

## RELATIONSHIP BETWEEN ROAD INFRASTRUCTURE CHARACTERISTICS AND HGV ACCIDENTS



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### Abstract

In a research programme on Heavy Vehicles and Road Safety Risks led by the Laboratoire Central des Ponts et Chaussées, data collected by a special device (VANI) were statistically analyzed in order to characterise the infrastructure's geometrical parameters and parameters linked to road surface characteristics in different situations. Specific safety issues of Heavy Goods Vehicles (HGV) were identified. If a HGV is involved in an accident, the risk of a fatality is multiplied by 2.6. Where an HGV and another vehicle are involved, the latter are more frequently responsible for the accident. This paper highlights some infrastructure characteristics which increase the risk of severe accidents involving a HGV, with injured people, such as slopes, bends and pavement surface conditions (dry or wet).

**Keywords:** Trucks, Safety, Accidents, Heavy good vehicles, Infrastructure, Skid resistance, Geometry.

### Résumé

Dans un programme de recherche sur les poids lourds et les risques routiers animé par le Laboratoire Central des Ponts et Chaussées, une exploitation statistique des données collectées par un appareil spécial (VANI) a été réalisée pour extraire les éléments caractérisant les paramètres géométriques de l'infrastructure et ceux liés aux caractéristiques de surfaces des chaussées dans différentes situations. Les problèmes spécifiques aux poids lourds en termes de sécurité ont été mis en lumière. La présence d'un poids lourds dans un accident multiplie par 2,6 le risque d'avoir un tué. Dans les accidents avec un poids lourd et un autre véhicule, l'autre véhicule est plus fréquemment à l'origine de l'accident. Certaines caractéristiques de l'infrastructure jouent un rôle dans les accidents corporels dans lesquels un poids lourd est impliqué, notamment les pentes, les virages et l'état de la chaussée.

**Mots-clés:** Poids lourd, sécurité, accidents, poids lourds, infrastructure, adhérence, géométrie.

## 1. Introduction

In a research programme on Heavy Vehicles and Road Safety Risks led by the Laboratoire Central des Ponts et Chaussées, all the measurements taken by a special device (VANI) from December 2000 to August 2005 were statistically analyzed. These measurements concerned the geometrical parameters of the infrastructure and the parameters related to road surface characteristics in various situations. These analyses revealed some heterogeneities of these parameters which could increase the risk linked to these type of vehicles. In addition, comprehensive accident research associated with specific simulations made it possible to establish the threshold values related to infrastructure (curve radius, superelevation, slope, skid-resistance).

## 2. VANI Device

A vehicle to analyzed itineraries (VANI, Figure 1), used by the Lyon laboratory since 1987, provides rapid and computerized data on the road and its environment, for the purpose of road safety studies. VANI has examined more than 20 000 km of roads to date. The geometrical parameters taken into consideration during measurements are the radius of curvature, the slopes and superelevation. The surface characteristics measured are skid resistance, macrotexture and the vertical acceleration of a wheel. All these parameters are measured every 1 m and are displayed in graphic form.

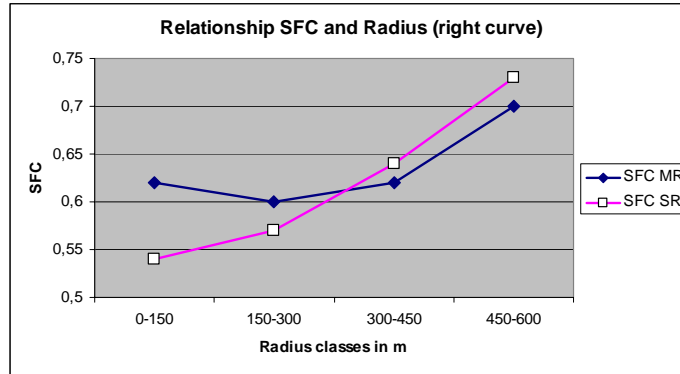


Figure 1 – VANI device

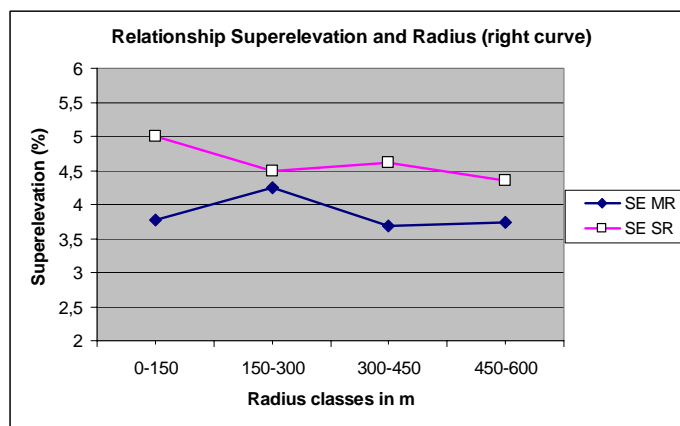
## 3. Data exploited, results and comments

The data exploited concerned all the measurements carried out by the VANI apparatus on main roads (MR) and secondary roads (SR) from December 2000 to August 2005. The total linear length represents 2 430 km of main roads (MR) and 369 km of secondary roads (SR).

The average values obtained for different curve radii showed:

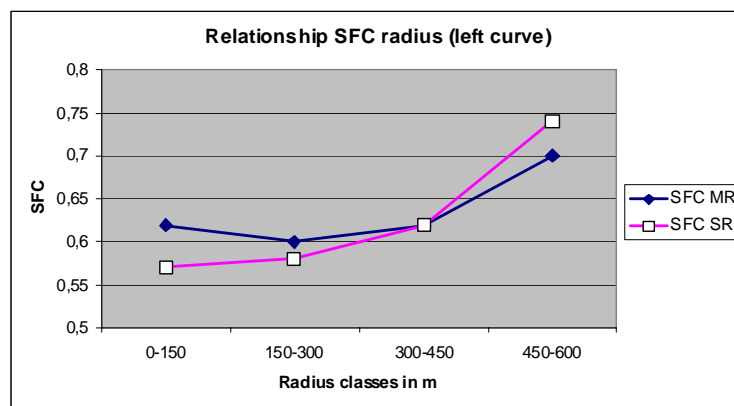


**Figure 2** – Relation between SFC and radius of curvature to the right

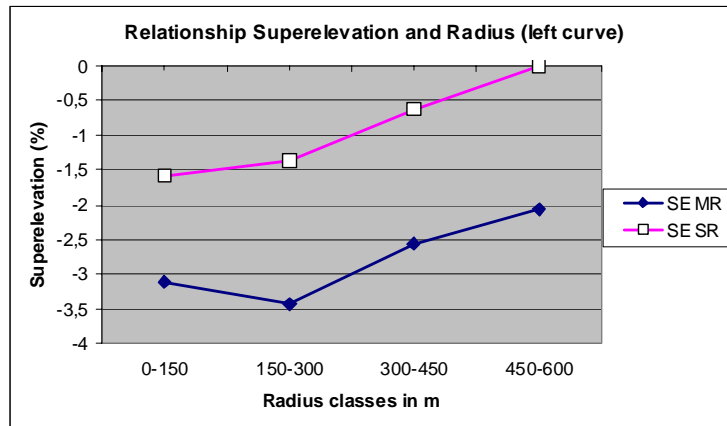


**Figure 3** – Relation between superelevation (SE) and radius of curvature to the right

- o The relation between SFC and radius (see figure 2 and 4). For left or right curves it can be noted that on SR, the lower the radius, the poorer the SFC. On MR the difference between low and high radii seems less significant on average .
- o The relation between superelevation and radius: The figures 3 and 5 show that the superelevation in left-hand curves are much lower than they were for right-hand curves and in particular for SR .



**Figure 4** - Relation between SFC and radius of curvature to the left



**Figure 5** – Relation between superelevation (SE) and radius of curvature to the left

This first statistical study on the relations between surface characteristics and geometrical characteristics of the roadway highlights several anomalies. On average and with comparable situations:

- the skid-resistance of the coatings on SR is definitely lower than that on MR and this even more so on roundabouts,
- the superelevation figures are in general much lower than the recommendations for MR, as for SR,
- the superelevation of left-hand curves seem particularly neglected on SR,
- the superelevation of roundabouts on MR seem particularly low (less than 2% on average),
- the skid-resistance of the low radii on MR seems to be particularly reduced.

These elements were used to best understand accidents involving heavy vehicles.

#### 4. Statistics and accident research

##### *The problem*

The French heavy goods vehicle (HGV) fleet comprised more than 500 000 vehicles in 2005 for a total of 27 billion kilometres travelled per annum, to which can be added 8 billion kilometres travelled by HGV registered outside France. On average, a HGV travels 49 000 kilometres per annum, whilst a light vehicle (LV) travels approximately 13 000 kilometres. HGV differ from light vehicles by their considerably larger size, different dynamics (trailers, multiple axles...) and the fact that their drivers are trained professionals with more practice than other road users.

##### *National data*

In 2005, 4 410 accidents involving at least one HGV vehicle caused 727 fatalities (13.7% of road fatalities), 2 115 hospitalised injured and 3 197 light casualties. The severity of accidents with HGV vehicles is 16.5 fatalities for 100 accidents, which is 2.6 times higher than the severity of all accidents.

Whereas HGV account for 6.31% of the kilometres travelled in France, they account for 3.3% of the vehicles involved in personal injury accidents and 13.4% of the vehicles involved in fatal accidents. In relation to other vehicles, HGV are thus less involved in personal injury accidents, but those accidents that do occur are more serious.

Out of the 4 730 HGV involved in a personal injury accident in 2005, 39% were isolated vehicles of more than 3.5 tons, 2% were road tractors only, 23% were road tractors with trailers and 36% were road tractors with a semi trailer.

In 14.6% of cases, the HGV was the only vehicle involved (4.8% of these accidents involved one or more pedestrians), in 65.1% of the cases the accident involved a HGV and another vehicle (a private car in the large majority of the cases) and in 20.3% of the cases, the accident involved 3 vehicles or more.

Out of the accidents involving at least one HGV in 2005, 17.7% occurred at an intersection and 82.3% outside an intersection. HGV accidents tend to occur more often outside intersections than other accidents (72.7%). Accidents are more serious outside intersections (17.4 fatalities for 100 accidents) than at intersections (12.2).

HGV accidents are much more frequent in the open country than other accidents and 2.2 times more serious in the open country than in urban environments (20.8 against 9.65).

The following table shows the share of accidents involving with HGV in relation to all accidents, according to road category.

**Table 1 – Share of HGV accidents**

Road category	HGV accidents	All accidents
Motorways	21.0%	6.1%
Main roads	22.9%	12.5%
Secondary roads	28.0%	28.0%
Other categories of roads	28.0%	53.4%

It is on the secondary roads and the “other” roads (mainly minor local roads) that most HGV accidents occur. The proportion of accidents on motorways, and to a lesser extent on main roads, is higher for HGV accidents than for all accidents. This is explained partly by a different use of the networks by HGV, which mainly travel on major roads.

Since 2001, the number of personal injury accidents in France involving at least one HGV has fallen in a similar manner to all personal injury accidents (respectively – 27.0% and – 27.6%). On the other hand, the number of fatal accidents involving at least one HGV has fallen less quickly than for all fatal accidents (- 27.0% and – 29.8% respectively).

### ***Industrial vehicle accidents***

A study relating to 581 accidents involving 616 HGV provided the following results. The HGV was alone in 33% of the cases: in 20% of the cases, the vehicle rolled over, in 11% the vehicle left the road, and in 2% the vehicle jack-knifed. 88% of fatalities were not HGV users.

109 overturned HGV accidents were studied: they mainly occurred when the vehicle left the road (70), on a bend (54) and in normal weather (60). In 19 cases the vehicle rolled over on a roundabout. In 64 accidents the HGV rolled over on the roadway and in 35 on the verge.

It can be noted that nearly 25% of rolled over vehicle accidents cause a road closure of more than 5 hours. Heavy goods vehicles are thus particularly involved in accidents causing major traffic disruption.

### ***Accident-causing infrastructure characteristics***

An analysis was carried out for the Rhone-Alps area. The principal database consisted of 2 443 accidents, which occurred from 2000-2004 and involved at least one HGV (HGV alone with a total load >7,5t, HGV+trailer, road tractor only or with semi-trailer). In total, 2 579 HGVs were involved.

The main manoeuvre prior to the accident was “no change in direction” in 57% of the cases.

By analysing the horizontal alignment, it can be noted that 73% of the accidents occurred on a straight section, i.e. in a zone where the vehicle’s transverse dynamics are not much called upon.

The data show that 77% of the accidents took place on flat sections and 19% on a slope.

76% of the accidents took place on normal roadway conditions and 20% on wet roads. These figures contradict certain studies carried out in Scandinavian countries showing little influence of skid resistance for HGVs.

In relation to the total number of accidents, it can be noted:

- that accidents on curves and/or slopes involving a HGV alone are twice as many.
- there are twice as many accidents on right-hand curves than on left-hand curves (25% and 13% respectively) when two vehicles are involved,

By studying manoeuvres prior to the accident, it can be noted that:

- in about half of the cases, no manoeuvre was undertaken,
- the number of manoeuvres to the left are higher in accidents involving two vehicles.

The accident rate for a HGV alone or a HGV and another vehicle is twice as high in a situation combining a curved alignment and a wet roadway, in relation to all accidents.

The accidents occurring on curves located on slopes are considerable: they account for 30% of the accidents involving a HGV alone.

Based on the accident report files produced by the Central Normandy CETE during safety studies, 4 main families were established, which alone represent nearly 70% of accidents:

- Loss of vehicle control accounted for 24% of the HGV accidents. Among these 47 accidents, 43 took place outside an intersection, on a straight section in half of the cases, on a left-hand curve in 14 cases and on a right-hand curve in 9 cases. The longitudinal profile is not always specified, but the loss of control on a curve occurred on a slope in at least 14 cases out of 23.
- In 38 cases, i.e. 18% of the sample, the accident would probably have occurred without the presence of the heavy vehicle. These accidents correspond to loss of control of another vehicle, independent of the presence of a HGV. This situation therefore especially arises outside intersections. These accidents are particularly serious.
- In 17% of the accidents, the HGV was surprised by a slow vehicle or a user who slowed down in front of it. Contrary to the loss of control, these accidents occur not only outside

intersections but also at intersections: In 24 cases, the HGV was surprised by a user at an intersection or a frontage access, and in 11 cases by a user slowing down outside an intersection.

- The last main family is that of “traffic merging”, when a vehicle coming from a minor road is hit by a HGV travelling on the main road. Both vehicles are therefore travelling in the same direction, the vehicle coming from the minor road attempting to merge with the traffic on the main road. This raises the issue of users’ perception of HGV and in particular their speed.

### ***Specific case of roundabouts***

Roundabouts deserve particular attention due to their specific geometry. In spite of their good results in term of accidents, they are frequently blamed for rolled over heavy vehicles. The Central Normandy CETE conducted a study on this subject. It concerned 39 accidents on 27 roundabouts.

In 95% of the cases, the final position of the HGV vehicle was outside the ring, on its right side. Accidents involving the overturning of HGV are always spectacular but generally not serious. In 95% of cases the vehicle is an articulated lorry. Lorries with a high centre of gravity are also vulnerable.

All the overturned vehicle accidents occurred on roundabouts whose circulatory roadway has an outward facing superelevation, which is the typical configuration in France.

## **5. Influence of infrastructure on HGV behaviour**

Several accident file studies have highlighted the fact that HGV accidents are divided into three categories: rollovers, jack-knifing, and run-off-the-road accidents. The principal factors at the origin of these accidents are: insufficient visibility which leads to a poor perception of the road, a speed poorly adapted to the infrastructure, and insufficient skid resistance which generates accidents on wet, snowy or icy roads.

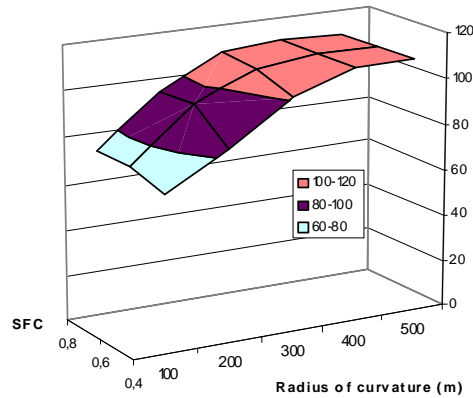
Several accident studies conducted during the last few years have highlighted four critical zones for HGV: curves, low radius curves such as motorway exit slip roads, roundabouts, and high gradient slopes (> 5%). These four zones were studied using digital simulations in order to determine threshold values for the various infrastructure parameters.

### ***Simulation results***

The study concerned the four configurations previously quoted and required several hundred simulations. Only the principal results are presented. The simulations carried out during the project made it possible to establish recommendations in terms of infrastructure characteristics.

#### ***Curves***

Figure 5 shows the simultaneous influence of skid resistance (via the SFC) and the radius of curvature on the value  $S_{max}$ . One can observe an increase in  $S_{max}$  according to the radius of curvature of about 35 km/h in the case of a roadway with low skid resistance. This deviation is a little lower when skid resistance increases.



**Figure 6** – Maximum speed according to the radius of curvature and the SFC (superelevation = 3%) (Cerezo et al. PIARC 2007)

Curves with a low radius (100 to 300 m) raise difficulties for HGV due to the size of this type of vehicle. Simulations made it possible to highlight two accidents mechanisms dependant on skid resistance and superelevation. In the zones that have both a high superelevation (> 5%) and a good level of skid resistance (SFC > 0.8), the vehicle's dynamic parameters reach values beyond which the risk of rolling over is high. On the other hand, in the zones with low skid resistance, simulations mainly led to vehicles leaving the road.

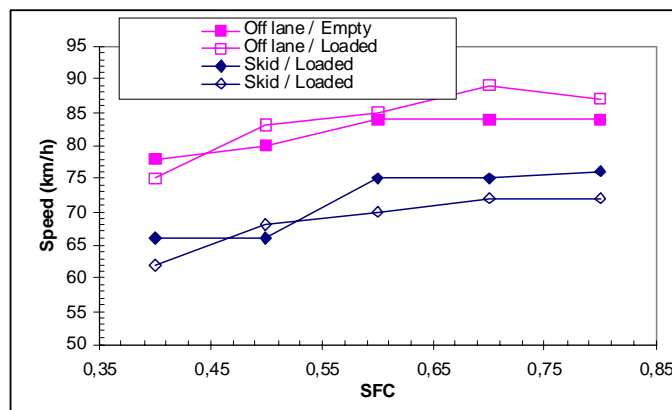
Limiting the superelevation to 5% should make it possible to limit vehicle rolling over, Moreover, a speed ranging between 50 and 60 km/h seems to be a valid safety threshold value whatever the skid resistance level.

Lastly, the simulations carried out in curves of radius higher than 500 m did not reveal situations likely to provoke to an accident, as long as the legal speed limit is respected.

**Exit slip roads (curves of 120 m radius)**

Simulations made it possible to obtain the following limit values for a loaded HGV:

- Skidding at 70 km/h with a SFC > 0.80 and at 65 km/h with a SFC < 0.60,
- Running off the road at 80-85km/h on a dry road and 75 km/h on a slippery road
- Overturning occurring only for a SFC > 0.7.



**Figure 7** – Speeds on a right-hand bend for a radius of 120 m (Briet et al. SIV 2004)



The superelevation tends to raise the threshold for skidding or running off the road: the higher it is, the higher the speed at which the curve can be approached (5 to 10 km/h higher between a superelevation of 7% and 3%: refer to figure 7) and the more the acceleration limit thresholds are raised. However, beyond a certain threshold, it no longer has any influence, as the acceptable dynamic limits of the vehicle are reached.

As for skid resistance, the SFC value = 0.50 can be regarded as a particularly relevant threshold. Indeed, below this value, the risks of swerving and running off the road are increased considerably. However, it can be noted that for an average or low SFC (lower than 0.60) it is practically impossible to roll over a HGV. This study would seem to show that vehicle rolling over is induced by two parameters: a high centre of gravity of the load, and high skid resistance.

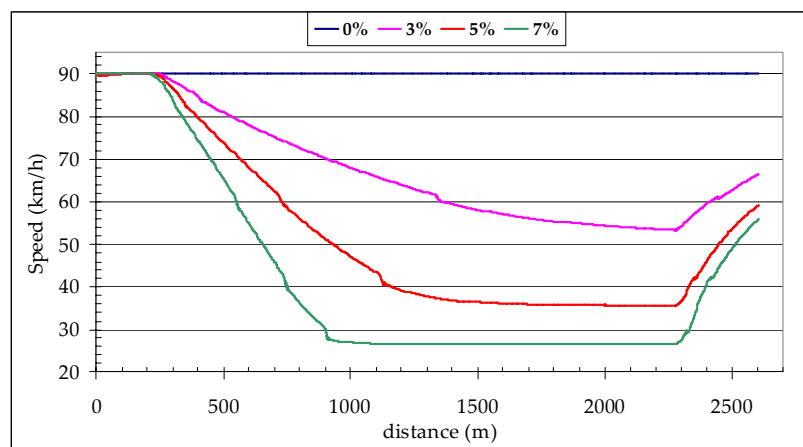
However, according to several observations, a semi-trailer loaded in a homogeneous manner and without excess weight has practically no risk of rolling over, as long it does not travel at an inappropriate speed. Overloading therefore constitutes a third factor that can cause rolling over, even if “*rolling over remains more to do with the height of the centre of gravity than with overload*”. In all configurations, speed on slip roads should not exceed 60 km/h to limit the risk of skidding or rolling over.

### Roundabouts

The simulations carried out on roundabouts showed the significant importance of maintaining a satisfactory level of microtexture (SFC > 0.60) in order to avoid run-off-the road accidents due to transverse sliding. However, it does not seem useful to use a high performance coating, as a SFC level that is too high generates roll angles and speeds that are too high (therefore leading to a risk of vehicle rolling over). Concerning superelevation, a threshold value around 3% or 4% seems to exist, beyond which the behaviour of HGV changes (Cerezo and Gothié, 2006). It would thus be advisable to limit the superelevation on the ring to these values.

### Slopes

Gradients higher than 5% over large distances prove to be dangerous because they generate speed differentials (see figure 8) between the various road users that are higher than 30 km/h, thus increasing collision risks. It is therefore advisable to create specific slow vehicle lanes.



**Figure 8** – Speed evolution of a loaded semi-trailer (23 T), along a 2 000 m slope preceded by a straight section of 300 m

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