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HEAVY GOODS VEHICLE ACCIDENTS ON ROUNDABOUTS: PARAMETERS OF INFLUENCE

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ABSTRACT

Numerous accidents occur on roundabouts without being taken into account in safety studies, due to the fact that the risk of fatal injuries in this situation is relatively low. This type of accident represented only 1% of injuries in 2001. However, they generate damage to the road and create disruptions for drivers by causing traffic jams. For this reason, research work has been undertaken by the LCPC (the French Central Laboratory for Roads and Bridges) and the Laboratoire Régional de Lyon (Regional Laboratory of Lyon) in order to highlight the link between infrastructure characteristics and HGV accidents. Part of this work focused on the parameters influencing accidents occurring on roundabouts and was divided into three steps.

Firstly, a literature review was made, in order to identify several roundabouts where accidents occur. This work was done with the CETE Normandie Centre (a technical service of the French Ministry of Transport, which is specialised in road safety). The whole study selected three roundabouts for simulations. This article presents the results obtained with one of the three.

Secondly, a software called PROSPER was used, which allows the simulation of vehicle and road interactions. This software was first validated by a study on Heavy Truck Rollover Simulations (Delanne et al., 2002). Specific dynamic tests were carried out with an instrumented truck and PROSPER was proved to give accurate predictions of vehicle dynamics parameters such as yaw speed or wheel lift.

Lastly, geometrical parameters (crossfall) and surface characteristics (Sideway Force Coefficient) were modified in order to evaluate their influence on road accidents. The study particularly focused on the maximum longitudinal speed, the lateral acceleration, the maximum roll speed and the roll angle of the vehicle.

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1. INTRODUCTION

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. Thus, most of the crashes at intersections are avoided, which represents a gain in terms of safety and costs considering the injuries and traffic jams entailed by accidents. These are the main reasons for roundabout development in Europe and the United States (Kiattikomol and Urbanik II, 2005). As an example, accidents on roundabouts represent only 1% of the fatal injuries in France between 2000 and 2004.

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 where there is material damage only.

Heavy Goods Vehicles (HGV) that roll over or run off the road on roundabouts are also part of this category. These kinds of accidents most often involve a HGV and no other vehicle, occur at low speed and rarely entail injuries. Nevertheless, they have economic consequences due to road damage, trucks damage and subsequent major traffic jams. For this reason, the LCPC (the French Central Laboratory for Roads and Bridges) and the LRL (the Regional Laboratory of Lyon) decided to carry out a study on truck accidents on roundabouts.

The study began by a brief literature review, which aimed both to make an assessment of the roundabouts' characteristics, which seem to play a role in accidents, and to identify actual roundabouts where accidents had occurred.

Following this, a simulation software called PROSPER was used to reconstruct real-life accidents (Briet, Cerezo and Gothié, 2004b). This step enabled HGV characteristics to be

determined for the simulations. The second step of this work was the use of PROSPER to study the influence on HGV dynamics when the crossfall (transversal slope of the road) or the SFC (Sideway Force Coefficient) surface characteristic evolve. We were therefore able to obtain an evaluation of the influence of infrastructure on HGV behavior.

The present article will propose possible directions for future research on this subject.

2. THE CHOICE OF ROUNDABOUT

A research team in Rouen (France) identified examples of roundabouts where HGV accidents occurred, through safety studies carried out over the last ten years. This task proved to be rather difficult, as accidents of low severity are not taken into account in French databases. The team therefore had to go to authority offices in order to read the accident reports and collect interesting data. They selected three interesting roundabouts for this study. The authors have chosen to focus on only one of the three in this paper.

The chosen roundabout is on a major road (“nationale 29”) located in Longueau (Somme), between the towns of St Quentin and Amiens. The radius of the ring is 20 meters with 2 lanes of 4 meters each (Figure 1). The simulations considered trucks going from Amiens to St Quentin. These trajectories seem to be the most dangerous on this roundabout.

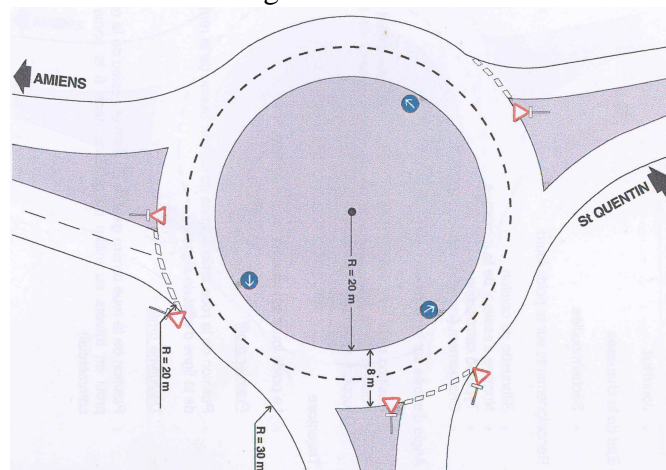


Figure 1: Geometrical characteristics of the roundabout (C.E.E.S.A.R. and CETE Normandie Centre, 1999)

3. SIMULATION SOFTWARE “PROSPER”

1.1 Characteristics of the software

PROSPER is a 3D road vehicle dynamics simulation software developed by a French company called SERA-CD. This software is based on a 3D computation engine, with 29 Degrees of Freedom and more than 600 variables. It allows a wide range of input parameters, which cover vehicle characteristics (suspension, truck dimensions, center of gravity height, tire characteristics...), different driver reactions and road characteristics (geometry, SFC, gradient,

crossfall...). In terms of output, the work focused on the position of the vehicle in relation to its theoretical trajectory, the lateral acceleration, the roll velocity and the roll angle. More than fifty parameters were available in total.

The results given by this software were validated by comparison with measured values obtained with an instrumented truck for different maneuvers (Delanne, Schmitt and Dolcemascolo, 2003). They used a French military truck with a maximum load of 10 000 kg (model TRM 10000 which is a logistic vehicle). Their work showed a good accuracy of the longitudinal and lateral accelerations, yaw, pitch, roll angles and velocity values. They even managed to simulate the lift of the inner wheels on the roundabout.

1.2 Hypothesis for the simulations

The simulations are made with a semi-trailer (5 - axels articulated vehicle). The vehicle is fully loaded (38 t) and the centre of gravity is 1800 mm high. A former study showed that the maximum velocity on a bend is lower when the vehicle is fully-loaded than when it is empty (Figure 2) if a fixed loading is considered. However, the influence of a moving load couldn't be studied with PROSPER. This is one of the limitations of the work carried out, considering the fact that moving charges are responsible for most rollovers because they considerably increase the roll effect.

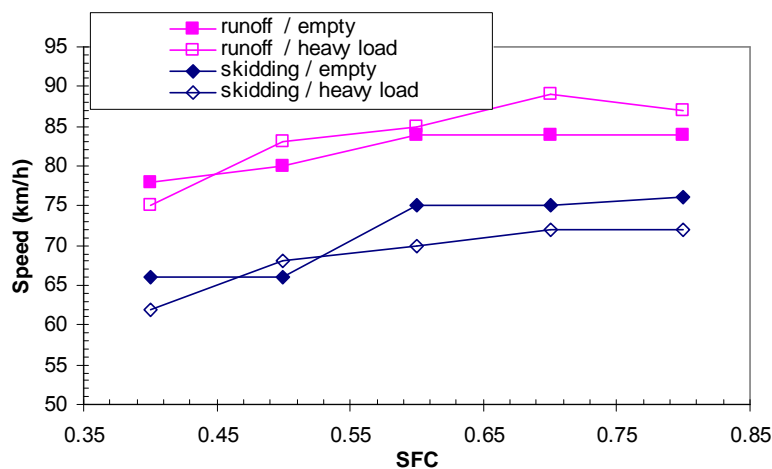


Figure 2: Influence of the load on the speed limit in a left bend with a radius of 120 m and various SFC (Briet, Cerezo and Gothié, 2004a)

Suspension characteristics were chosen in view of representing average French truck characteristics. The Michelin Company provided tire parameters and the friction coefficients were calculated with Pacejka's magic formula.

This work only considered the behaviour of an HGV that was alone on the roundabout. Interactions with other vehicles were not taken into account. Crashes were also excluded from the study. Only rollovers and vehicles running off the road were taken into account.

The crossfall is the technical word meaning transversal slope of the road. It was assumed to be constant in the ring and covered the following values: -3%, 3%, 5% and 7%. The crossfall of the entering lane was 2,5%. Rules relating to the use of plus and minus symbols took into consideration the distinctive trajectory of vehicles on roundabouts due to the specificities of the superelevation, which differs from that which can be observed on a typical bend. The crossfall was considered positive when the left side of the lane was higher than the right side of the lane.

The HGV trajectory was chosen in view of minimising the dynamic stress on the vehicle. A statistical study on an instrumented roundabout showed that more than 50% of trucks use the left lane on the ring (C.E.E.S.A.R. and CETE Normandie Centre, 1999). Moreover, the same study proved that 80% of the trucks have a trajectory, which makes an angle with the entering lane axle. This behaviour helps to diminish the stress on the trucks. The speed of the vehicles is supposed constant during the manoeuvre and equal to the entering speed.

1.3 Results of the simulations

1.3.1 Longitudinal speed and lateral acceleration

Simulations allowed the maximum speed to be determined for the truck entering the roundabout, for three levels of skid resistance (SFC = 0.4, 0.6 and 0.8). The maximum speed is defined as the maximum speed value borne by HGV before running out of the lane. Figure 3 shows that the maximum speed decreases when skid resistance decreases. This is a well-known and logical result.

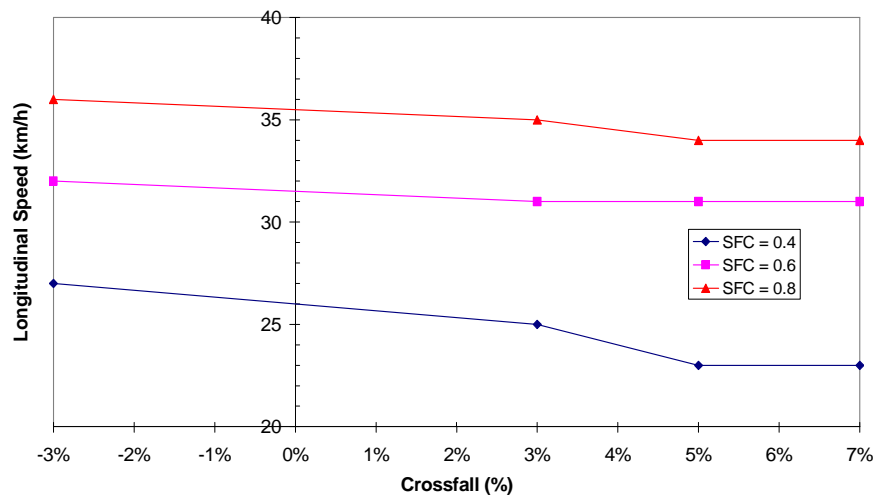


Figure 3: Maximum speed of the truck at the centre of gravity of the tractor -trailer on the roundabout

Nevertheless, the simulations showed another result, relating to the role of the crossfall. For a high level of skid resistance, the crossfall has a very limited influence on the maximum speed value (no more than one or two kilometres/hour). The maximum velocity level is stable. On the other hand, the maximum speed is more dependant of crossfall when the skid resistance is low. For a low SFC, HGV tends to skid and runs off the road. A positive transversal slope increases

this effect (this positive slope is in the opposite direction of a normal crossfall on a bend). A gap of 3% to 5% exists for velocity. Above these values, the maximum speed is constant. Interestingly, the French guidelines for safe road design (Brenac, 1992) indicated a maximum value for crossfall of 3% to avoid rollover. This limit was obtained by experimental studies, fifteen years ago.

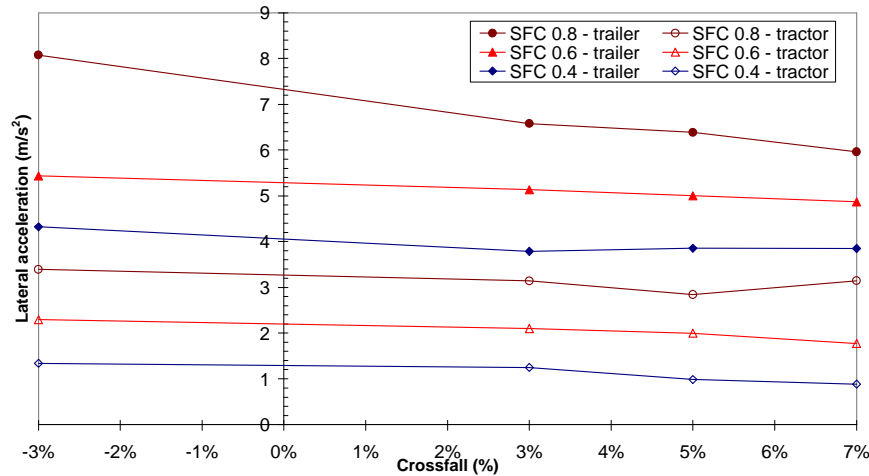


Figure 4: Maximum lateral acceleration at the centre of gravity of the tractor and trailer on the roundabout

Thus, the maximum lateral acceleration γ_L that can be borne by the tractor is the half of that borne by the trailer for each skid resistance level. For positive crossfall values, γ_L ranges from 1.2 m/s^2 to 3.2 m/s^2 for the tractor and from 4.0 m/s^2 to 6.6 m/s^2 for the trailer. The level seems to depend less on crossfall (Figure 4), than on skid resistance. For a negative crossfall, γ_L ranges from 1.2 m/s^2 (SFC = 0.4) to 8 m/s^2 (SFC = 0.8). In this case, crossfall generates an opposite stress to the dynamic stress applied on the truck and the maximum value of γ_L increases.

1.3.2 Roll angle and roll velocity

The roll angle of both the tractor and the trailer were evaluated at a constant speed. For each skid resistance level, a maximum speed was taken. It corresponded to the lowest of the maximum speeds determined in 1.3.1. for each SFC value.

The roll angle of the tractor ranges from 1° to 3.3° and the roll angle of the trailer ranges from 0.5° to 0.9° . The roll angle for the tractor is higher than that of the trailer because the stiffness of the suspensions (S.S.) is less for the tractor than for the trailer ($S.S._{tractor} = S.S._{trailer} / 2$).

The evolution of the roll angle in relation to crossfall is therefore different for the tractor and the trailer. For the tractor, the roll angle slowly increases when crossfall increases. The stress generated by the transversal slope has a complementary effect with the centrifugal force. Nevertheless, this phenomenon is not preponderant. On the other hand, the roll angle of the trailer slowly decreases when crossfall increases.

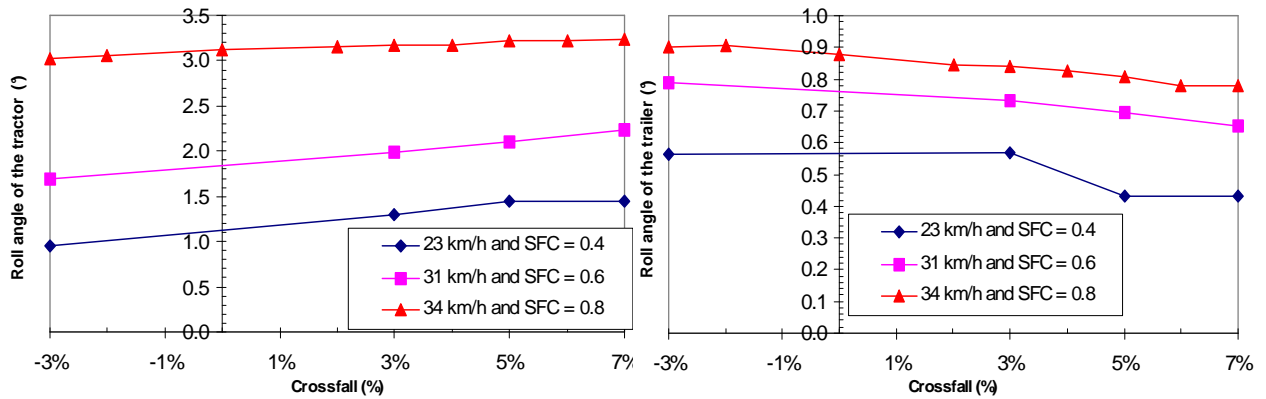


Figure 5: Tractor (a) and trailer Roll angle (b) for different skid resistance levels as a function of the crossfall

Moreover, the roll angle is very low when the SFC is low, as trucks tend to skid and run off the road, rather than roll over.

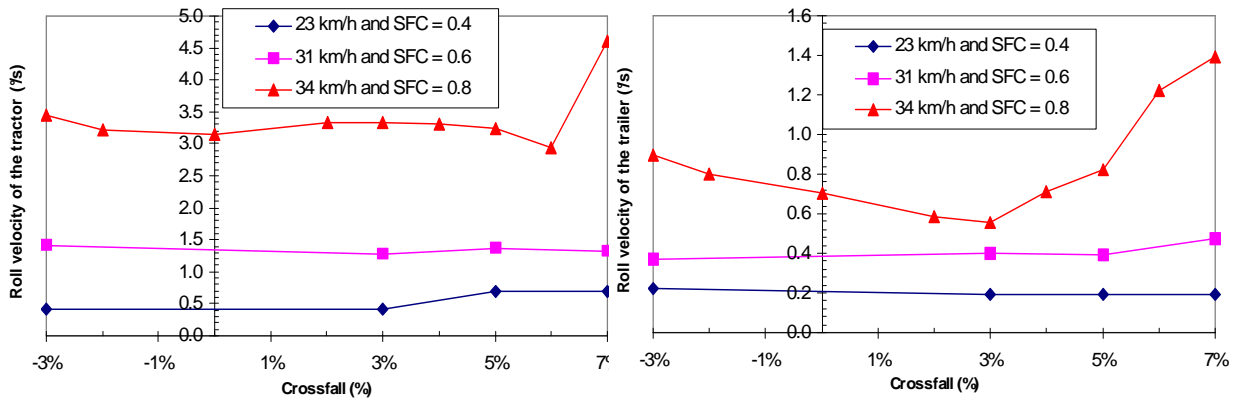


Figure 6: Roll velocity of the tractor (a) and the trailer (b) in relation to crossfall

For roll velocity, the values range from 0.5°/s to more than 4°/s depending on whether the tractor or trailer is considered. The roll velocity of the trailer is three times lower than that of the tractor. This is due to the stiffness of the suspension.

The evolution of the roll velocity depends on the skid resistance of the road. For a low SFC, the roll velocity in relation to the crossfall is almost constant both for the tractor and trailer. For a high SFC, the behavior is rather different. The roll velocity of the tractor is stable if the crossfall is below 6%. Above this limit, roll velocity strongly increases and the tractor starts to become unstable. For the trailer, simulation results showed a decrease in roll velocity for a crossfall below 3% and an increase for a crossfall above 3%. There would appear to be a limit beyond which the dynamic behavior of the vehicle changes.

4. CONCLUSIONS

This paper presents the first results obtained from research on HGV behavior on roundabouts for various crossfalls and skid resistance levels. The first conclusion is the need for a high level of skid resistance on roundabouts, considering the fact that speed limits and lateral acceleration limits are directly dependant on the level of SFC. Crossfall plays a role only in cases of low skid resistance because it generates a transverse stress on the vehicles, which is added to the effect of the centrifugal force and leads to vehicles running more frequently off the road.

A second point of the study focused on the roll angle and the link with various crossfalls. The first results of simulations led to the conclusion that the impact of crossfall is rather limited on roll angles. Skid resistance has a greater influence than crossfall on this parameter. Nevertheless, the roll angle of the tractor slowly increases with crossfall and the roll angle of the trailer slowly decreases. A higher velocity and the radius of curvature could accentuate this tendency. This is one of the next points that will be tested by the LRL in the next months. The aim will be to modify the radius of curvature of roundabouts to complete this work and explore the consequences on the dynamic behavior of trucks.

Similar conclusions can be drawn for roll velocity. For SFC values below 0.70, roll velocity is independent of crossfall. When skid resistance becomes high, a limit appears for crossfall. For the roundabout used in this work, the limit is 3%. The variations of roll velocity are reversed. Above this critical value, the roll velocity rises and may become dangerous. Thus, it would be better to limit the crossfall value to +3 or +4% on roundabouts, due to the fact that the transverse slope is on the outer side of the bend.

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