The use of the software PROSPER for safety studies

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Synopsis

The understanding of responsibilities of infrastructure in Heavy Goods Vehicles (HGV) accidents may help to improve safety on roads. An European project named VERTEC and managed by Pirelli Company is led in this aim.
Starting from bibliographic studies and from real accidents database, some critical situations closely linked to infrastructure can be detected. The case of a right curve is treated into the following paper. Simulations are realized with the software PROSPER in view of determining the influence of some parameters like crossfall, load or skid resistance on HGV behaviour. The speed limit and the limit of lateral acceleration before accident occurs are precisely studied. The simulations mainly aim at finding limits of use of the infrastructure. Comparisons of the speed limit and the limit of acceleration are done for several crossfalls and loads. Considering the crossfall, the results show that with weak Sideway Force Coefficients (SFC), the crossfall has a moderated influence on the limits. However, the maximal speed and acceleration before accident tend to the same values for high SFC.
Considering the load, the simulations indicate the existence of a stage on the curves giving the speed limit and the limit of lateral acceleration as a function of the SFC. The stages seem to be independent of the load, which indicate that load does not play the main role in the mechanism of accident for a value of SFC up to 0,60.
Moreover, the software PROSPER is used in view of reconstructing some real accident situations. This approach aims at determining the influence of some road parameters on the mechanisms of accident by modifying step by step the values and studying the linear and angular accelerations of the truck.
The first results are relatively uncourageous but raise some questions as the degree of precision needed for the data. Other multidisciplinary investigations on real sites could improve and complete the simulations in view of defining rules for a safer road.

The use of the software PROSPER for safety studies

Security is one of the main preoccupations of people, considering the high number of persons killed or injured in road accidents every year. Accident is an event, which occurs when several conditions are mixed. The different safety studies led to distinguish human origin causes and road origin causes in road accidents. Human causes as speed or alcohol are treated by repressive methods and their success mainly depend on the human being and its maturity. On the contrary, infrastructure can be improved when risks are detected by changing the surface characteristics or the geometrical characteristics as radius of curvature or crossfall. Thus, a global study is done in view of determining situations where infrastructure seems to have responsibilities in accidents. We were particularly interested in Heavy Goods Vehicles (HGV). A bibliographic study and an accidents database are used for this first step. Then, simulations are realized with the software PROSPER CALLAS to define the influence of road parameters on vehicle behaviour. Lastly, some real accident situations are reconstructed trying to define the influence on some parameters like speed in the appearance of the accident. This approach is used for the European founding project called VERTEC and managed by Pirelli Company.

Determination of the critical situations for HGV

Origin of the data

Each year, a database named CARMAT is informed about the characteristics of all the accidents involving physical injuries, which happened on the French roads. These data are collected by the authorities (police, gendarmerie…) and transmitted to a national observatory at the SETRA (the French service in charge of the technical study about roads and motorways). Statistical corrections of the data are done taking into account the fact that some information written can be wrong. Then, the database is divided into files, each file corresponding to the accidents occurred into one department. The file is transmitted to the C.D.E.S. (the service in charge of the departmental security studies). The C.D.E.S. of each department complete the lacking data and valid the final file. Thus, this final file is treated with the program CONCERTO and a local study of the road accidents' characteristics is realised. The aim of this work is the determination of some common points between road accidents in view of detecting the dangerous area and understanding the responsibilities of infrastructure in accidents.

Moreover, some bibliographic researches show that accidents with HGV are the most damaging. As an example, they represent 6 % of the accidents occurred in France in 2001, but 13 % of the fatal injured people. This fact explains the great stake into understanding the role of infrastructure on HGV accidents in view of improving road safety.

Another point into studying HGV accidents lies in the fact that this kind of vehicle is characterised by high dimensions. Thus, HGV quickly reaches the limit of use of infrastructures and gives a best regard on the link between accident and road characteristics.

Accidents occurred in Rhônes-Alpes between 1996 and 2000

Details of the method

Considering the high number of HGV in Rhônes-Alpes, the data analyses focussed on this French region. During the period 1996 - 2000, 54 000 accidents with corporal damages were listed among which 4 300 involved one HGV or more. So, this sample is considered to be representative to conclude about some conditions of accident.

The accidents are classified according to three criteria: geometrical characteristics, state of the surface and driving conditions. The geometrical characteristics include the road category (departmental road, national road, motorway…), the radius of curvature, cross-fall, longitudinal gradient. The state of surface is directly linked to the skid resistance (Sideway Force Coefficient, Braking Force Coefficient). The driving conditions refer to the speed, the type and the load of the vehicle, the manoeuvring before having the accident.

The method consists in pointing out the geometrical characteristics of the road and the surfaces where accidents are numerous. Then, these different cases are crossed with the driving conditions to eradicate accidents due to the driver. Finally, only accidents due to infrastructure stay.

Results of the analyses

The results of the statistical analyses are given through the following graphics.

Considering the type of road, accidents are evenly distributed on the road network (fig.1). Nevertheless, the departmental roads seem to be a little more dangerous than the others (30 % of the accidents). The explanation leads in the fact that this category of road is less adapted to HGV traffic (narrow roadway, small radius of curve).

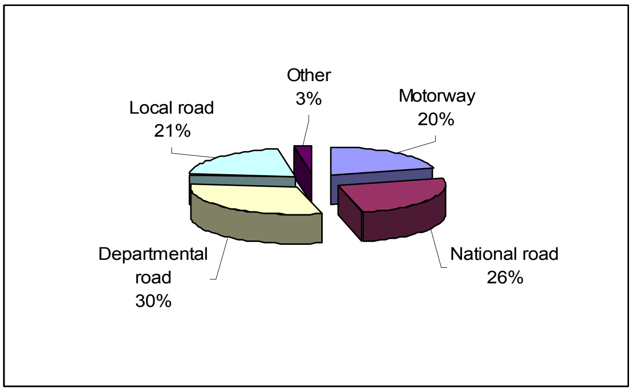
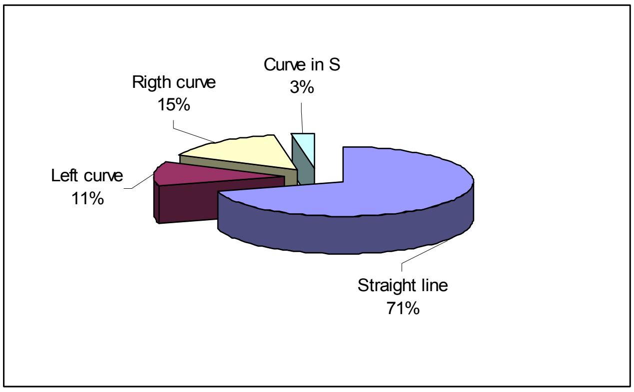


Figure 1 : Distribution of HGVs' accidents on the road network

Most of the accidents occurs in straight line and flat section (fig.2). Thus, the geometrical characteristics are not really concerned in these accidents. Most of the time, speed is the main factor of responsibility.
On the other hand, accidents in curve represent 26 % of the events and longitudinal slope in road represents 21 %.
These configurations can be considered as an interesting track to work on infrastructure effect on accidents.



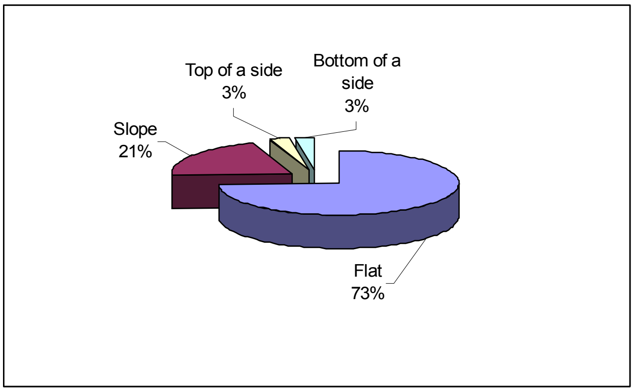
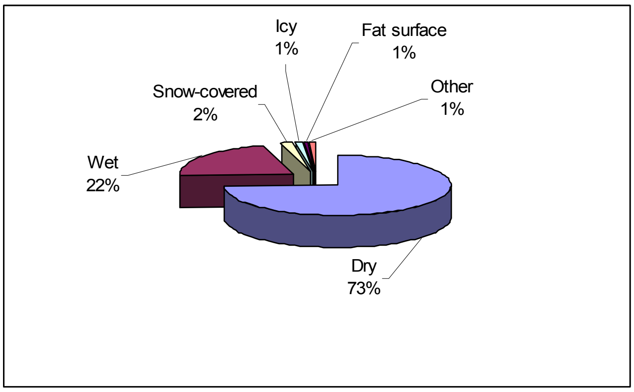


Figure 2 : Cross-section and longitudinal section of the road where accidents occur



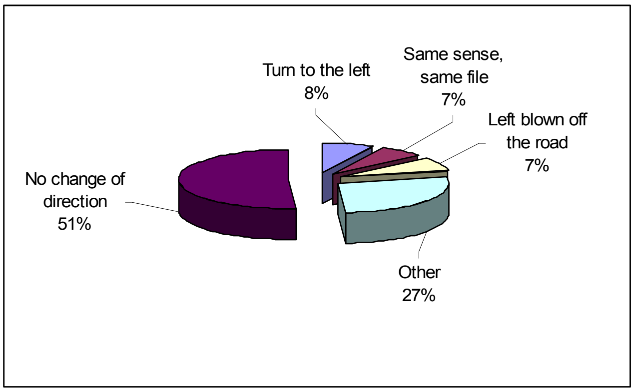


Figure 3 : Share of accidents as a function of the surface characteristics and the manoeuvring

Moreover, the comparison between the different pavement surface characteristics shows that most of the accidents occurs on dry road (75 %). However, the skid resistance is relatively good in these cases. Infrastructure is rarely at the origin of the problem except in the case of damaged roads (rutting, polishing...). On the contrary, 22 % of the accidents happen on wet surfaces, where skid resistance strongly decreases (fig.3). Thus, the skid resistance represents one of the main varying parameter of this work in view of determining its effect on HGV accidents.
Lastly, the manoeuvrings before accidents are listed. In more than a half of the cases there is no change of direction of the vehicle. Two explanations can be imagined. First, the driver is surprised by an event and he has not the time to react and execute an emergency manoeuvre. In this configuration, infrastructure could represent a risk factor and explain accident. The second possibility is that the driver makes alone a driving error, which entails the accident. These cases are excluded of this work considering that we are only focussing on infrastructure responsibility.

To conclude, the configuration, which seems to be interested considering both the accidents data and the infrastructure particularities, is a curve with a small radius and a varying skid resistance.

The simulating software PROSPER

Description of the tool

The software PROSPER (PROgram of SPEcification and Research components) is developed by the French company SERA-CD. It was initially used for simulating military vehicles behaviour. Then, the software has been adapted to trucks dynamic behaviour.

The calculation algorithm is based on a coupled and non-linear system with 29 degrees of freedom and 600 variables. Tyres follow a Pacejka's model.

The input parameters can be dived into two categories: the road profile and the parameters of the vehicles.

The output parameters we are interested in are the speed limit, the lateral acceleration limit before skidding and going off the roadway.

Parameters of the simulations

Road tested

The study is led on a departmental road, with two ways of traffic. The roadway wide is 6 m with no slope. The road profile is composed of a right curve, with a radius of 120 m and a crossfall going from 3 % to 7 %. The curve is preceded by a clothoïde with a crossfall going from 2,5 % to the one of the curve.

The skid resistance of the pavement surface is given only through one parameter. Considering the work issue, the Sideways Force Coefficient (SFC) is inputted because it is the involved force in curves. This coefficient is measured with the SCRIM device. SFC goes from 0,40 to 0,80 in the simulations. The value of 0,40 corresponds to a safety limit before repairing the road surface. The value of 0,80 corresponds to a dry surface with a good skid resistance.

HGV characteristics

The trucks are pre-designed in user's libraries where we can choose number of axles and axle spacing. A 5 - axels articulated vehicle type is used in this work. The vehicle is fully loaded (38 t) and the centre of gravity is 1800 mm high.

The speed, the trajectory and the acceleration braking instruction are imposed at the beginning of the simulation. The speed vehicle begins at 50 km/h and goes until the limit where accident occurs. For the whole simulation, the pilot is supposed to be able to correct the trajectory and to do his best to avoid accident.

Determination of the skid and the go off the road

A right curve on a two ways road is considered for the simulations on PROSPER software. Each way of traffic is 3 m wide. HGV is supposed driving at the centre of the way (fig.4). Considering the tyre thick, HGV leaves its way when the skid is superior to 0,30 m and goes off the road when the skid is superior to 3,30 m. For a skid under 0,30 m, there is no loose of control by the driver.

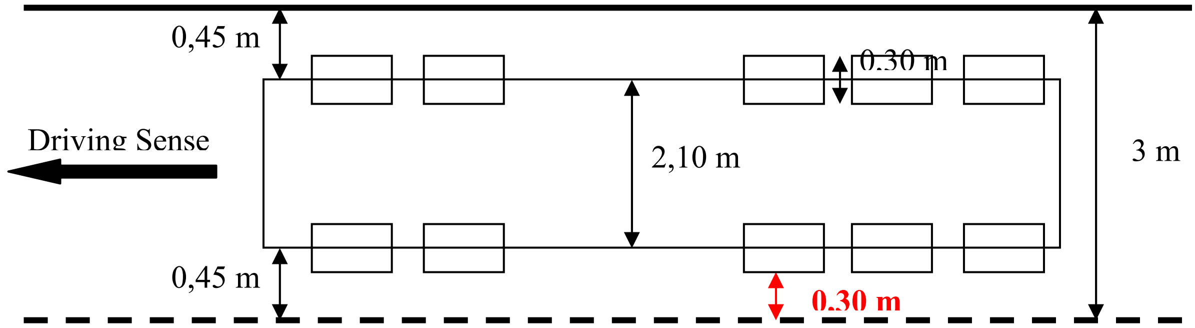


Figure 4 : Dimensions of the truck and the road

The aim is to identify the speed and the lateral acceleration γ_t corresponding to a skid of 0,30 m and 3,30 m.

Results

Influence of the crossfall on HGV behaviour

The simulations on the software PROSPER are led with two crossfalls: 3 % and 7 %. The SFC takes the following values: 0,40 / 0,50 / 0,60 / 0,70 / 0,80.

Speed limit

The speed limit globally growths with the SFC of the roadway. However, the behaviour of the HGV is not the same with a crossfall of 3 % or a crossfall of 7 %.

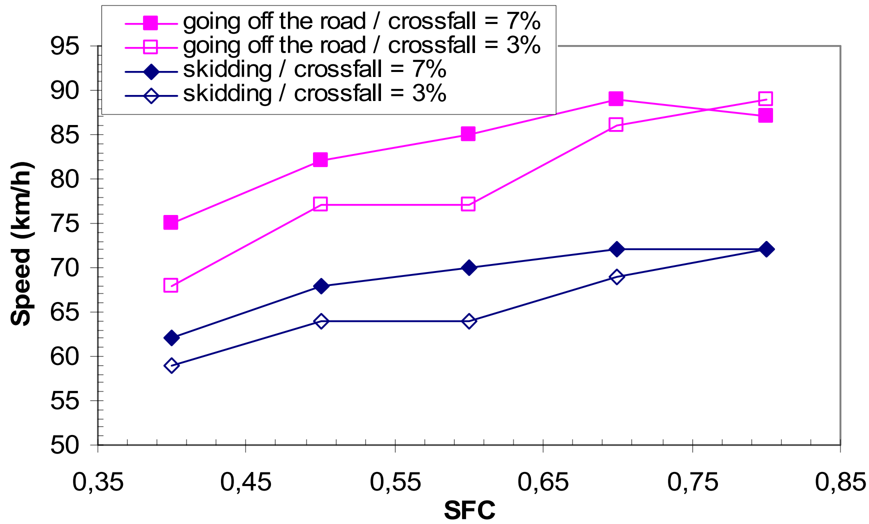


Figure 5 : Speed limit as a function of the crossfall and the SFC

For a crossfall of 7%, the speed limit increases until reaching a stage, which corresponds to the maximal speed bored by the infrastructure. The simulations show that the HGV try to skid on the road for high speed, but the important crossfall coupled to correct SFC limit this inclination.

On the contrary, the evolution of speed limit for a crossfall of 3 %, presents two steps (limit of SFC around 0,55), which can be explained by studying the mechanisms of accident.
When the SFC lies between 0,40 and 0,50 speed limit increases and the HGV (tractor + trailer) skids. The SFC and the crossfall cannot avoid skidding of the whole vehicle. Then, a stage is reached for 0,50 < SFC < 0,60. This speed value is the maximal speed for a skidding mechanism of accident.
When the SFC exceeds 0,60 the behaviour of the HGV evolves. The speed limits are more important and the HGV trailer skids. The skid resistance is efficient to keep the whole vehicle on the road, even if the crosswall is relatively weak.

Limit of lateral acceleration

The curves of the limits of acceleration present the same shape as the speed limits ones, whatever the crossfall considered (3 % or 7 %).

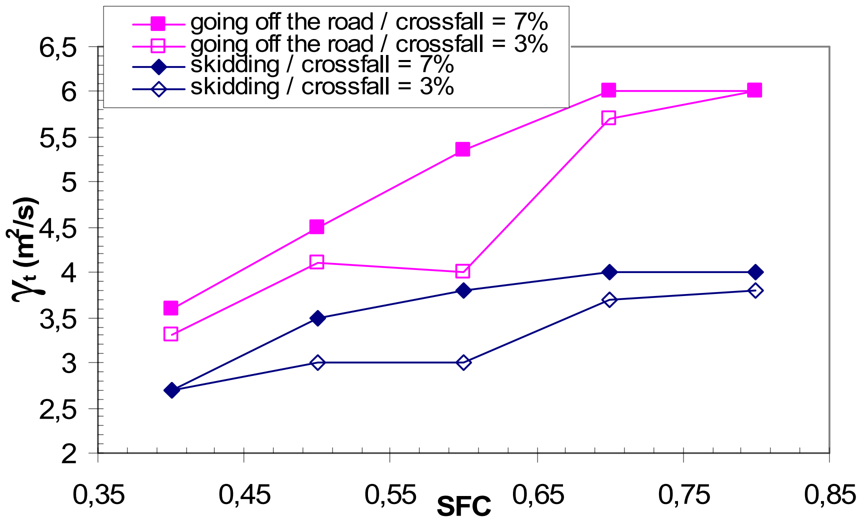


Figure 6 : Limit of lateral acceleration as a function of the crossfall and the SFC

Considering the values obtained by the simulations, they are superior to the safety values. Indeed, a curve with a radius of 120 m has a speed limit of 60 km/h, which corresponds to 2,5 m/s^2. The simulations show that we are widely above these values even for a weak SFC when skid begins.

Influence of the load of HGV

The influence of the crossfall is studied with full HGV. However, the load and the position of this load play an important role into the HGV behaviour. Indeed, the skid resistance and the possibility of monitoring the vehicle are closely linked to the friction. In this part, the load is supposed to be uniformly distributed in the HGV and the centre of gravity is fixed.
The comparison of the behaviour is done between an empty HGV and a fully loaded HGV, which represent the two extreme limits met on the roads.

Speed limit

The curves of speed limit as a function of SFC present two phases (fig.7). First, the limit increases when the SFC increases. This result is logical considering that the more the SFC is important, the more the vehicle keeps its trajectory even for high speed. Then, the curves reach a stage, which is almost the same whatever the load. This level corresponds to the limit born by the driver with this road geometry. The skidding appears for a speed of 70 km/h and the going off the road is effective for a speed of 85 km/h. These values are rather high and exceed the speed limits in a curve with a 120 m radius.

We can conclude to a weak influence of load on speed in the simulations. Nevertheless, these results are obtained with a fixed load and do not take into account a possible trailer shed due to a moving load like water in a tank. The theoretical roll given in the simulations is undervalued as compare to the real roll of the HGV.

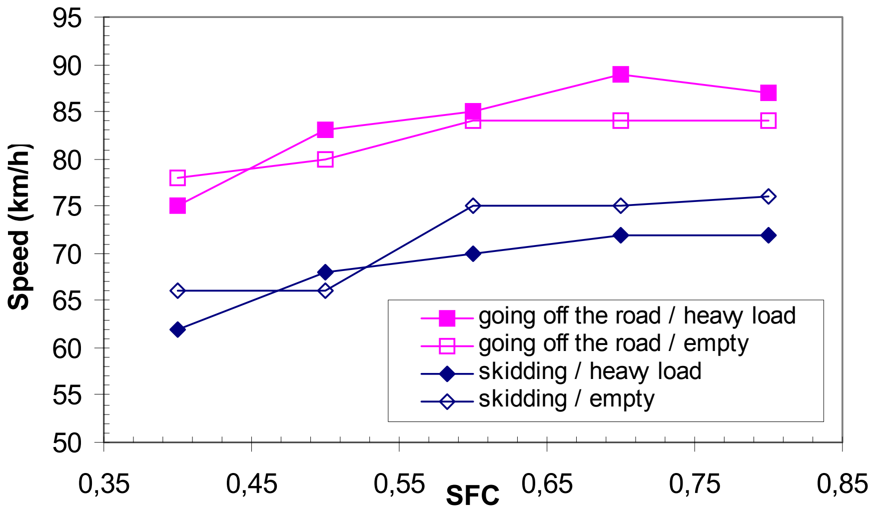


Figure 7 : Speed limit as a function of the load of HGV and the SFC (radius = 120 m and crossfall = 7 %)

Limit of lateral acceleration

The curves obtained with the lateral acceleration present the same shape as the speed ones with an increase of the acceleration until reaching a stage which is relatively independent of the load (fig.8).

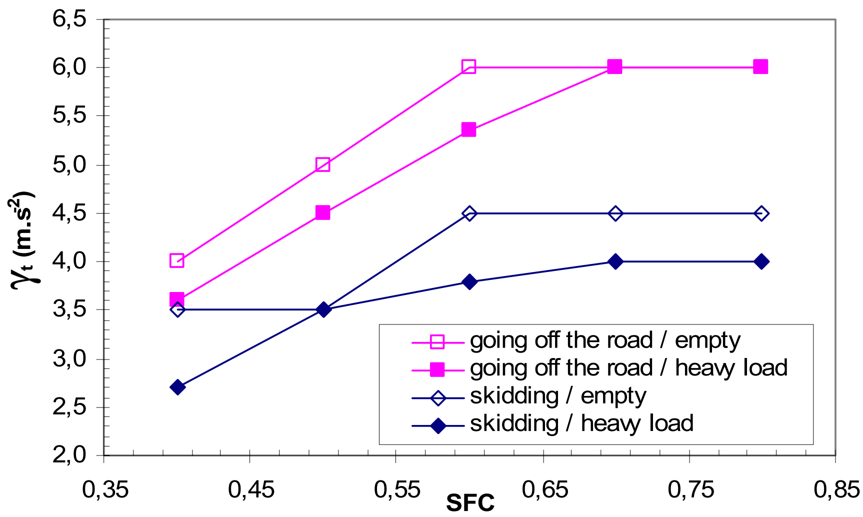


Figure 8 : Limit of lateral acceleration as a function of the load of HGV and the SFC (radius = 120 m and crossfall = 7 %)

We can notice that the limit values are widely above the recommended limit of 2,5 m/s^2.
Lastly, the stage seems to begin for a SFC around 0,60, which is a value commonly met in safety studies. The PROSPER CALLAS simulations tend to confirm the use of this limit and show that the gain is close from zero for a value of SFC up to 0,60.

Application to real accident

The aim of simulation work is both the comprehension of the phenomenon and the prediction of the future behaviour on similar situations with some variations of parameters. After evaluating the influence of load and crossfall on speed limit and lateral acceleration, the results are used to try to reconstruct real accidents and understand what happened. One example is treated in this paper in view of showing the future possibilities of such an approach.

Description of the situation

The accident occurred in a curve at a city entrance. The radius of curvature is 71 m. The HGV was composed of a tractor and a tank. The truck was 24 t weights. The speed of the vehicle was 90 km/h and the speed limit 45 km/h. The driver lost the control of the truck, tried to brake and skidded until crashing into a wall. The weather was nice and the pavement surface didn't present any problem of skid resistance.

Results of the simulations

The simulations on PROSPER are realized with a braking force of 50 daN and the SFC of the road laid between 0,65 and 0,69. The following figures show the linear and angular accelerations at the centre of gravity of the trailer and the tractor during the simulation (fig.9 and 10).

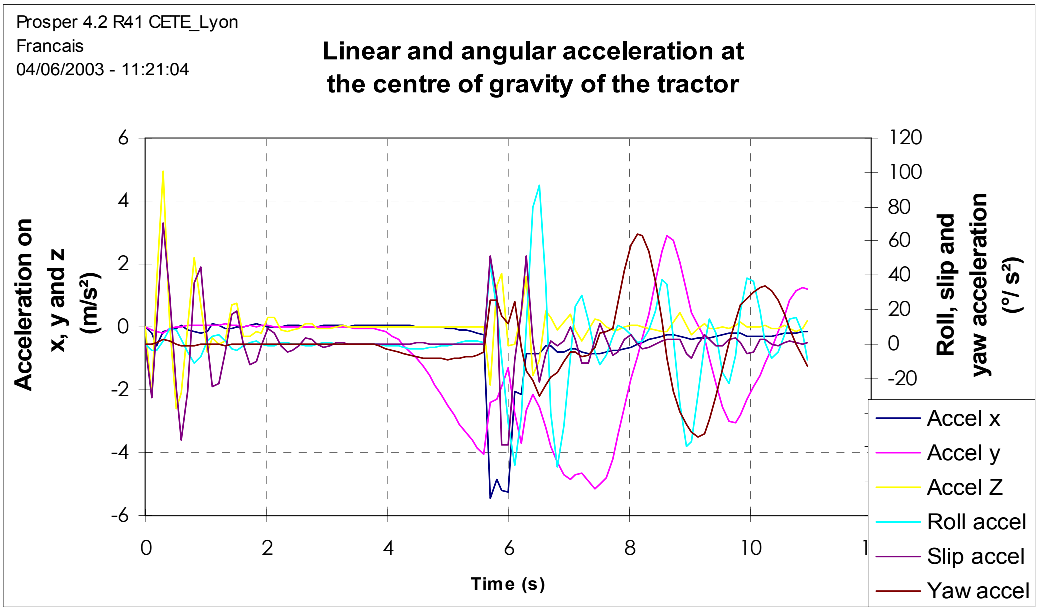


Figure 9 : Linear and angular acceleration at the centre of gravity of the tractor

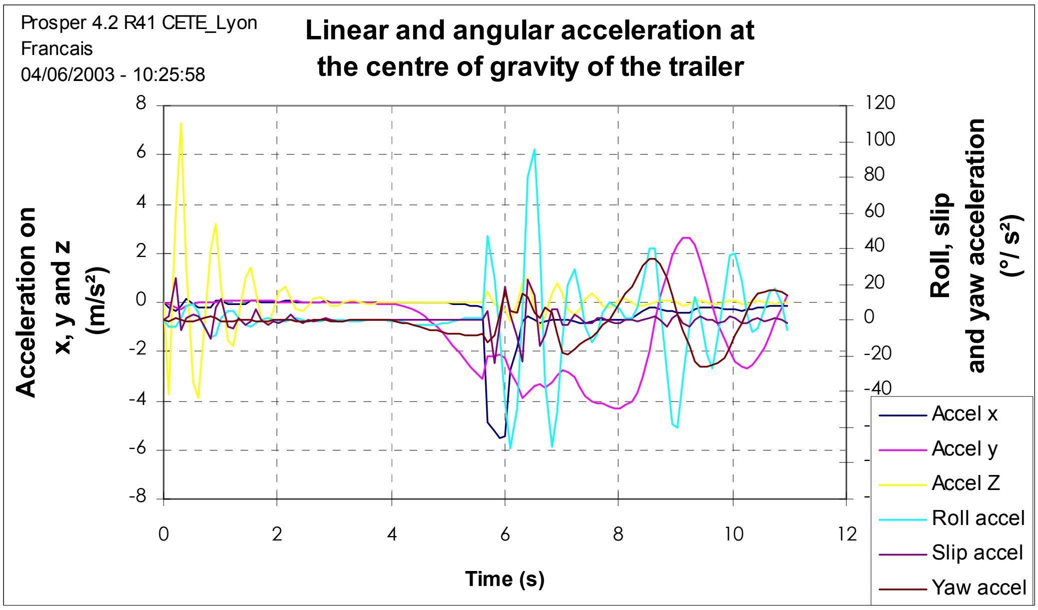


Figure 10 : Linear and angular acceleration at the centre of gravity of the trailer

The values obtained with these parameters show that the maximal lateral acceleration of the tractor is 5 m/s^2 and the trailer one is 4,2 m/s^2. They explained the skid observed by the witnesses.
The high rolling acceleration explains the loose of control of the vehicle.

Other simulations were realized by increasing the SFC value but the software PROSPER indicated that there were just a little skid (about 0,50 m). Thus, accident should be avoided which is not the case. The skid resistance hypothesis seems to be close from reality. However, it was impossible to obtain the detachment of the right wheel, which was reported by the witnesses. The hypothesis according to the load was fixed may be wrong. We could think that the tank was not totally full and the move of the liquid could have entailed the detachment of the wheel. Another possibility lies in the presence of a footway, which could have blocked the truck during skid and entails the wheel detachment.

To conclude, PROSPER simulations give results close from the situation described in the police report. So, we can suppose that the hypothesis done about the road characteristics (SFC) and the driver behaviour are not so far from reality.

Conclusion

PROSPER is a global software aiming at studying dynamics behaviour of the trucks. This article aims at showing different applications of this software for safety study.
On the one hand, it is possible to realize simulations on special road area like curves and to play on the road characteristics in view of finding limits born by the trucks before having an accident. In this article, the example of the crossfall is taken by studying the link between road SFC, speed limit and road crossfall. The different simulations tend to conclude that the speed limit of 60 km/h imposed on this kind of infrastructure is adapted to trucks.

On the other hand, it is possible to try a reconstruction of an accident by making an inverse analysis. Indeed, the approach is based on a iterative method where the parameters of simulations are slowly modified until reaching a situation close to reality. Thus, the software help people to identify the lacking data like the real load of the trailer or the place where the skid of the truck begins. Indeed, it is easy to know the final position of the HGV, but not the place where the loose of control appears.
Moreover, this tool can be used to verify if changing some parameters like speed limit, crossfall, skid resistance or load limit could improve road safety and decrease the number of accidents on the studied area.

This study is continuing in the VERTEC project by including other road parameters and vehicle characteristics. A research direction could be the use of moving centre of gravity of the load in view of including lateral forces and accelerations due to it.

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