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METHOD FOR DETERMINING VEHICLE DECELATION ON A ROLLOVER ROAD

Momčilo Sladoje[190]; Asib Alihodžić[191]

Abstract

Increasing the level of traffic safety is a constant task of professional circles. The consequences of traffic accidents are very big. Nowhere in the world is there an absolutely safe traffic system. To increase the level of safety, it is necessary to analyze conflict situations, the consequences of which are the occurrence of an accident. Various international professional organizations and individuals deal with in-depth analyzes of traffic accidents. Based on such an analysis, measures are proposed to improve the level of traffic safety. The amount of kinetic energy that the vehicle possesses in the accident zone is directly proportional to the mass of the vehicle and the square of the speed. During the collision process, the vehicle does not lose mass, but loses speed, and the kinetic energy changes into other forms, so in the stopping position, the amount of kinetic energy and the speed of the vehicle are equal to zero. The vehicle "uses" speed in various stages of the pre-crash, crash and post-crash process. In this paper, the loss of speed in the post-collision phase will be analyzed, when the vehicle rolls over and rotates around the center of support - the place where the vehicle makes contact with the ground. It is specific that then the vehicle does not move on the wheels and does not achieve deceleration based on the coefficient of friction of the wheels sliding or rolling on the surface, and it is necessary to apply a different engineering method of calculating the speed of the vehicle at the moment of contact.

Key words: *Traffic accident, speed, deceleration, overturning.*

Introduction

Road traffic safety is an inexhaustible topic at all scientific and professional conferences and is always in the focus of daily events. No form of traffic is absolutely safe, but road traffic is the most unsafe form of traffic. Safety is expressed in the number of traffic accidents, the number of fatalities, serious and minor injuries or the amount of material damage caused. The European Union, as its priority, has set a

[190] Momčilo Sladoje, PhD, Full Professor, East Sarajevo, Bosnia and Hercegovina
[191] Asib Alihodžić, PhD, Full Professor, East Sarajevo, Bosnia and Hercegovina, asibdr@gmail.com, ORCID 0009-0007-7919-4096

rapid reduction in the number of traffic accidents on the roads, with a precise timetable for increasing the level of safety.

In order to increase the level of safety, it is necessary to determine what are the most common causes of traffic accidents, and to define precise measures to eliminate them. In order to determine the cause and course of traffic accidents, it is necessary to carry out an in-depth analysis of the majority of traffic accidents that occurred in the observed area. When conducting an in-depth analysis, it is necessary to determine the characteristics of the collision and determine the amount of kinetic energy that the vehicle has at the moment of entering the collision process. The analysis of a traffic accident, whether it is done by a professional organization, an individual or a certified software program, has the task of determining the way and path of vehicle movement before entering the collision process, the course of the collision process itself and the path and way of vehicle movement in the post-collision phase. In this paper, only one segment from the in-depth analysis of the traffic accident will be analyzed, which is the way and method of determining the speed of the vehicle at the moment of leaving the collision position, if the vehicle overturned in the post-collision phase of the vehicle's recovery.

Vehicle speed in the accident zone is one of the basic elements for an in-depth analysis of a traffic accident. Various methods are used to determine the speed, at the beginning and at the end of the collision process, or in any other characteristic phase of the collision process. If we cannot read the speed of the vehicle on one of the measuring devices installed in the vehicle, various empirical patterns are used to determine the speed. The necessary input data for the application of such forms are the condition of the roadway, traces on the roadway, the way and path of the vehicle in the accident zone, the entry of the vehicle into the collision position, the degree of damage to the vehicle, then the geometric elements of the road, the configuration of the terrain next to the roadway and various other parameters.

Analysis of vehicle movement in the accident area

The consequences of a traffic accident depend on the amount of kinetic energy the vehicle has when entering the collision position. Kinetic energy is a vector quantity that has its own intensity, direction and direction of action. The amount of kinetic energy is directly proportional to the product of the mass and the square of the collision speed of the vehicle, i.e.

$$E_K = \frac{mV_S^2}{2}$$

During the collision process, the mass of the vehicle does not change, or these changes are relatively small. So, during the collision process, the speed of the vehicle is a variable, so the change in the amount of kinetic energy almost exclusively depends on the change in the speed of the vehicle. That is why speed is the component that determines the amount of kinetic energy available to the vehicle in the collision process. Namely, speed can have a direct causal relationship with the occurrence of an accident, it can contribute to the occurrence of an accident or the possibility of avoiding it, regardless of whether it is causally related to the occurrence of an accident, the consequences of a traffic accident always depend on the collision speed of the vehicle.

Determination of the factual situation (investigation)

During the investigation at the scene of the accident and possibly during the subsequent visit to the scene, the following parameters are thoroughly determined:

- Participants in the traffic accident and all others who could potentially have an influence on the cause and course of the accident or were witnesses to the accident are identified,
- An inspection of the microlocation of the accident site, which includes determining the condition of the roadway, the geometrical elements of the road and the configuration of the terrain next to the road, should be carried out,
- Identification and marking of all tracks on the road is carried out. It is necessary to eliminate traces that are on the road and do not originate from the accident in question. After that, the positioning and measurement of the traces is carried out, in relation to the landmark of the traffic accident.
- The consequences of the traffic accident are ascertained. This includes listing the injured or dead participants in the accident, with or without listing and describing the injuries. Damage to the vehicles of the participants is visually determined and any damage to the road facilities and equipment is recorded.
- After the investigation, the documentation on the traffic accident is completed, which must at least include the Record of the accident scene, the Sketch of the accident scene and a photo-elaboration of the accident scene.

Analysis of the vehicle movement path in the accident zone

After the documentation from the investigation is completed, experts or professional organizations approach the analysis of the traffic accident, which in most cases is the determination of the actions of the participants in the accident that can be linked to the occurrence of the accident. One of the most important data that is determined is the speed of movement of the accident participants. Various methods or empirical patterns are used to determine the vehicle speed in the accident zone. To calculate the speed of the vehicle, it is necessary to clearly determine the way and path of its movement in the accident zone. During the investigation, a Sketch of the scene is made, on which the traces are precisely recorded, on the basis of which it can be determined whether they are traces of driving, braking, drifting, scraping, rotating, or some other traces on the roadway.
On the example shown in picture no.1. the trajectory of the vehicle in the accident zone is presented, where it can be observed that the driver, knowingly or unknowingly, steers his vehicle to the right. At that moment, the central axis of the vehicle forms an angle of 15^{o} with the central axis of the roadway. The destabilization phase begins on the roadway, where only traces of braking of the left wheels on the roadway are

visible. After the initial destabilization, the vehicle moves from the roadway to the embankment next to the right edge of the roadway, then lands down the slope of the embankment and onto the terrain next to the road. On the way to calm down, the front left part of the vehicle hits a rock sticking out of the ground, after which it rotates around the center of rotation, which is the place where the vehicle rests on the ground. After flying through the air, the vehicle hits the ground with its rear right part and continues rotating through the air, until it stops on the meadow. In the final stopping position, the vehicle was overturned on its roof.

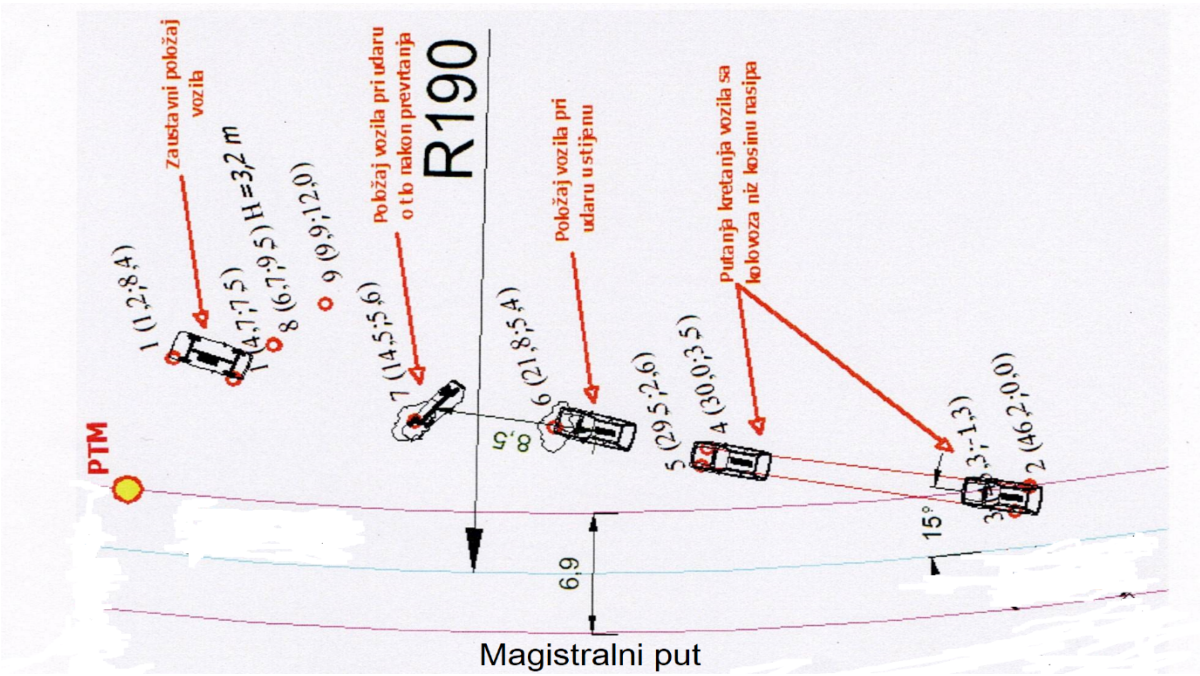

Figure 1. Display of the vehicle movement path in the accident zone

Identification of tracks on the road and terrain

The first trace that the vehicle makes is the deceleration (braking) trace of the left wheels on the road, while the trace of the right wheels begins on the embankment. At this moment, the vehicle is still supported by the wheels on the ground. The length of the braking track on an asphalt surface is:

$$S_{uspa} = 4{,}9\ m$$

This track is followed by a braking track on the embankment (sand surface) and on the slope of the embankment next to the right edge of the roadway (the surface is a combination of soil and sand, and is partially overgrown with grass). The length of the deceleration (braking) track of the left wheels on the bank and slope is:

$$S_{uspb} = \sqrt{(40{,}3 - 29{,}5)^2 + (2{,}6 - 1{,}3)^2} = 10{,}88\ m$$

After that, it follows moving vehicles without significant reliance on the ground to the point of contact of the front left frontal part of the vehicle with a stone sticking out of the ground. The road on which the vehicle does not make full contact with the ground, and therefore does not have the full effect of deceleration, amounts to:

$$S_{l1} = 29{,}5 - 21{,}8 = 7{,}7\ m$$

From the place of the vehicle's first impact with the stone to the final stopping position, the vehicle makes contact with the ground twice and makes a rotation of one full circle and another 270^{o}.

Characteristics of a traffic accident

Overturning of the vehicle is most often caused by a disturbance of its dynamic stability. During a rollover, the vehicle describes a complex trajectory, and a special problem in traffic accidents of this type is determining the speed at the beginning of the initial destabilization. When a vehicle overturns, two phenomena are characteristic, which can alternate several times (hitting the ground - flying through the air, and so on several times) on the complete path of calming down.
The path of movement of the observed vehicle, viewed from the aspect of changing the mode and speed of movement, shows the following stages:

- The first phase, the impact of the vehicle on the ground, when there is an enormous reduction in the speed of movement, i
- The second phase, the movement of the vehicle through the air, without contact with the ground, when the loss of speed is insignificant.

Due to the above reasons, the continuous deceleration of the vehicle cannot be applied on the complete stopping path, but the specifics related to the overturning of the vehicle must be taken into account. The deceleration achieved by the vehicle during a rollover is obtained using parameters determined by various crash tests and case studies of real traffic accidents, which are monitored and documented by video. The basic principle for determining the speed of the vehicle is based on the energy method, which includes the estimation of the equivalent of the speed lost during deformation work, as well as the part of the speed lost during the rotation path, with the adoption of the empirical value of the deceleration.

Theoretical basis for the analysis of these types of traffic accidents

When the vehicle hits the ground during a rollover, action and reaction forces collide at the point of contact. With the force of action, the vehicle acts on the ground, and it is opposed by the reaction. The forces of action and reaction are identical in intensity and speed of action, only they are in the opposite direction. The action force acts in the direction that connects the points of contact with the vehicle's center of gravity, and is directed away from the vehicle's center of gravity. The action force is divided into components that act horizontally and vertically. The force component that acts

vertically causes deformation of the vehicle and the ground, so that amount of kinetic energy is spent on deformation work and possibly on the vehicle's bounce (jump) from the ground. The difference in vehicle speed at the beginning of contact with the ground and at the end of contact (exit speed) is for the amount of kinetic energy that the vehicle spends on deformation work. The component of the force acting horizontally prevents the continued rotation of the vehicle.
As already stated, the deceleration of the vehicle on the rollover path is not constant, and ranges from 0 when the vehicle is in the air, without resting on the ground, to the value g (9.81 m/s2) at the moment of the first contact of the vehicle with the ground. Scientists agree that deceleration depends on the position of the vehicle at the moment of contact with the ground. Thus, they experimentally obtained that the deceleration is significantly greater if the vehicle makes contact with the wheels of the vehicle compared to when the vehicle makes contact with the roof of the vehicle.

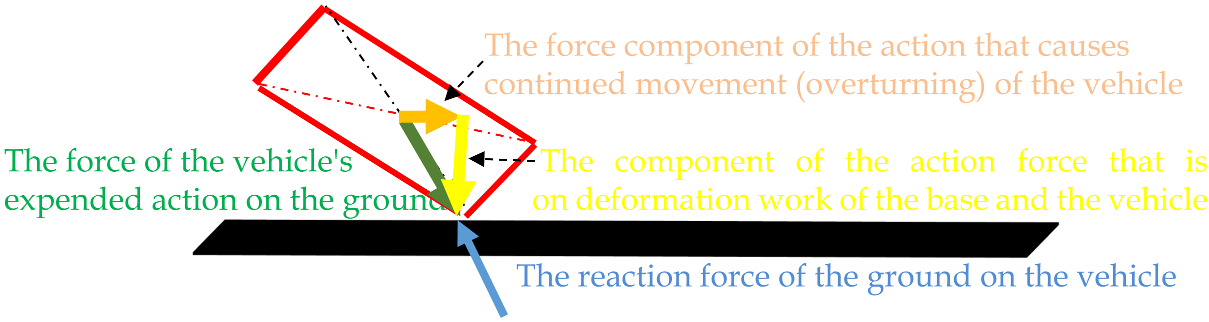

Figure 2. Display of the interaction of forces during the fall of the vehicle's support on the ground

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A number of scientists have dealt with this problem, that is, defining the real deceleration that a vehicle achieves on the road of overturning. One of the more important theoreticians, whose test results greatly helped the understanding of these problems, is Orlowski. Using special equipment, he caused 8 experimenters to overturn the vehicle and found that an average deceleration was achieved[192]:

$$b_{p8} = 0{,}43 * g = 4{,}22\ \frac{m}{s^2}$$

[192] Orlowski R.K., Moffatt A.E., Bundorf R, and Helcomb M.: Reconstruction of Rollover Collisions, Tehnical Papers 1989.

Orlowski, Segal and Young conducted experiments independently and on 41 examples they obtained that the average deceleration is [193]:

$$b_{p41} = 0{,}42 * g = 4{,}12\ \frac{m}{s^2}$$

Anderson analyzed videos of rollovers in real conditions, and found that the decelerations achieved by the vehicle's center of gravity had considerable dispersion, and ranged within the following limits:

$$0{,}2 * g < \ b_{pan} < 0{,}6 * g \ \leftrightarrow \ 1{,}96\ \frac{m}{s^2} \ < \ b_{pan} < 5{,}89\ \frac{m}{s^2}$$

The results obtained by Anderson depended on the construction of the vehicle, then on which part of the vehicle made first contact with the ground, and mostly depended on the ground on which the vehicle overturned.
In his publication published by Henderson, it was stated that they conducted the test by pushing a Ford Expedition off a specially made platform at a speed of 70 km/h. The platform was inclined at an angle of 23°. The base on which the test was carried out was made of slightly compacted (rolled) sand mixed with soil. The crushed vehicle stopped after 4 full laps on the 36.5 m length of the settling road. The average deceleration of the vehicle achieved on the rollover path:

$$b_{pfe} = 0{,}52 * g = 5{,}1\ \frac{m}{s^2}$$

A group of researchers, led by scientist Nathan, announced in their scientific paper that they carried out a rollover research in real conditions, which was recorded on video. They presented a case in which the rollover path of the "GMC Yukon Denali" vehicle was analyzed. It was estimated that the rollover of the vehicle occurred at a speed of 77 km/h, that the vehicle stopped after 44.0 m, and that it achieved an average deceleration on the rollover path:

$$b_{pgmc} = 0{,}53 * g = 5{,}2\ \frac{m}{s^2}$$

Determination of vehicle speed from the analyzed case

The vehicle's speed in the accident zone is spent on:
- During the deceleration before the place of hitting the stone (before the rollover), and
- In the path of rotation (overturning) to the final stop position.

[193] Orlowski R.K., Moffatt A.E., Bundorf R, and Helcomb M.: Reconstruction of Rollover Collisions, Tehnical Papers, 1989.

Table 1. The distance and deceleration achieved by the driver in the accident zone

Movement path	Way of moving	Track length	deceleration
Braking mark on asphalt surface (left brake mark)	Movement at an angle of 15° in relation to the roadway axis	S_{ap} = 4,9 m	Range (5,4–7,3) b_{ap} = 6,5 m/s²
Dužina traga kočenja na kosini nasipa i livadi	Nastavak kretanja nakon silaska sa asfaltne podloge	S_{tp} =10,88 + 7,7 =18,58 m	Raspon (2,0–4,2) b_{tp} = 3,1 m/s²
The length of the deceleration path when the vehicle rolls over	A trajectory combined with hitting the ground and flying through the air	S_{pr} = 21,21 m	Deceleration obtained experimentally: b_{pr} = 5,2 m/s²

a) The part of the speed that the driver loses on the way to decelerate before hitting the stone, amounts to:

$$\Delta V_{4k} = \sqrt{2 \bullet [(\mathrm{b}_{ap} \bullet S_{ap}) + (\mathrm{b}_{tp} \bullet S_{tp})]} = 13{,}43 \frac{m}{s}$$

b) Part of the speed that the driver loses when rolling over is:

$$\Delta V_{pre} = \sqrt{2 \bullet b_{pr} \bullet S_{pr}} = 14{,}85 \frac{m}{s}$$

The speed that the driver possesses at the beginning of the braking marks is:

$$V_{1o} = \sqrt{\Delta V_{4k}{}^2 + \Delta V_{pr}{}^2} = 20{,}02 \frac{m}{s} \approx 72 \frac{km}{h}$$

The speed that the driver has in the accident zone is:

$$V_{0o} = V_{1o} + \frac{b * t_3}{2} = 20{,}67 \frac{m}{s} \approx 74 \frac{km}{h}$$

Conclusion

The behavior of participants in a traffic accident is very important from the aspect of determining responsibility for the occurrence of the accident. For this reason, the actions of each participant in the accident are analyzed individually, as well as their connection with the actions of other participants. When analyzing each extraordinary event, it is necessary to determine the specific actions of the participants in the accident and compare them with the actions they were obliged to take. So, the responsibility of the participants is determined based on the actions they do and don't do, and they were obliged to do them.

Vehicle speed is one of the most common causes of traffic accidents. The speed of the vehicle, whether or not it is causally related to the occurrence of the accident, always has a direct impact on the consequences of the accident. For this reason, it is very important to determine the exact speed at which the vehicle was moving at the beginning of the conflict situation. For an in-depth analysis of a traffic accident, tracks on the road and damage to the vehicle are objective input data, on the basis of which the manner and path of movement of the accident participants can be determined. However, if in the post-collision phase, one of the participants in the accident rolled over one or more times, then classical empirical patterns cannot be used to determine the speed of the vehicle at the beginning of the conflict situation. In such cases, the speed of movement is related to the distance of the vehicle's stopping distance. From the complete work, it is important to draw the conclusion that the vehicle does not have a constant deceleration during the complete overturning path, but its deceleration is diametrically opposite in individual phases. When flying through the air, the vehicle has a minimal deceleration caused by air resistance, and when it hits the ground, the deceleration is maximum and reaches the size of (one) 1*g.

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