ACCIDENTOLOGY AND DEVELOPMENT OF ENERGY ABSORBING STRUCTURES FOR HEAVY VEHICLES

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Abstract

In this work, it is made a study concerning accidents with heavy trucks that occurred in 2005 in Portugal, with the objective of identifying the magnitude of the injuries caused in the drivers of these vehicles and to characterize the fatalities and injuries that resulted from these accidents. It is also determined the main causes, type of roads and intersections, months and time of the day these accidents most occur.

Real accidents reconstructions with trucks are made to know reasons that lead to the existence of accidents with these vehicles and so that there could be developed measures to reduce road accidents.

A list of countermeasures that are considered important to be applied to heavy trucks and its drivers and roads is proposed.

Another study is made concerning available structures that are used to reduce the damage that results from rear or side impact of light vehicles into heavy trucks or (semi-)trailers.

Finally, there are developed computer models to simulate the impact of a small vehicle into a semi-trailer rear and side impact guards. The methodology used for the development is based in the finite element theory.

All models are developed in a CAD 3D program (Solid Works), and then being exported to a finite element program (ANSYS LS-DYNA), so that it can be tested how the structural characteristics of each impact guard influence the deformation of the vehicles’ front and the decelerations that cause in it.

The results show how certain structures are more effective than others and how structural and geometrical improvements on them help to reduce the consequences of these accidents.

Keywords: Accidentology, Heavy trucks, Finite elements models, Contact, Impact, Crashworthiness

1. Introduction

1.1. Motivation

Road accidents are still one of the main death causes in Portugal. From 1991 until 2005 it was able to reduce the number of annual fatal victims from more than 3200 to less than 1250. Despite the 60% reduction in the number of annual fatal victims, Portugal is still one of the European countries where a large number of road accidents take place. Though many campaigns have been made to alert drivers, many victims are due to inadequate behavior by public roads users.

According to CARE Database, [1], since 1996 that the number of fatal victims in Portugal has been reducing, being in 2005 below countries like Greece, Hungary, Czech Republic and Poland. Nevertheless, we must bear in mind that most of these countries just entered the EU in 2004.

In Figure 1.1, it is represented the number of heavy trucks occupants fatalities in each country of the EU (the 15 countries EU, except Luxembourg and Germany) since 1991, for each 10 million inhabitants.
Figure 1.1 – Evolution of road accidents involving heavy trucks in Europe, [1].

In this case, it can be verified that Portugal is close to countries such as Spain, France and Greece. However, these countries (with the exception of Greece) are central European countries where many truck drivers cross to go to other countries, while Portugal is a country on the extreme of Europe and it must be compared to countries with the same geographical situation such as United Kingdom, Sweden or Finland which have a much lower rate of number of heavy trucks occupants fatalities.

1.2. Bibliographical references

1.2.1. Accidents with heavy trucks

In an accident involving heavy trucks and other vehicles, there is a low probability that its occupants will die or get seriously injured, happening exactly the opposite to the occupants of the other vehicles. Because of that, many studies have been made to detect the main causes of accidents with heavy trucks.

The USA is a country that due to its dimensions has a large number of heavy trucks traveling its roads every day. Due to that, it is one of the countries where more accidents with heavy trucks happen, and consequently one of the countries where more research is made to prevent road accidents with this type of vehicles. A study made in the USA, [2], concerning accidents between light vehicles and heavy trucks indicates that in an accident between these types of vehicles, the first one is always in disadvantage considering the differences in structural characteristics and mass between these vehicles, and reveals that in these accidents 98% of the victims are the occupants of the light vehicles. It also concludes that the tendency of the relation of heavy trucks to light vehicles traveling in the roads is to increase, which also increases the probability of occurring accidents between these vehicles.

But as it is obvious, the major causes of accidents with heavy trucks vary from country to country. In Australia, much of the transportation done by heavy trucks is made through rural areas, most of them fairly deserted. So, it is understandable that one of the major causes of accidents with heavy trucks in Australia is fatigue due to the great distances that heavy truck drivers have to go under extreme temperatures, and being sometimes hours without seeing anyone else. A study made in Australia, [3], revealed that from 1988 to 1994 the...
percentage of accidents caused by fatigue or where “loss of concentration” was considered a contributing factor almost quadruplicated. Recent studies pointed out that in Australia, fatigue is responsible for 30% of the accidents that occur in rural areas and 16% of the total of accidents. Fatigue was considered a very dangerous factor being somehow compared to driving under the effect of alcohol, for causing effects such as slowing the reaction time in an emergency situation, or reducing the ability to process information.

Another study made in Australia, [4], alerts to one of the great dangers of collisions of light vehicles into heavy trucks which is underride. The underride, which will be much better described in chapter 4, is basically when the front of a light vehicle or other small vehicles slides under and collides with the rear end of a truck or a trailer. Underride occurs because the rear end of a truck or trailer is relatively high off the ground and there is too little structure under the rear end to resist the striking vehicle, or the structure present is not strong enough to accomplish that purpose. This type of crash typically results in substantial damage to the smaller vehicle and injury to its occupants if the truck is not equipped with effective anti-underride structures.

Due to the serial consequences of these type of collisions some organizations, [5], [6], have worked to try to alert and sensitize governments to change the current standards for conception of underride protections, since statistics prove that the currents are ineffective.

1.2.2. Finite elements studies

Besides statistical studies that have the objective of determining the main causes of accidents with heavy trucks, other studies have been made to design and improve roadside hardware such as rails and concrete walls using finite elements programs. Roadside hardware is subjected to large impacting forces, applied very rapidly, which often results in the failure of the hardware. Such structures undergo large deformations, and nonlinear changes in material and geometric properties make it difficult to predict their response.

Several studies performed in the United States whether by universities, [7], whether by governmental agencies responsible by road traffic, [8], have the objective to test how current roadside hardware react to the impact of several types of vehicles.

1.3. Work objectives

The main objectives of this work are to study road accidents involving heavy trucks in Portugal to identify its main victims and causes, make real accidents reconstructions to know reasons that lead to the existence of accidents with these vehicles, and design and compare several energy absorbing structures that prevent rear and side underride. To do so, it will be created simplified 3D models of a light vehicle, a semi-trailer and several energy absorbing structures, which will be imported into a finite elements program and tested through dynamic analysis.

2. Accidents with heavy trucks in Portugal in 2005 analysis

2.1. Victims resulting from accidents with heavy trucks analysis

According to CARE Database, [1], Portugal stayed in third place, in 2005, in terms of more fatalities of heavy trucks occupants per each 10 million inhabitants as it can be seen in Figure 2.1, being Luxembourg in the top of the list, but its results can’t be correctly compared to other countries due to its reduced population.

However, once again Portugal must be compared to countries that have the same geographical situation such as Greece, Finland, Sweden or United Kingdom, and in that case Portugal was the country with the highest rate with 3.3 fatalities of heavy truck occupants for each million inhabitants.
Figure 2.1 – Heavy trucks occupants’ fatalities in the EU, for each million inhabitants, in 2005.

From the database containing all the accidents with heavy trucks that occurred in Portugal in 2005, [9], it was discovered that 1730 accidents with victims involving heavy trucks occurred in Portugal, causing 124 fatalities, 215 serious injuries and 2020 light injuries. From the study of the database, [9], many conclusions were taken.

Relatively to what happens to heavy truck drivers, it can be seen in Figure 2.2 that the great majority stayed unharmed after an accident.

Figure 2.2 – Heavy truck drivers’ lesions after crashes, in 2005.

It can be seen in Figure 2.3, the percentage of fatalities that resulted in accidents with heavy trucks according to the type of vehicle.

Figure 2.3 – Fatalities in accidents with heavy trucks according to the type of vehicle, in 2005.

It was concluded that for each fatality of a heavy truck occupant there five fatalities of another vehicle occupant. It was also concluded that the others (occupants of any type of light vehicle or heavy passenger vehicles) were responsible for most of the fatalities, which can be due to the fact that most of the accidents with heavy trucks are from collisions with light vehicles, that there were approximately as much pedestrian fatalities as there were of heavy truck drivers, and that all two wheel vehicles categories together represented a bigger percentage than those two categories.
2.2. Accidents with heavy trucks general analysis

From the general analysis made to the database containing all the accidents with heavy trucks that occurred in Portugal in 2005, [9], it were taken conclusions such as:

- the district with most accidents per 100,000 inhabitants was Santarém (see Figure 2.7 in the report);
- approximately the same amount of accidents occurred inside and outside populated areas (see Figure 2.9 in the report);
- the accidents that occurred outside populated areas were more serious because they produced a higher rate of fatal victims and seriously injured victims (see Figure 2.10 in the report).

2.3. Type of accidents

From the same database, [9], it was concluded that the accidents that happened more often were side, rear and frontal collisions with other vehicles (as it can be seen in Figure 2.13 in the report). These collisions could very well be of heavy trucks into other vehicles as well as they could be of other vehicles into heavy trucks.

It was also observed that these were the accidents that were responsible for most of the victims (fatalities and injuries) resulting from accidents with heavy vehicles, as it can be seen in Figure 2.4.

![Figure 2.4 – Victims according to the type of accident, in 2005.](image)

It was concluded that the side, rear and frontal collisions were responsible for more than two thirds of the fatal victims and for approximately 70% of the seriously and lightly injured.
2.3.1. Accidents by side collision with another moving vehicle

Given that accidents by side collision were the ones that happen the most (see Figure 2.13 in the report), it was decided to take a deeper look at them to know in which locations, roads or intersections they happened the most. It was concluded that they occurred:

- approximately as many times inside or outside populated areas, but the ones that took place outside populated areas were more serious since they caused more fatal victims (see Figure 2.16 in the report);
- in normal road (no intersection), being followed naturally by T sections and crossroads (see Figure 2.18 in the report);
- most of the times in National roads, followed by local roads (see Figure 2.19 in the report);

2.3.2. Accidents by rear collision with another moving vehicle

The same analyses were made for rear collision accidents. The conclusions taken were that rear collision accidents occurred:

- twice as many times outside populated areas than inside them, and that the ones that took place outside populated areas were much more serious since they were responsible for great part of the fatal victims and seriously injured (see Figure 2.21 in the report);
- in normal road (no intersection), being followed by T sections and crossroads (see Figure 2.23 in the report), just like the side collisions;
- most of the times in National roads too, but almost just as many times in Highways (see Figure 2.24 in the report).

2.4. Accidents location

2.4.1. Road type

From the database, [9], it was concluded that the roads where more serious accidents occurred (accidents that caused fatal victims and seriously injured) were the National roads, being responsible for 44% of the serious accidents, followed by streets with 21%, and the Highways came in third with 13% (see Figure 2.25 in the report).

2.4.2. Intersection type

The same analysis was made to the several types of intersections. It was concluded that most serious accidents occurred in normal road (no intersection) with approximately 60% of serious accidents, followed by junctions with 15%, and the crossroads coming in third with 5% (see Figure 2.26 in the report).

2.5. Accidents temporal analysis

2.5.1. Months of the year

A time analysis was made to the database, [9], to know in which months occurred more accidents with heavy trucks. It was concluded that the months that produced more accidents with heavy trucks were February, July, August and September. It is curious that the months that produced fewer accidents were months that usually don’t present good weather conditions such as March, April or November (see Figure 2.27 in the report).

2.5.2. Hours of the day

The same analysis was made to the database, [9], but relatively to the hours of the day. It was concluded that most accidents occur between 11am and 5pm, with a peak between 3pm and 4pm that corresponds to the time of the day when the human body is more fatigued (see Figure 2.28 in the report).
3. Real road accidents with cargo vehicles reconstruction

3.1. Methodology for road accident reconstruction

Road accident reconstruction is based in a dynamic analysis of the time evolution of the vehicles’ trajectories. That analysis is made through adjustments, within acceptable limits of some physical parameters that are characteristics of the collision itself.

The software used is PC-Crash, [10], that effects those adjustments automatically with the help of a genetic optimization algorithm that from the vehicles’ initial positions optimizes their trajectories within a predefined limit.

3.1.1. Building the accident scenario

The first step in road accident reconstruction is the building of the accident scenario. In the scenario it are included the road, ditches, sidewalks, obstacles, horizontal and vertical signaling, trees, houses, etc., so that the real conditions can be represented the best way possible (see Figure 3.1 in the report).

3.1.2. Vehicle models

The vehicles’ models, although they don’t include models of the occupants are much used to optimize the trajectories and initial velocities, allowing an estimative of the initial conditions with an acceptable error. The error value is defined by the user, being usually used as reference a 10% error.

After the refinement of the initial conditions and the results optimization made by the software, it is possible to see the initial velocities, pre-impact velocities, obtain the vehicles’ kinetic energies, dissipated energies in impact, verify trajectories, etc.

After obtaining the wanted results, it is possible to verify the accidents’ dynamics in a 3D scenario (see Figure 3.3 in the report).

3.2. Real cases examples

3.2.1. Collision between two heavy trucks

In this accident, Vehicle 1 is exiting a curve when he sees a light vehicle parked in the ditch and partially in the road. Since it can’t pass due to the fact that Vehicle 2 is approaching from the other direction, Vehicle 1 brakes with full power to try to stop, but its rear wheels block making its rear going off trajectory and colliding with the front of Vehicle 2. After the collision, Vehicle 2 exits the road and slides through the ravine that is on the side of the road, tipping over several times until it reaches the bottom.

The day is clear, the road is dry, and none of the drivers have alcohol in their blood.

The determined vehicles’ speeds were (see Figure 3.10 in the report to see the accident sequence):

<table>
<thead>
<tr>
<th>Circulation:</th>
<th>Impact:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle 1: 45-55 km/h</td>
<td>Vehicle 1: 16-26 km/h</td>
</tr>
<tr>
<td>Vehicle 2: 35-45 km/h</td>
<td>Vehicle 2: 35-45 km/h</td>
</tr>
</tbody>
</table>

Although the main causes for the occurrence of this accident were human factors (excessive speed and bad judgment by the driver of Vehicle 1), it would have been possible to avoid it or at least diminish its consequences if the Vehicle 1 had an ABS system so that it wouldn’t have blocked its rear wheels and being able to still control its direction.

By looking at the photographs of the damaged vehicles (see Figures 3.6 to 3.8 in the report), it is possible to conclude that if the Vehicle 2 had seatbelts and stiffer A pillars maybe its driver could still be alive or at least suffered less injuries during the accident.
3.2.2. Collision of a light passenger vehicle in the rear of a semi-trailer

In this accident, Vehicle 2 (light passenger vehicle) is traveling in the right lane of the Highway when a couple of hundred meters in front of him, Vehicle 1 (heavy truck with semi-trailer) that is parked in the ditch decides to reenter into the Highway. When doing so its driver doesn’t take the necessary precautions (like signaling his maneuver), so the driver of Vehicle 2 only sees it when he is too close and although he brakes he can’t avoid the collision, underriding the semi-trailer.

At the time of the accident it is night, the road is dry, and none of the drivers have alcohol in their blood.

The determined vehicles’ speeds were (see Figure 3.18 in the report to see the accident sequence):

<table>
<thead>
<tr>
<th>Circulation</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle 1: 14-24 km/h</td>
<td>Vehicle 1: 14-24 km/h</td>
</tr>
<tr>
<td>Vehicle 2: 92-112 km/h</td>
<td>Vehicle 2: 67-87 km/h</td>
</tr>
</tbody>
</table>

The main cause of this accident was negligence by the driver of Vehicle 1 that didn’t signal correctly his maneuver. Nevertheless, if the semi-trailer was equipped with a system that could have prevented the underride of Vehicle 2, maybe there wouldn’t have resulted 4 fatal victims from this accident

3.2.3. Collision of a light cargo vehicle in a motorcycle

In this accident, Vehicle 1 (motorcycle) is exiting a roundabout to enter a street when he sees an oncoming light cargo vehicle (Vehicle 2) that is traveling in the middle of the road due to the fact that there cars parked in both sides of the street. Since there is little maneuvering space for Vehicle 1 to pass between Vehicle 2 and the parked cars its driver brakes, blocking the rear wheel causing the motorcycle to fall and starting to slide along the road. The driver of Vehicle 2 realizing the situation brakes, but he can’t avoid running over the diver of Vehicle 1.

The day is clear, the road is dry, and the driver of Vehicle 2 has a rate of 0.69g/l of alcohol in his blood.

The determined vehicles’ speeds were (see Figure 3.24 in the report to see the accident sequence):

<table>
<thead>
<tr>
<th>Circulation</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle 1: 26-36 km/h</td>
<td>Vehicle 1: 3-9 km/h</td>
</tr>
<tr>
<td>Vehicle 2: 62-72 km/h</td>
<td>Vehicle 2: 23-33 km/h</td>
</tr>
</tbody>
</table>

This accident occurred mainly due to the fact that the driver of Vehicle 2 was traveling too fast inside a populated area and under the influence of alcohol. Of course that the fact that the driver of Vehicle 1 was very young and had few experience in driving also contributed to the accident. This is a good example of a fatality that could have been prevented if those vehicles had protections that avoided motorcyclists to slide under them.

3.2.4. Collision of a light passenger vehicle in a light cargo vehicle and a motorcycle

In this accident, the Vehicle 2 (light passenger vehicle) is traveling by the right in the right lane when he collides with his right side in the rear of Vehicle 1 (light cargo vehicle) that is parked in the exit of a garage. With the freight, the driver of Vehicle 2 pushes his car a little to the left to get away from the danger and he invades the lane of opposite direction where Vehicle 3 (motorcycle) is traveling. The driver of Vehicle 2 becomes aware of its presence and starts to brake but he can’t avoid the frontal collision with Vehicle 3.

The day is clear, the road is dry, and none of the drivers have alcohol in their blood.
The determined vehicles’ speeds were (see Figure 3.32 in the report to see the accident sequence):

<table>
<thead>
<tr>
<th>Circulation:</th>
<th>First impact:</th>
<th>Second impact:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle 1: 0 km/h</td>
<td>Vehicle 1: 0 km/h</td>
<td>Vehicle 1: 0 km/h</td>
</tr>
<tr>
<td>Vehicle 2: 56-66 km/h</td>
<td>Vehicle 2: 56-66 km/h</td>
<td>Vehicle 2: 38-48 km/h</td>
</tr>
<tr>
<td>Vehicle 3: 40-60 km/h</td>
<td>Vehicle 3: 40-60 km/h</td>
<td>Vehicle 3: 40-60 km/h</td>
</tr>
</tbody>
</table>

This accident was mostly due to natural causes. The occurrence of the second collision was very much probably due to the fact that occurred a first collision, and the first collision was due to the fact that the driver of Vehicle 2 was blinded by sunlight, not being able to see properly. And once again, it can be seen the fragility of two wheels’ occupants relatively to other vehicles, since that they were one more time the only victims that resulted from an accident with a motorcycle (one fatal victim and one seriously injured).

4. Energy absorbing structures

4.1. Current situation

Nowadays accidents between heavy trucks or trailers with other vehicles are very serious mainly because of the collision zone. Most recent light vehicles are designed to have a frontal structure that absorbs energy during frontal impacts, but the problem is that in a collision with a heavy truck that is not the impact zone. All heavy trucks are designed to have a very stiff chassis due to the very heavy things they carry, what becomes a problem in a collision because the chassis is approximately at the same height that is a persons’ head that travels in a light vehicle, so when these vehicles collide the light vehicle will slide under the heavy truck and hit directly in its chassis with the A pillars (a zone that is not designed to resist frontal impact forces), sometimes happening that part of the heavy truck or trailer crashes through the windscreen and penetrates the passenger compartment, occurring the underride that can either be from the side or from the rear (see Figures 5.1 and 5.2 in the report).

4.2. The underride phenomena

The underride is when a light vehicle collides in a heavy truck or trailer that is not equipped with effective underride structures and slides under it through the so called wedge effect (see Figure 5.3 in the report). The top of the penetrating vehicle is crushed by the guillotine effect (see Figure 5.4 in the report) and its occupants can suffer severe head injuries or even get decapitated. Rear underride guards for heavy trucks and trailers were considered compulsory elements in 1953, but most of existing devices are usually defective, being too high relatively to the road or too fragile to prevent the underride.

Most cases of side underride occur at night when a heavy truck with a trailer stops on a roadway and the driver begins a backing maneuver into a driveway or loading dock area. It can also happen when the driver pulls the rig out onto the highway from a loading zone or driveway, but this occurs less often. On-coming motorists, unaware that the trailer is across the road, see the headlights of the heavy truck and merely assume the lights are of a truck in its proper lane. Of the three typical trailer side marker lamps, one is blocked from view by the heavy truck and the other is off the roadway into the driveway. That leaves only the center marker lamp visible to the motorist of the on-coming vehicle. As the amber light is quite small, it may be mistaken for a roadside reflector, the type used on mailboxes, utility poles and as driveway delineators. Although it can be seen, the motorist does not perceive it as a hazard until it is too late.
4.3. Solutions adopted by some heavy vehicles builders

Because these accidents are becoming more common, it is very important to design effective structures that can prevent underride, absorb energy during the impact and that can be easily placed in the sides or in the rear of a heavy truck or trailer. Some heavy trucks builders (like VOLVO or RENAULT) and trailers builder (like BENALU) have a greater concern relatively to vehicles’ safety and have made studies of collisions between light and heavy vehicles and of design of underride preventing structures (see Figures 5.6 to 5.8 in the report).

4.4. Recent studies

Besides the heavy trucks or trailers builders, some universities or enterprises that work close to governments of countries like the United States, Brazil or Canada have worked to study the consequences of collisions of light vehicles into heavy trucks and try to develop structures that reduce those consequences. Studies, [6], [11], have proven that effective underride protections can prevent underride of the light vehicles and that the heavy truck or trailer crashes into the passenger compartment (see Figures 5.9 and 5.10 in the report).

4.5. Existing standards

Obviously, given the importance of these structures they can’t be designed in any way. In the present, there are standards for the design of underride guards such as the FMVSS223 and the FMVSS224 in the United States, or the E.C.E. R58 in Europe. These standards define the guards’ dimensions and the dimensions relatively to the side and rear extremities of the heavy truck or trailer, and the static loads that they must support.

4.6. Standard to implement

Although there are currently standards to design underride guards, the opinion of many experts in the area is that they are inadequate and that such parameters like the distance to the ground or to the rear of the heavy truck or trailer should be reduced, while others like the static load they must support should be increased.

5. Measures to reduce road accidents

5.1. Measures to heavy trucks

By making the statistics of accidents with heavy trucks through the database, [9], solving real cases of road accidents with those vehicles and through bibliographical research a lot of measures were thought or discovered that could help to reduce road accidents with heavy trucks.

According to ERSO, [12], if heavy trucks had ESP (system that helps to correct the trajectory of a vehicle in a curve by reducing the engines’ torque and braking the wheel necessary to stabilize the vehicle) their safety while describing a curve could increase in about 40%. ERSO also alerts to other measure that has recently been made mandatory in Europe, which is the equipping of seatbelts in all the new heavy trucks.

One measure that has recently been made mandatory in Portugal and that can help reduce road accidents with heavy trucks is the use of digital tachographs, since the analogical ones (discs) were very easily cheated. By obliging the use of the digital ones (which are not only more accurate as they record other informations besides the speed and driving/rest times), the speed of heavy trucks can be much better controlled.

ERSO also alerts to many dangers of heavy trucks and provides good measures to reduce them. One danger they alert to are the amount of dead spots that a truck driver has (zones where he can’t see other vehicles, specially two wheel vehicles, traveling on the road) and advises the upgrade of the performance of rear view mirrors to increase the field of indirect vision by retrofitting heavy trucks with blind spot mirrors and cameras. Another danger they alert to is driving under the influence of alcohol and advise as measure to fight that, the
installation of alcohol interlock systems where the heavy truck driver has to blow into an in-car breathalyzer before starting the ignition (of course the driver will only be able to start the vehicle after the analysis reveal a rate of alcohol in the blood lower than the one allowed by law). Finally, they also alert to the underride problem and advise improved front, rear and side energy absorbing underrun protections since the existing ones are not very effective (research indicates that such measures could reduce pedestrian and cyclist deaths by about 10%).

5.2. Measures to heavy truck drivers

The measures to apply to heavy truck drivers can pass mostly by campaigns to alert and sensitize them to certain dangers such as driving under the influence of alcohol or fatigue.

Although many campaigns are made to alert drivers to the effects of driving under the influence of alcohol such as increased reaction time, loss of decision ability and low muscular control, still many drive with rates of alcohol in the blood above the ones allowed by law. However it sometimes happens that they drive in those circumstances because they don’t have a correct perception of what rate of alcohol in the blood will correspond to what they drink, or because they are used to drink that just one more glass won’t make a difference. A measure that already is applied in some countries (like Spain, Austria or Australia) is the reduction the rate of alcohol in the blood limits to professional heavy vehicles’ drivers. A serious measure could be applying more expensive fines or reducing the conditions that lead to the cancellation of the drivers’ license.

However, another important factor that affects many heavy truck drivers due to the great distances they have to travel and that is not as advertised as alcohol is fatigue. A study made in Australia, [13], concluded that an individual with a sleep deprivation of 17 to 19 hours experiences the same effects of an individual with a rate of alcohol in the blood of at least 0.5g/l.

5.3. Measures to roads

It was revealed in chapter 1.2.2 that finite elements studies are made to test and design roadside hardware. Nevertheless most of those studies are made using models of regular trucks (pickup trucks) and not heavy trucks, making the designed roadside hardware not suited to deal with impacts from these vehicles. A study, [14], concluded that current rails and concrete walls are too low to stop heavy trucks from overriding them.

6. Impact simulation with finite element models in LS-Dyna

6.1. Three-dimensional models

Several 3D models such as a light vehicle, a semi-trailer and rear and side absorbing structures were developed in Solid Works and then exported to ANSYS so that the energy absorbing structures could be tested in dynamic analysis. To minimize the computational effort all structures were simplified before being exported. The light vehicle was modeled according the EuroNCAP and USNCAP trolleys, and although it is a simplified model it fulfills all the trolleys’ specifications of dimensions and mass expressed in the Side impact testing protocol, [15]. The simplified models of the light vehicle and of the semi-trailer can be seen in Figure 6.1.

![Figure 6.1 – Simplified models.](image)
Although the front of the light vehicle is a solid block (in the reality the frontal zone of the trolleys is composed by a honeycomb structure made of aluminum), the properties of that zone were assigned so that it corresponds to the reality in terms of mass and stiffness, [16]. The material used for the semi-trailer was the steel AISI1045.

6.2. Impact in rear energy absorbing structures

Several structures were developed and analyzed so that it could be concluded how they deform, how they deform the front of the light vehicle and which ones are better in absorbing energy, preventing the light vehicle from underriding the semi-trailer.

![Diagram of underride guards](image)

**Figure 6.2** – Tested rear underride models.

Rear underride guard 6.2a) was designed according to the current standards and given a thickness so that it wouldn’t deform much during the impact (just like current underride guards that just have the objective of preventing underride, and not of absorbing energy), and placed 300mm from the rear of the semi-trailer like it is stated in the current standards. Rear underride guard 6.2b) was based in models developed in Brazil (see Figure 5.9b) in the report). Rear underride guard 6.2c) was based in the one designed by BENALU (see Figure 5.8 in the report). Rear underride guard 6.2d) wasn’t based in any current guard, but based in the theory of frontal deformation of light vehicles where the beginning is deformable in order to absorb energy, followed by a rigid zone (usually the beginning of the passenger compartment in the light vehicles) so that the colliding vehicle won’t penetrate from a certain distance of the rear. These three last guards were aligned with the semi-trailers’ most rear section.

All these guards were then placed in the semi-trailer, and dynamic analysis were made by colliding the light vehicle in them at 50km/h (14mph). The obtained results are presented in Figure 6.3.

![Stresses and strains](image)

**Figure 6.3** – Stresses and strains for the light vehicles’ maximum penetration distance with each rear underride guard (for more detail see Figures 6.5, 6.8, 6.11, and 6.14 in the report).
Besides the vehicles’ deformation, another very important parameter to evaluate in collisions is the deceleration resulting from the impact. For that it was chosen a node close to the drivers’ position to see how its deceleration evolved along the dynamic analysis. According to the EuroNCAP Assessment protocol and biomechanical limits, [17], the maximum value of deceleration that can exist in an impact is 88G, being however a 20% risk of injury to the passengers. The obtained results are presented in Figure 6.4.

**Figure 6.4** – Obtained decelerations for each of the rear underride guards.

The maximum value of deceleration with each of the rear underride guards was 420m/s$^2$ (43G), 420m/s$^2$ (43G), 290m/s$^2$ (30G) and 320m/s$^2$ (32G) respectively.

From the results obtained from the first rear guard it was possible to conclude that it is very stiff since it presented nearly no deformation unlike the front of the light vehicle. It was also concluded that due to the distance of the guard to the rear of the truck there was a great penetration of the light vehicle which can be very dangerous for vehicles that have a short front. The maximum deceleration it caused in the light vehicle was high but it wasn’t close to the maximum that can exist in a collision, [17]. From the results obtained from the second rear guard it was possible to verify that this is a stiff guard too, since the deformation caused by the collision was practically all in the light vehicle. It was possible to conclude however that due to the position where it was placed there was less underride of the light vehicle. The maximum deceleration caused in the light vehicle was the same obtained with the previous guard. From the results obtained with the third rear guard it was possible to conclude that it is a guard that absorbs energy since it deformed in the impact. It was able to effectively reduce the light vehicle underride and the maximum deceleration caused in it was quite lower than the obtained with the previous guards. From the results obtained from the fourth rear guard it was possible to conclude that the deformation of the light vehicle was very distributed in its front. As expected, the light vehicle only penetrated until it reached the supports. The maximum deceleration caused in the light vehicle was higher but very close to the obtained with the previous guard.

### 6.3. Impact in side energy absorbing structures

Relatively to side underride guards, few studies have been made. In Figure 6.5 it is possible to see a common side underride guard and a simplified 3D model of it, which was the first one tested for side collisions in the report.
The side guard was then placed in the semi-trailer to make the dynamic analysis of the light vehicle colliding the side guard at 50km/h. The obtained results are presented in Figure 6.6.

The maximum deceleration value obtained was 310m/s² (31G).

However, these guards have a huge problem that is the distance to the ground making it easy for the driver of a two wheel vehicle or a pedestrian to slide under them in an accident ending up crushed by the heavy truck or trailer wheels, for it would be benefic if these guards had a lower distance to the ground. Nevertheless, that represents a problem considering the locations where sometimes heavy trucks or trailers have to pass where the ground is not very regular, and where too low guards can easily be damaged. So the ideal is to have a guard with a low distance to the floor but that is not fixed so that it can contour obstacles in the ground.

Thinking in that it was designed a side guard that has vertical movement through rotation in the supports. The mechanism is independent to each side and is shown in Figure 6.7.

The mechanism is designed, so that during an impact the upper arm enters in a slot in the support making the same effect as if it was fixed in it. To reduce the computational effort it was placed the side underride moving mechanism in only one of the sides. The obtained results are presented in Figure 6.8.
Figure 6.8 – Obtained results for the side underride moving mechanism.

The maximum deceleration value obtained was $530\text{m/s}^2$ ($53\text{G}$), which was greater than the one obtained with the previous guard.

From the results obtained from the first side guard it was possible to conclude that it prevented the underride, but it didn’t absorb much energy. However, it presented a danger which is the fact that after the impact the front of the car stays in the alignment of the semi-trailers’ wheels which can be very dangerous if the semi-trailer is moving. From the results obtained from the side moving mechanism it was possible to conclude that prevented effectively the underride as well as it prevented the danger present with the previous side guard that was the fact that the front of the car was in the alignment of the semi-trailers’ wheels after the impact. However, the maximum value of deceleration was greater than the obtained with the previous side guard.

7. Conclusions and future developments

7.1. Conclusions

From the analyses of accident databases it was possible to conclude that in Europe, Portugal is one of the countries with the highest rates of accidents with heavy trucks and victims that result from those accidents.

It was also possible to evaluate the great importance of road accidents reconstruction to the reduction of road accidents through the creation of measures based in the resolution of real accidents, as well as the identification of the accidents parameters that allow to identify its causes and their responsibles.

Besides the measures that were considered important to be implemented relatively to heavy trucks and their drivers and roads, it was also concluded that other drivers should be alerted or even taught to how to share the road with heavy trucks.

By making this work, it was possible to conclude that even though there are standards to the design of equipment that can prevent or reduce the damage of a collision, they’re not always the more effective or the ones that best adjust to the safety needs of the vehicles’ passengers.

Through the dynamic analysis made to test the designed guards, it was possible to conclude that effective guards can prevent the underride of light vehicles and reduce the damage inflicted in them as well as their deceleration in an impact.

The first three rear guards were based in real models. From the results obtained it was possible to conclude that rear guards 6.2a) and b) are very stiff since they presented nearly no deformation and caused large deformation in the front of the light vehicle. The rear guard 6.2c) is a much better designed rear guard since it absorbs much more energy during impact which can be concluded from the reduced deformation in the front of the light vehicle and from the deceleration that caused in it that was much lower than with the previous rear
guards. The fourth rear guard was customly designed but it proved to be effective in preventing rear underride and absorbing energy since the results obtained were close to the ones obtained with the third rear guard.

The first side guard proved to prevent underride although it didn’t absorb much energy, but it presented another danger in side collisions with heavy trucks or trailers that is that after the impact the front of the car stayed in the alignment of the semi-trailers’ rear wheels which can be very dangerous if it is moving. The side moving mechanism proved to prevent that problem although it was a bit stiffer that the first side guard causing bigger deceleration on the light vehicle, but that are however not dangerous to the occupants traveling in it.

7.2. Future developments

In future works it would be important the development of more realistic models that can contemplate the different values of stiffness that are present in the front of the vehicle (such as the hood, the bumper or the chassis for example), since the current model presents the same stiffness in all of the front.

Besides that, it would be important to simulate non centered impacts, or impacts at different speeds of the light vehicle into the energy absorbing underride guards to see how they react, because the collisions don’t always occur in the conditions that were tested in this work.

Not directly related to this work but within the same investigation area, it would be important the design of impact areas for pedestrians in the front of heavy trucks, given their fragility towards these vehicles.

Another important theme to develop within this area of investigation, is the impact of heavy trucks into roadside hardware such as rails or concrete walls with the purpose of improving the current ones.

References

