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The influence of the suspension upon the axle weight distribution for heavy trucks

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Abstract. Due to the increasing number of heavy trucks, the number of the overweight trucks have increased, and most of them, were recorded with axle overweight. This may lead to fines for the transportation companies, and to the road damage. One of the main reasons of axle over-weight is the COG displacement, which is influenced by several factors. The main objective of this paper is to determine the way that a suspension setting can influence the cargo load distribution inside a truck-semi-trailer assembly. In order to achieve the proposed objective, a calculation principle in regarding to the influence of the suspension setting upon the axle weight distribution for heavy trucks is presented. This calculation method was validated through experimental tests. The results indicates that the suspension setting plays a great role in the uniformly distribution of the cargo load, and using a wrong suspension setting, overloading on a certain axle may appear.

1. Introduction

The number of heavy commercial trucks is growing every day, and on this background, the number of overweight trucks has the same tendency, leading to a great challenge not only for the roadway maintenance but also for the truck weight enforcement [9].

During its movement, the heavy trucks are subjected to high external forces during braking and steering, while the cargo loading plays a great role in the truck stability [10]. The movement of the cargo, and the way it is positioned in the trailer/semi-trailer, may influence the coordinates of the COG (center of gravity). The COG modification can overload a certain axle, which not only may lead to significant fines for the transportation companies, but the road infrastructure will be damaged [7].

A study conducted in USA reported that in Tennessee more than 50% of the heavy trucks were recorded with axle overload; while for a gross overweight a percentage of 16.8% was reported [8]. Subjects such as the influence of load upon the rolling resistance respectively the fatigue assessment upon the rear axle due to the service loading were approached by J.Ejsmont et.al, respectively Zhao et. al. but, very few literature approach the subject of the influence of the suspension settings upon the axle weight distribution. The weighting process of a truck with a semitrailer is made on each axle, and the allowable values for each axle are the following: for the truck front axle is 7500 kg, the rear axle 11500 kg, while for the semi-trailer the total allowable mass is 8000 kg for each axle of the trident. In case of exceeding, the transportation company receives a fine, proportional with the exceeding [1], [2], [4].

In this study, will be presented a study case where we will show the influence of the suspension settings upon the overload on the driving.

2. Testing Procedure Methodology

For the measurements of the axle loadings, there can be used two types of measurement capable to determine this parameter. One of the measurements is measuring the static loading, while the second one is capable to determine the axle loading dynamically. Both of the measurements have an allowable exceeding value of 4%. Therefore the two procedures are as follows [6]:

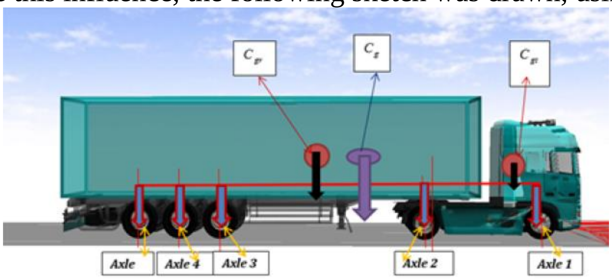
The loaded truck is stopped with approximately 4 meters before the entrance to the measuring device. He is slowly accelerated on an inclined plane, such that the truck can be lifted on a horizontal platform, in order to enter with the first axle on the device for the measurements. As soon as the first axle is positioned horizontally on the device, and a short amount of time (approximately 1 minute) passed since the first axle was positioned properly such that the cargo will be stabilized, the first measurement is taken. This procedure will be repeated for all the axles, and in the end the full report will be printed.

In the second type of procedure, the truck is moving with a constant speed that may not exceed 5 km/h, on a special platform capable to determine the axle loadings, dynamically.

3. Case Study

A loaded truck is heading to the loading measurement device, but before entering to the platform, the driver observes that due to the inclined plane that is heading to the horizontal platform, he has to lift the truck’s pneumatic suspension, positioned on the rear axle, due to the fact that truck’s ground clearance was too small. The main objective here is to determine the influence of the lifted pneumatic suspension.

In order to determine this influence, the following sketch was drawn, using the notations:



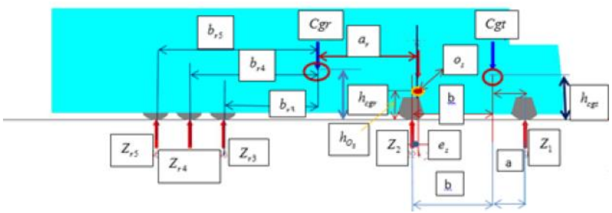


Figure 1. Sketch of the forces that are subjecting the static truck and semi-trailer

h_{gt} - Truck COG Height

C_{grt} - Truck COG location

h_{cgr}- Semi-trailer COG Height

C_g- Truck/trailer assembly COG location

O_s - Coupling point position

a –Distance between the truck's front axle (axle 1) to the C_{gr}

h_{os}- Coupling point height

b – Distance between the truck's rear axle (axle 2) to C_{gt}

C_{gr} - semi-trailer COG location

$Z_{1,}$, Z_2 - Normal reactions of the ground, for the axle number 1 respectively axle number 2 of the truck

$Z_{r3,}$ Z_{r4}, Z_{r5} - Normal reactions of the ground, for the axle number 3, axle number 4 respectively axle number 5 of the semi-trailer

At the semi-trailers with 3 axles, the suspension is provided with two air cushions for each axle, being fueled with compressed air. These cushions take over and distribute uniformly the cargo's weight on each axle, ensuring the correct equilibrium, according to the approval of vehicle's technical rules set.

The used semi-trailer, has the following specifications: M_0 = 7220 kg – Unladen mas; M_{TMA} = 39000 kg – Maximum allowable mass; M_{UMA} = 31780 kg – Maximum allowable payload capacity; distribution of maximum allowable mass per each axle: Rear axles (axles 3,4,5) – M_{rs} = 24000 kg

For the trucks with two axles, the suspension is provided with two air cushions for the rear axles, capable to take over and distribute uniformly the weight, ensuring equilibrium. According to the approval of vehicle's technical rules set, the specifications are: M_0' = 8456 kg – Unladen mass, M_{TMA}' = 18600 kg – Maximum allowable mass; M_{UMA}' = 12920 kg – Maximum allowable payload capacity.

Distribution of maximum allowable mass per each axle: Front axle (axle 1) – M_{tf} = 7500 kg; Rear axle (driving axle 2) – M_{ts} = 11500 kg; M_U = 23800 kg – Maximum cargo load limit

Knowing the value of maximum cargo limit, we were able to determine the correct load distribution on each axle. This procedure was made by determining the percentage of each maximum load capacity on each axle, and adapting it to our maximum cargo limit (e.g. the driving axle load percentage from the maximum total truck-semi-trailer assembly mass of 40 000 kg represents 28.75%, leading to a load re-distribution using the total mass of 38680 kg, on the driving axle of 0.2875* 38680=11120.5 kg). Using this procedure we obtained: M_{TOTAL} = 38680 kg < 40 000- Total mass of the truck and semi-trailer assembly; M_{AXLE1} = 7252.5 kg, M_{AXLE2}= 11120.5 kg; $M_{AXLE3} = M_{AXLE4} = M_{AXLE5}$ = 6769 kg

By checking the semi-trailer suspension specification provided by the manufacturer, a lifting of the suspension can reach a maximum value of 80 mm. In our calculation, we will consider a value of H= 70 mm (DAF, 2013).

Using the measured values presented in the Figure 2, we were able to write the momentum equilibrium equations restricted to the truck and semi-trailer assembly' COG as follows:

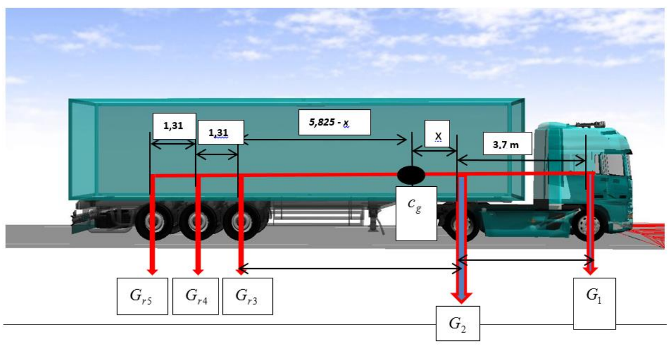


Figure 2. The sketch of the truck-semi-trailer assembly with the force distribution per axles

$$G_1 \cdot (x+3.7) + G_2 \cdot x - G_{r3} \cdot (5.825 - x) - G_{r4} \cdot [(5.825+1.31) - x] - G_{r5} \cdot [(5.825 + 2 \cdot 1.31) - x] = 0 \quad (1)$$

The geometric parameters taken into account in order to calculate the truck-semi-trailer assembly such as the distances between axles respectively truck's front and rear overhang were measured (Figure.2).

The load distribution on each axle was determined as follows:

$$\begin{cases} G_1 = M_{AXLE1} \cdot g = 71150N \\ G_2 = M_{AXLE2} \cdot g = 109100N \\ G_{r3} = G_{r4} = G_{r5} = 66400N \end{cases} \quad (2)$$

where g = 9.81 m/s2 is the gravitational acceleration

Solving equation (1), the value of x was obtained as x=3.05 m, x representing the initial location of the truck-semi-trailer assembly COG location along X axis, before suspension lifting.

Distance from axle I to the COG: D1 =3.84+x = 6.89 m

Distance from axle II to the COG: D2 = x = 3.05 m

Distance from axle III to the COG: D3= 5.823 -x = 2.773 m

Distance from axle IV to the COG: D4= 5.823 - x + 1.31 = 4.083 m

Distance from axle V to the COG: D3= 5.823 -x + 2.62 = 5.393 m

In Figure 3 it is presented a sketch of the forces after the elevation caused by the suspension lifting leading to a modification of the center of gravity (denoted by C2).

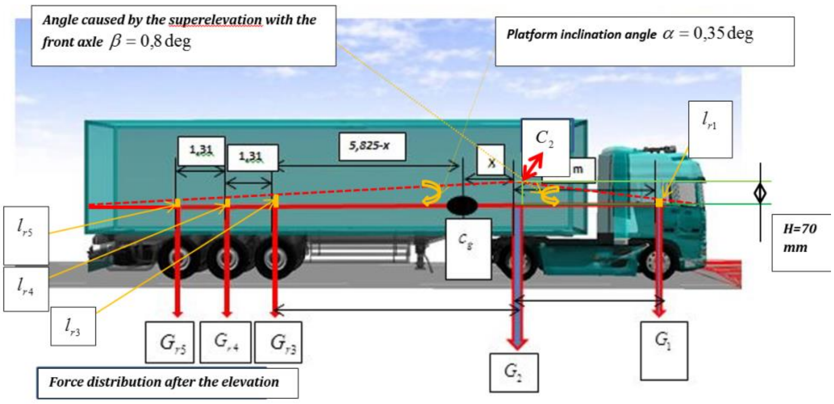


Figure 3. The sketch of the forces after the elevation occurred

The next step was to determine the values of lr1,3,4,5,, which represent the displacement of the axles 1, 3, 4 and 5, caused by driving axle suspension lifting. These values were determined geometrically, using similar triangles presented in Figure 4.

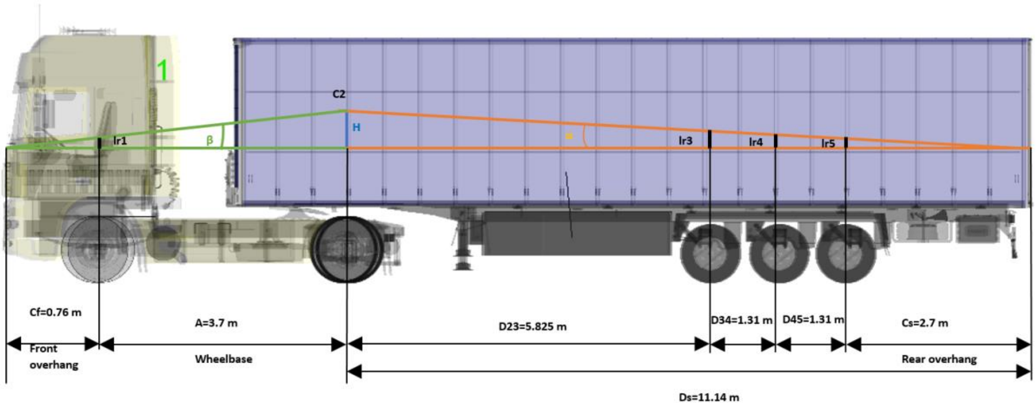


Figure 4. The triangles described by the suspension lifting

Using the notations from Figure 4, the equations for the lr can be written:

$$\begin{cases} lr1 = Cf \cdot \dfrac{H}{A+Cf} = 0.012m \\ lr3 = H \cdot \dfrac{Cs + 2 \cdot D34}{Ds} = 0.033m \\ lr4 = H \cdot \dfrac{Cs + D45}{Ds} = 0.025m \\ lr5 = H \cdot \dfrac{Cs}{Ds} = 0.017m \end{cases} \quad (3)$$

In this case, by writing the moment equilibrium equation in point C2, we obtained the following equation in function of α:

$$H \cdot F_{1C_2} = (H - l_{r3}) \cdot G_{r3} \cdot \sin\alpha + (H - l_{r4}) \cdot G_{r4} \cdot \sin\alpha + (H - l_{r5}) \cdot G_{r5} \cdot \sin\alpha \quad (4)$$

The moment equilibrium equation can be written in function of β in point C2, as follows:

$$M_{2C_2} - M_{G1} = 0 \quad (5)$$

Where M_{2C2} – represents the moment on axle 2 applied in the point C2,

M_{G1} – represents the moment on axle 1 caused by weight G_1

$$H \cdot F_{2C_2} = (H - l_{r1}) \cdot G_1 \cdot \sin\beta \quad (6)$$

By adding relation 3 with 5, it is obtained:

$$F_{1C_2} + F_{2C_2} = \frac{1}{H} \cdot [(H - l_{r3}) \cdot G_{r3} \cdot \sin\alpha + (H - l_{r4}) \cdot G_{r4} \cdot \sin\alpha + (H - l_{r5}) \cdot G_{r5} \cdot \sin\alpha + (H - l_{r1}) \cdot G_1 \cdot \sin\beta] \quad (7)$$

Therefore, knowing parameters such as α, β, H, Gr we determined the overloading of the driving axle:

$$F_{1C_2} + F_{2C_2} = 2007N \quad \text{– overloading on the axle 2 (driving axle)} \quad (8)$$

Representing an overloading mass on the measuring device of M_{ov} = 204.58 kg

By comparing the weight distribution on axle 2, in normal equilibrium conditions with G2, results:

$$\frac{F_{1C_2} + F_{2C_2}}{G_2} = \frac{1915}{109100} \cong 1.84\% \quad (9)$$

Therefore the influence of the suspension lifting with 7 cm in this case, can lead to an increasing of weight distribution on the driving axle of 1.84 %, which may cause significant fines for the transportation companies.

5. Results And Discussion

In order to test the influence of the suspension settings upon the axle load distribution, there were performed both types of measurements on a heavy truck, with the same cargo. In one of the test, the truck had the air cushion set at 0 level, while for the second test the driving axle suspension air-cushion was lifted. For the first test the static measurement was performed, while for the second one we used the dynamic measurement. The data obtained is summarized in the table 1.

Table 1. The measurements obtained for both tests

Load measured	***Test 1 - Static measurement [kg]***	***Test 2 - Dynamic measurement [kg] - Lifted suspension***	***Maximum allowable value [kg]***	***Maximum allowable value with 4% exceeding value [kg]***	***Exceeding value - Test 1 [kg]***	***Exceeding value - Test 2 [kg]***
Total mass	38680	38680	40000	-	0	0
Mass on axle 1	7510	7780	7500	7800	0	0
Mass on axle 2	11800	11980	11500	11960	0	20
Mass on axle 3	6550	6340	8000	8320	0	0
Mass on axle 4	6490	6220	8000	8320	0	0
Mass on axle 5	6330	6360	8000	8320	0	0

It can be observed from Table 1, that in the first test the cargo load on each axle is within the allowable values, while for the second test (suspension lifted) the exceeding value of 20 kg on the driving axles occurs and represents an exceeding of 1.53% in comparison with the static test measurement, where the suspension's air cushion was at 0 level. Was observed that in the test where the suspension was lifted, the masses on the semi-trailer trident were reduced, and the main reason of this is that by moving the COG backwards along the X axis, the length of the force lever arm is reduced, leading to a reduced torque value on the trident.
Using the presented calculation principle, the overloading on the driving axle can be determined using as input value the measured driving axle load of 11800 kg, when the suspension setting was set to 0 level, and we can determine the height of the suspension setting for the second measurement (dynamic measurement), where the overloading occurred. By performing this calculation, we obtained a value for the suspension air cushion height, H of 61 mm, representing an overloading mass of 180 kg.
In order to obtain a diagram of the overloading force in function of the suspension displacement, was developed a Mathcad program. In this program, the suspension displacement (H) was used as a range variable, with values from 10-80 mm, with a step increment of 10.

The obtained diagram of the overload force in function of the suspension displacement is presented in Figure 4.

Another diagram that was extracted was the one including the overload percentage of the driving axle in function of the suspension displacement. This diagram is presented in Figure.5

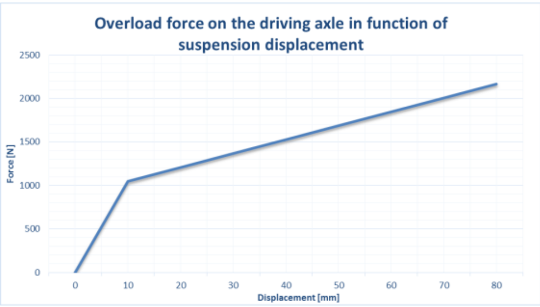


Figure 4. Overload force on the driving axle in

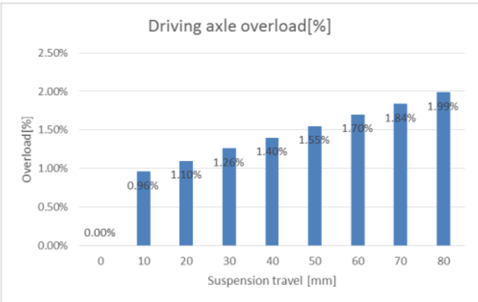


Figure 5. Driving axle overload in

function of suspension displacement function of suspension displacement

It can be observed that a small suspension modification leads to significant overloading on the truck's driving axle. At a modification of 10 mm, we can discuss of an overload of nearly 1%, considering the reference value the maximum allowable mass on the driving axle (11500 kg), while for the case where the suspension is set at a height of 80 mm, the overload is doubled.
The main reason of this phenomena, is the fact that the suspension modification leads to a COG modification, and the higher is the suspension lifted, the greater is the truck-semitrailer COG modification

6. Conclusion

This paper presents a calculation principle, meant to determine the influence of a truck's pneumatic suspension upon the load distribution, and the way that this influences the overloading on the driving axle. By analyzing the data obtained in the case study, we can argue that the suspension setting plays an important role on the axle load distribution. By lifting the air cushion provided by the driving axle suspension with 80 mm, can lead to the axle overload of 2%.
The calculation method was validated through measurement tests, and it is an accurate method to predict the overloading on the driving axle in function of the air cushion suspension settings.
Transportation companies can easily receive fines in case of the drivers will not set the suspension properly before they reach the cargo weighing device.
The suspension setting represent an important factor to distribute correctly the cargo load, but may be influenced by other factors. Future research will be conducted on the suspension modification in case the cargo will be hanging of the semi-trailer sealing, and during the vehicle motion, this cargo will produce a pitch movement of the truck/semi-trailer assembly

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