HOW DESIGNING SAFER ROADS FOR HGV?

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ABSTRACT

The design of a road infrastructure must take into account the type of vehicles, which will use it. Indeed, Heavy Goods Vehicles (HGV) represent a significant part of the road vehicles, with specific geometrical and dynamic characteristics, which make them more aggressive to road wear and more sensitive to the road profile for stability and safety. This paper investigates geometrical and surface characteristics of the most critical road sections with respect to rollover and knife-jacking of lorries.

The first step of the study aims at detecting critical situations where trucks are involved (curves with small radius, roundabouts…). Through statistical analyses of accidents' databases, CETE of Lyon made a virtual mapping of the most dangerous situations depending on the geometrical and surface characteristics of infrastructure.

Then, a simulation software called PROSPER is used to study the impact of geometrical parameters on the dynamical behaviour of trucks. The parameters of the lorry model contained in PROSPER are optimised in view of fitting real data. Simulations were carried out to evaluate geometrical limits for infrastructure (longitudinal slope, crossfall…) and skid resistance taking into account maximal values of roll angle and velocity, longitudinal speed and lateral acceleration.

Thus, an analysis of the results allowed the proposition of design values for curves, ramps, motorways exit and roundabouts in view of minimising risks for trucks.

Keywords: HGV, infrastructure, risk of accidents, crossfall, slope, SFC

1. INTRODUCTION

The number of Heavy Goods Vehicles (HGV) is continuously increasing in the last decade, being over 500 000 nowadays in France. The average annual course of HGV is 49 000 kilometres, which is four times superior to the number of kilometres done by a car.

First, 3% of the vehicles involved in accidents with corporal damages and more than 9% of the vehicles involved in fatal accidents are HGV. Accidents database relative to the years 2004 and 2005 showed that 13% of the road users are killed in accidents involving heavy vehicles. However, trucks drivers only represented 1,5% of the killed people. Thus, HGV represent a real danger for road users by increasing the risk of fatalities (DOLCEMASCOLO and all., 2006).

Moreover, HGV accidents generate strong damages to infrastructure (road, safety gates, street lamps can be destroyed) and create disruptions for drivers by causing traffic jams. The economic consequences and the repairs cost several millions of euros each year.

Then, the decrease of the number of accidents observed since three years in France mainly concerns passenger cars. The number of HGV accidents stays high. This fact can be explained by the specificities of HGV. Their dimensions are definitely higher than those of passenger cars and their dynamic behaviour is rather different (multi-axles, attachment of the trailer…). That's why engineers must take into account these distinctive features for designing safer infrastructures.

The work presented in this paper is divided into three steps. In a first time, some safety studies are analysed and a mapping of the most dangerous situations is provided. In a second time, numerical simulations are realized on some dangerous areas like curves or ramps in view of finding limits for the geometrical parameters and surface characteristics of infrastructure. In a third time, perspectives and next steps of this work are presented.

2. MAPPING OF THE MOST DANGEROUS SITUATIONS FOR HGV

2.1 HGV accidents characteristics in France

First, 83% of HGV accidents occurred apart from intersections (against 73% of accidents involving passenger cars) and 61,5% of HGV accidents occurred in rural area in 2005 (against 40% of accidents involving passenger cars). HGV accidents distribution is regular between 6h00 and 18h00 without phenomenon of peak hour like for passenger cars accidents.

Then, HGV accidents mainly occurred on straight lines with flat longitudinal profile (74% of injury accidents) whereas areas with a longitudinal slope represent 21% of injury accidents involving at least one HGV.

Considering surface characteristics, 3/4 of HGV accidents occurred on normal conditions whereas 22% of accidents occurred on wet conditions. The percentage of HGV accidents depending on Sideway Force Coefficient (SFC) is given in figure 1. The rate of accidents is calculated for categories of SFC determined with a path of 0,20 (GOTHIE, 2006).

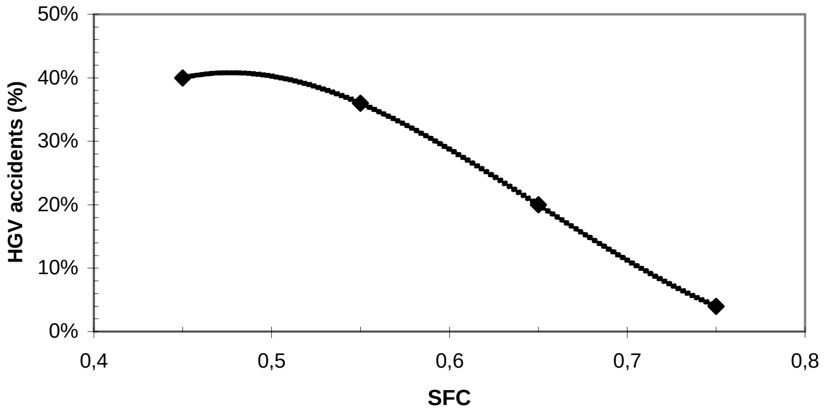

Figure 1 Percentage of HGV accidents occuring on wet conditions versus SFC

Moreover, HGV accidents can be divided in three categories (DOLCEMASCOLO and all., 2003) :

- Rollover,
- Jack-knifing,
- Go out off the road.

The main factors that can explain these accidents are :

- A lack of visibility which entails a misunderstanding of the road characteristics and a misfit driving behaviour,
- A misfit speed in comparison with the characteristics of the infrastructure,
- A weak skid resistance (accidents on wet, icy and snowy roads).

Lastly, tractor semitrailer are the most involved in accidents (more than 50% of trucks' accidents).

2.2 Safety studies results

2.2.1 French national studies (DOLCEMASCOLO et all., 2007)

The French Ministry of Transportation does statistical analysis relative to the accidents with corporal damages each year. The aim is a better understanding of the factors playing a role in accidents. The results presented in this paper don't take into account the factors linked to human behaviour but focus on infrastructure parameters.

The analysis of the rate of accidents shows that the risk of accident is twice more important when HGV circulates in a curve with a longitudinal slope and that this situation represents almost 1/3 of accidents involving a HGV alone.

On secondary roads (single carriageway roads), an accident on two is a front-front collision. On motorways (dual carriageway roads, highways with three lines…), half of the accidents are side-side collisions and a little more of the third are front-rear collisions. These collisions mainly occur on ramps with important length (> 1500 m) and high longitudinal slope (>5%).

2.2.2 VERTEC project results (VERTEC, 2006)

A study carried out in 2003 within the framework of European project VERTEC (6th PCRD) allowed collecting additional information on the dangerous situations. Accidents data coming from France, Italy, Finland and the United Kingdom were aggregated (data collected between 1999 and 2002). The analysis of this database highlighted several configurations of accident according to the category of road considered.

On rural highways (dual carriageways roads), 20% of accidents occurred in intersection or motorways exits. However, curves with radius ranging from 500 m to 1000 m seemed to be the most dangerous whatever the type of HGV considered. The accident rate was 0,52 per million vehicles-kilometres whereas the accident rate on straight line was 0,39. Moreover, a third of accidents occurred on wet surface, which increased the level of fatalities.

On primary roads (single carriageways with high traffic), 45% of accidents occurred in curves with small radius of curvature (< 300 m), 40% of accidents occurred on wet surface and 47% occurred on critical areas like intersections.

2.2.3 American study

Some data extracted from American safety studies can be analysed (MOONESINGHE and all, 2005).

Eliminato: ce qui n'est guère surprenant

Three quarter of American HGV accidents occurred in straight lines and 80% occur out of intersection. Moreover, 68% of HGV accidents occurred on rural areas.

A longitudinal slope increased strongly the risk on accidents. Rollover and jack-knifing mainly occurred in curves with weak level of skid resistance due to bad weather conditions. The rollover risk on curves was multiplied by six by comparison with the risk on straight lines.

Moreover, the authors evaluated the impact of some parameters on the rollover risk. They concluded that an increase of the speed of 15km/h doubled the rollover risk. An increase of 10% of the load increased the rollover risk of 10%. An increase of 10% of the HGV length increased the rollover risk of 10%.

2.2.4 Conclusion

Four situations with a high risk of accidents were detected through these studies:

- Curves with a high radius of curvature and a weak skid resistance lying on secondary roads and rural highways,
- Curves with a small radius of curvature and a weak skid resistance on primary roads (like motorways exit),
- Large curves in descent,
- Ramps.

3. ANALYSIS OF SPECIFIC AREAS

The analysis of each configuration is done with the software PROSPER (PROgram of SPEcification and Research components). In a first part, the software is described. Then, the main results obtained in the different situations are given.

3.1 Description of the software

PROSPER is a software developed by the French firm SERA CD in the 90's. The calculation algorithm is based on a coupled and non-linear system with more than 100 degrees of freedom and hundreds variables.

A 5-axles articulated vehicle (tractor-semitrailer) is used. The vehicle is considered as a two rigid multi-body system. Tyres follow a Pacejka's model with the parameters values determined by Michelin. The weight of the truck ranges from 15 000 kg to 38 000 kg, depending on the load in the trailer.

The driver model used corrects the commands (steering wheel angle and accelerating rate) during the simulation to follow the theoretical trajectory on the road with a reacting time of 0,3 s.

The input parameters are the geometrical parameters of the road (radius of curvature, longitudinal slope, transversal profile…) and the SFC values.

The results obtained on several road configurations are given besides.

3.2 Ramps

Ramps are inclined roadways connecting different levels. In this work, we were interested into straight lines with a slope varying from 3% to 7%, which are the most common configuration of ramp met on French highways.

The simulations were run with a tractor semitrailer driving at 90 km/h. The straight line is 2000 metres long and the slope is constant in each simulation ranging from 3% to 7%. The aim was the determination of the final speed on the top of the ramp depending on the load of HGV and the slope.

The simulations revealed a decrease of the initial speed varying from 10 to 30 km/h as a function of the load and the slope. Recent trucks or empty HGV can keep the initial speed all along the ramp whereas fully vehicles show an important decrease of the initial speed. This fact brings two vehicles with a wide gap of speed together on the same lane.

These simulations confirm the results of an experimental study ran by safety experts on three ramps (CETE Normandie Centre, 2001). They measured the speed of HGV on four positions on the ramps. They observed that the average speed of the slowest trucks (15% of HGV) decreased from 73 km/h to 50 km/h between the bottom and the top of the ramp, whereas the average speed of the fastest trucks (15% of HGV) decreased from 90 km/h to 83 km/h on the same time. Thus, the gap of speed between these two types of trucks was superior to 30 km/h.

So, this configuration can be dangerous. The risk of front-rear collision strongly increases. Thus, a Specific Way for the Slow Vehicles could be a good solution to diminish the risk of collision due to a high difference of speed on the same lane.

As a conclusion, the creation of a specific lane for slow HGV seems essential as soon as ramps of about 2000 m and a slope superior to 5% are built.

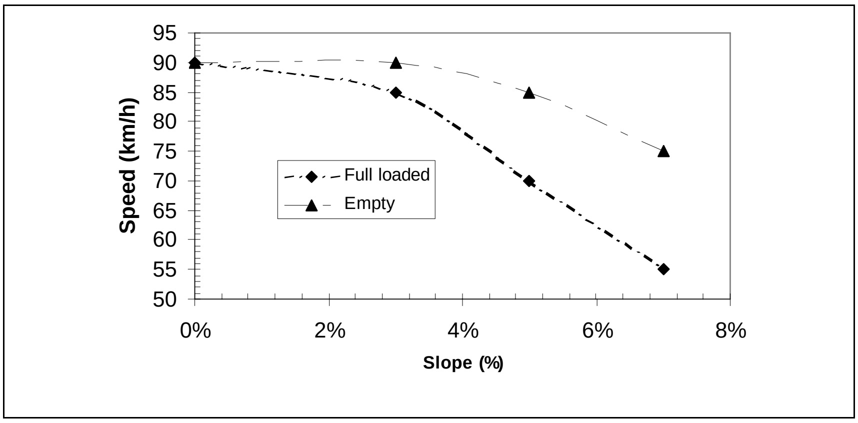

Figure 2 Final speed of HGV at the top of the ramp

3.3 Motorways exit

Highways are built with high radius of curvature and long straight line in view of fostering high-speed values for the vehicles. A large part of HGV accidents occurs on the motorways exit by rollover.

The exits are right curves designed with small radius of curvature (around 120 m). Three parameters were considered in the simulations: skid resistance (SFC), crossfall (i.e. transversal slope) and the load of HGV. Indeed, the load of the HGV is directly responsible of the height of the centre of gravity of the vehicle. This height increases the risk of rollover, especially for moving freight. Nevertheless, only fixed load were simulated with software PROSPER.

The simulations lead to two mechanisms of accidents depending on the skid resistance of the road. When SFC is inferior to 0,60 accidents occur by skid. HGV go off the road or are victims of jack-knifing. The maximum lateral acceleration is 3,5 m/s^2 on dry surface and 3 m/s^2 on wet surface before skidding. The crossfall has a negligible influence on the maximum speed. The impact of load is just a small variation of the maximum speed: empty HGV can pass the curve with a higher speed limit of 5 km/h than a fully loaded HGV.

When SFC is superior to 0,70 rollover can be observed when the height of the centre of gravity is superior to 1800 mm (in the terrestrial line), which corresponds to a loaded semi-trailer.

Figure 3 represents the lateral acceleration as a function of the height of the centre of gravity when the skid resistance is rather high (SFC = 0,80) and the speed is equal to 87 km/h. The curve has an inversed “S” shape. The acceleration globally decreases when the height of the centre of gravity increases. When the height reaches the value to

1600 mm, the rear axle of the semitrailer raises. When the height ranges from 1600 to 1700 mm, the side of the tractor semitrailer raises. When the height reaches 1800 mm, rollover happens.

The same curve is obtained by fixing the crossfall value to 3%. The simulations confirm the fact that crossfall has a weak influence on rollover.

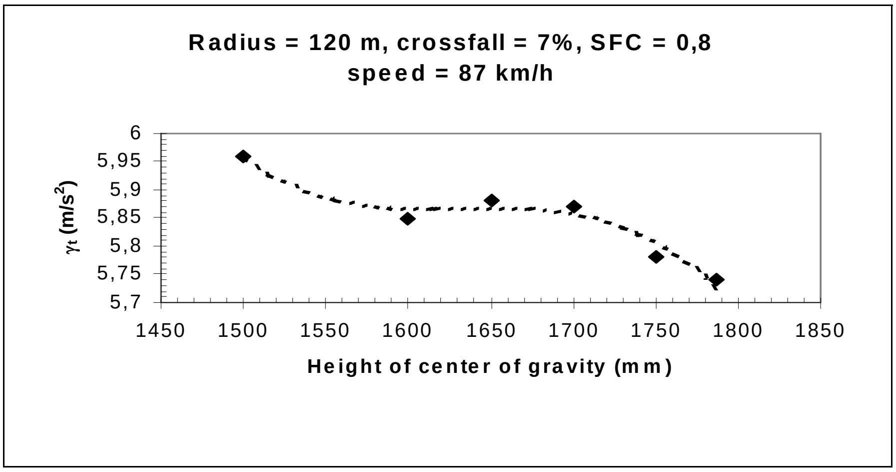

Figure 3 Lateral acceleration of the semitrailer versus height of the center of gravity

3.4 Roundabout

A roundabout is one of the safest control devices for regulating traffic flow at intersections. It allows a reduction in the speed of vehicles and a modification of driver behavior just before entering the roundabout. However, these statistics don't reflect the reality of the situation. Indeed, most of the accidents on roundabouts have a particular typology, which is not taken into account in accident statistics. Statistics focus on injuries and fatalities and not on cases with material damages. HGV that rollover or run off the road, belong to this category. These accidents most often involve a HGV and no other vehicle, occur at low speed and rarely entail injuries. A previous paper presented the results obtained on a global study about the influence of geometrical characteristics of roundabouts on HGV accidents (CEREZO and GOTHIE, 2006). The object of this paragraph is just to remember the main problems and conclusions.

The difficulty lies in the fact that the steering wheel angle is highly changing during the manoeuvre whereas the crossfall (i.e. transversal slope) is evolving too. The crossfall can vary from 3% at the entering of the roundabout to 7% in middle of the ring.

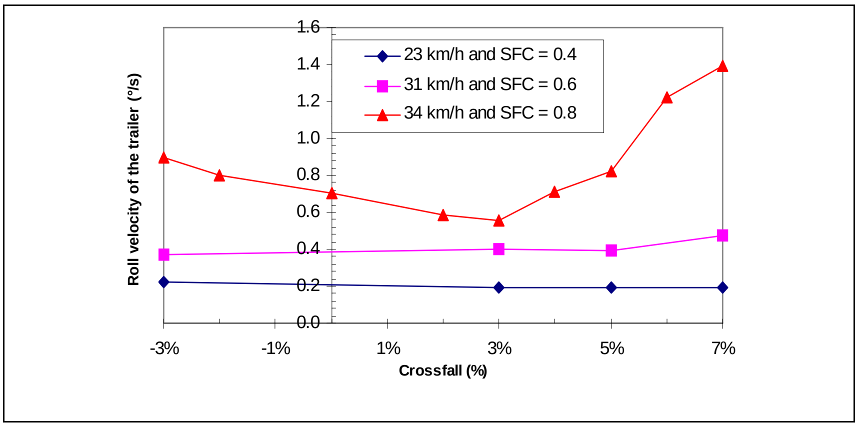

Figure 4 Roll velocity of the trailer versus crossfall on roundabouts

The study focussed on the maximum speed, the maximum lateral acceleration, the roll angle and the roll velocity of the tractor and the semitrailer. It shows that:

- The maximum speed on roundabouts increases when the SFC value decreases,
- The maximum speed doesn't depend on the crossfall value when SFC is superior to 0,60
- The maximum speed decreases when crossfall increases when SFC is 0,40
- The risk of rollover can be diminished by limiting the crossfall value to 3% (figure 4).

3.5 Bends

Accidents in turns represent a wide part of HGV accidents. The geometrical characteristics of curves can explain some of them. The work focuses on finding the maximum speed for different configurations (radius ranging from 100 to 500 m, crossfall ranging from 3% to 7% and SFC ranging from 0,40 to 0,80).

Maximum speed in each case is determined following two criteria. First, HGV is driving in the middle of its lane at the beginning of simulation. HGV must stay in its lane until the end of the simulation (i.e. after having passed the curve). Then, the maximum lateral acceleration is limited to 4,5 m/s^2, considering the high risk of rollover. If this value is reached during the simulation, the simulation stops even if HGV is still in its lane.

The synthesis of the results allows obtaining graphics like figures 5 and 6. First, HGV maximum speed is not connected to the radius of curvature when the value is superior to 300 m. The limit of 110 km/h obtained in simulations is the legal limit on french primary roads. Thus, the simulations tend to proove that accidents are rather due to human errors. For small radius of curvature, a speed regulation of 60 km/h seems necessary.

Then, figure 6 shows that crossfall has an influence on maximum speed value whatever the skid resistance value when a bend with a small radius of curvature is considered. High values of crossfall allow increasing the speed in the curve from 15 km/h.

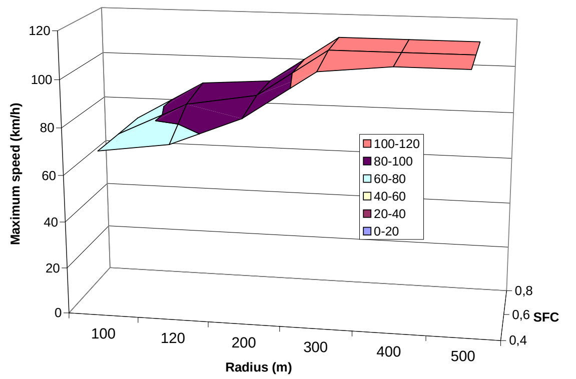

Figure 5 Maximum speed depending on radius and SFC (crossfall = 7%)

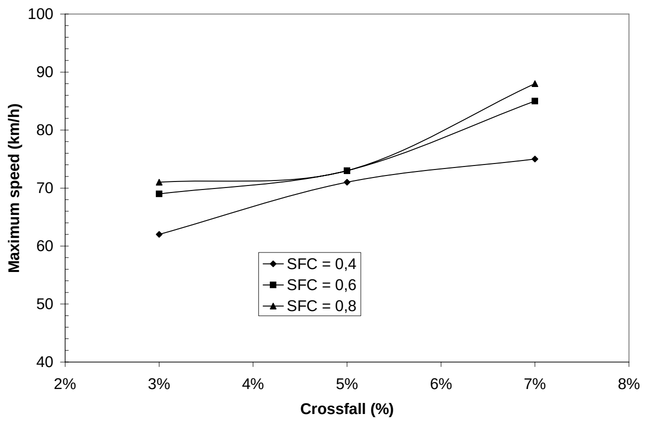

Figure 6 Maximum speed depending on crossfall and SFC (radius = 100 m)

4. CONCLUDING REMARKS

The bibliography and the analysis of databases containing accidents with corporal damages allowed detecting four situations with a high risk of rollover, jack-knifing or go off the road. These critical areas were studied thanks to a software simulation called PROSPER. Simulations were run on:

- Ramps,

- Roundabouts,
- Exit of motorways,
- Bends.

The simulations run with PROSPER led to the proposition of some design value for infrastructure. First, a minimal value of SFC can be fixed to 0,50. Indeed, this value allows avoiding skidding in turns or roundabouts.

Moreover, it seems to be a good thing to limit the crossfall value to 5% in turns with a small radius of curvature to avoid rollover. This is particularly true for new bituminous mix with a high level of microtexture.

In the same way, the limitation of crossfall to 3% in the ring of roundabouts could diminish the risk of accidents.

Lastly, longitudinal slopes higher than 5% over big lengths raise difficulties. Thus, a specific lane for the slow vehicles could be a good answer to solve problems linked to ramps.

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