, V. A., Garbin, L., and Santos Neto, C. R. 2008. "Lateral Dynamics Simulation of a Truck with Modified Rear Suspension." SAE Technical Paper 2012-36-0020, Society of Automotive Engineers.