

Vehicle dynamics influence on traffic safety in case of a certain route deceleration

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Abstract. The present paper is aimed at determining the kinematic and dynamic parameters of a vehicle during braking on a road in alignment. Closely related to the determining the braking capability, we need to consider the key parameters that characterize the maximum braking capabilities of a vehicle, i.e. maximum deceleration, minimum braking space and minimum braking time. Hence, resorting to the ADAMS Car software platform, we carried out a case study to determine the kinematic and dynamic parameters of a vehicle in the braking situation on the road in alignment. The virtual modeling developed within our case study consisted of five full-vehicle analyses of the braking situation on a track in alignment. The initial speeds of the vehicle and the gearbox shift varied for each of five analyzed cases, while the rest of the input parameters did not change. The initial speeds considered were: 30 km/h, 50 km/h, 80 km/h, 100 km/h and 120 km/h. Following the numerical processing, we set out to determine the forces and moments at the wheel at the braking moment. The processing of the numerical results envisaged a comparative analysis of the vehicle kinematic and dynamic parameters for the five cases analyzed.

1. Introduction

The contemporary accelerated development of the automotive industry has opened the door for multiple research perspectives within the field of vehicle study, hence various research studies focused both on the increase of vehicles' safety and passengers' comfort, as well as on the achievement of higher dynamic performance.

Since vehicles are not subject to microscopic-level investigations, we need to analyze it within the road traffic system as a whole. Adopting this approach, various research papers such as [1] evaluate through a series of applied mathematical methods the effect of different lane grouping and critical lane group concept on the saturation flow rate.

Other research perspectives have focused on the study of the security systems. In [2] the authors address the topic of active security systems, and resorted to the "quarter" vehicle model to validate the ABS/ASR system working algorithm over the braking or starting processes. Passive safety and, in particular the influence of the geometric parameters of the frontal vehicle profile in case of car-to-pedestrian collisions are highlighted in [3].

Further in-depth studies on vehicle dynamics in terms of stability are approached in [4], as the authors put forward a mechanical model of the vehicles with two axles, taking into account the lateral deflection of the tire. Also, in [5] the speeds influence on vehicle stability when changing the lane is analyzed via experimental tests. Experimental determinations have been applied in [6], as well, in order to develop an analysis of vehicle behavior during a dynamometer performance.

Vehicle ride comfort has been studied by means of a half-car model in [7] that led to a comparison of the main semi-active suspension systems used in a passenger car. In the same line, in [8], further research studies have been carried out taking into account that the nonlinearity of the model is contributed by the damper models.

2. An analytical method to determine the braking capability

Among the vehicles' dynamic performances frequently analyzed, we highlight vehicles' braking capability. The parameters that feature the maximum braking capabilities of vehicles are: the maximum acceleration, the minimum braking distance and the minimum braking time. The implications of high efficient braking capability contribute to increasing road safety, hence reducing the number of traffic accidents.

2.1. Analytical determination of the braking time

The braking process starts from the moment when an actual need to stop arises, causing the vehicle to brake, and, ends when the vehicle stops. This process covers the following time stages: the time elapsed during the involuntary delays (T_{if} – the physiological delays, T_{im} – the mechanical delays) and the time elapsed between the start of the braking process and the moment the vehicle stops.

The general relation to determining the total stop time, if we know the initial speed, is [9]:

$$T_t = T_{if} + T_{im} + 0,5 \cdot t_3 + \frac{K_e v_a}{3,6 g \varphi_{red}} \quad (1)$$

where:

t_3 - is the time elapsed between the start of the braking process and the lock of the wheels

φ_{red} – is the average value of the adhesion coefficient when braking

v_a [km/h] – is the vehicle speeds at the start of braking

The analytical determination of the braking time was achieved for five distinct cases, considering different speeds parameters, i.e. 30 km/h, 50 km/h, 80 km/h, 100 km/h and 120 km/h. The mathematical model was developed in a flexible structure, by means of the Maple software, a sequence that allows for rapid change of input parameters and new braking analysis. Table 1 below summarizes a part of the sequence developed:

Table 1. Maple sequence to determine the braking time and space

<pre> > Tii := Tif + Tim + 0.5*t3; > va1 := 30; va2 := 50; va3 := 80; va4 := 100; va5 := 120; > for i from 1 by 1 to 5 do Tf_i := (ke*va_i) / (3.6*g*fred) end do; Tf_1 := 1.061841658 , Tf_2 := 1.769736097 , Tf_3 := 2.831577756 , Tf_4 := 3.539472195 , Tf_5 := 4.247366634 > for i from 1 by 1 to 5 do Tt_i := Tii + Tf_i end do; Tt_1 := 2.061841658 , Tt_2 := 2.769736097 , Tt_3 := 3.831577756 , Tt_4 := 4.539472195 , Tt_5 := 5.247366634 > for i from 1 by 1 to 5 do Sii_i := Tii * (va_i / 3.6) end do; Sii_1 := 8.333333334 , Sii_2 := 13.888888889 , Sii_3 := 22.222222222 , Sii_4 := 27.77777778 , Sii_5 := 33.33333334 > for i from 1 by 1 to 5 do Sf_i := (ke*va_i*va_i) / (26*g*fred) end do; Sf_1 := 4.410726889 , Sf_2 := 12.25201913 , Sf_3 := 31.36516899 , Sf_4 := 49.00807652 , Sf_5 := 70.57163020 > for i from 1 by 1 to 5 do St_i := Sii_i + Sf_i end do; St_1 := 12.74406022 , St_2 := 26.14090802 , St_3 := 53.58739121 , St_4 := 76.78585430 , St_5 := 103.9049635 </pre>
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2.2. Analytical determination of the braking space

Establishing the initial vehicle travel speeds [km/h], in accordance with the elements previously set, we can determine via computation the total braking space results from the sum of the space run during the duration of the involuntary delays and the actual braking space [9]:

$$S_T = (T_{if} + T_{im} + 0,5t_3) \frac{v_a}{3,6} + \frac{K_e v_a^2}{26gf_{red}} \quad (2)$$

As with braking time, the total braking space was determined by means of the analytical method, considering the same input parameters, i.e. the speeds values.

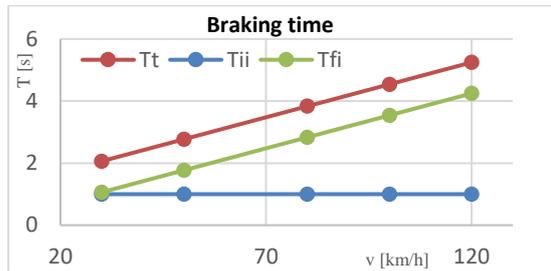


Figure 1. Analytical determination of the braking time.

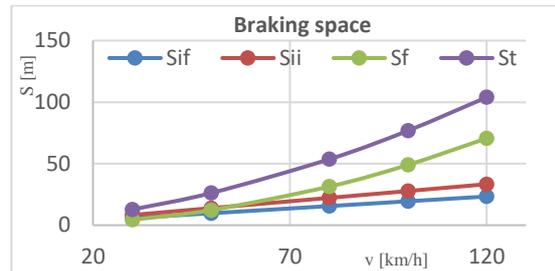


Figure 2. Analytical determination of the braking space.

3. Determining the kinematic and dynamic parameters via the Adams Car software

3.1. Input parameters and simulation development

The first step to develop our simulation was to create a new full vehicle assembly. For the purpose of defining a new assembly, we must select and input all the component subassemblies. The main subassemblies to be defined in the vehicle structure are: the front suspension system, the rear suspension system, the steering system, the front wheel drive, the rear running system, and the vehicle bodywork.

In order to analyze the vehicle kinematic and dynamic behavior in the event of braking, we need to take into the following components, as well: the braking system, the propulsion system of the vehicle, the traffic lane (road) on which the vehicle will travel.

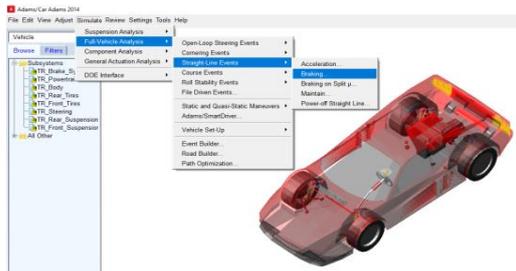


Figure 3. Selecting the analysis type.

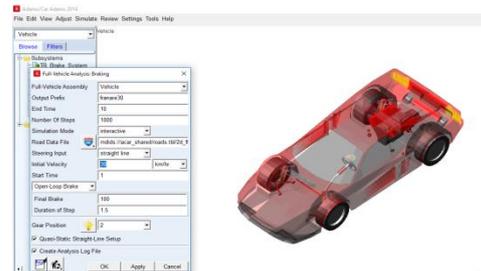


Figure 4. Defining the analysis parameters - braking at 30 km/h.

The case study carried out consisted of five full-vehicle (vehicle assembly) analyses for the braking situation on the road in alignment – see Figure 3. For the five analyzed cases, the initial speeds of the vehicle and the gearbox shift varied, while the rest of the input parameters remained the same. The initial speeds considered were: 30 km/h, 50 km/h, 80 km/h, 100 km/h and 120 km/h.

The input parameters for kinematic and dynamic vehicle analysis when braking on the road in alignment at an initial speed of 30 km/h are illustrated in Figure 4. Following the numerical processing,

as illustrated in Figures 5 and 6, we determined the forces and the moments on the wheel, at the simulation endpoint, for the speeds of 30 km/h, respectively of 120 km/h.

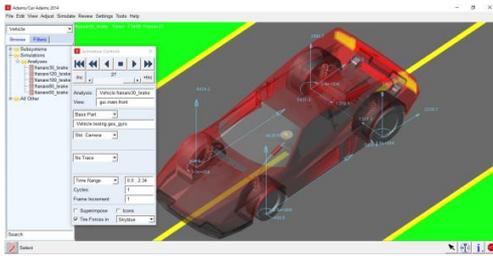


Figure 5. Forces and moments on the wheel when braking at 30 km/h.

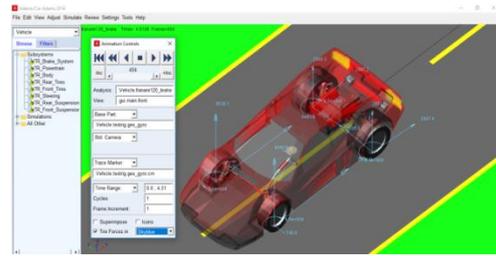


Figure 6. Forces and moments on the wheel when braking at 120 km/h.

3.2. Results interpretation

The processing of the numerical results aimed at a comparative analysis of the vehicle kinematic and dynamic parameters for all five analyzed cases. Figure 7 illustrates graphically the distance traveled during braking until the vehicle is stopped at an initial speed of 30 km/h, 50 km/h, 80 km/h, 100 km/h and 120 km/h.

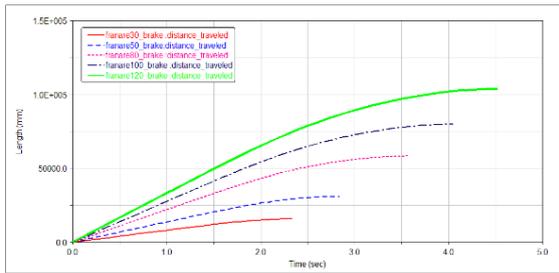


Figure 7. The distance traveled during braking.

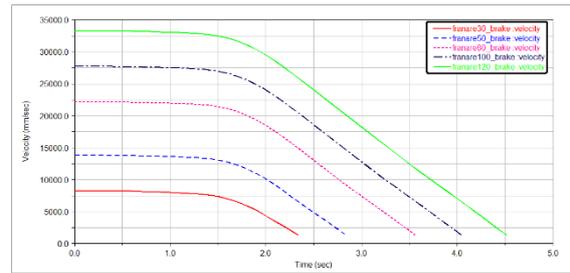


Figure 8. Speeds variation during braking.

The speed variation during the braking maneuver is indicated in Figure 8. According to the same figure, we can establish the total braking time for each analyzed situation.

The variation of the deceleration values during braking is illustrated in the Figure 9 diagram. The maximum longitudinal deceleration for the first case, i.e. the initial speed of 30 km/h, is $10000 \text{ mm/s}^2 \approx 1,01 \text{ g}$. The maximum deceleration reached is $11500 \text{ mm/s}^2 \approx 1,17 \text{ g}$, and has been reached in all four situations, starting at an initial speed of 50 km/h, up to the last considered case, i.e. the initial speed of 120 km/h. The target parameters were applied to determine the tire forces for both front and rear axle tires. The components of the forces in the longitudinal direction for the front tires are graphically illustrated in Figure 10.

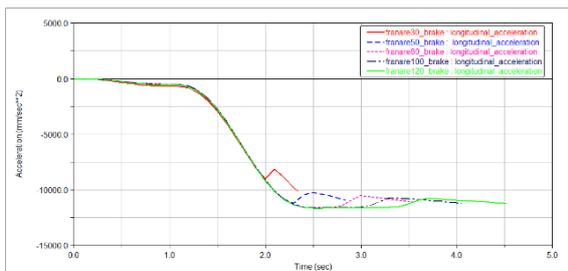


Figure 9. Longitudinal deceleration variation during braking.

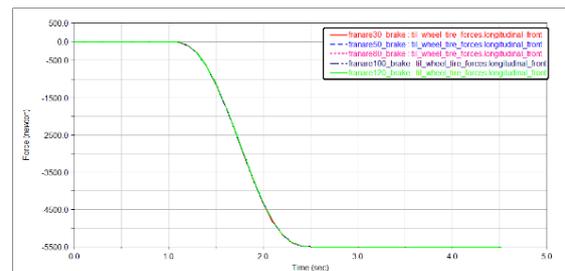


Figure 10. The force in the longitudinal direction of the tire - front.

4. Conclusion

In order to determine the vehicle kinematic and dynamic parameters during braking on the road in alignment, we carried out a case study while applying two distinct methods. First, we resorted to the Maple software platform to develop a flexible sequence for the analytical determination of time and braking space. The second method involved the realization of five virtual modeling cases via the ADAMS Car platform.

The case study carried out envisaged five full-vehicle (vehicle assembly) analyses for the braking situation on the road in alignment.

The processing of the numerical results aimed at a comparative analysis of the vehicle kinematic and dynamic parameters for the five analyzed situations. The minimum braking time is of about 2.1 s for an initial speed of 30 km/h, reaching about 5 s at an initial speed of 120 km/h.

The minimum braking distance is of 13 m (virtual model) and 12.75 m (analytical method) for a speed of 30 km/h; it increases to 27 m (virtual model) and 26.15 m (analytical) at a speed of 50 km/h; 54 m (virtual model) and 53.58 m (analytical) for an initial speed of 80 km/h, 77 m (virtual model) and 76.78 m (analytical) for 100 km/h respectively, thus the maximum braking distance is obtained for the initial speed of 120 km/h and 104 m (virtual model), i.e. 103, 90 m (analytical). Another set of results focused on the determination of tire forces for both front and rear axle tires.

The values obtained as to determine the braking capability, at different speeds, indicate similar variations, both by applying the analytical method and the virtual simulation of a vehicle braking on the road in alignment, hence validating the model developed within our research study.

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