THE DANGER OF RAMPS FOR HEAVY GOODS VEHICLES

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Abstract
The design of a road infrastructure must take into account the type of vehicles, which will use it, above all with respect to road safety. Indeed, Heavy Goods Vehicles (HGV) represent a significant proportion of road vehicles, with specific dynamic characteristics, which make them more sensitive to the road profile. This paper investigates the risk of accidents in ramps and proposes a solution to diminish it. Ramps are long inclined roadways connecting different levels. First, experts in safety studies ran an experimental study on three ramps of a French highway close to Paris and showed that front-rear accidents between two heavy-vehicles or between a heavy vehicle and a passenger car occurred in the same places on the three ramps. They concluded that accidents were due to a high difference of speed between the vehicles. Then, numerical simulations were realized with a view to evaluating the influence of some parameters (longitudinal slope, load, speed) on the risk of accident. Thus, this work gave indications as to how to design safer ramps in the future.

Keywords: Heavy vehicles, Ramps, Longitudinal slope, Distribution of speed

Résumé
La conception des infrastructures doit prendre en compte les spécificités des véhicules qui l'empruntent afin de garantir la sécurité des usagers. Les poids lourds représentent une part importante des véhicules circulant et leurs caractéristiques les rendent particulièrement sensibles au profil de la route. Cet article traite du problème des accidents de poids lourds en rampes, de leurs causes et des solutions possibles. Dans un premier temps, des experts en sécurité routière ont réalisé des études de sécurité sur différentes rampes situées sur une autoroute proche de Paris. Ils ont conclu que la majorité des accidents étaient des collisions avant/arrière dues à des différentiels de vitesses trop importants. Dans un deuxième temps, une approche par simulation a permis d'étudier l'influence de la pente longitudinale, du chargement et du type de poids lourds sur la vitesse en rampe et d'étudier ainsi le risque d'accident.

Mots-clés: Poids-lourds, rampes, pente longitudinale, profil de vitesse.

1. Introduction

The design of a road infrastructure must take into account the type of vehicles, which will use it, above all with respect to the road safety. Indeed, Heavy Goods Vehicles (HGV) have specific dynamic characteristics, which make them more sensitive to the road profile for safety. This paper investigates the risk of accidents on ramps. Ramps are long inclined roadways connecting different levels. In France, we mainly find ramps on highways. In this work, the authors were interested in straight lines with a slope varying from 0% to 7%.

First, safety studies on three ramps of a French highway were performed. The average daily traffic on this infrastructure was 18000 vehicles per day. French experts analysed how accidents occurred and what was the real speed of heavy vehicles on the ramps. Then, numerical simulations with software were performed with a view to evaluating the impact of the longitudinal slope and the weight on the speed of several types of heavy vehicles. These results allow conclusions to be drawn regarding good practice for the design of ramps.

2. Safety Studies Results

2.1 Typology of accidents

Safety studies realized on French highway close to Paris, between 1995 and 2001 showed that a great number of heavy vehicles' accidents occurred by front-rear collisions on ramps. Safety experts focussed both on the corporal and material accidents (CETE Normandie Centre, 2001). They noticed that more than one third of heavy vehicles' accidents occurred on a section of five kilometres, which represents only 2% of the highway length. Accidents were mainly located after 1500 m of rising as it is shown on figure 1.

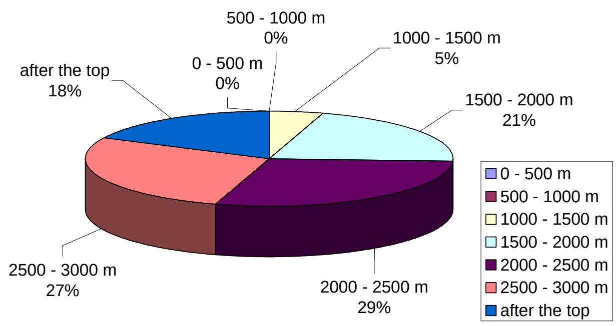


Figure 1 - Distribution of heavy vehicles' accidents on the ramps

These accidents seem to be due to a wide gap of speed between the vehicles involved. In most of the cases, a truck or a passenger car, which drove faster than the heavy vehicle behind it crashed. The average speed of the slow vehicle was around 40 to 50 km/h.

2.2 Speed

Considering the influence of the speed of heavy vehicles on this type of accident, their speed was measured at different positions along the ramp. Four locations were chosen and measurements were performed using pneumatics sensors on the right lane. Then, the distribution of speed was analyzed. The following figure shows the speed distribution for heavy vehicles. We can notice that speed seemed to follow a Gaussian law on the beginning of the rise (loc.1). The peak of the curve was around 85 km/h, which will be the reference of speed for the simulations. Then, the distribution of speed was spreading and the peak value slightly decreased to 78 km/h (loc.2). After 2000 meters of rising, two populations of heavy vehicles appeared (loc.3 and loc.4). The first one was able to keep their speed and the second one showed a decrease in speed ranging from 20 to more than 40 km/h.

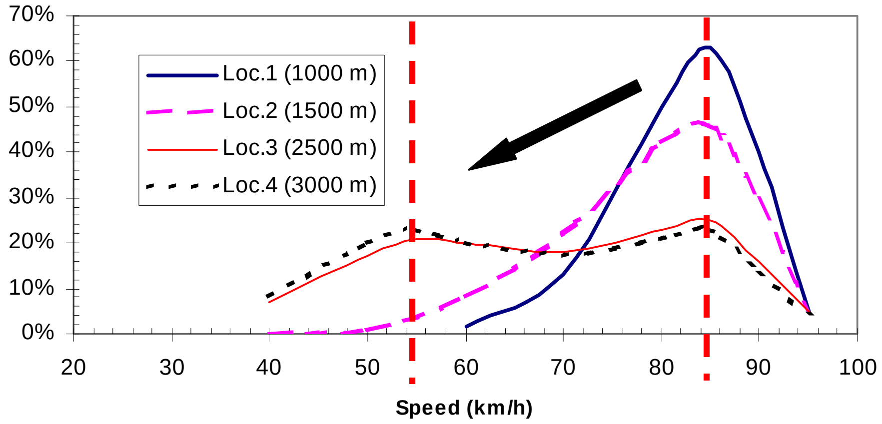
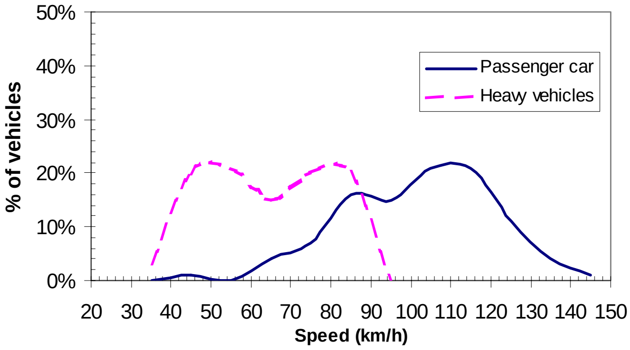


Figure 2 - Distribution of heavy vehicles' speed on different locations on the ramps

A similar work was performed for passenger cars to compare the speed distribution with the heavy vehicles' one. The passenger car speeds decreasees less. The average speed decreases from 105 km/h to 94 km/h.



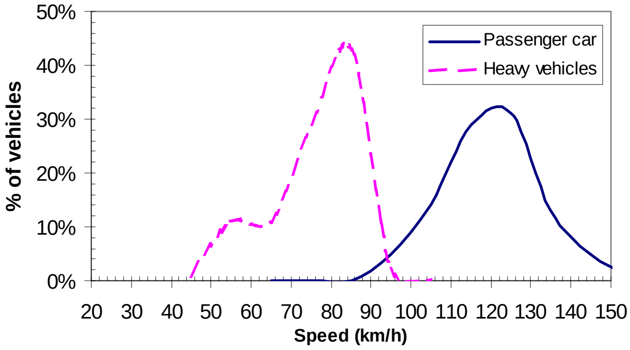


Figure 3 – Distribution of speed on the top of the ramps in the right lane (left figure) and the middle lane (right figure)

To compare the speed on the right and middle lanes, the speed was measured with radar. The measurements were realized before the top of the ramps, on the right lane and on the middle lane of the road. On the right lane, the speed distributions were spreading between 30 and 140 km/h. For each type of vehicle, the distribution showed two peaks, which meant a difference of speed even in the same category of vehicle. The average speed was 121 km/h for passenger cars and 77 km/h for heavy vehicles, which meant a wide gap of speed even in the lane used for overtaking.

2.3 Conclusions

Safety studies performed on this French highway showed that heavy vehicles accidents occurred after 1,5 kilometer of rising on 4% ramps. This seemed to be due to the fact that a wide difference of speed between the vehicles was responsible for accidents. The study of speed distribution of passenger cars and heavy vehicles was realized to verify this hypothesis.

It showed that the speed distribution seemed to be Gaussian at the beginning of the ramp whatever the type of vehicle. Then, the speed distribution law stays Gaussian for passenger cars but not for heavy vehicles. A double peak appeared which meant that two “populations” with an average speed separated by more than thirty-five kilometers per hour were driving on the right lane of the road.

Thus, the risk of accidents strongly increases considering that drivers could be surprised by the weak speed of the vehicle ahead. The risk of front-rear collision is important. Moreover, drivers tend to overtake in this situation, which represents a second risk of accident. That’s why it could be interesting to split traffic into two different lanes with a special lane for slow vehicles to avoid this configuration.

3. Software Simulations

3.1 Characteristics of the simulations

Simulations were run with a software called PROSPER (PROgram of SPEcification and Research components). The French firm SERA CD developed this software 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 of variables. The input parameters are the geometrical parameters of the road (longitudinal slope, transversal profile…), the surface characteristics (skid resistance values) and the characteristics of heavy vehicles (type, load…). The output parameters are the dynamic state of the heavy vehicle (speed, accelerations…). Ramps were modelled by straight lines 2300 metres long and the slope was supposed constant in each simulation with values equal to 3%, 5% or 7%. The transversal slope was 2.5%.

Two types of heavy vehicles were used in the simulations (a 5-axles articulated vehicle – tractor semi-trailer - and a 2-axles rigid vehicle). Tyres follow Pacejka’s model with parameters values determined by Michelin. The weight of the tractor semi-trailer ranged from 15000 kg to 38000 kg, depending on the load in the trailer and the weight of the 2-axles rigid vehicle ranged from 13000 kg to 19000 kg. The heavy vehicles drove at 90 km/h at the bottom of the ramps. The driver used the optimal gear in view of minimizing the stress on the engine.

The parameters of the engine were chosen to be representative of heavy vehicles (more than ten years old), which are less powerful than new trucks and more sensitive to longitudinal profile variations.

The simulations focused on determining the final speed on the top of the ramp depending on the load of HGV and the slope.

3.2 Results

The analyses of the results focused on two points: the link between speed variations and longitudinal slope value and the impact of the type of heavy vehicle on the speed variations.

Influence of the longitudinal profile

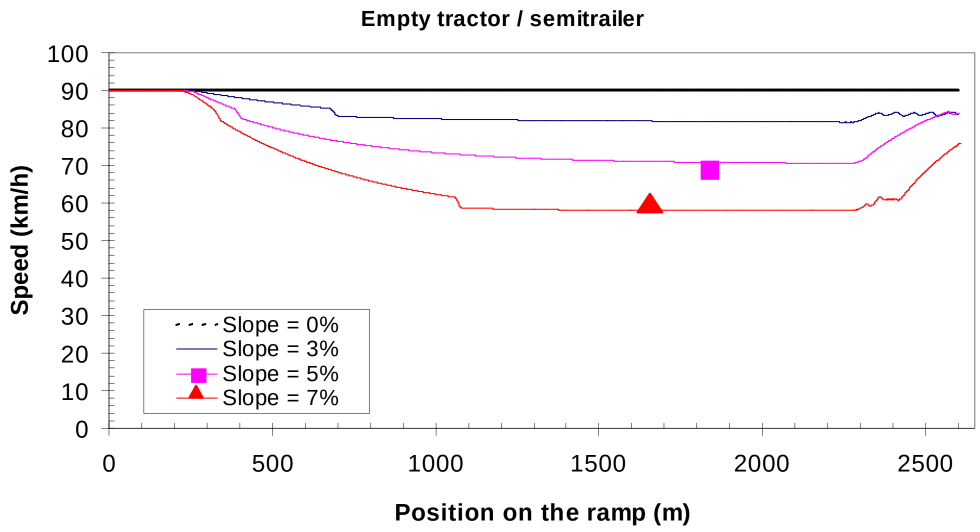


Figure 4 – Speed variations all along the ramp for empty tractor semi-trailer

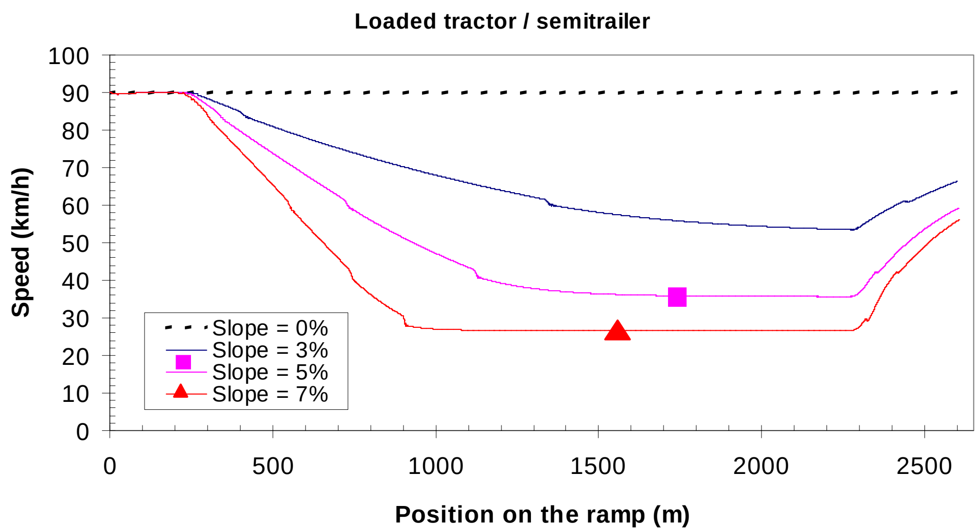


Figure 5 – Speed variations all along the ramp for fully loaded tractor semi-trailer

First, simulations revealed that the decrease of speed happened in the first 1500 meters of the rise (figures 4, 5). Then, the speed is rather stable until the top of the ramp. The shape of the curves is the same for tractor semi-trailer and trucks with 2 axles. This result is similar to the real speeds distribution evolution all along the ramp (figure 1).

Figure 6 shows that slope has a great influence on the speed variation. Doubling the value of the longitudinal slope multiplies by two the speed decrease.

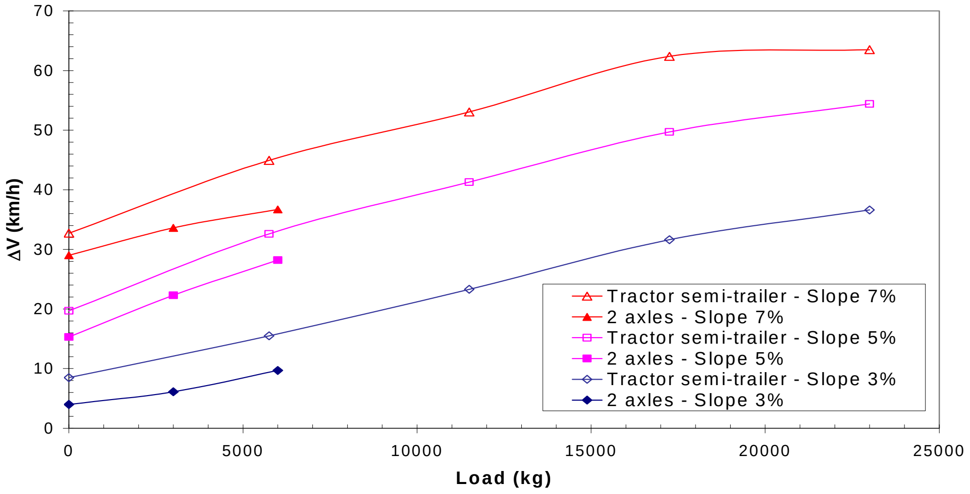


Figure 6 – Variation of speed between the top and the bottom of the ramp ($\Delta V = V_{max} - V_{min}$)

Influence of the type of vehicle and its load

Then, a comparison of the results obtained with tractor semi-trailer and a 2 axle trucks is performed. The curves show a decrease of speed ranging from five to thirty-five kilometers per hour for trucks with 2 rigid axles and from eight to sixty kilometers per hour for tractor semi-trailer depending on the slope and the load (figure 6).

Criterion of limit

The analysis of the data corresponding to the speed distribution on the ramps proves that above 2000 meters of ramps, the situation is evolving (figure 1). The distribution presents two peaks instead of one, which means that two groups of vehicles with different speeds are driving on the same lane.

Safety experts usually consider that a variation of speed of more than thirty kilometers per hour strongly increase the risk of accident. Figure 6 shows that this situation always appears in the case of a longitudinal slope of 7%, whatever the type of heavy vehicle considered. In the case of a longitudinal slope of 5%, this criterion is reached for load superior to 5000 kg, which is rather common for tractor semi-trailer. When the longitudinal slope is 3%, the speed variations don't reach the value of thirty kilometer per hour. Thus, limiting the longitudinal slope to 5% and the length of the ramps to 2000 meters could allow limiting the risk of accidents on ramps.

Lastly, safety experts read the authorities report on accidents. They concluded that the majority of accidents occurred when the speed of the slow vehicles reached 40 km/h. The analysis of the minimal speed reached by heavy vehicles in the ramp as a function of the longitudinal slope and the load allowed detecting the situation where the speed of 40 km/h was reached (Figure 7). We notice that the 2-axle truck never reached this speed whereas the tractor semi-trailer reached this speed in the case of a half-loaded and a full-loaded trailer. Considering the high number of tractor semi-trailer in Europe, the restriction of the slope value to 5% could allow avoiding very slow speeds on the road. When this limitation is not possible, a special lane for slow vehicles could be built.

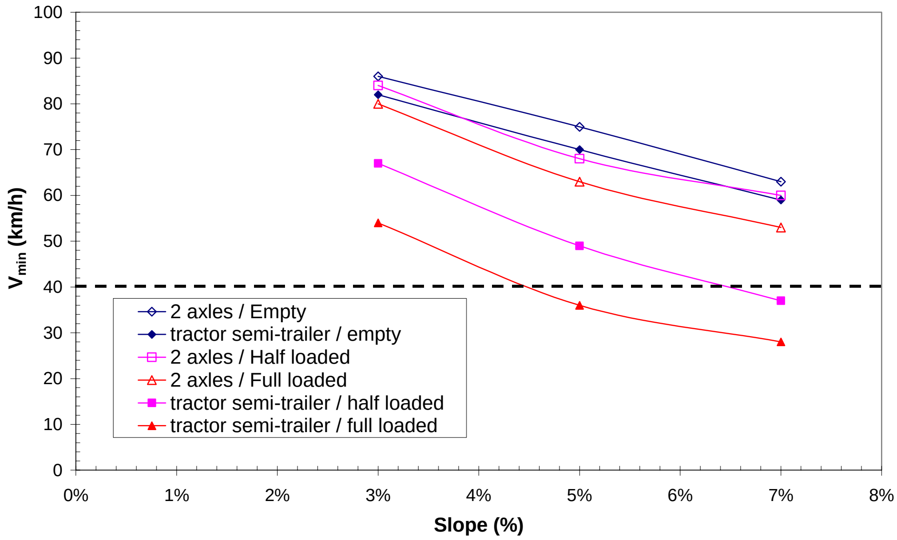


Figure 7 – Minimal speed reached by trucks in the ramp

4. Conclusive remarks

Safety studies performed on different ramps showed that a wide gap of speed can explain accidents. The speed measurements especially proved that ramps generate a situation where slow heavy vehicles are driving on the same lane as other vehicles. Indeed, recent trucks or empty heavy vehicles can almost keep the initial speed all along the ramp whereas fully loaded vehicles showed an important decrease of the initial speed. The probability of front-rear collisions therefore strongly increased.

As a conclusion, a specific lane for slow vehicles could be a good solution to diminish the risk of collision due to a high difference of speed on the same lane. 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.

5. References

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