Contribution of simplified vehicle dynamic models to road safety analysis

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Abstract

The skid resistance analysis is one part of the complex process which is involved in road safety analysis for a road project or for road maintenance. As early as the design phase, the road geometry choice is linked to the skid resistance for a given level of service. In the road maintenance case, different conventional measurements are performed on the road and by analyzing them together, risks can be enlightened. Currently, this analysis is done by comparing these data. This is time consuming and requires dedicated skills. The final objective of our work is to simplify this procedure by developing a software with models of vehicle, digitalized roads, tires, water height and other parameters. With this software, it will be possible to simulate different vehicles on a given road in order to evaluate if the skid resistance supplied by the road meets its demands of the traffic. The key of this development is to assess the prediction capacities of the models. In this paper, a first step in this evaluation process is presented. It consists in a comparison between the skid resistance predicted by simplified vehicle dynamic models, by a reference commercial model and the actual skid resistance measured on a real vehicle taking a curve at high speed. These experiments took place on our test track at Nantes with our fully instrumented car. This study is oriented towards road manager needs which are to know if these dynamic models can improve their analysis. The chosen models have to be versatile enough in order to take into consideration the road characteristics. The objective is not to predict a crash for a given car but to detect a possible source of crash for a class of vehicle due to improper road characteristics. First results show the interest of intermediate models for road manager needs, between the point and commercial model. Their advantages are mainly to be more realistic than the point model and to require less information than commercial software.

1. Introduction

A study on about 100 accidents involving a lone vehicle in a corner shows that nearly 40% are due to road infrastructure (Michel, 2005). For that reason, road managers need to have tools permitting to grasp the risk level associated to a specific corner. This risk is influenced by different road factors such as road camber, curvature, slope, texture, evenness, wetting state and visibility. Today, all these factors can be measured and by analyzing them together, risks can be enlightened. The idea of this project is, using an optimal vehicle dynamic model, to develop a software estimating the risk level by combining the different road characteristics. This software has to take into account a large range of vehicle and has to model digitalized roads to evaluate the importance of each factor in accidents mechanism. In order to select a suitable model, comparisons between experiments and various models have been lead.

2. Models description

Models used in this study are the point model, the transversal model, the four wheel model and the commercial Sera-cd Callas® model.

2.1 Point model

This model, used by road managers to design the road curvature and banking (Setra,2006), (Brenac, 1996) represents the vehicle as a mass concentrated in a point (Figure 1). Contact forces $\vec{F}_y$, $\vec{F}_z$, the centrifugal force and the weight are represented. θ is the road camber.

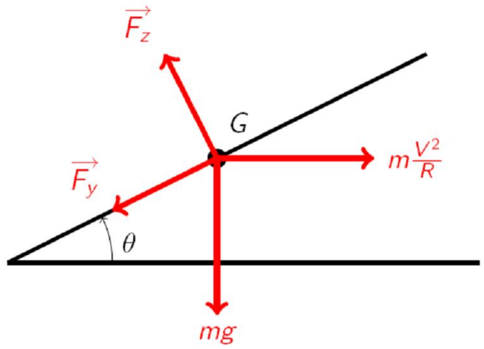

Figure 1. Point model

2.2 Transversal model

The transversal model is an enhancement of the point model. The lateral load transfer is taken into account. This model needs the vehicle track v and the centre of gravity height h_g (Figure 2) in order to obtain the contact forces on the left and on the right side. Considering no longitudinal load transfer and knowing the longitudinal position of the centre of gravity, the contact forces on each wheel can be assessed. (Brossard, 2005), (Stephant, 2002).

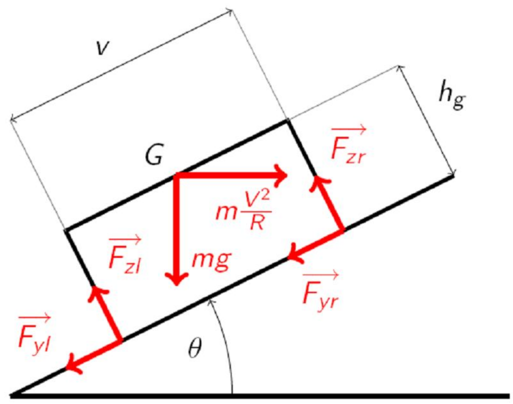

Figure 2. Transversal model

2.3 Four wheels model

This model represents the four wheels of the car, its suspension, anti roll bar, braking system. It has been implemented by S. Glaser (Glaser, 2004). The model complexity begins to increase and parameters like suspension stiffness and damping, anti roll bar stiffness or tire coefficients should be furnished.

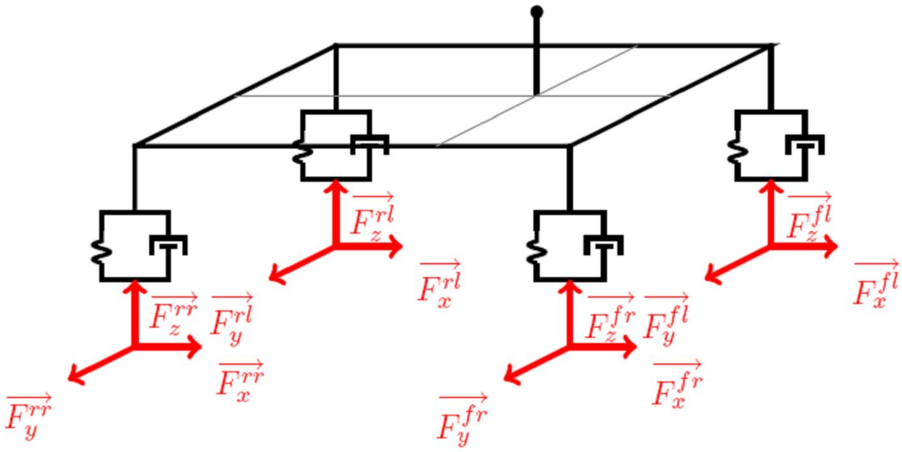

Figure 3. Four wheels model

2.4 Commercial model : Sera CD Callas 4.4

This commercial model fully describes the car and its elements. Each part of the vehicle is modelled close to the reality. This model has been tested by many laboratories, proving its quality and precision. However, it requires very precise parameters which vary with time and could not be easily estimated.

3. Experiments exploitation

On the LCPC test track (Figure 3) at Nantes (France), three radii (90m, 110m and 130m) has been plotted using a centimetrical GPS and have been followed by a fully instrumented vehicle (406 Peugeot) at various speeds (from 60 to 100 km/h). The sensors used were a Kistler dynamometrical wheel, a Correvit speedometer and a Crossbow inertial measurement unit. As it can be seen on Figure 3, the trajectory is made of an entry clothoïd, a radius constant corner and an exit clothoïd.

Figure 4. LCPC test track

A complete experiment plan was performed. In this short paper, it is not possible to present all the results. We focused on three sorts of results.

- Dry surface, constant speed
- Wet surface, constant speed
- Dry surface, acceleration

As the frame of our work is controllability default, the results presented are high solicitations tests, i.e., the speed is about 80 km/h for a 110 meters radius in the case of the wetted surface. The first run is the hardest test from the point of view of the centrifugal force. It enables us to check if our models are meaningful in this extreme condition. The second run represents a real risky situation: the rain stopped, but the road is still wet. So the potential skid resistance is smaller but drivers are not aware of this change for the skid resistance. The last test is a test with coupled solicitation. It is well known that this situation is difficult to model because it is very non linear.

The experimental consumed grip has been calculated from the dynamometric wheel results (Equation 1).

$$\mu_{cons} = \frac{F_y}{F_z} \qquad \text{(Eq. 1)}$$

Of course, this expression is a simplification of the reality because; the wheel camber angle, the tire deformation and the hysteretic behaviour of the tire are neglected. Withal, this approximation is a first step in our approach to compare different vehicle models.

4. Results

4.1 Dry surface, constant speed

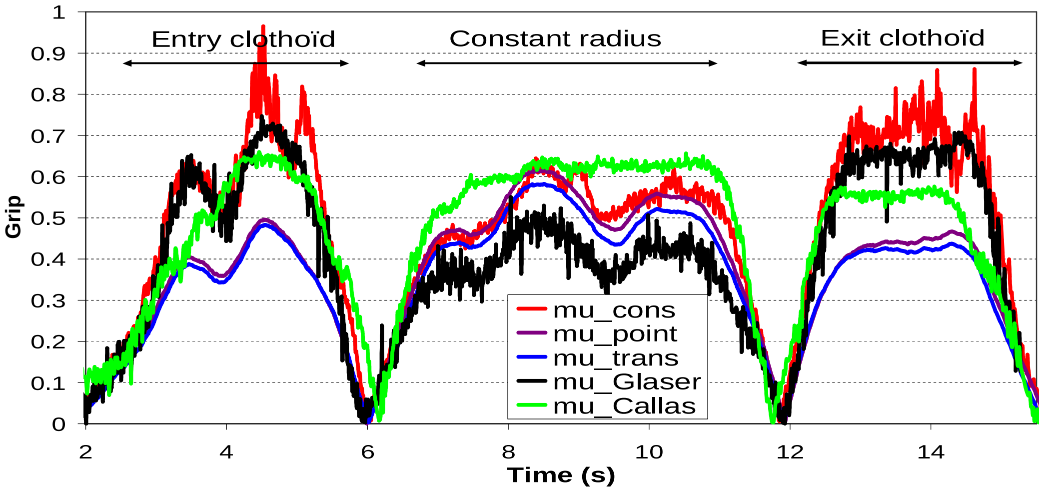

Figure 5. Consumed grip, v=88km/h, r=110m, dry surface

On Figure 4 is represented the consumed grip on the experimental trajectory. All models have been tested with the same parameters. In red, the experimental consumed grip is about 0.7 in the transitional phases (clothoïds) and up to 0.6 in the stabilized period (Central radius). It can be seen that Glaser model is accurate during transitions but it is not good enough in the central radius. The simplest models are good when the radius is constant but their performances are dramatically reduced during the transitional phase: they predict only about 50 % of the real consumed grip. As expected, Callas model is the best model if the entire trajectory is considered. However, its performances are worse than Glaser model concerning the prediction of consumed grip peaks. These ones are the most interesting point for our purpose: they are the most risky.

4.2 Wet surface, constant speed

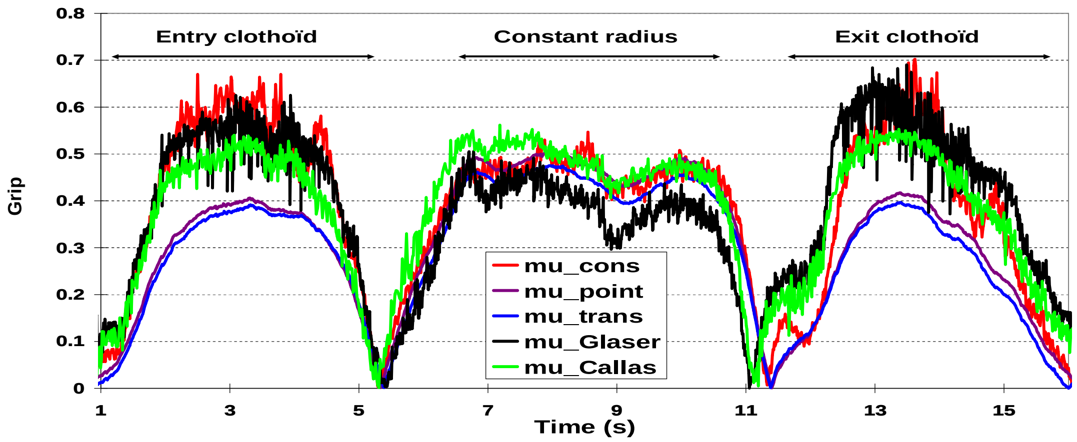

Figure 6. Consumed grip, v=82km/h, r=110m, wet surface

On Figure 6 is represented the consumed grip on the experimental trajectory. The experimental consumed grip is about 0.6 in the transitional phases (clothoïds) and up to 0.5 in the stabilized period (Central radius). The analysis of models is about the same as previously. It can be seen that Glaser model is precise during transitions but it is not good enough in the central radius. The simplest models are good when the radius is constant but their performances are dramatically reduced during the transitional phase. As expected, Callas model is the best model if the entire trajectory is considered. Its performances are similar as Glaser model concerning the prediction of consumer grip peaks.

4.3 Dry surface, acceleration

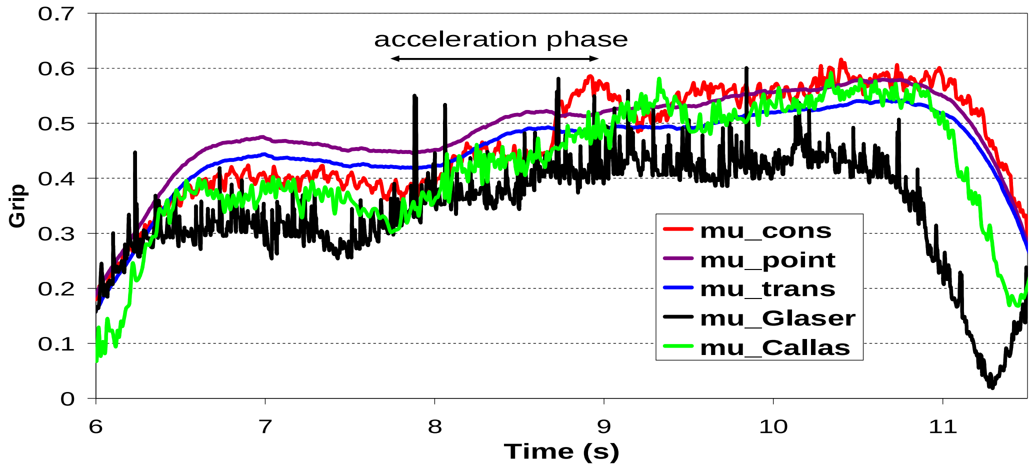

Figure 7. Consumed grip, v=80km/h, r=110m, dry surface, acceleration

The figure 7 presents grip data obtained when the vehicle accelerates on the radius constant part of the trajectory. The experimental grip grows of 40% between t = 7s and t=10s. This increasing includes two effects: the augmentation of the transversal grip linked to centrifugal forces, but also the augmentation of the longitudinal grip due to engine torque. It is the reason why, it is called coupled solicitation. A rapid analysis of point and transversal models (mu_trans, mu_point) seems to prove that these models are good enough. However, these models take only into account the first effect: the augmentation of the transversal grip. This implies that they underestimate the augmentation of the mobilised grip (20%). As expected, Callas model is accurate and exhibits 43% of acceleration augmentation. The Glaser model underestimates the mobilised grip but it has a good prediction of its augmentation (38%).

5. Conclusions

Simplified models allow to suitably predict consumed grip on the constant radius part of the trajectory for non coupled solicitations. Callas model is highly capable and is the best of all tested models but needs a lot of parameters which are difficult to estimate on every car. Glaser model lightly underestimate the consumed grip but enable to take into account transitory peaks and only needs a simplified parameters definition. More deepened studies on this model will permit to make this model matching our needs.

6. References

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