DEVELOPMENT OF AN IMPACT ABSORBER FOR ROADSIDE BARRIERS

Carlos M. Vieira, Henrique A. Almeida, Irene S. Ferreira, Joel O. Vasco, Paulo J. Bártolo, Rui B. Ruben and Sérgio P. Santos

Centre for Rapid and Sustainable Product Development
INDEA (Campus 5), Rua das Olhalvas, 2414-016 Leiria, Portugal
www.cdr-sp.ipleiria.pt

Summary:

The work presented in this paper was developed with the objective of increasing road safety for motorcycle drivers. Guardrails are traffic barriers placed along the roadsides to protect vehicles from hazards behind the barriers. These guardrails are constructed using standard steel W-beam mounted on spaced posts. When accidents involving motorcycles occur, the barrier posts are extremely dangerous causing severe injuries on motorcycle passengers. In order to reduce these injuries, an energy-absorbing system was developed. This protective device will be placed on the guardrail post and would minimize the injuries and reduce the impact accelerations. This impact attenuator was designed respecting the European standards EN1317. In this research, numerical simulation software was used (LS-Dyna) to determine the effects of the proposed impact attenuator system on motorcyclists regarding dynamics and injury criteria.

The impact attenuator model was based on an elastic-plastic material capable of absorbing the high kinetic energy of the dummy. The geometry of the energy-absorber was designed obeying the requirements of an extruding manufacturing process. The section profile of the proposed 3D geometry model has various layerss intelligently oriented so that the deformation process may present a buckling behaviour.

With this research, a low cost impact attenuator device was developed in order to protect motorcyclists against post barriers crashes. The new protector device guaranties a HIC lower than 1000, as required for EN1317 European Standard accident conditions.

Keywords:
ROAD SAFETY, MULTIBODY DYNAMICS, STRAIN ENERGY, ELASTIC-PLASTIC BEHAVIOR, HIC

1 INTRODUCTION

The main function of roadside safety barriers is to be capable of capturing and redirecting errant vehicles in order to protect vehicle occupants from hazardous roadside features. These roadside barriers are normalised under CEN norm EN 1317. According to this standard, the restraint system must sustain the impact of different vehicle types (from passenger cars to trucks or buses), under different collision conditions (i.e. vehicle's velocity, angle of impact and road conditions). Therefore, it is expected that no harm can be caused for a wider range and type of vehicles, but unfortunately, the existing guardrails don´t guarantee motorcycle's riders protection from the impact (no mention of motorcycles is made in EN 1317). Recently, as a result of an increase in fatalities and high severity injuries damages caused by motorcycle accidents, the recognition of dangers involving motorized vehicle suffered a considerable increase. For instance, the Federation of European Motorcyclists' Associations (FEMA) published in 2000 the "Final report of the motorcyclists and crash barriers protect" that attempts to aware road authorities in order to reduce injuries severity in accidents of motorcyclists against safety barriers. Portugal, as the majority of European countries, adopted the w-beam guardrail that have a "W" profile (Figure 1) that can be used with a variety of pillar configurations (in Portugal there are two configurations: C125 and UPN120). For more detail see Figure 2.

Figure 1 – Typical w-beam guardrail elements Right) Portuguese w-beam solution

Figure 2 – Existing Portuguese pillars configurations Right) UPN profile, Left) C125 profile

The most common situation of accident involving motorcycles occurs when the motorcyclist lose the control of his vehicle and lead off the road. On losing control, motorcycle riders may suffer a collision with other vehicles, hit with other objects like trees or lamp pillar, or collide with road guardrails, which is the second most frequent struck object by motorcycle (Ibitoye, Hamouda et al., 2006). The literature suggests that the most dangerous aspect of guardrails with respect to motorcyclists is exposed guardrail pillars where the probability of being killed by it rises from 2.2% to 10.9% (Ellmers, 1998). The most common injuries caused by the impact against guardrail are head and cervical injuries, caused by the high level of energy absorbed, and lacerations made by the exposed edges of guardrail pillars. In this sense, since the guardrail pillar has been identified as the main impact point, it must be covered by an appropriate energy absorber in order to prevent the jagged edges and to allow high energy absorbing (this solution was recommended by Koch and Schueler (Koch and Schueler, 1987) and Sala and Astori (Sala and Astori, 1998)). In Portugal, a norm has been introduced (Law nº33/2004) that makes compulsory the placement of crash barrier systems that are safe for motorcycles, especially in black spots (e.g. shoulders, grade, fixing obstacles). This law defines also that these safe solutions can be individual, protection for each pillar, or continuum ones, as a second lower rail. Regarding these two options, individual solutions, so called impact attenuators, have been proven to be popular from a cost-benefit point of view (Koch and Brendicke, 1988). Nevertheless, any proposed solution must be tested under specific conditions in order to get its homologation (D.R nº. 3/2005). To get that, a dummy II-III with 80.5Kg±0.5Kg is thrown against the proposed system restraint at a 60 km/h±6% speed with a 30°±°2 angle. The dummy is sliding on its back and hits the barrier head first, through position A or B (Figure 3). The severity of injuries is measured through Head Injury Criteria (HIC) evaluation, which must be lower than 1000 in order to get the homologation.

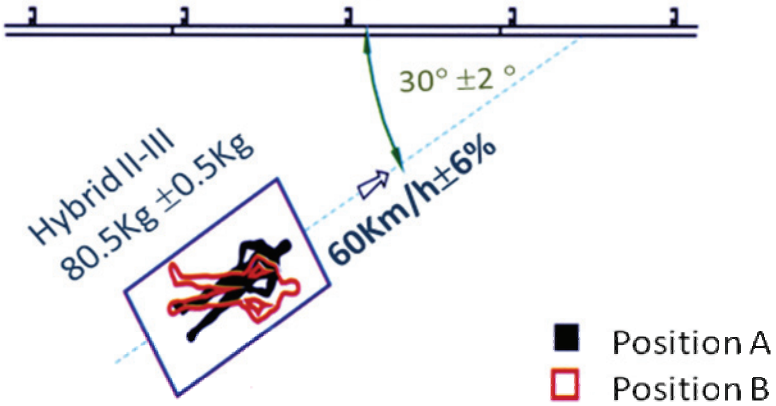


Figure 3 – Simulation conditions imposed by D.R nº. 3/2005 (Portuguese regulation)

Attempting to conceive one impact attenuator solution to protect motorcyclists from direct impact against safety barriers, it was necessary to identify the main design requirements of the impact attenuator. This was achieved through Quality Function Deployment application (Figure *4*). Based on that, it is possible to observe that four main functional requirements must be considered in the impact attenuator design: Impact attenuation; Installation, Durability and Costs. In this sense, the solution must guarantee a higher absorption level of energy, which will be achieved by an appropriate material selection and innovative geometry, as well, be adaptable to the existing guardrail pillars configurations (mainly function of geometry, shape and assembly system). In addition, durability and costs functional requirements will be also accomplished through mainly adequate materials and manufacturing process selection in order to get a feasible solution.

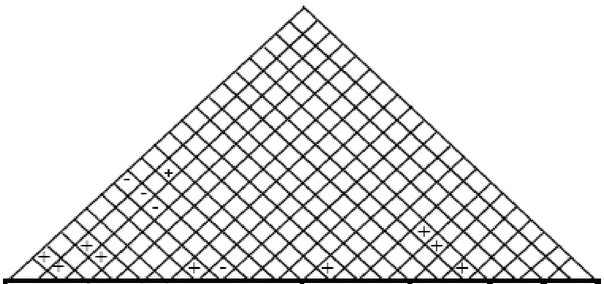
Considering the specific case of Portugal, some additional conditions were taking in account, namely:

- the new solution must be capable of being adapted to the two different pillar profiles existing in Portuguese roads (profile U120 and C125);
- Easily installation of the solution in the existing W-beam system;
- Respect D.R n.º 3/2005 obligations;

In addition, concerning process conditions, it was decided that the solution must be manufacture by plastic extrusion: The main reason for that option was the existence of a plastic extrusion cluster in the region (easy accessibility to production facilities) and a good knowledge about this manufacturing process. Afterwards, several solutions were generated through geometry, shape and material definition. Amongst the proposed solutions, and according to the previous requirements, the best solution was encountered. Then, its performance was studied by Ls-Dyna in order to achieve the best possible solution regarding the HCI. The Ls-Dyna was adopted because it is recognized as an effective tool for impact simulation, which allows simultaneously the kinetic/mechanical behaviour of system performance, through finite element analysis, as well, the severity assessment of rider's injuries, through multibody studies.

Us	*
Competitors	
U crash absorber •	
+	Positive
-	Negative

•	Strong
o	Medium
Δ	Weak



Technical requirements / Functional requirements			Material											Geometry				Shape			Assembly		Fixing		Benchmarketing				
			σR	σC	E	Density	Impact resistance	Humidity resistance	Agentes Estabilizadores (UV)	Life cycle duration	Service temperatures	Flame retarders	Material	Internal parallel dimension	Internal perpendicular dimension	Height	Thickness	Without sharp edges	Adjustable height	Área de Impacto	Form	Type	Form	Type	1	2	3	4	5
			↑	↑	↑	↓	↑	↑		↑	↑	↑				↑		↑		↑									
Impact attenuation	Protect sharp edges	5	•				•				o		•				•	•		o								•	
	Absorb impact energy	5	o	•	•		•				o		•				•			•				•			•		
	Resistant to impact	5	o	•	•		•				o		•				•			•				•			•		
	Avoid direct contact with post	5				o	•						•			•	•		•	•		Δ		Δ			•		
Installation	Safe against vandalism	3											o								•	•		o	•				
	Maintain position	5														o							•	•			•		
	Adjustable to the barriers	4												•	•	•			•		o	o	o	o			•		
	Don't exceed the barriers limits	3															•												•
	Adjustable to the barrier terminations	5														•			•									•	
	Easy to install or replace	4				•										•	o		•	o	•	•	•	•				•	
Durability	Stable to Ultraviolet radiation	4							•				•															•	
	Humidity resistance	4						•					•															•	
	Resist high temperatures due to impact	4									•		•							o									
	Working temperatures	4									•																	•	
	Resist corrosion against solvent agents	3							•				•																
	Anti flame	3										•	•																
Costs	Minimize costs	4						o	o			o	•			•	•		•	•		o		o		•			
	Recyclable or reusable	4							o				•														•		
	Technical Difficulty																												

Figure 4 – Functional and technical requirements for one impact attenuator

To compare the developed solution with the existing alternatives available in Europe, it was collected the solutions in used and the patented solutions. Some examples of the solutions encountered can be observed in the figures below.

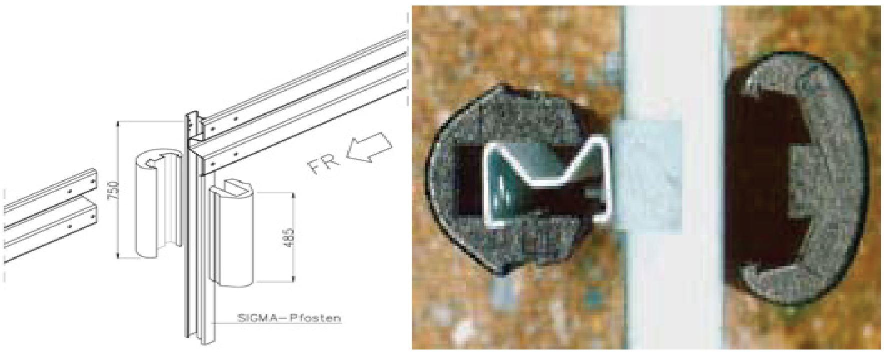


Figure 5 - SPU Crash Absorver – solution from Germany (www.volkmann-rossbach.de)

Figure 6 – Examples of solution adopted from Spain

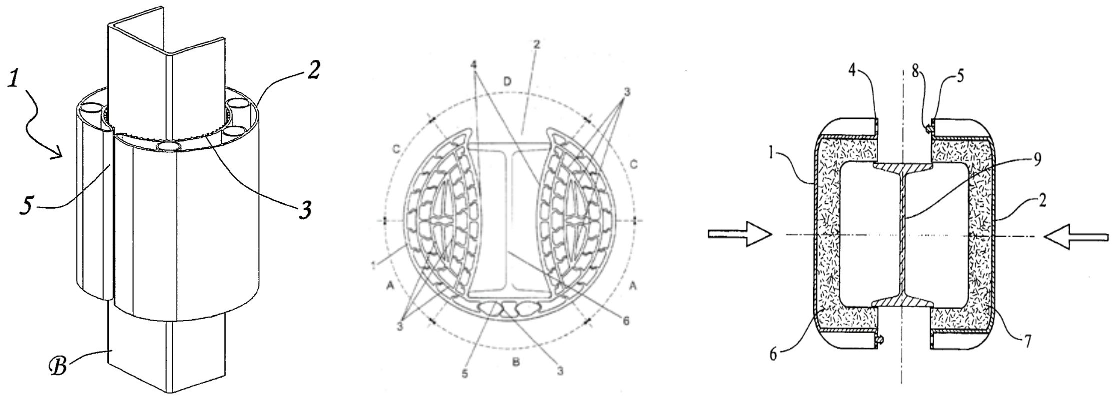


Figure 7 – Examples of patents solutions Right) ES 2 200 726, Midle) WO 2005/075745 A1, Left) EP 1 428 938 A2

2 Ls-Dyna Simulation Scenario

2.1 Rail and Dummy characterization

The evaluated road restraint system is made of construction steel S 235. The W-shaped guardrail is made of approximated 3 mm thick metal sheet. The usual length of the w-segment is 4200mm; where the splice length is equal to 200mm. Supporting sheet metal is 6 mm thick and is welded to the distance spacer. The distance spacer is U-shaped with dimensions 120mm x50 mm and 260mm in length. The pillar is C-shaped with dimensions 55 mmx120 mmx4mm and is usually 1,9m long. The distance between pillars depends on the required containment level and can be equal to 2m or 4m. Pillars are always oriented with the closed profile face towards the traffic flow direction. W-beams, pillars and distance spacers are joined with screws M16 x 35 mm of strength class 5.8. Some of its mechanical proprieties are illustrated in the next table.

Table 1 – W-Bean guardrail properties

Density (kg/m^3)	7.86E3
Young´s modulus (Pa)	2.0E11
Poisson ration	0.28
Thickness (m)	2.67E-3
Yield stress (Pa)	3.45E8

A standard Hybrid III 50th percentile was used to represent the motorcyclist. The whole-body motion of the motorcycle and dummy was simulated to crash into a w-beam guardrail at angles 0º and 30º with an impact speed of 60Km/hour, according the D.R nº. 3/2005 obligations (Figure 8).

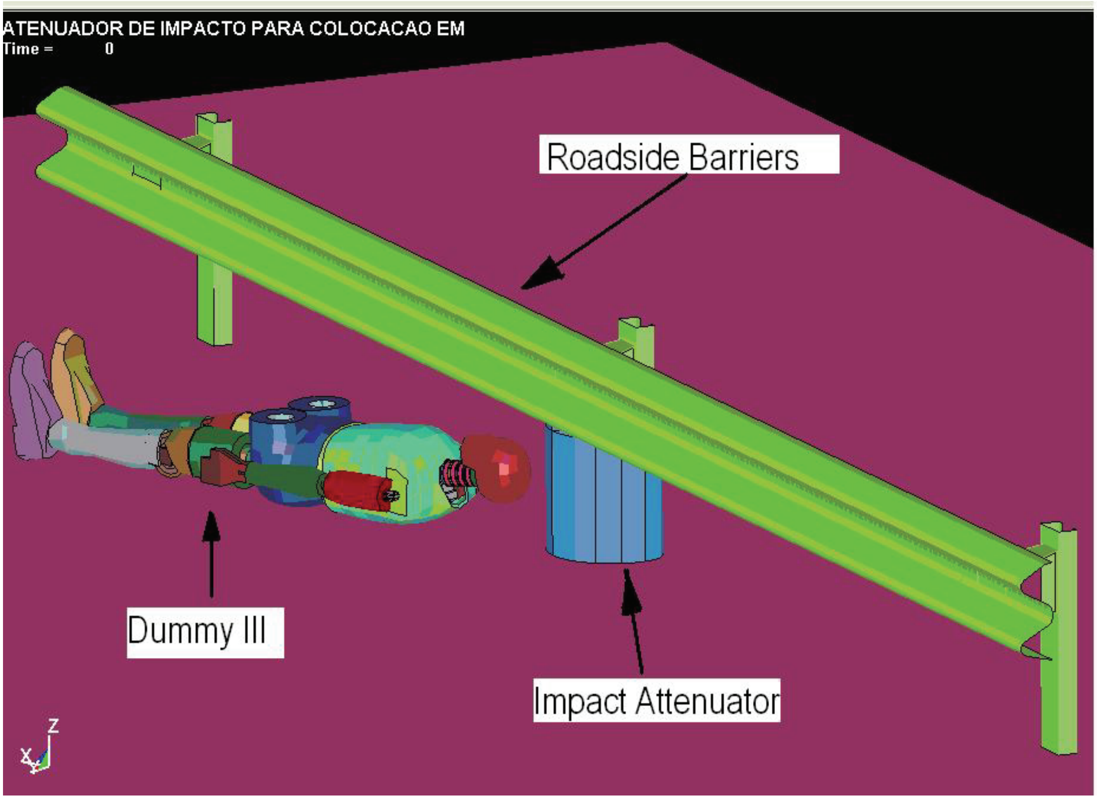


Figure 8 – Dummy and rail characterization

3 Impact absorber concept and HIC

Considering the main goal of the impact absorbing device, i.e. to obtain a lower HIC (<1000) along the motorcyclist accident impact, the principal idea was to treat this issue as an energy transfer problem where the kinetic energy of the dummy must be equal to the strain energy. The maximum width of impact absorber is imposed by the existing geometry of guardrail (distance between the pillar and the limit of W-profile rail). Therefore, threshold value for deflection is 200mm. In order to guarantee a lower HIC, the energy absorption must be constant along the impact process. Typically, an isotropic material has a linear stress-strain curve along the elastic region and continues with a non-linear behaviour. Then, the strain energy can be computed as the area below the curve. The efficiency of the impact absorber is strongly related with the non simultaneous plastic deformation of the layers. The ideal situation, where the strain energy is constant (Figure 9), will result in a constant impact acceleration.

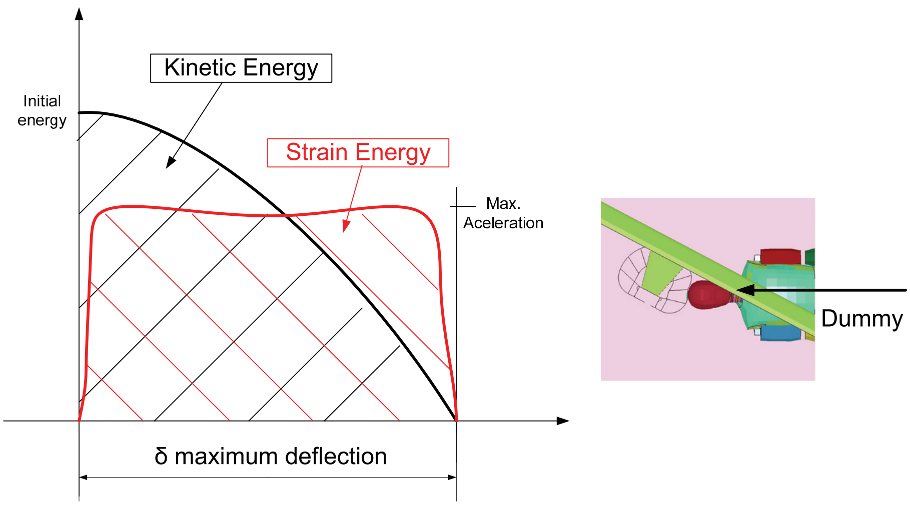


Figure 9 - Relation between Kinetic and Strain Energy

Regarding this criteria, the geometry of the shock absorber must obey to an *organized* deformation. In this sense, the safety device was improved by incorporation of several layers, which will be under buckling state, in order to maximize the strain energy dissipated along the deflection.

Head's injuries are responsible for a high rate of death in motorcycle accidents . Aimed to decrease these fatalities, lot of research have been carried out to develop better safety devices in order to protect head injuries. The HIC is an index, created to categorize the possible human head injuries, function of the acceleration level and the impulse duration. This criteria makes possible to evaluate the injury level in numerical simulations. The HIC calculation was defined by NHTSA in 1972, Eq. (1), computed for an exposed acceleration of 36 milliseconds. Later research by NHTSA proposed reducing the maximum time for HIC calculation, from 36 milliseconds to 15 milliseconds.

$$HIC = \left[\frac{1}{t_2 - t_1}\int_1^2 a\,dt\right]^{2,5}(t_2 - t_1) \qquad (1)$$

In the present work, both HIC_{36} and HIC_{15} were determined for the developed safety device by Ls-Dyna. These indexes were used as the principal point of selection amongst designed solutions.

4 Impact Absorber Device

4.1 Modelling

According to the former requirements, several solutions and respective simulation models were generated (Figure 10). At this point it is important to mention that the solutions need a minimum concordance radius as well a small thickness in order to be produced through plastic extrusion manufacturing. In addition, the profile must register an invariable thickness in order to be easily manufactured. If this is not possible, the transition between different layers thickness must be smooth in order to reduce temperature gradient and, consequently, concentrated stresses and geometric distortion. The figures below illustrate some examples of tested models in LS-Dyna.

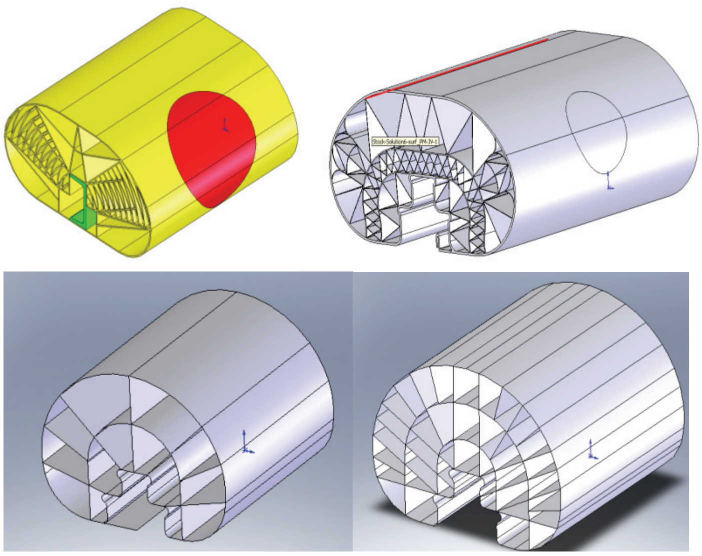


Figure 10 – Experimental models for energy-absorber device

The numerical study of energy-absorber device was made in a simulation scenario that includes the complete guardrails fixed on the ground (Figure 11). The energy-absorber device has a defined place for housing the guardrail pillar which allows pillars with C or U profiles.

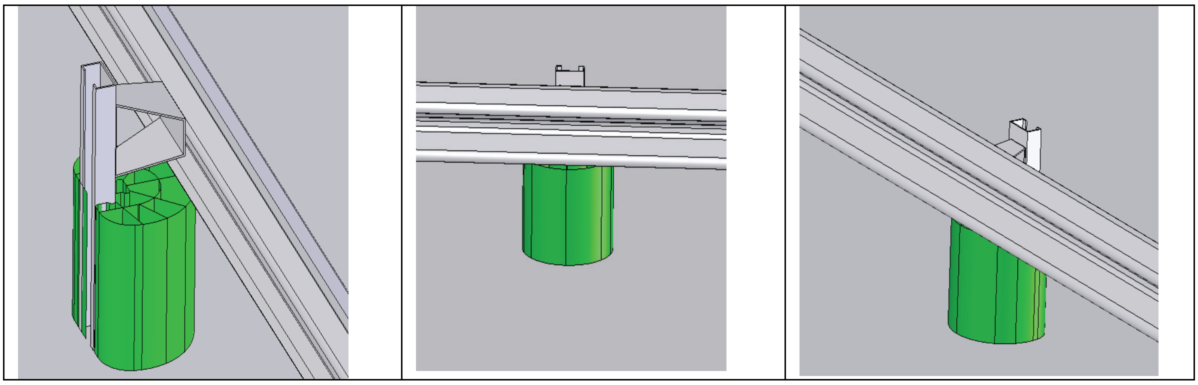


Figure 11 – Simulation scenario

4.2 Mechanical Properties of Materials

The properties of materials used on the energy-absorber device are listed below (Figure 12). The Mechanical behaviour of selected materials were defined by card *MAT_PIECEWISE_LINEAR_PLASTICITY in Ls-Dyna. The stress strain curve was imputed using a ten points table.

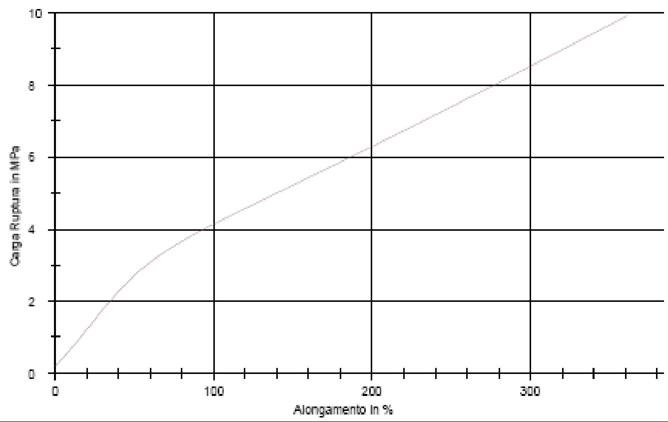
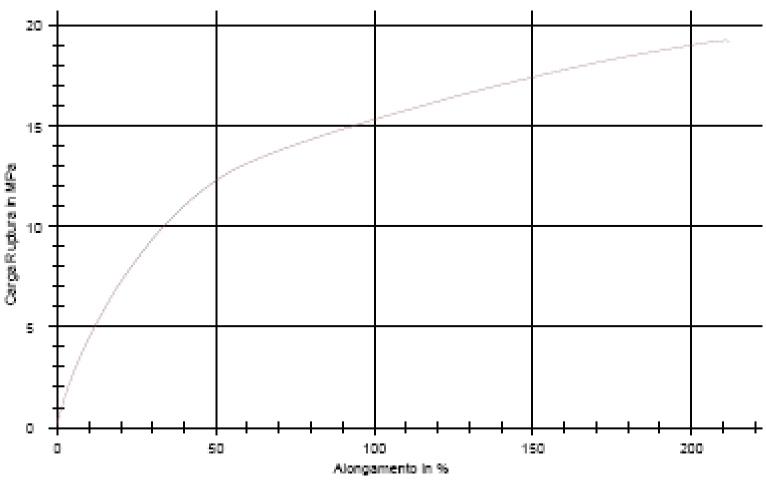
	Test Standard: ASTM D142 Pre-load: 0,5 Kg/mm Pre-load test: 500 mm/min Test speed: 500 mm/min Ultimate strength: 9,91MPa Max. Elongation: 361,22%
	Test Standard: ASTM D142 Pre-load: 0,5 Kg/mm Pre-load test: 500 mm/min Test speed: 500 mm/min Ultimate Strength:19,21 MPa Max. Elongation: 211,85%

Figure 12 – Material's proprieties

5 Simulations with LS-Dyna

5.1 Numerical Simulations

All the numerical simulations were carried out according to the European Standard tests conditions, namely the initial speed of dummy and the angle of impact. Therefore, the solution was optimized through variation of inner and outer ribs/layers thickness, core geometry, as well, using several types of material for safety device. Some examples of the solutions tested in Ls-Dyna are described in the next tables, with the respective HIC values. From the results, we conclude that the best solution was found for a 12 mm thickness with a Vinyloop PVC hardness 90 material.

Table 2 – Characterization of tested solutions

Test conditions - Simulation 1		
Thickness	**Outside**	12 mm
	Inside	12 mm
Material	PVC hardness 90	
Profile	C	
Impact angle	30º	
HIC_{36}	630	

Test conditions - Simulation 2		
Thickness	**Outside**	10 mm
	Inside	8 mm
Material	PVC hardness 90	
Profile	C	
Impact angle	30º	
HIC_{36}	1914	

Test conditions - Simulation 3		
Thickness	**Outside**	10 mm
	Inside	12 mm
Material	PVC hardness 90	
Profile	C	
Impact angle	30º	
HIC_{36}	1504	

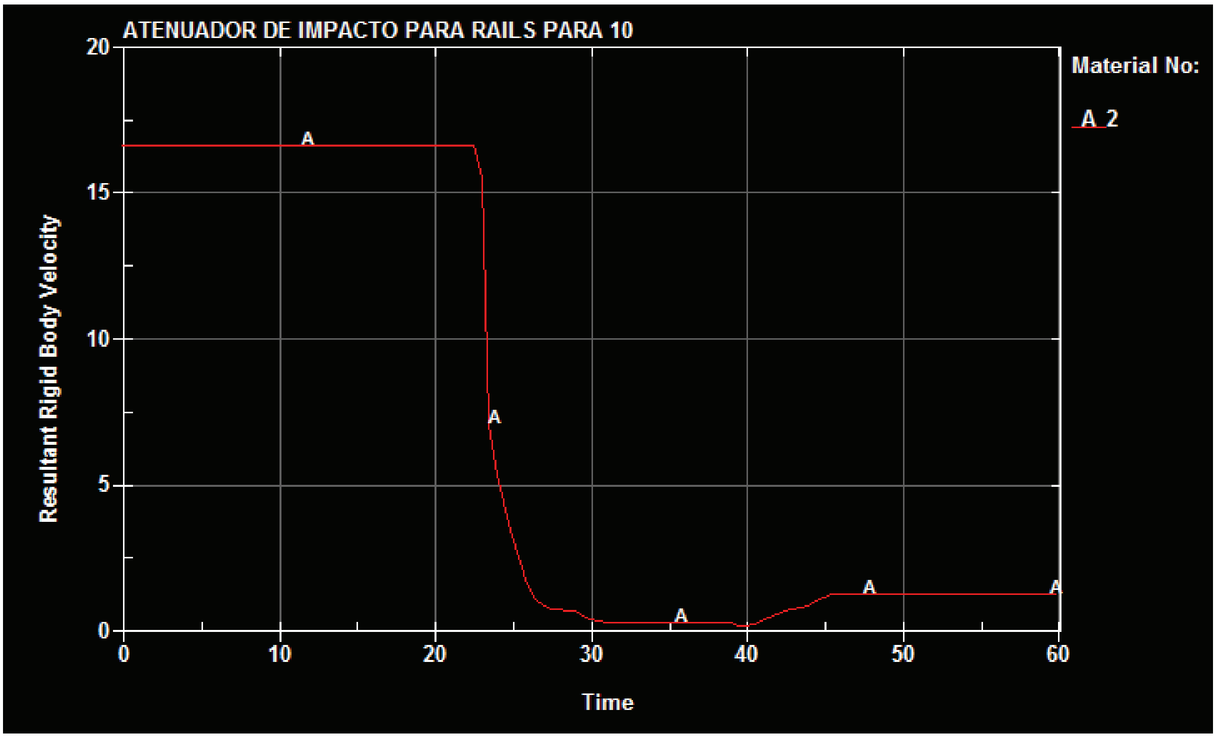


Figure 13 – Impact velocity for simulation 1

6 Conclusions

This works attempts to design one impact absorbing device that allow protecting motorcyclists when they collide against safety barrier's pillars. In this sense, several solutions were studied in order to accomplish the European Standard obligations (in especial Portuguese D.R nº. 3/2005), as well, some additional conditions, such as extrusion manufacturing, inclusion of recycled materials, geometrical constraints due to existing guardrails, etc. The generated solutions were selected and optimized regarding HIC minimization computed by Ls-Dyna simulations. It is important to highlight that any admissible solution, tested in specific conditions, must allow a HIC lower than 1000. The final solution obtained is characterized by a wall's thickness of 12mm. Near the intersection points the material's thickness can raise up to 16mm, thus that will not cause major difficulties in the design of the extrusion die, neither in the manufacturing process. The energy-absorber device has a mass of 38,25kg per meter. Nevertheless, since the maximum height of the guardrail is 350mm the resulting device will have a maximum 13,5kg per unit. The research perspectives of this work will be the simulation of a real dummy impact into to the guardrail, as well, the investigation of the influence of this device in a car collision.

7 References

[1] European Committee for Standardization. European Standard EN 1317-1, EN 1317-2, Road Restraint Systems, (1998).

[2] Livermore Software Technology Corporation, *LS-DYNA theory manual*, (2006).

[3] Ellmers, U. (1998). Guardrail post-protection for improving the safety of motorcycle riders BAST.

[4] Ibitoye, A. B., A. M. S. Hamouda, et al. (2006). "Simulation of motorcyclist's kinematics during impact." Advances in Engineering Software **37**: 56-61.

[5] Koch, H. and R. Brendicke (1988). Motorcycle Accidents with guardrails Intitute für Zweiradsicherheit.

[6] Koch, H. and F. Schueler (1987). Reduction of injury severity involving guardrails by use of additional w-beams, impact attenuators and 'sigma posts' as a contribution to the passive safety of motorcyclists. 11th International Technical Conference on Experimental Safety Vehicles, Washington.

[7] Sala and Astori (1998). New concepts and materials for passive safety of motorcyclists. IRCOBI, Göteborg.

[8] Berg, F. A., Rücker, P., Gärtner, M., König, J., Grzebieta, R., & Zou, R. (2005). Motorcycle impacts to roadside barriers - real word accident studies, crash tests and simulations carried out in Germany and Australia. *ESV 19th Enhanced Safety of Vehicles.* USA.

[9] Ibitoye, A., Hamouda, A., Wong, S., & Radin, R. (2006). Simulation of motocyclist's kinematics during impact with W-Beam guardail. *Advances in engineering Software* , 56-61.