NUEVO SISTEMA DE PROTECCIÓN DE MOTOCICLISTAS FABRICADO EN CAUCHO RECICLADO

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NEW MOTORCYCLISTS PROTECTION SYSTEM MADE OF RECYCLED RUBBER

ABSTRACT:
The aim of this paper is to design a safety barrier to protect motorcyclists using, as a basis, rubber from used tires.

The increase in motorcyclist's protection has been a constant demand of this collective in European countries for years. The designed barrier tries to respond this demand and in turn, create a new alternative for reuse rubber from used tires, thus contributing to solve the environmental problem created by this type of waste.

The standard UNE-135900 defines the test methods to assess the the safety barriers behavior and the protection level against motorcyclists impact.
It has been created a finite element model of the safety barrier in LS-DYNA to reproduce the experimental tests which are necessary for the acceptance of the protection system.
It has been used a model of the dummy that sets the standard, to which has been added a helmet. The model was validated and adjusted using test data from a previous prototype.
Afterwards, several modifications over the original barrier were made in order to meet the requirements of the standard.

The final model of the barrier shows a lower severity than the initial prototype. In view of the results, it the use of rubber appears technically feasible for the manufacture of these motorcyclists protection systems.

Keywords: Recycled rubber, system protection, motorcyclists, guardrail, UNE-135900, road safety, used tires.

RESUMEN:
El propósito de este trabajo es el diseño de una barrera para la protección de motociclistas utilizando como base caucho procedente de neumáticos fuera de uso.

El aumento de la protección de los motociclistas es una demanda constante por parte de este colectivo en los países europeos desde hace años. La barrera diseñada pretende dar respuesta a esta demanda y a la vez, crear una nueva alternativa para la reutilización del caucho procedente de los neumáticos usados, contribuyendo así a solucionar el problema medioambiental generado por este tipo de residuo.

La norma UNE-135900 define los métodos de ensayo que permiten evaluar el comportamiento de las barreras y el nivel de protección ante impacto de los motociclistas. Se ha creado un modelo de elementos finitos de la barrera de protección en LS-DYNA para reproducir los ensayos experimentales que son necesarios para la aceptación del sistema de protección. Se ha utilizado un modelo del maniquí de ensayo que establece la norma, al cual se ha añadido un casco integral. El modelo se ha ajustado y validado a partir de los datos de ensayo de un primer prototipo. Después, se han realizado distintas modificaciones al diseño original para cumplir con los requisitos exigidos por la norma.

El modelo final de la barrera de protección de motociclistas muestra una severidad menor que la del prototipo inicial. A la vista de los resultados, parece técnicamente factible la utilización de caucho para la fabricación de estos sistemas de protección de motociclistas.

Palabras clave: Caucho reciclado, sistema de protección, motociclistas, guardarraíl, UNE-135900, seguridad vial, neumáticos usados.

1.- INTRODUCTION

1.1.- ROAD SAFETY AND MOTORCYCLE

During the last years, the public administrations have made great efforts aiming to increase road safety by investing in the improvement of roads and in awareness campaigns for its users. Car manufacturers have also contributed to the increase in road safety by including in their vehicles systems that increase the safety of both the vehicle occupants and the rest of road users. Thanks to these efforts, the number of fatalities has dropped by 43% in the last 10 years. Even so, in Europe, each year 250,000 people are seriously injured in road accidents [1].

Analyzing in detail these data reveals that the risk of perishing on the road differs depending on the user group. Users that circulate in motorcycle and moped accounted for only 2% of the total users on European roads, however the number of dead motorcyclists represents 15% of the overall fatal accidents [2].

Both on European roads [2] and on the spanish roads [3] the accident data over last decade shows a reduction of the fatalities in traffic accident of all groups of users, except for motorcyclists, whose number of deaths has remained virtually constant (Fig. (1)). If these data are weighted according to the vehicle feet distribution [3], the vulnerability of the motorcyclists is even more evident. In 2013, motorcycles accounted for 8.9 % of the spanish fleet, but there were 104 deaths per every million motorcycles, a relation 3 times higher than that of the passenger cars.

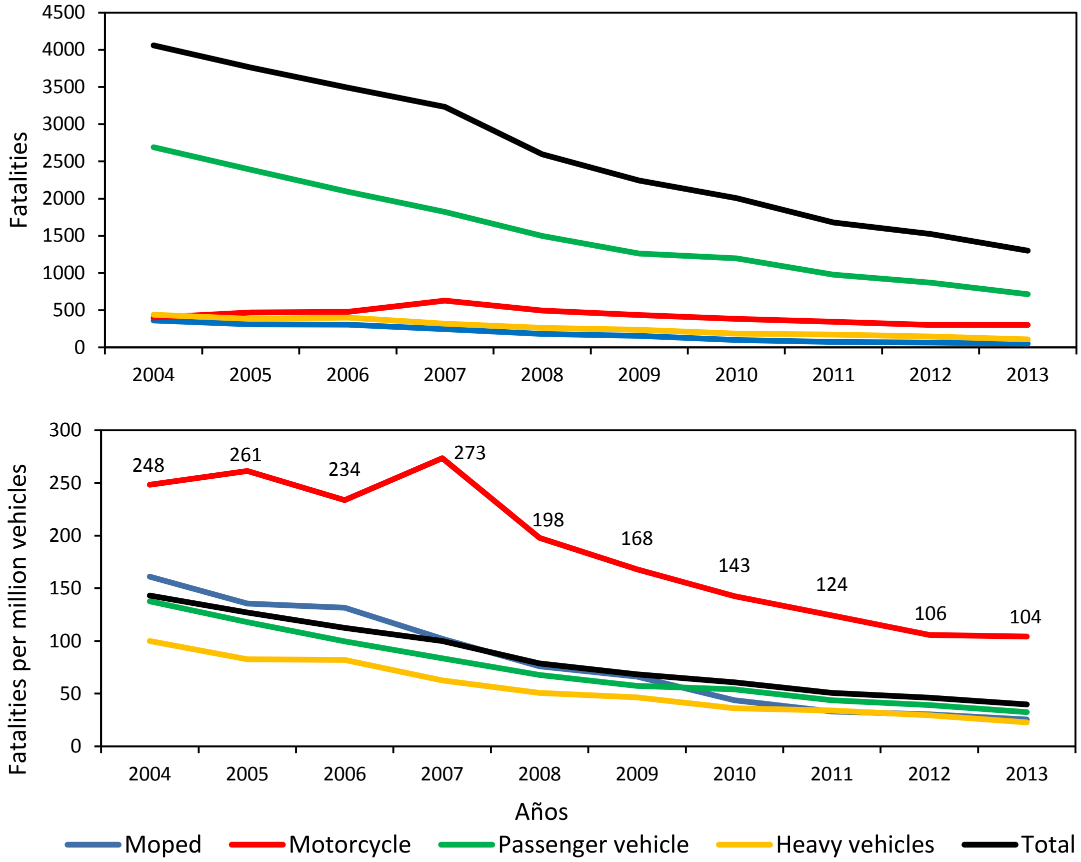

Fig. 1: Number of fatalities according to the vehicle type in Spain (above) and the relationship of fatalities per million vehicles of each type in Spain (below) [3].

Compared with passenger cars, motorcycles and mopeds are less stable, less visible and offer less protection to their occupant, making them the group with the greatest risk of a serious accident. One of the main actions to improve the motorcyclists safety has been the implementation of motorcyclists protection systems (MPS). The MPS prevent the motorcyclist from going off the road and colliding with dangerous objects such as ditches or walls. Moreover, MPS minimize the injuries caused by the impact with the guardrail, which have been designed for containment of vehicles without taking into account the two-wheeled vehicles users. It is estimated that in the 4.7 % of accidents involving injured motorcyclists, these injuries are caused by the impact with the guardrail. However, the damage caused by these accidents is so severe that it represents the 15% of the motorcyclist fatalities [4].

The first breakthroughs reducing the severity of motorcyclist accidents appeared with the replacement of the support guardrail posts. The traditional H-shape posts made of steel were very harmful for the motorcyclists who impacted against them, producing oftenly amputations or severs. These posts were gradually replaced by ones without edges in the area where motorcyclists may impact.

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The next step was the installation of continuous beams, similar to those that form the guardrail, at the bottom of the post. This system has proved to be a very effective method for the reduction in the severity of the injury of the motorcyclists, because it helps to distribute the impact energy over a larger surface and prevents the victim from going under the guardrail and from colliding with more damaging elements.

At European level, in addition to promoting the development and use of MPS, it has been developed several projects aiming to improve the motorcyclist protection on the road. These projects address, for example, the collection of information on accidents in two-wheeled vehicles (MAIDS project [5]), essential to undertake any other action, the study of the effectiveness of the protective equipment of motorcyclists (MOSAFIM [6] and COST 327 [7] projects), and the definition of good practices, awareness campaigns and training (eSUM project [8]).

1.2.- REGULATORY FRAMEWORK

Currently, in Europe there are several protocols for testing the MPS in similar situations to those produced in real accidents. These protocols can be classified into three large groups: those based on the Spanish, on the French and on the German standards [9].

In the German standard, which was developed by the BASt (the Federal Highway Research Institute from Germany), the motorcyclist riding a motorcycle is launched against the guardrail at 60 km/h. In this standard a specially designed dummy is used, the Motorcyclist Anthropometric Dummy Test Device (MATD-Dummy). Acceleration and force data measured in the dummy are compared with the biomechanical admissible limits to approve the MPS [10]. The MPS needs to be tested in two different configurations: one with the motorcycle in an upright position and another one with the motorcycle lying on the floor and sliding until it collides with the barrier.

The French standard, the L. I. E. R. Test Protocol that was also adopted by Portugal, was defined by L. I. E. R. (french testing laboratory). The dummy selected to perform this tests is an assembly of elements coming from other standardized dummies (Hybrid II chest, limbs and shoulders; Hybrid III head and instrumented neck) as well as a special pelvis to allow the upright position. This dummy is thrown against the barrier at a speed of 60km/h with an impact angle of 30º. There are two different tests configurations: one with the dummy aligned with the trajectory and with the head in front, so this is the first part that impacts against the barrier and, another configuration in which the dummy is aligned with the guardrail so that the shoulder and the arm receive the first impact [11].

In Spain was published in 2005 the standard UNE-135900 [12], which has also been adopted by Italy and Norway. The test protocol defined in this standard reproduces a scenario where a motorcyclist who has fallen down and slides on the floor in supine position until it collides with the MPS. The main differences between the aforementioned standards are: impact speeds, the dummy orientation, the impact point on the barrier and the admissible biomechanical values [9, 10]. In addition, only in the German standard the dummy is riding a motorcycle.

These differences between regulations make that a MPS may be approved in a country and doesn't fulfill the requirements in another European country. In the near future, a European standard is going to enter into force which will harmonize the acceptance criteria for the MPS and will increase the international market for these safety barriers. This European standard, the EN-1317-8, is very similar to that standard used in this article, the UNE-135900 [9].

The UNE-135900 makes a distinction between continuous and punctual protection systems. In this article a continuous MPS is studied. In spite of being more expensive, continuous MPS are more effective than punctual MPS since they protect the motorcyclist from the impact against the barrier posts and they prevent the run off the roadway and the impact with nearby objects. The Spanish standard defines two different test configurations to be performed for the evaluation of the continuous MPS (Fig. (2)). In the first configuration, the dummy trajectory forms a 30° angle with the security barrier, and it is launched against the projection on the floor of the center of mass of the barrier post. In the second configuration, the theoretical point of impact coincides with the middle of the segment that connects two consecutive posts.

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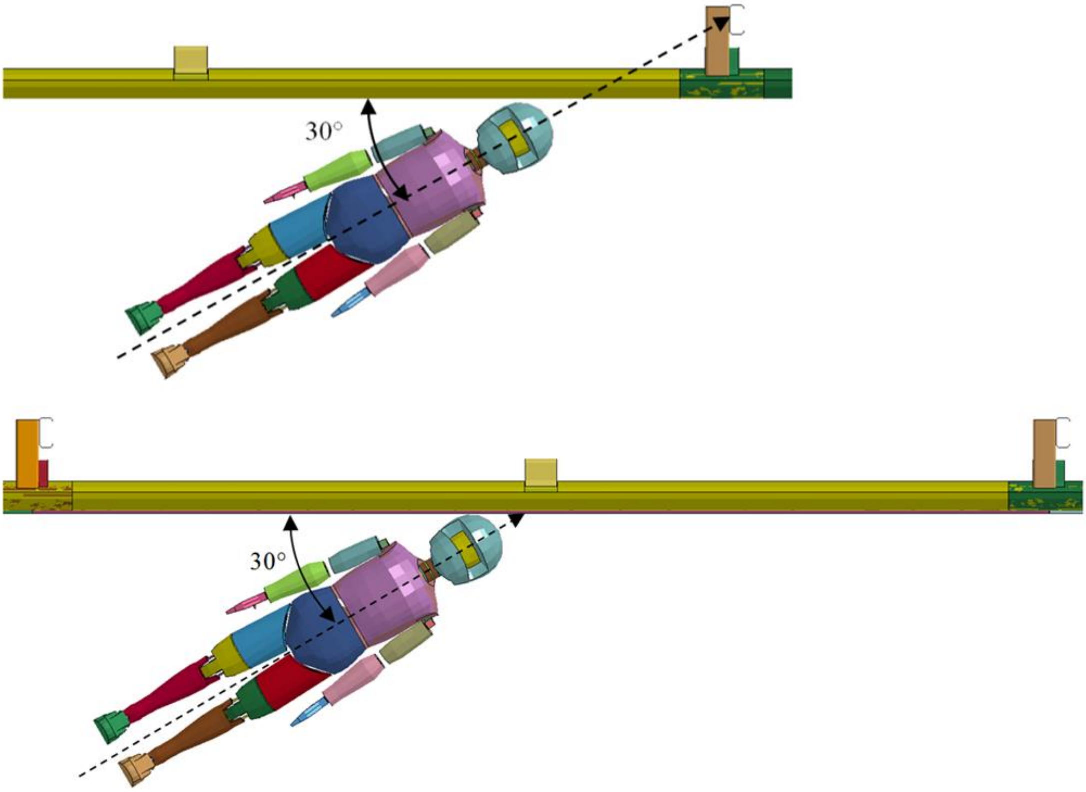

Fig. 2: Test configurations: impact against the post (above) and impact in center of the span (below).

The dummy used is the Hybrid III 50th Percentile Male [13] with some modifications: the pelvis and lumbar spine must be replaced by other models that allow the upright position of the dummy, and the clavicle of the impact side must be replaced by a fuse part that simulate the breakage of the motorcyclist clavicle to a certain force. The dummy is equipped with an integral helmet with a polycarbonate smooth shell, a leather body suit, long-sleeved cotton shirt, leather gloves and boots. The total weight of the instrumented and equipped dummy must be 87.5 ± 2.5kg.

Impact speeds specified in the regulation are 60km/h and 70 km/h that. This test speed determines the two different levels of protection for which can be approved the barrier. The biomechanical values that have to be evaluated are the HIC36 (standardized head injury criteria, obtained from the triaxial accelerations measured in the head), forces and moments in the neck. Depending on the results obtained for these indexes is assigned a Level of Severity I or II. In this way, a MPS may be approved for a Level of Protection 60 or 70 depending on the test speed, and with a Level of Severity I or II according to the test results.

1.3.- WHY A RECYCLED RUBBER BARRIER

The Decree 18/2004 [14], which came into force in January 2005, established the obligation to comply with the standard UNE-135900 for all MPS installed in Spain, and defined a catalogue authorized protection systems. Most of currently authorized MPS are made of steel plate. Their operation is based on redirecting the trajectory of the motorcyclist to avoid a collision against the post or objects adjacent to the road.

This article talks about the development of a SPM manufactured using as a base material rubber coming from used tires. The recovery and recycling of used tires is a requirement established by the Spanish “Waste National Plan”. There are 38 tire recycling plants in Spain and in 2004 were produced more than 305.000 tons of scrap tires, from which only the 50% were reused or revaluated.

Although over last year several uses for this type of material have been developed the problem is not fully resolved yet and it is necessary to study new uses and forms of recovery the rubber from used tires. Its use in the manufacture of new safety barriers will open up a new way for recycling this material, thus helping to solve the environmental problem caused by this type of waste. However, it is necessary to evaluate previously their technical feasibility and possible contribution to the decrease in the severity of motorcyclist injuries.

The use of this material could help to reduce the peak values of head acceleration and the neck forces, thanks to its deformability and its energy absorption capacity. But it is necessary to ensure that the local deformation and friction with the barrier do not prevent the motorcyclist from being redirected and continue sliding to achieve a progressive deceleration.

This article shows the barrier development process, on the basis of a first prototype previously designed by the recycling of tires company MCE Mezclas Caucho. After the study and the optimization of the mechanical properties of the recycled rubber composite, the first prototype was designed and tested. This MPS consisted of a 4 m long rubber barrier, including an inner core of steel plate for reinforcement. This core was perforated to ensure a correct adhesion with rubber. This barrier, whose geometry can be seen in Fig.(3), is installed under the guardrail, hanging thereof by using steel supports.

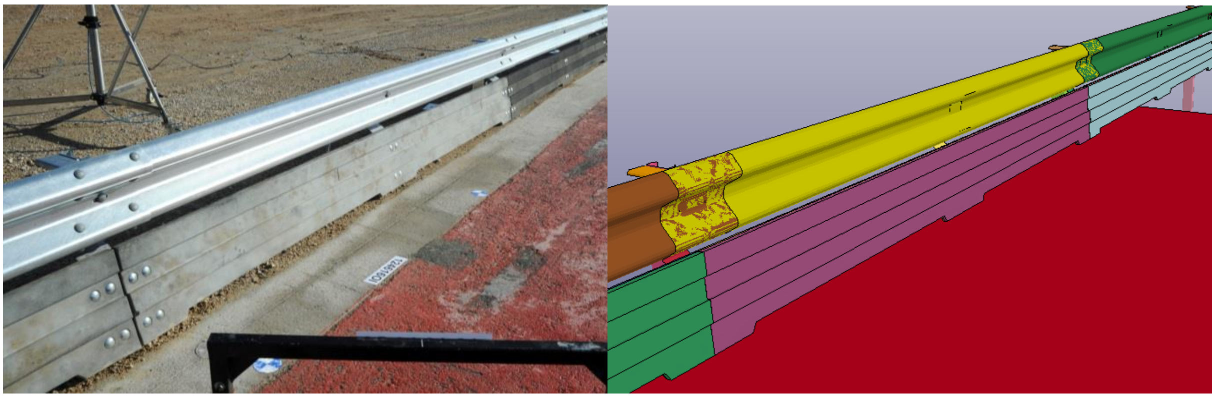

Fig. 3: Perspective view of the original prototype of MPS (left) and its model in LS-DYNA (right).

In the first tests done over the prototype, the limits established in the standard for traction-compression force in the neck were exceeded. In addition, in the test against the center of the span between posts, the barrier was lifted, the arm **went** under it, and was caught by the barrier. Although the norm allows the existence of entrapment provided that the release of the dummy does not require tools, it is not a desirable behavior. In a real accident it would lead to serious injury in extremities and make more difficult the assistance of the injured person.

Therefore It was decided to undertake the design optimization by the simulation of the tests. A Finite Element Method (FEM) model of the MPS was used. This model was validated from the previous experimental results, as described in next chapter.

2.- MATERIALS AND METHODS

For the development of MPS it was carried out a FEM model of the barrier, the dummy and the contacts between them and the ground, using the explicit finite element software LS-DYNA. This model was set and validated from the available experimental data, and was used to simulate the tests defined in the standard UNE-135900. The use of this model permitted to test multiple design modifications of the barrier, assessing its behavior and optimizing the MPS design to comply with the standard requirements.

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2.1.- SAFETY BARRIER MODEL

The barrier geometry was generated by CAD from the drawings of the original prototype. Then it was meshed with ANSYS, and subsequently exported to LS-PrePost. To simulate the rubber behavior 8-nodes Solid elements were used. A hyperelastic Mooney-Rivlin material model was used for the rubber. The material model parameters were adjusted taking as reference the behavior of rubber samples in uniaxial compression test made in laboratory (Fig. (4)). For the front of the MPS was used the composite 3, which has a lower coefficient of friction although it is more rigid. To the back of the MPS was used the composite 2, lighter and cheaper. The inner reinforcement was modeled with Shell elements with Belytschko-Tsay formulation and an elastoplastic material model. The material choice for the steel plate was de S235 structural steel, very common in this type of applications [14]. The coefficient of friction between barrier and helmet was also measured experimentally, obtaining an average value of 0.8.

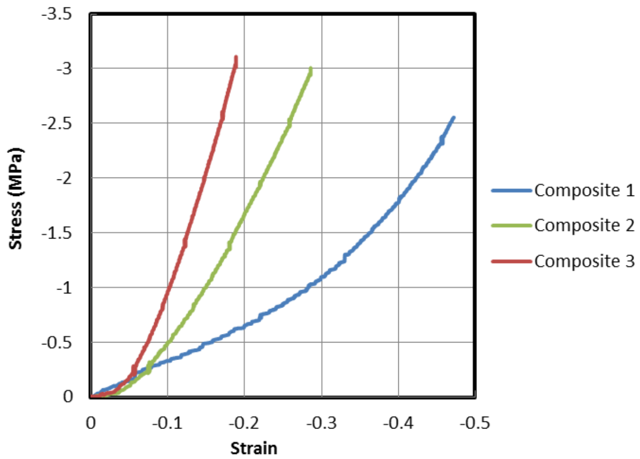

Fig. 4: Result of uniaxial compression tests on samples of recycled rubber composite.

The bolted connections of the rubber barrier with the supports were modeled by Beam elements. The bolted connections between guardrail, poles, separators and other steel elements were modeled using surface-to-surface contacts. Although it was considered the failure capacity of connections, it is worth mentioning that it was not detected any breakage of bolted connections in the simulation nor full scale test.

2.2.- BOUNDARY CONDITIONS AND GROUND

Three guardrail and MPS stretches of 4m long were modeled. In order to simulate the continuity of the barrier the displacement of the nodes at the ends of the model were constrained in the longitudinal direction. The effect of these constrains and the effect of simulating additional stretches were compared and no significant differences were found in deformation of the MPS or in dummy forces.

The ground on which the dummy slides was modeled as a rigid material. Typical concrete properties were assigned for the stiffness of contact calculation.

The determination of the mechanical properties of the soil is highly complex. For the study of collisions between four-wheeled vehicles and guardrails, where the displacement of the post below ground level is significant, it is often modeled by introducing a series of Beam elements with variable stiffness depending on depth [16, 17]. Another method is to create a soil with solid elements [18], which requires a higher computational cost.

In a previous stage of the project the second method was used. As the deformation of the ground was low and the computational cost increased considerably, it was decided to simplify the model constraining the displacement of the deeper nodes of the posts and the nodes at half depth. The kinetic energy of the dummy at 60km/h is much lower than

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that of a passenger vehicle at 100km/h and the soil deformation is lower. Thus the differences in the results were not significant and the latter method was considered accurate enough for this application.

2.3.- NUMERICAL MODEL OF THE DUMMY

Other authors have used in previous works a LS-DYNA model of the Hybrid III 50th dummy, which they modified to help its positioning lying on the ground and making additional changes in clavicle and head [18, 19, 20]. In this work a modified version of the same dummy was used, the LSTC .H3_50TH_STANDING.100630, which has been developed by LSTC. In this version the hip allows extended position of the legs.

The clavicle model was not modified to incorporate the fuse elements that describe the UNE-135900-1. Instead, in the shoulder revolution joint was included the failure capacity at the force levels that specify the standard.

Motorcyclist clothing was not modeled, due to the challenge of simulating the behavior of these elements and their friction with the ground. Nevertheless, clothing only prevents abrasion of dummy parts as a result of friction with the ground and does not vary significantly the dummy dynamics.

A helmet FEM model was added to the dummy. The model was created from measurements taken in a real helmet whose features are those indicated in the norm. All of the biomechanical indexes considered for the approval of the MPS (head acceleration, forces and moments in neck) are influenced by the helmet properties and its energy absorption capacity.

The outer layer of the helmet is usually made of thermoplastic polymer such as polycarbonate or ABS with a thickness of between 2 and 5 mm. This layer was modeled using Shell elements with Belytschko-Tsay formulation and using a elasto-plastic material model. The inner polystyrene foam, lighter than helmet shell, is responsible to absorb the greater part of the impact energy (approximately 85%) [21] and to distribute the force on the motorcyclist head thereby helping to the reduction of maximum head acceleration. For the polystyrene foam simulation Solid elements and a specific low-density foam material model were used. The mechanical properties of the helmet materials were obtained from literature [18].

2.4.- MODEL VALIDATION

Before suggesting a new barrier design and its optimization using the FEM model, the results coming from the full scale test of the first prototype were compared with the simulation results in order to ensure the good agreement between them. In the model validation it has been paid special attention to the neck effort due to fact that this is the only parameter that showed adverse values in the tests. The contact stiffness and the material damping were adjusted iteratively, stablishing as an acceptance criterion that the peak values calculated for traction and compression efforts were within a range of -0/ +10% of the real test values.

The neck forces measured in the impact against post at 60km/h, the neck force obtained in the simulation and the limits imposed by the standard UNE-135900 are compared in the Fig.(5). In the neck force curve, it can be seen a compression peak at 7ms which exceeds the limits stablished by the standard. This peak force corresponds to the first contact of the helmet with the rubber barrier. After 72ms the neck force exceeds the stablished limit again, this time due to traction. The excess takes place when the shoulder reaches the joining area of two barrier stretches. On the same figure it can be appreciated the good correlation between the FEM model results and the experimental data.

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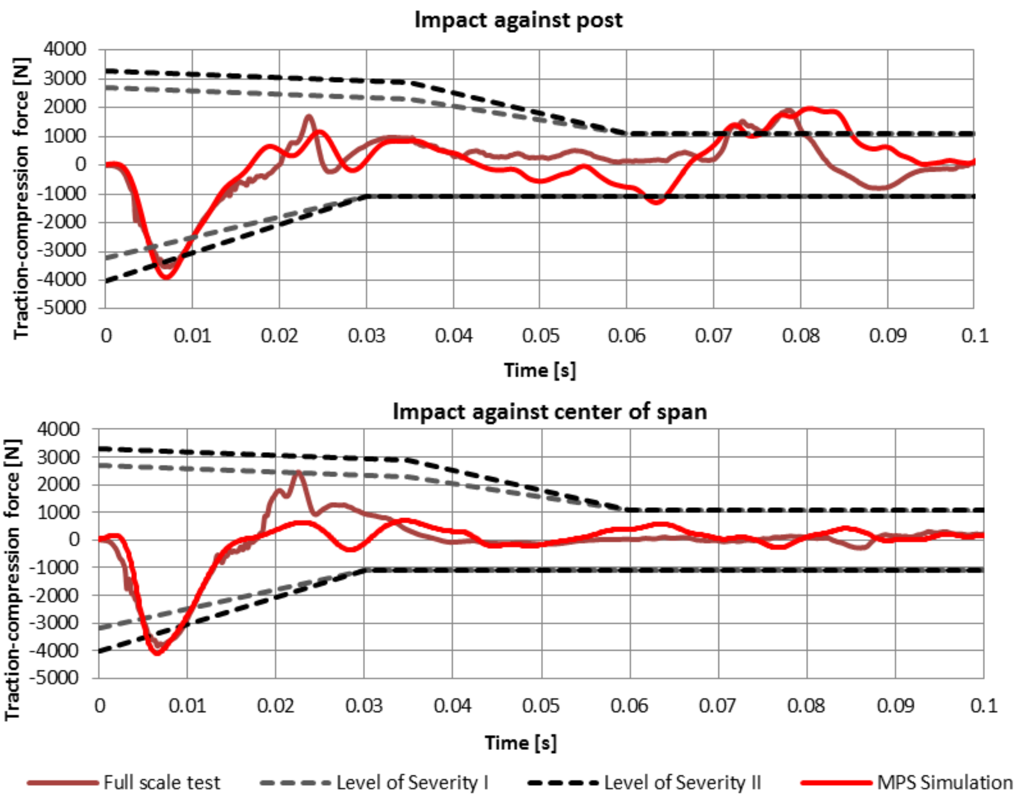

Fig. 5: Neck traction-compression force in full scale test and FEM simulation.

In the impact test at 60km/h against the center of the span a similar peak of neck compression force was detected. In this test, there is no other moment in which the biomechanical limits were exceeded. Moreover, none of the other indexes defined in the UNE-135900 (HIC36 and moments in occipital condyle) exceed the limits during the experimental test. The Fig.(6) shows how the model of the initial prototype of the MPS also satisfactorily reproduces the arm entrapment when it pass under the barrier.

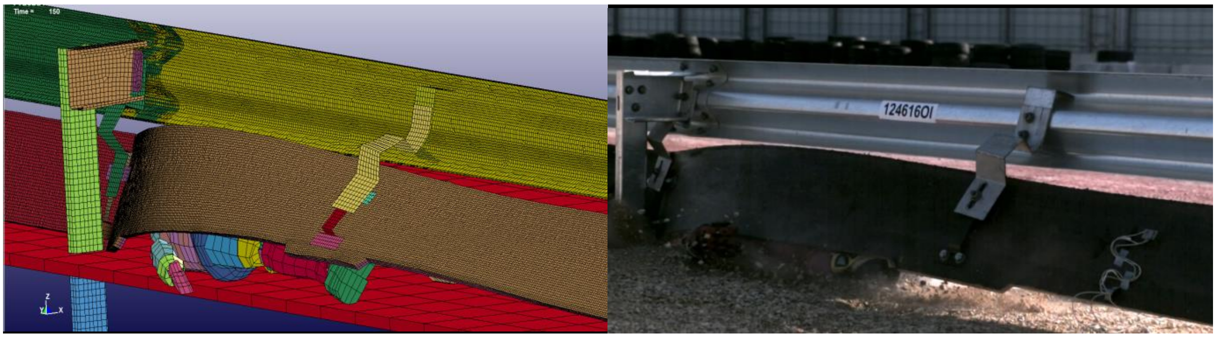

Fig. 6: View of the arm entrapment during impact test against the center of the span.

3.- RESULTS

The MPS was redesigned to solve the problems encountered in the barrier prototype during the certification tests. In particular, the barrier geometry was redesigned (Fig.(7)) by modifying its cross-section and the characteristics of the inner reinforcement. These changes were introduced to avoid exceeding the limits of traction-compression force in the neck during test. The new geometry of the barrier surface where the motorcyclist impacts allows a more progressive contact between helmet and MPS. As a result, the initial compression peak force on the neck is reduced.

Moreover, the new geometry redirects the head trajectory at the beginning of the contact, so that the maximun force always occurs with the contact area at the same height. This improves the repeatability of the test, avoiding the problem studied by other authors for other types of MPS [22]. The possibility to introduced changes in the recycled rubber composite have also been studied, analyzing the influence of different friction coefficients, densities and material stiffness.

An additional problem encountered during the impact test against the posts was the excess of traction force in neck (Fig. (5) above). That problem was solved by redesigning the inner reinforcement of the barrier and the connecting parts between MPS stretches. The new MPS redirects the motorcyclist trajectory in a more efficient manner, and reduces the deformation in the joining area. As a result the neck forces produced when the dummy reaches the post region are reduced.

In addition, the support parts for joining the MPS to the guardrail were redesigned again, taking into account that the MPS has to be installed on the roads without need of modifying the existing guardrails. Moreover, the new design introduces the possibility of being installed in 2 or 4 meters long guardrails using the same support parts.

The problem of entrapment of the dummy arm does not occur when the rubber barrier is installed over a guardrail with 2 meters long stretches. For 4 meters long guardrails, the new joining parts make that the steel guardrail provides the necessary stiffness in the central barrier section to prevent the barrier raising and arm entrapment.

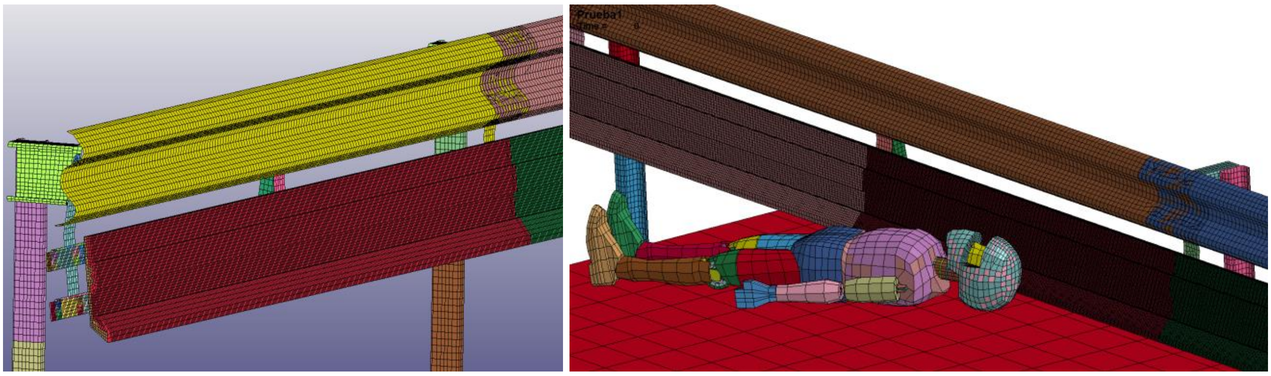

Fig. 7: Finite element model of the redesigned rubber barrier.

The neck forces obtained in the simulation of the new MPS have been included in blue in Fig.(8). In light of the results, the new design fulfils the regulation requirements, and its approval as a motorcyclist protection system with a Level of Severity I in the Level of Protection 60 (test at 60km/h) would be possible. In addition to reducing the force levels in the neck, the new geometry avoids the motorcyclist entrapment and limits the bounce that could bring it back to the road where it could be run over by another vehicle. This behavior was verified by the simulations.

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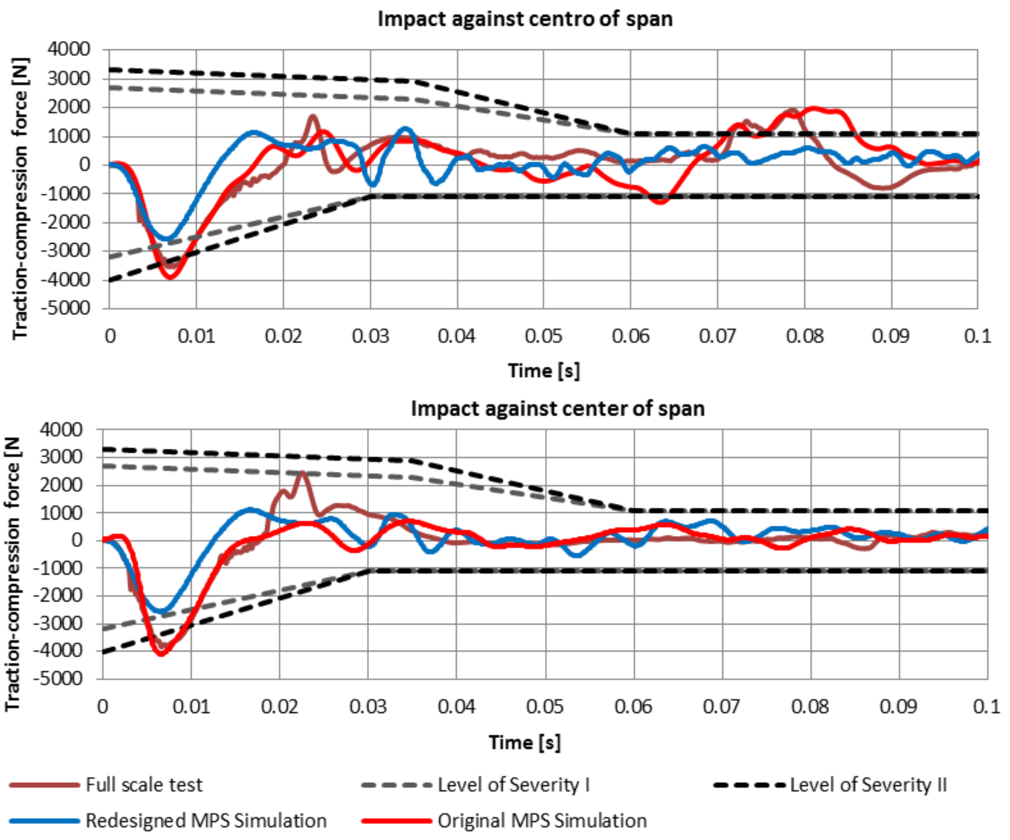

Fig. 8: Neck force obtained with the new optimized design and with the original prototype.

4.- CONCLUSIONS

In spite of the last decades advances in road safety, it is necessary to continue improving the safety on the roads, specially for the most vulnerable users, such as motorcyclists.

As a conclusion of the work that has been shown, a motorcyclist protection system technically feasible has been designed, made of recycled rubber from end of life tires. After the optimization of the design, once the problems encountered in the first prototype were solved, favorable values for the biomechanical indexes which indicate the severity of the accident have been obtained in the simulation. Although final validation must be performed, it can be claimed that this kind of recycled material can be used in barriers helping to reduce the injuries in case of motorcyclist accidents.

Furthermore, the viability of this MPS may constitute a new alternative for the reuse of the rubber from scrap tires, helping to solve the environmental problem caused by this type of waste.

Finally it has been shown that the Finite Element Method is an important help in developing safety barriers. The simulation results of the MPS show a good agreement with the experimental data in the cases discussed in this work, and the biomechanical parameters are properly estimated.

In addition to the economic advantages of FEM reducing the number of expensive tests, the simulations provide wider information about forces, strain, stress and accelerations of the elements involved in the impact, which is essential to understand the operation and weaknesses of the MPS and to optimize its design.

The next stage in the development of this MPS is the performance of full scale test for approval according to the regulations. The compliance with the requirements will allow the commercialization of the recycled rubber barrier. At a

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later stage it will be necessary the overcoming of the test for the Level of Protection 70. A comparative study with the current metallic SPM will be also interesting for assessing the potential improvements achieved.

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