ROAD CHARACTERISTICS AND SAFETY

Analysis of influence of road factors on single vehicle run-off-the-road accidents: use of a Vehicle/Road model

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In France, even if injuries and fatalities resulting from road accidents are continuously decreasing, they remain at an unacceptable level: in 1996, 8080 people lost their live and 170117 people were injured (figure 1)! This is an enormous socio-economic loss to the country. Governmental authorities have recently insisted on the necessity to speed up the reduction and have called road and vehicle communities to act toward this objective.

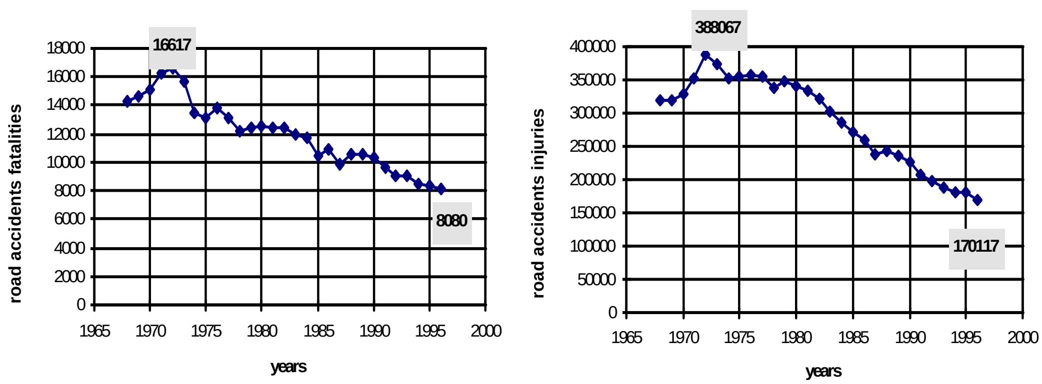

Figure 1: evolution of road accidents fatalities and injuries in France 1968-1996 [1]

Regarding vehicle, primary and secondary safety has been tremendously improved in the past ten years: braking, handling capabilities, crashworthiness, occupant's restraints and protections (seat belts, airbags). Research and development on occupants protection are still under way and progress in reduction on injuries severity can be expected.
Now, more attention is paid to the actual requirements for the car driver in respect to safety. This led to a new challenging Research and Development subject: equipment to help drivers to avoid accident (i.e. vehicle trajectory control, potential collisions warning) [2-3-4]. In this view, it is accepted that drivers are liable to commit unintentional errors, consequences of these errors must be as harmless as possible.

Road designers and road engineers can also play their parts in this challenge. During the three past decades Road Geometric Design Standards were improved [5]. New elements regarding roadside features were introduced:

- shoulders width
- shoulders paving
- side slopes

- clear zone
- safety hardware design

The objective is to build roads where people do not pay with their live when vehicles inadvertently leave the roadway.

Regarding roads in service, improvement of safety has been so far mainly based on accidents records. Waiting for accidents to occur, to determine if a section of road warrants a countermeasure, is costly in terms of property damage and human suffering.
In France, a progress was made when an "on site safety evaluation" by experts was defined and organised (1993). This evaluation is based on key points defined in a reference book [6]. These points are summarised hereafter:

- visibility (sight distance)
- violation of driver expectancy
- road/vehicle dynamic consistency
- collision avoidance and safe recovery possibilities
- reduction of gravity of collision on obstacles
- roadway and road environment consistency
- traffic flow monitoring with regard to safety.

The first principle of safety engineering is to anticipate every possible type of accident, which may occur. The second principle is to see how to reduce the consequence of human inattention or malfunction.

From safety evaluation, improvements are suggested: road geometry local modifications (lane width, alignment, superelevation correction), roadside geometry and features (shoulders width and covering, obstacle elimination, roadside safety hardware), road resurfacing (surface regularity, evenness and friction improvement). Due to the little amount of resources available only few operations can be planned and authorities want these operations to be the most cost-effective.

Current knowledge on relationship between accidents and specific road infrastructure features and characteristics are based on two types of information: statistics of accidents and in depth investigations. Despite the widely acknowledge importance of road features, no clear relationships have been established with substantial confidence. The effect of road features is obscured by the presence of a variety of other factors affecting road safety (i.e.: weather, pavement conditions,...). As a matter of fact most accidents result from a combination of factors interacting in ways that preclude determining a single accident cause. Interaction between road, driver, and vehicle characteristics complicates attempts to estimate the accident reduction that can be expected from a particular safety improvement.

Investigation with a road/vehicle dynamic model

Investigation realised with a vehicle dynamic model including a realistic road description and an interactive driver model enables a detailed reconstruction of the vehicle behaviour in current and emergency manoeuvres. Various simulations, taking into account different driver commands, vehicle characteristics (car basic properties, technical defaults like tyre inflation pressure,...) and infrastructure characteristics (skid resistance, road transverse and longitudinal profiles, rutting, pavement edge...) can then be carried out, this makes a parametric performance analysis possible and bring about a better understanding of the interactions between driver, vehicle and road factors. This investigation is mainly concerned with run-off- the road accidents which represent more than 60% of single vehicle accidents on curves. From this analysis remedial treatment of defect can be defined and a better knowledge of threshold for road surface characteristics keeping a correct safety margin [7-8-9] can be gained.

LCPC and INRETS are currently analysing the possibilities of the Driver/vehicle/ Road model "CALLAS" to conduct this investigation.

CALLAS a Driver/Vehicle/Road model

CALLAS is a 3D road vehicles dynamic simulation and analysis software developed by SERA-CD French Research and development Company involved in road vehicles analysis and design.
The CALLAS 17 Degrees of Freedom model includes:

- 6 body degrees of freedom,
- 4 wheel rotations,
- 4 wheel loaded radii,
- 1 engine rotation independent when de-clutching or converter slip,
- possible cruise control,
- 2 steering wheel angles (rack and hand wheel).

Suspension is described in a functional fashion; *i.e.* every layout can be described.
Suspension is taken into account by:

- independent suspension, beam or rigid axle,
- non-linear curve force vs. wheel travel with bump/droop stops and anti-roll bar,
- non-linear 3D kinematics vs. travels,
- non-linear 3D compliance vs. forces,
- tire radius vs. normal force and speed.

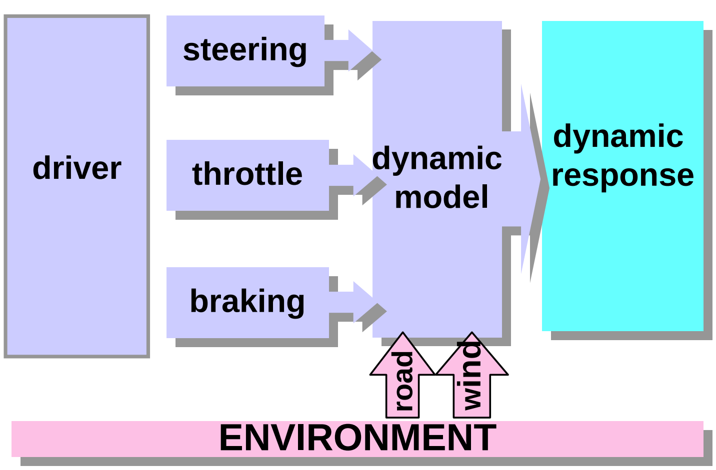

Figure 2: open loop version of CALLAS

CALLAS “open loop” works as defined in figure 2: the vehicle is submitted to driver command (steering, braking, and throttle) as well as to road and atmosphere disturbances. This software runs quickly on a PC with Windows NT interface. The vehicle model is non-linear: the dynamic behaviour is valid up to and beyond the adhesion limit [10].
A three years programme aiming at testing the validity and the limits of CALLAS has recently been completed. This programme involved SERA-CD Paris, INRETS-MA (the French National Institute for Transport and Safety Research, Department of Accident Mechanism Analysis) of Salon de Provence, LCPC-IRV (Road and Bridges Central Lab, Road Vehicle Interaction) of Nantes, DGA-ETAS (Military Technical Testing Centre) at Angers. This programme benefited from contributions of a car and a tire manufacturer.
Comparison between simulation and data measured during ground tests were made for four different types of light vehicle. About 200 progressively difficulty tests of pure longitudinal, lateral, vertical dynamics and various combinations of these, from low solicitation up to and beyond the limit of tire adherence, on two different test tracks under dry and wet conditions, were performed. CALLAS has proved to provide a high level of relative validity within the confidence interval of measured values; precision depends on solicitation levels and car parameters relevance [11, 12].

Examples of validation results are given figures 3-4 and 5, on these figures dotted lines correspond to measured values, continuous lines correspond to simulation. Good correlation is obtained between measured and computed data as shown in these examples for lateral acceleration.

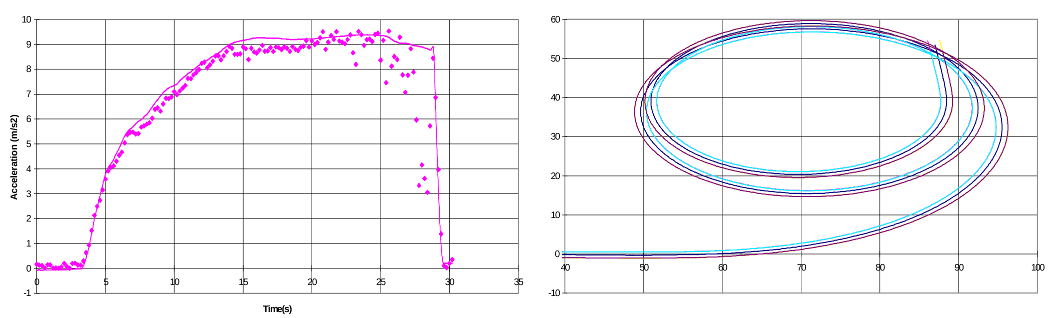

Figure 3: spiral curve, Peugeot 605 SR, 50 km/h,
lateral acceleration (left) and centre of gravity and tires trajectories (right)

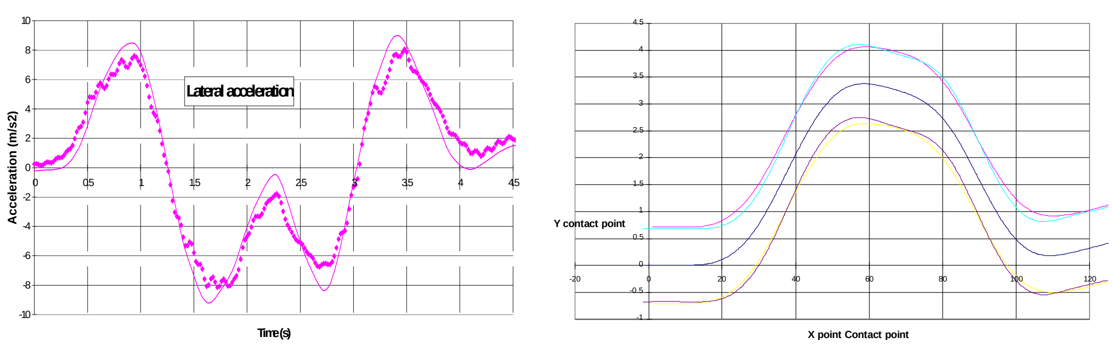

Figure 4: ISO chicane Citroën BX 110 km/h (maximum possible speed)
lateral acceleration (left) and centre of gravity and tires trajectories

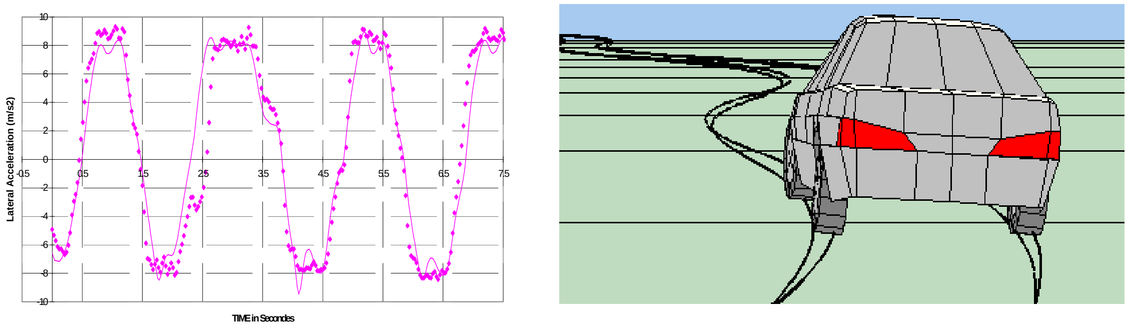

Figure 5: 605 SR : slalom 65 km/h to the adherence limits

Application of CALLAS (open loop version 2.4) to simulate run-off-road accidents

The objective is to simulate single car run-off-the-road accidents. Results of a parametric analysis of the trajectory of a car (Peugeot 605) in a curve with various road characteristics leading sometimes to run-off-the-lane and run-off-the-road trajectories are given on figures 8-9-10-11.
A steady state turn is simulated with the steering command given in figure 6. A computer generated animation can be made with CALLAS as shown in figure 7.

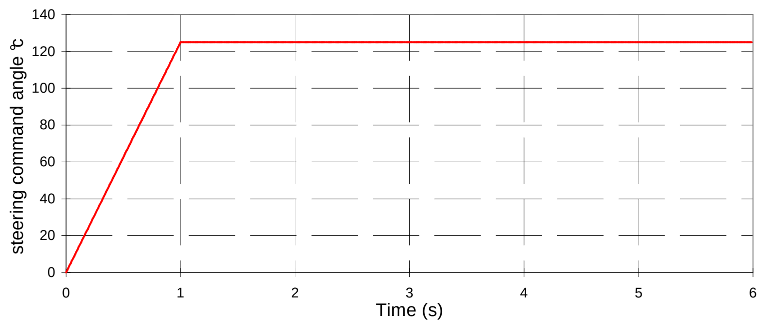

Figure 6: steering command

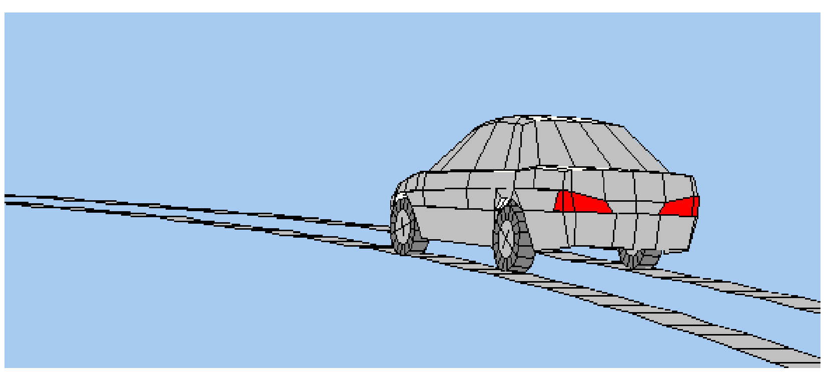

Figure 6: computer generated image, 605 in the curve

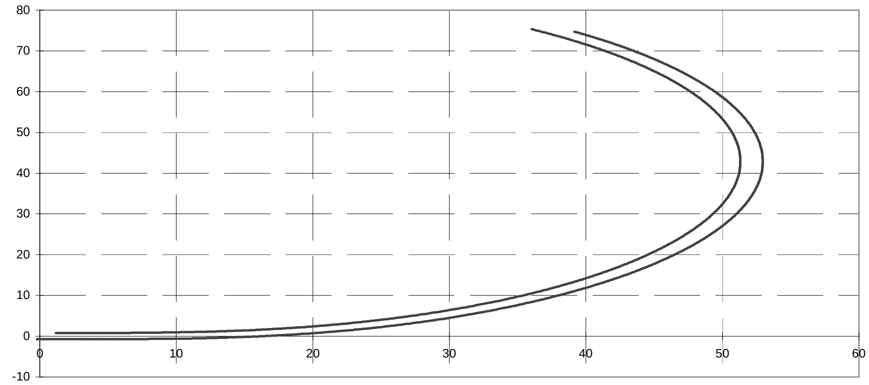

Figure 8: curve radius 100m speed 65 km/h, flat road

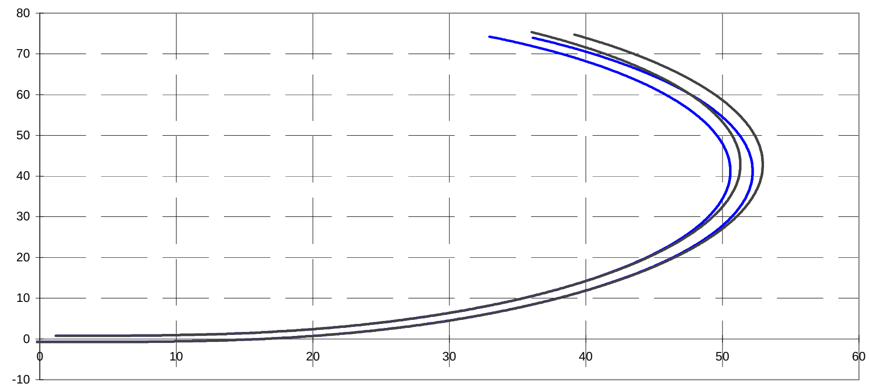

Figure 9: comparison of results for a flat road and a road with superelevation

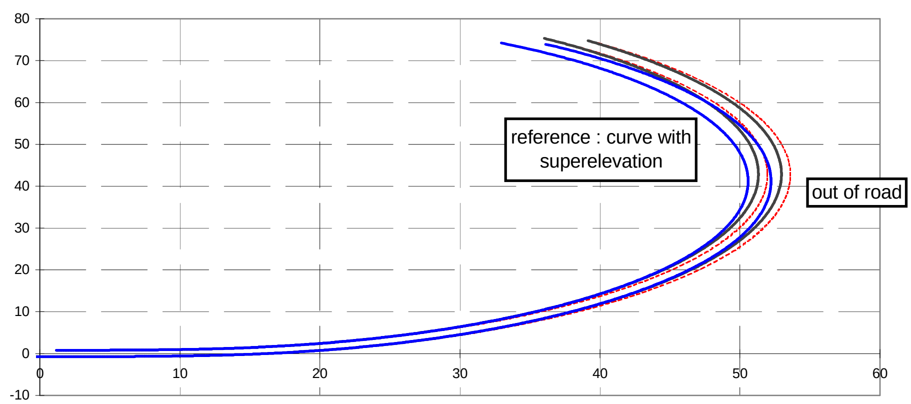

Figure 10: comparison for a flat road and a road with superelevation and 5% friction drop

On figure 9 one can notice that, with the same command input, superelevation in the curve gives more lateral forces yielding a smaller curve radius. Then, effect of traffic wear on road surface skid resistance was simulated, in this case the car runs off the road (figure 10). On the next step, a superelevation inversion in the curve was added (figure 11) the trajectory gets larger (car on the road side).

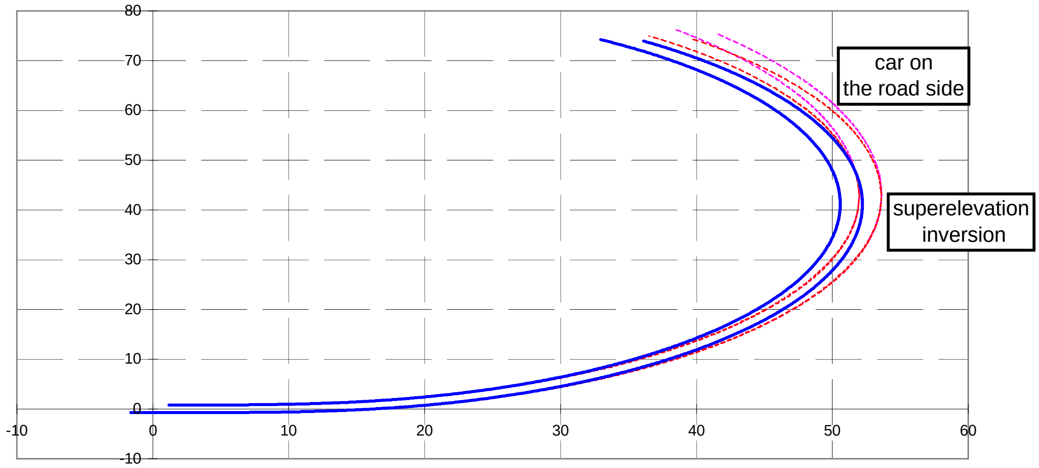

Figure 11: effect of a superelevation inversion in the curve

For the next case, a braking command is applied at the beginning of superelevation inversion. Commands are shown in figure12: front wheels are locked as shown on figure 13, in this case the car runs directly out of the road (figure 14).

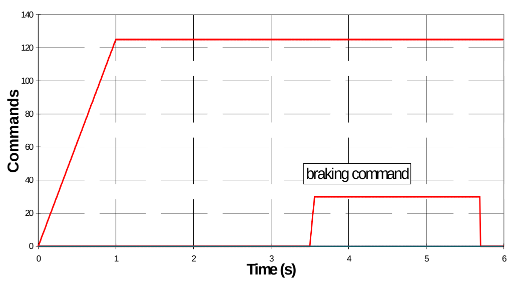

Figure 12: sterling and braking commands

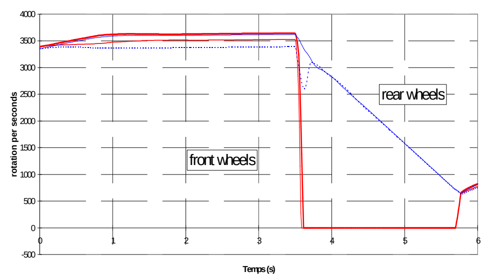

Figure13: front wheel locking

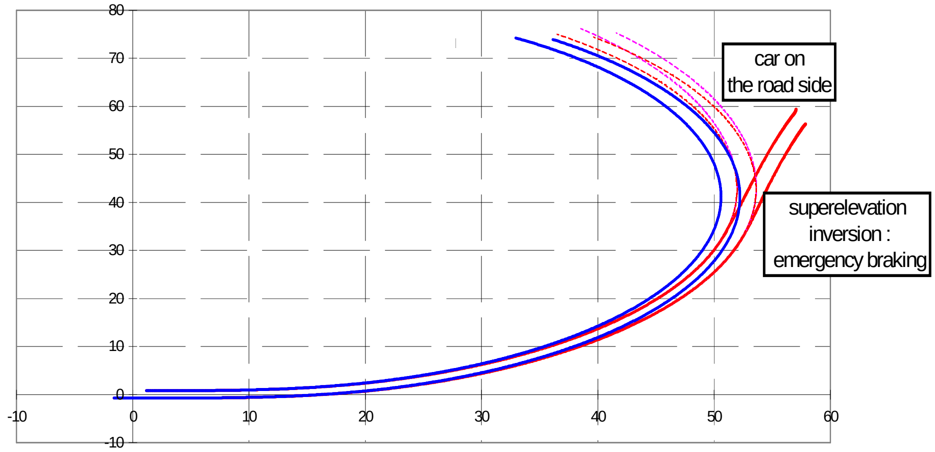

Figure 14: braking at the superelevation inversion location

The final case (figure 15) shows the influence of speed (same command, curve with superelevation) on the trajectory.

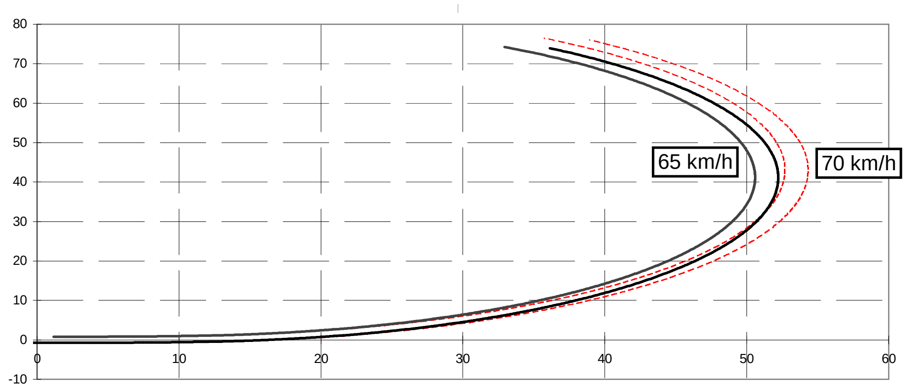

Figure 15: speed effect on the trajectory

These examples illustrate the capability of CALLAS to analyse the effects of some road features on the margin of safety at various speeds on curves. In our examples tire friction performances and road geometry were simulated: this lead to restriction in the operational applicability of our investigations.

Considerable improvement of the validity of this type of analysis will be gained if road inputs will be more representative of road characteristics on accident prone sites. The problem is how to get from in site easily implemented methods useful data enabling us to take into account actual road surface characteristics including local defects. This question is briefly addressed in the two next sections.

Evaluation of tire friction performances from measurements

Obviously, for strong solicitations the validity of simulation is very sensitive to the relevance of tire/road model. This point was clearly demonstrated in our validation programme [11].

Unfortunately, we do not know how performance models (F_x , F_y = f (F_z), figure 16)) on a trafficked friction course for different state of road surface (dry, damp, with different water depth and with snow and ice) can be estimated from on site practicable measurements.

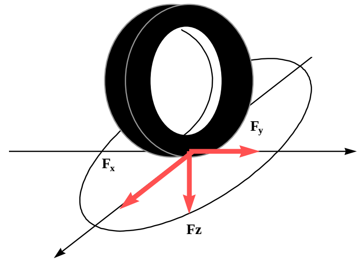

Figure 16: tire contact forces

Defining necessary and sufficient data to get on site needed to transform accordingly basic tire manufacturer’s model is a subject that has been approached in our validation programme. This problem will be part of a new 3 years programme starting at end of this year.

Ground inputs

In simulations previously presented in figure 9-10-11 the road profile was defined from a simulated file. CALLAS 2.4 version has a ground input module: $2 \times 2D$ profiles can be read (fig:16), vertical dynamic response of unsprung masses is taken into account, giving an accurate value for F_z on each wheel.

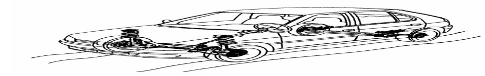

Figure 16: ground inputs in CALLAS 2.4

Figure 17 illustrates influence road profile inputs in the 100m radius curve. Two digitised 1.8m wavelength, magnitude 10 mm, out of phase sine wave were computer generated. On the curve with constant superelevation, "sine wave" unevenness leads to a larger trajectory : the car is out of lane.

Error! Not a valid embedded object.

Figure 17: Influence of road unevenness input (2 sines)

CALLAS 3.0 version has an additional ground input module allowing to roll on a 3D road as shown on figure 18. In this case the ground geometry was simulated.

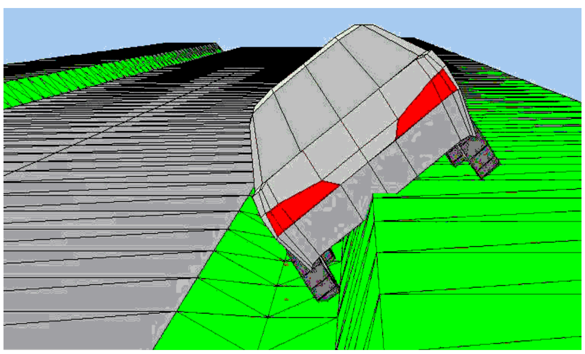

Figure18: computer generated image with CALLAS 3.0

As previously mentioned, validity of this type of analysis will be improved if road inputs is more representative of road profiles on accidents prone sites. Unfortunately no easily implemented methods can be applied to measure road profiles.

Regarding road profile mapping, three solutions have been tested:

- rod and level,(figure 20)
- rotating laser and mobile rod (figure 21)
- the LCPC road profile analyser (APL)

It is easily understandable that the two first methods can be used only on test tracks.

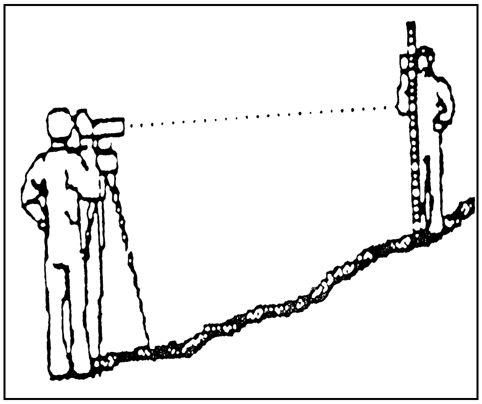

Figure 20: rod and level

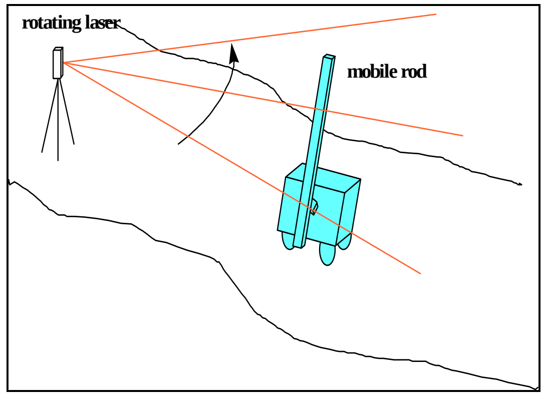

Figure 21: rotating laser and mobile rod

The APL is a pass-band profilometer this limit considerably possibilities to get true profile.

Input of the simulation package regarding profile needs to include: slope, superelevation, longitudinal and cross profile. Works on a new technique: laser on car board with gyroscopic unit and a differential GPS positioning system have started This research will be carried out in the new programme.

Close loop version of CALLAS

A close loop version of CALLAS including a driving automate has been developed. It defines the driver input starting from a ideal line to follow. This problem, easy at low speed and solicitation becomes difficult when the car is starting to slide: driving is difficult, and driving task modelling even more difficult. Near the limit, an oversteering car need to be countersteered to avoid the spin, even it seems paradoxical. This version has been validated by comparison with real driver inputs (the **W**-signature) on several vehicle.
Its application in accident reconstruction was tested by INRETS. The case investigated was a loss of control in a bend which curvature radius was around 70 metres. This accident was subject of an in depth investigation. Measurements with an instrumented car were carried out, good agreement was obtained between simulations and actual data. Then, explorations regarding vehicle commands and possible defects (such as tire deflation) and road characteristics were made. This version proved to be well adapted to carry out a parametric performance analysis and investigate interactions between driver, vehicle and road factors in the analysis of single vehicle accident. This application is described in a FISITA98 paper [13].

New development are under way with regard to the driver automate: more realistic commands needs to be simulated involving fuzzy logic application in this matter.

Conclusion

After a 3 years programme and more than 200 proving ground tests with 4 very different cars (Peugeot 605 and 306, Renault Espace Quadra, Citroën BX) the basic version of CALLAS has been validated. Good results were obtained until and beyond limit of adherence.

Applications of the open loop version to simulate single car run-off-road accidents demonstrate its usefulness in investigating influence of road factors. Effects of vehicle factors and defects can be investigated as well.

Steady state command were applied in our examples but more complicated commands determined for example from on site driving tests or from in depth investigation (accident reconstruction package) can be applied. With regard to this point the close loop version has proved to be more suitable.

Basic conclusion of this paper is that a Driver/Road/vehicle simulation can be very helpful in exploring whether road always provides adequate dynamic safety of driving at curved sites, giving more elements to define new design standards and countermeasures strategies.

Confidence in simulation results and correspondingly suggested solutions to improve road safety will certainly be gained if road surface characteristics are taken into account with all relevant nuances:

- local fluctuation of friction potential (i.e.: track wear and water depth)
- road irregularities and road geometrical parameters local variations

Forces on tire/road contact area variation in space and time have to be known accurately.

Progress in these last points and improvement of CALLAS capability to meet all requirements for road/vehicle dynamic adequacy and accident reconstruction will be made in the new research programme entitled:

"Wet Road accidents:
Adherence demand and offer in emergency manoeuvres and loss of control"

This programme is supported by the French Ministry in charge of Research. in the framework of a national programme called PREDIT. Five partners: PSA Peugeot-Citroën, SERA, LCPC, INRETS, LCPC and Meteo France are involved in this applied research.
The objective of this programme regarding road safety is to define all possible actions (vehicle, driver, road characteristics and road environment) which could reduce number and gravity of wet road accidents.

This research is an example of a collaboration between different actors for road safety benefit.

Acknowledgements

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