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APPLICABILITY OF FRONT-WHEEL BRAKING PROCEDURE TO EVALUATE ROAD AVAILABLE GRIP

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Abstract

Tire manufacturers and road managers use specific vehicles and systems to assess road grip between reference roads or tires. This study details the development of a front-wheel braking method, enabling grip measurement with or without anti-lock braking systems (ABS). By modifying a vehicle to apply brakes only to the front wheels on a test track, this approach simplifies the grip calculation and increases safety by preventing rear wheel slip on low-texture roads and in wet conditions. Thus, this method provides the necessary safety conditions for evaluating braking with locked wheels on slippery surfaces, in addition to conventional tests with ABS. Both grip values, with and without ABS, can be used to construct a complete slip-grip curve, using a Pacejka model, from 0 to 100% slip. An instrumented passenger car was then used to measure grip on a test track and two highway sections at initial speeds of 50, 65, and 80 km/h. The method shows good repeatability across tests for given road conditions. A comparison between our "406" vehicle with the front braking method and a continuous grip measurement vehicle (CGM) showed about a 5% difference at key points of the curve, corresponding to locked and fully sliding wheel scenarios. Thus, our 406 vehicle's results may more accurately represent the grip of similar light vehicles than a dedicated vehicle using a small instrumented fifth wheel.

Keywords: road grip, tire performance, vehicle, brake testing, road safety

1 Introduction

Tire to road grip significantly impacts road safety by aiding vehicles in decelerating or maneuvering in response to sudden obstacles or changes in direction. Various experimental methods exist for measuring a vehicle's grip, from using highly instrumented vehicles with fine wheel angle sensors [1] to estimate grip from low tire slip variations, to intelligent tires equipped with strain gauges [2]. Road managers develop and use specific systems to monitor road grip levels and their evolution over time, such as braked trailers or large vehicles with an additional instrumented wheel [3].

Full-scale braking tests with real vehicles offer the most representative grip measurements but pose safety risks, especially on wet surfaces. The American Society for Testing and Materials (ASTM) has developed methods preserving the test safety levels, like diagonally braking vehicles [4]. Among these methods, the frontal braking method consists of carrying out emergency braking tests on a roadway, by deactivating the rear wheel brakes and activating and deactivating the ABS system. This procedure simplifies the calculation of grip mobilization compared to scenarios involving complete four-wheel braking, as it eliminates the need to ascertain the distribution of braking forces between the front and rear wheels.

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Moreover, this approach enhances safety, since the rear wheels remain unbraked, mitigating the risk of slippage, rear axle drift, or loss of control. Tests carried out by braking the front wheels without an ABS system will lead to their locking and sliding without rolling, the straight trajectory being then improved by the guidance of the unbraked rear wheels.
Employing the frontal braking procedure with an active ABS system enables the determination of the optimal longitudinal grip, also known as μmax. Conversely, disabling the ABS system allows for the assessment of longitudinal grip under compromised conditions, with the wheels in total slip, referred to as μlock. The implementation of frontal braking with and without ABS will make it possible the construction of a comprehensive grip curve relative to the slip rate, thanks to a Pacejka type model [5].
The aim of this article is to compare this frontal braking method to a high-performance instrumented vehicle designed for grip measurement. The advantage of frontal braking is economical when using a light vehicle, but the method also has the advantage of determining the grip for a vehicle very close to the users' vehicles.

2 Front braking methodology

In the following, we consider a vehicle subjected to a constant braking force on the front wheels, examining scenarios both with and without the activation of the ABS system, across a range of speeds from V1 to V2. The aim is to develop an expression of the mobilized longitudinal grip. The fundamental principle of dynamics, Eq. (1) and (2), give the expression of the longitudinal friction coefficient μ in function of the deceleration γ and the drag resistance Fdrag (aerodynamic and friction). The Eq. (3) gives the vertical force exerted on the vehicle's front axle, including the mass transfer from the rear axle due to the braking force and according to the center of gravity height h and the wheelbase length L.

$$\sum \overrightarrow{F_{ext}} = M \cdot \vec{\gamma} \tag{1}$$

$$\overrightarrow{F_{drag}} + \left(\mu \cdot \vec{Z}\right)\vec{x} = M \cdot \vec{\gamma} \tag{2}$$

$$\vec{Z} = \overrightarrow{Z_{ff}} + \Delta\vec{Z} = \overrightarrow{Z} + \frac{M \cdot \vec{\gamma} \cdot h}{L}\vec{z} \tag{3}$$

Due to its components, friction and aerodynamics, the resistance forces Fdrag is proportional to the mass and the speed of the vehicle, with α and β parameters determined beforehand during a deceleration test in free wheel Eq. (4). Frontal braking test are exploited from an initial speed V1 to a final speed V2. The value of Fdrag is averaged over this range of speed Eq. (5).

$$F_{drag} = M\left(\alpha + \beta \cdot V^2\right) \tag{4}$$

$$F_{drag} = M\left[\alpha + \beta \frac{\left(V_1 + V_2\right)^2}{2}\right] \tag{5}$$

By application of the kinetic energy theorem, the average deceleration of the vehicle braked over a distance d from speed V1 to V2 is:

$$\gamma = \frac{V_1^2 - V_2^2}{2 \cdot d} \tag{6}$$

Consequently, the average friction coefficient associated with the tires during the braking is precisely determined across the deceleration distance d Eq. (7) and (8):

$$\mu_{mean} = \frac{M \cdot \gamma - F_{drag}}{Z_f + \frac{M \cdot \gamma \cdot h}{L}} \tag{7}$$

$$\mu_{mean} = \frac{M\left(\left[\frac{V_1^2 - V_2^2}{2 \cdot d}\right] - \left[\alpha + \beta \frac{\left(V_1 + V_2\right)^2}{2}\right]\right)}{Z_f + M\left(\frac{V_1^2 - V_2^2}{2 \cdot d}\right)\frac{h}{L}} \tag{8}$$

Pacejka formulated a model incorporating four parameters B, C, D, E [5] to express the coefficient of friction, μ, as a function of the slip rate G Eq. (9):

$$\mu(G) = D\,sin\left(C\,arctan\left(G\left(B - E\left(B - \frac{arctan(B \cdot G)}{G}\right)\right)\right)\right) \tag{9}$$

The slip rate G itself is defined through the relationship between the wheel's center speed V, its angular velocity ω, and its radius R:

$$G = \frac{\omega R - V}{max(\omega R, V)} \tag{10}$$

3 Experimental setup

Front braking tests were conducted using a lightly instrumented vehicle, our “406” vehicle, which is equipped with an optical Correvit system positioned at the rear, giving the absolute vehicle speed (0). The speed of each wheel was measured through the vehicle's BUSCAN system. The vehicle drag forces coefficient α and β were determined on the test track of our laboratory, then experiments were conducted on two highway sections, specifically sections 4 and 5, with several repetitions of braking with and without the ABS system, for three speed cases and under wet contact conditions.

For comparative analysis, a Continuous Grip Measurement vehicle (CGM, 0) was employed to measure the longitudinal grip on the same highway surfaces and using the same selection of speeds. The results from this comparative study are detailed in the subsequent section.

Figure 1 Test vehicule “406” on the test track (Correvit sensor at the rear)

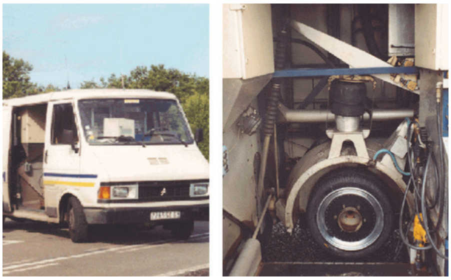

Figure 2 Continuous grip measurement vehicule (CGM); source: [3]

4 Results

4.1 Front Braking with the 406 vehicle

The 0 presents the measurements from the 406 vehicle on highway section 4 (red and green: front wheels and front suspensions; black and blue: rear wheels and rear suspensions). The upper part of the figure illustrates that the front suspensions have been compressed and the rear suspensions released. The center part of the figure shows the wheel speed, with the front wheel speeds (depicted in red and green lines) slightly lower than the rear wheel speeds. In fact, the front/rear wheel speed ratio is about 10 to 15%, correlating with the wheel slip ratio for optimal ABS operation. The lower part of the figure features a linear regression, indicated by a blue line, between two reference speeds marked by vertical green lines, based on the Correvit vehicle speed (red curve). As an illustration, 0 displays the wheel speeds for a similar braking test but with the ABS system disabled (same colors as for Figure 3).

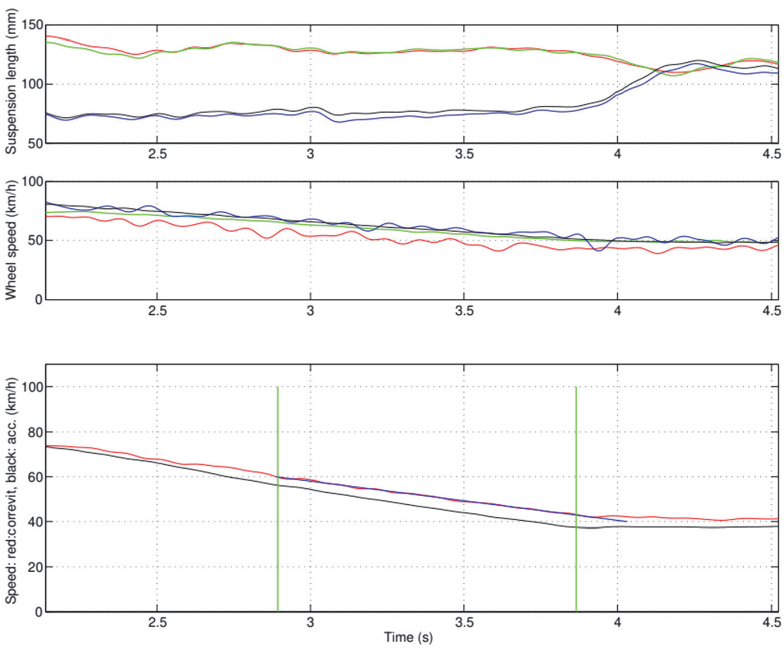

Figure 3 Measurements: front braking procedure, with ABS, wet surface

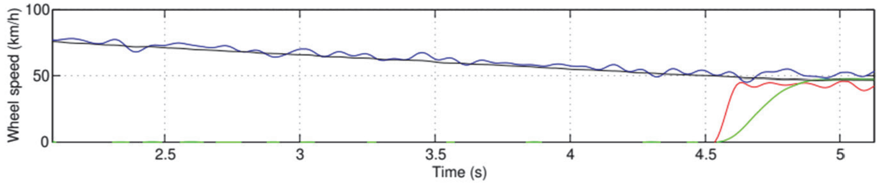

Figure 4 Wheel speeds, front braking procedure without ABS, wet surface

Through linear regressions, the μ values are estimated according to Eq. (8), and respectively 5 and 3 frictions coefficients are determined for the tests with and without ABS (highway section 4, wet condition, 60 to 40 km/h braking). These coefficients are illustrated in 0, with mean values marked by solid lines and variances by dashed lines. The application of the Pacejka formulas Eq. (9) results in the modeled slip/grip curve shown in 0. This curve is theoretical but it it based on the two experimental mean values, μmax and μlock.

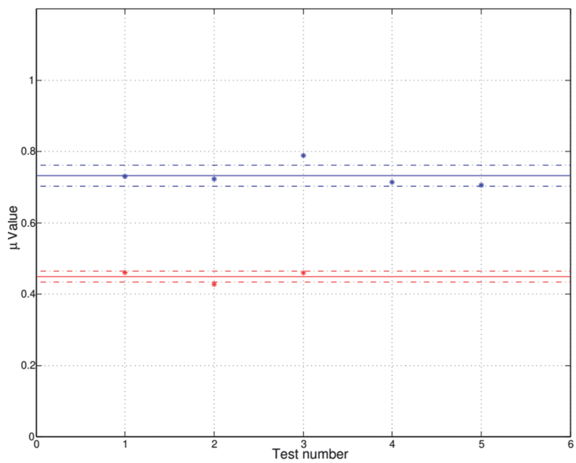

Figure 5 Longitudinal friction coefficients for several braking repetitions

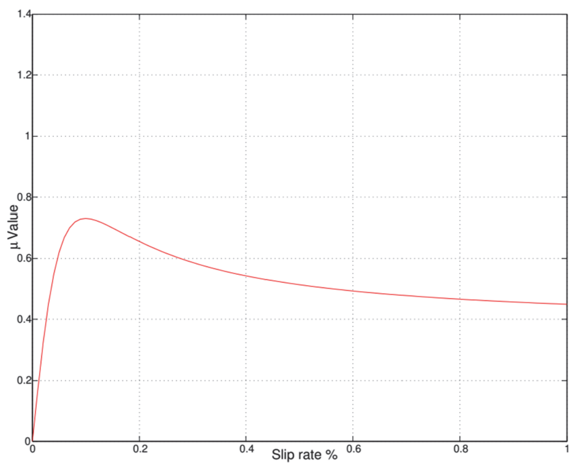

Figure 6 Grip/slip Pacejka model built on experimental results

4.2 Comparison of the grip model to CGM vehicle measurements

Measurements were conducted on two highway sections, sections 4 and 5, using the 406 and CGM vehicles, under wet surface conditions and for three initial speeds: 50, 65, and 85 km/h. 0 and 0 present the experimental results for highway sections 4 and 5, respectively. In these figures, the CGM vehicle values represent the direct measurement of the longitudinal friction coefficient for tire slip from 0 to 100%. The curves related to the 406 vehicle are generated with the Pacejka model built on the experimentally determined μmax and μlock values.

The 406 grip values decrease with speed, by about 5% for each 15 km/h increase, which aligns with a decrease in tire-to-road indentation and adhesion, and an increase in tire warming, degrading the grip.

Conversely, the CGM vehicle exhibits the opposite behavior around the μmax peak, with higher grip at higher speeds. This could be attributed to the wetting system of the fifth wheel, which likely creates a thicker water film at lower speeds. Nonetheless, for both highway sections, the 406 values align with the reference CGM values within a 5 to 10% confidence interval. This confidence interval is quite interesting since it takes into account the measurement precision, the repeatability and the large technical difference of the systems.

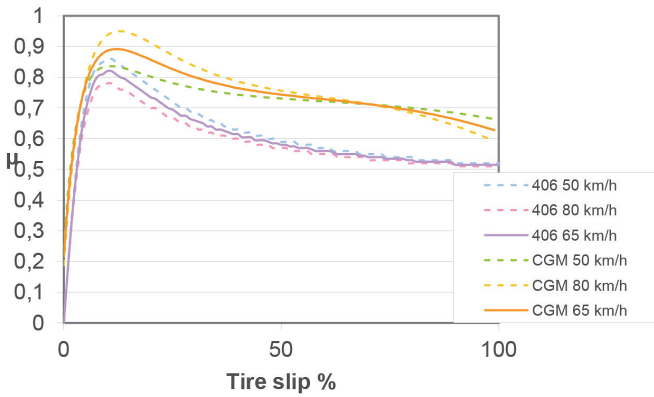

Figure 7 406 Grip model and CGM measurements, road section 4

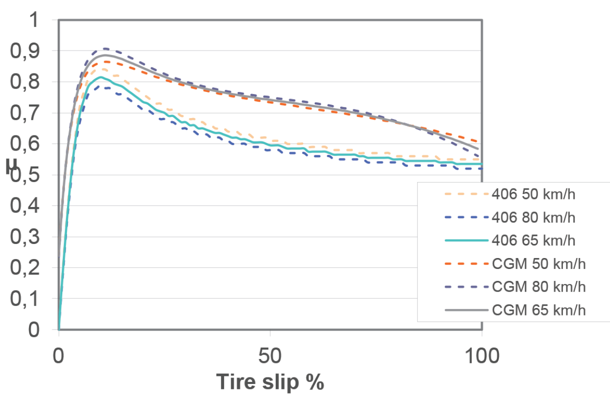

Figure 8 406 Grip model and CGM measurements, road section 5

5 Conclusion

Road safety is significantly dependent on the tire-to-road grip potential. To monitor the evolution of road grip over time, road managers employ specialized vehicles. In this study, an ordinary car, our “406 vehicle” equipped with a light instrumentation, is used to estimate tire-to-road grip through a front braking procedure. Several braking tests have demonstrated the good repeatability of this method. Tests conducted both with and without the ABS system enable the determination of μmax and μlock grip levels. Complete grip-to-slip curves have been constructed based on these levels using a Pacejka model, followed by a comparison with a dedicated continuous grip measurement vehicle (CGM). For two highway sections, the 406 values align with the reference CGM values within a 5 to 10% confidence interval. The differences are partly due to the specificity of the CGM tire; however, the 406 vehicle’s results are likely more indicative of the grip for similarly light vehicles. Both methods remain relevant for monitoring grip evolution, each within its own reference framework. Intrinsically the front braking procedure offers a good repeatability, and it could be an economical way to monitor grip evolution for road managers. Future work could involve additionally onboard water depth evaluation and road texture correlation with the help of laser systems to better describe grip evolution parameters.

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