Universidad Zaragoza

1542

Trabajo Fin de Grado

ENERGY ABSORTION DURING A CAR TO CRASH-BARRIER IMPACT CARRYING OUT NUMERICAL SIMULATION

Autor/es

Ángel García Betés

Director/es

DR. INZ. MARIUSZ PTAK

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1 INTRODUCTION

Crash design problem is one of the most complicated design problems, which has been under intensive investigation based on optimization problems.

Finite element analysis has been proven to be a powerful tool for analyzing various physical phenomena and to be an important part on the design process. Finite element models have been used for the evaluation of the full vehicle crashworthiness as well as component structural performance.

A lot of progress has been achieved since 1990's. However, the problem remains due to the high computing costs and nonlinearity of the crash problem. [1]

Therefore, due to the importance of this tool, we decide to carry out this project. This is based on the following points:

1. The review and analysis of crash barriers.

2. Material for energy absorption review.

3. Numerical model set-up in LS-Dyna.

4. Numerical tests of the barriers including various vehicle parameters.

5. The report submission

2 TRAFFIC BARRIERS

PURPOSE

The main objectives are keeping vehicles within their roadway and prevent vehicles from colliding with dangerous obstacles such as boulders, buildings, walls or large storm drains. [Figure 1]

Figure 1. Steel traffic barrier to keep vehicles inside roadway.[2]

LOCATION OF INSTALLATION

Traffic barriers are installed at the roadside, to prevent errant vehicles from traversing steep slopes or entering deep water, and within medians of divided highways, to prevent errant vehicles from entering the opposing carriageway of traffic and to reduce head-on collisions.

Barriers are normally designed to minimize injury to vehicle occupants, injuries do occur in collisions with traffic barriers. They should only be installed where a collision with the barrier is likely to be less severe than a collision with the hazard behind it. Where possible, it is preferable to remove, relocate or modify a hazard, rather than shield it with a barrier.

To make sure they are safe and effective, traffic barriers undergo extensive simulated and full scale crash testing before they are approved for general use. While crash testing cannot replicate every potential manner of impact, testing programs are designed to determine the performance limits of traffic barriers and provide an adequate level of protection to road users.

MAIN TYPES

The main four types of barriers are shown in the following table. Our study is based on the cable barrier.

2.1	2.2	2.3	2.4
STEEL	**PLASTIC**	**CONCRETE**	**CABLE**

Table 1. Main types of barriers.

2.1 STEEL BARRIER

DESCRIPTION

It is a metal alloy barrier, where the main materials are steel and zinc (70% of composition). Stiffness is given by steel and zinc allows a higher deformation of the material, which is necessary to absorb the impact energy. The standard length is 7,65 meters. It could be made of aluminum and have different shapes. The steel barriers need a galvanized treatment not to be oxidized. [Figure 2]

Figure 2. Galvanized steel barrier.[3]

USE

They are used in highways, mountain roads, bridges, for instance, to avoid vehicles run of the road, and protect the passengers. Its function is to absorb the vehicle impact and keep the vehicle within the road.

DISADVANTAGES

It is also important to say that the beginning and ending of each section is buried or bended to prevent the front vehicle impact directly to the barrier. In case of such an accident the barrier could goes through the vehicle and damage the passengers causing grave injuries to them. [Figure 3]

Figure 3. Accident due to the beginning of the steel barrier.[4]

Lots of motorbike riders have had serious accidents with these barriers. The body impacts against the posts, this could make injuries such traumas, amputations and sometimes it could cause the death. The body also could go under the barriers and enter the opposing carriageway, which is dangerous as well.

In case of trucks or heavy vehicles this barriers are not enough. They could be totally broken without absorbing impact energy. They also could make these vehicles rollover.

SOLUTIONS

Install a parallel barrier under the normal one in order to not allow the body goes under the barrier. [Figure 4]

Figure 4. Parallel barrier under the normal.[5]

Covering the posts with some softer material, which absorbs the impact (this solution has not been very successful in tests and it is not very used). [Figure 5]

Figure 5. Covered post.[6]

Figure 6. Plate of softer material.[7]

The best solution everybody agrees with is to put a plate of softer material in front of the barrier posts to prevent the direct impact of the body against them [Figure 6]. Its efficiency has been proof and has saved lots of riders so far.

2.2 PLASTIC BARRIER

USE

Their main use is provisional, as in works. We also use this kind of barrier when we have to change the direction of the way. There is water inside of these barriers which absorbs the impact energy.

Figure 7. Plastic barrier.[8]

ADVANTAGES

They are mobile, provisional (works), economic and very safety for motorbike riders and bikers.

DISADVANTAGES

They do not absorb much energy, and are not safety enough for heavy vehicles.

2.3 CONCRETE BARRIER

DESCRIPTION

A permanent concrete barrier will only deflect a negligible amount when struck by a vehicle. Instead, the shape of a concrete barrier is designed to redirect a vehicle into a path parallel to the barrier.

Impact energy is dissipated through redirection and deformation of the vehicle itself.

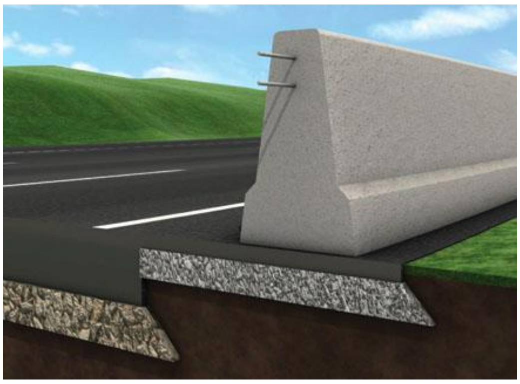


Figure 8. Concrete barrier.[9]

ADVANTAGES

It is not required maintenance. They keep the vehicle within the path in most of the cases.
They could be moved easily. High safety for riders.

DISADVANTAGES

The disadvantage is there is a higher likelihood of rollover with a small vehicle. Impact forces are resisted by a combination of the rigidity and mass of the barrier. Deflection is usually negligible.

They are expensive and they are not able absorb much energy.

2.4 CABLE BARRIER

They are made of posts, which are joined with steel cables [Figure 9].

ADVANTAGES

It has a low cost and an easy installation.

DISADVANTAGES

Not enough stiff neither safety because they are not capable to absorb the necessary energy sometimes, they cannot always keep the vehicle in the roadway. They are very dangerous for riders cause the cables could cut and injure them.

Figure 9. Cable Barrier.[10]

As we can see in the introduction, the last one type of barrier is the chosen to carry out the project.

This type of barrier has been chosen due to its simplicity when we are going to perform the calculation. During the project, our study is just based on the poste behavior, making it simpler.

3 OBJECTIVE

During the Project we are going to evaluate the crashworthiness, which is an ability of the structure for protecting occupants during an impact. It will be analysed the crash between a vehicle and barrier with Ls-Dyna program.

The explicit finite element program, which is called Ls-Dyna is widely recognized for crashworthiness analysis.

To expand variability of the crash type, we are going to use different values for velocities and angles. The election of the velocity has been based on the typical Spanish limits. The limits what we mentioned before is from following the text.

		50 km/h		70 km/h		90 km/h		120 km/h	
		VELOCITY (m/s)							
		13,9		19,4		25,0		33,3	
		Vx	Vy	Vx	Vy	Vx	Vy	Vx	Vy
ANGLE (°)	10	13,7	2,4	19,1	3,4	24,6	4,3	32,8	5,8
	25	12,6	5,9	17,6	8,2	22,7	10,6	30,2	14,1
	40	10,6	8,9	14,9	12,5	19,2	16,1	25,5	21,4
	55	8,0	11,4	11,2	15,9	14,3	20,5	19,1	27,3

Table 2. Values of the angle with its respective velocity.

Due to natural of the impact and the used vehicle, we are going to use different critters to determine the impact structure resistance.

In base of the established critters, we are going to study the simulation in terms of the overall impact Von Misses Stress, energy, and acceleration at various locations in the vehicle compare well with the full-scale test.

So, the main objective of this project is implementing a research about vehicles safety in order to be able to find solutions and improving Crash design. To achieve these solutions, it is the conductive study for passenger safety in vehicle.

In the following picture we can see the vehicle with its top view, and the position of the coordinate axes used in the program.

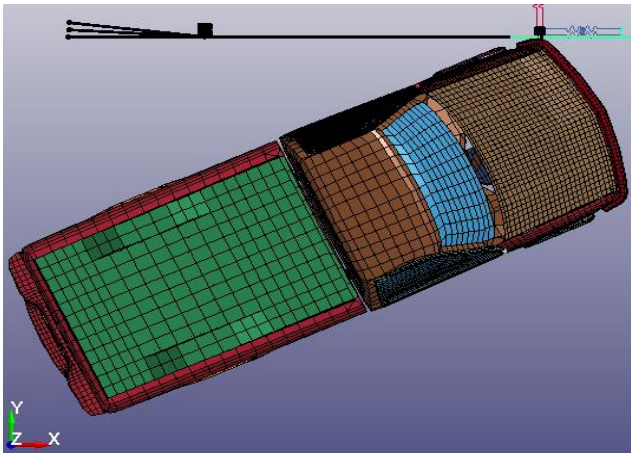


Figure 10. Top view of the car with its respective coordinate axes.

Following we are going to show the components of the analysis:

- VEHICLE

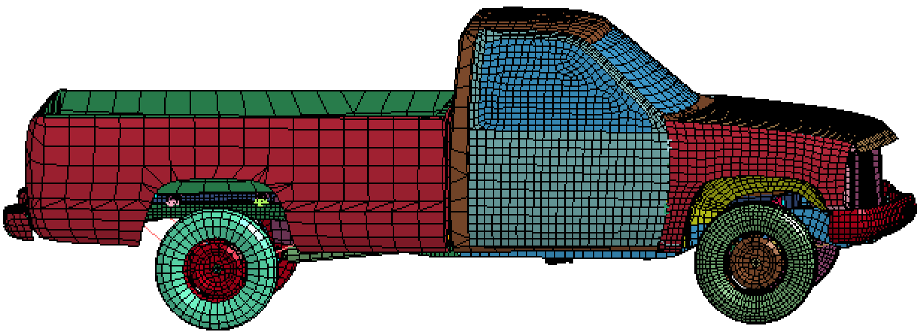


Figure 11. Finit element test vehicle.

- TRAFFIC BARRIER

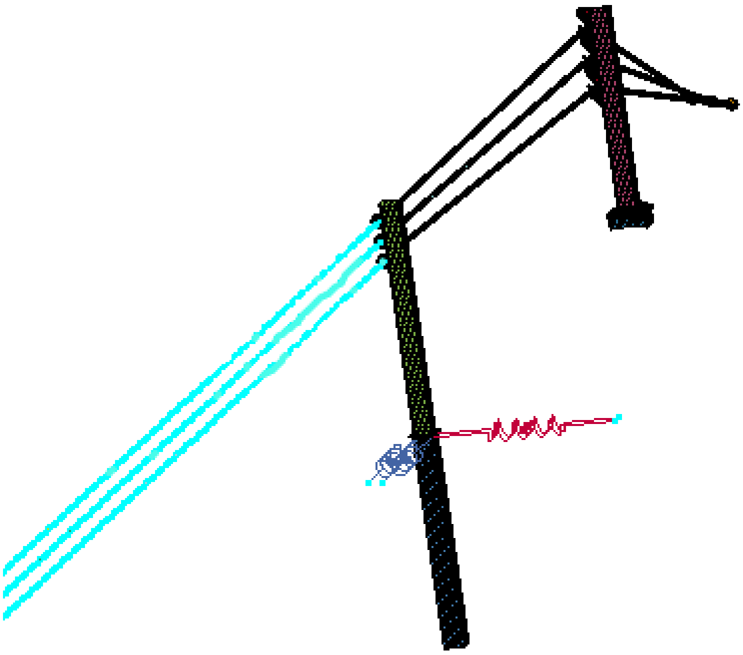


Figure 12. Finit element test traffic barrier.

4 STUDY

4.1 CASE 1

VELOCITY (km/h)	ANGLE (°)
120	10

Table 3. Values of the case 1.

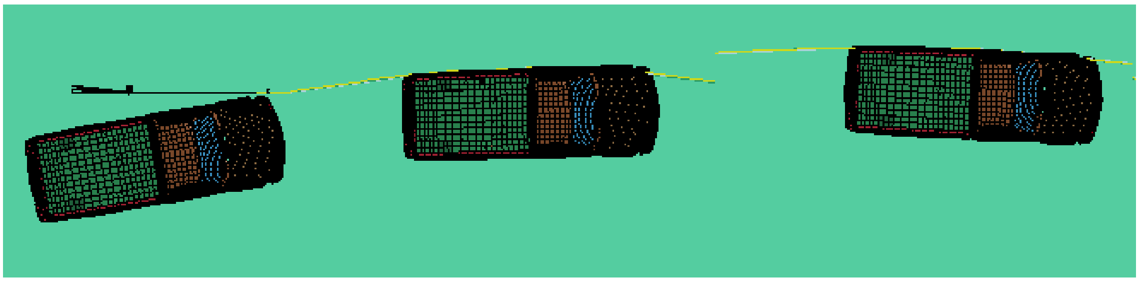


Figure 13. Sequence of the vehicle *movement in the case 1.*

Here a set of images showing Von Misses stress, where we can see some significantly changes between the different stages of the analysis. The vehicle impact has an initial velocity of 120 km/h and an approach angle of 10°.

The images show the base of a post belonging to the cable barrier. These were chosen in three different moments of the analysis, the starting point, intermediate point and the point of maximum deflection.

The chosen images we have used represent the base of the pole, view from two different sides. The image, which represents the values of this stress, is expressed in MPa.

BEFORE CRASH *(Time 0 ms)*

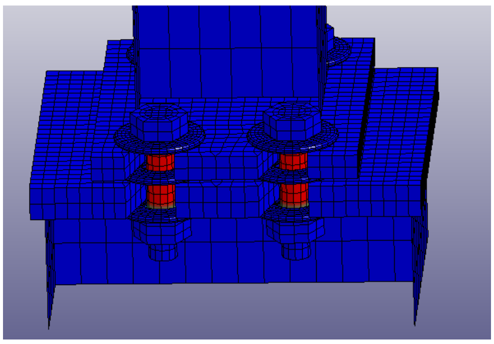


Figure 14. Frontal view

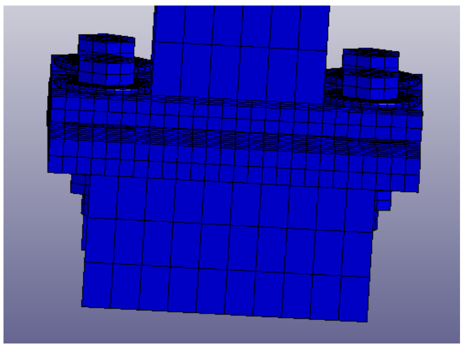
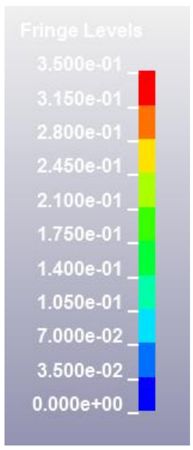


Figure 15. Side view



1

As we can see, the responsible screws for securing the post are under tensile stress due to its own pretension.
This represents a stress of 350 MPa (Plot 1).

<u>MIDPOINT</u> (*Time 200 ms)*

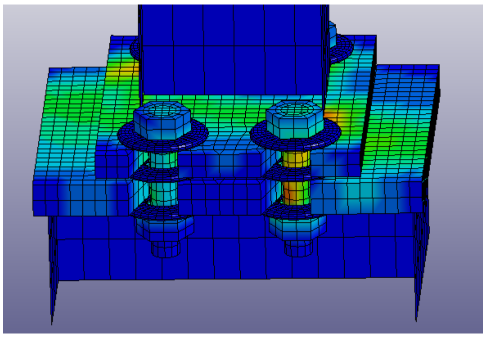


Figure 16. Frontal view

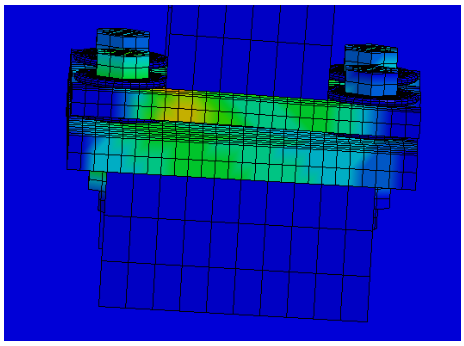
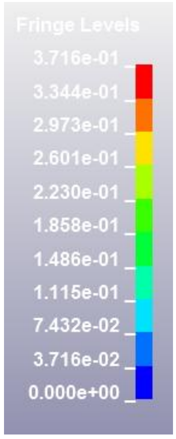


Figure 17. Side view



2

In the intermediate sequence we can see a slightly stress increment on the pole plates, but on the other hand, we also observed a slight decrease of the stress on the left screw.
This is due to the bending moment generated in the base of the post, one screw loses tension and the other one suffers a slight increase to a value of 370 MPa (Plot 2).

Between the plates we observe a slight separation.

<u>ACHIEVEMENT OF THE MAXIMUM STRESS</u> *(Time 340 ms)*

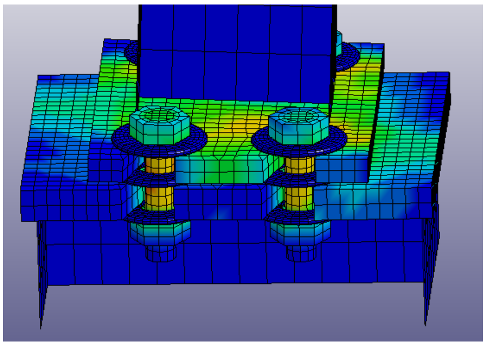


Figure 18. Frontal view

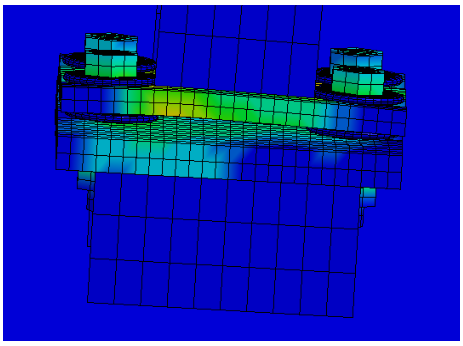
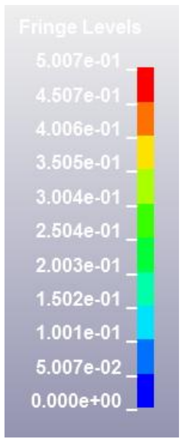


Figure 19. Side view



3

In the critic point when the maximum stress takes place, it is seen the tension of the screw can reach up to a value of 500 MPa (Plot 3.)

If we study the profile of the plates, it undergoes a significant deformation and separation.
The values obtained are significant, but do not reach the yield strength of steel screws.

Kinetic Energy is the energy of motion. As we can see in the following formula (1),

$K_e = 0.5 * m * v^2$ (1)

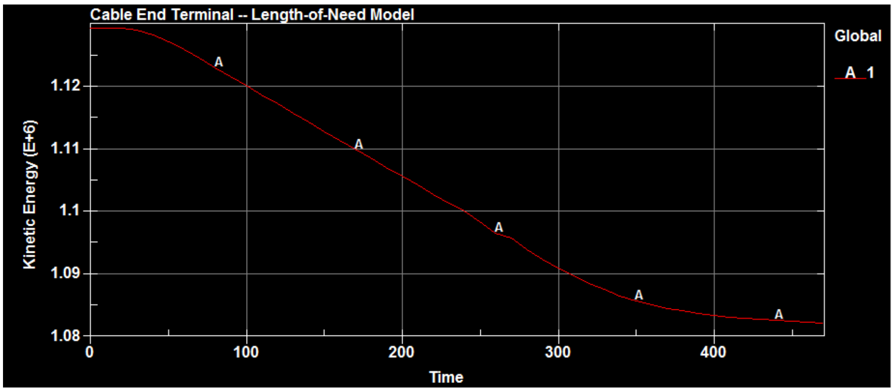


Figure 20. Plot Kinematic Energy (Time (ms) / Energy (J)).

This equation reveals that the kinetic energy of an object is directly proportional to the velocity squared.

As it is shown in the chart, once the vehicle hits the barrier, its kinetic energy decreases steadily until reaching stability. This is because the energy absorption of the barrier, decreasing vehicle velocity. The energy dissipation represents a value of 50 000 kJ.

The kinetic energy is converted into internal energy due to material deformation.

A dissipation of the internal energy is noted at the end of the graph, this is due to the elastic energy.

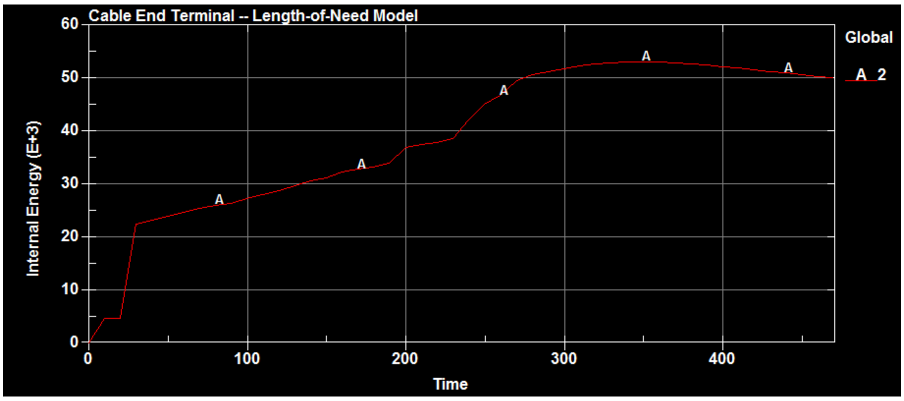


Figure 21. Plot Internal Energy (Time (ms) / Energy (J)).

We observe the principle of conservation of energy because we lost 50.000 kJ of Kinetic energy, and we gain 50.000 kJ of internal energy.

Finally, on the node number 3659, the acceleration of the vehicle increases significantly by the time of 150 ms.

This reaches a value of 1450 m/s^2, which is quite a high value, but probably it will cause injuries on the passengers.

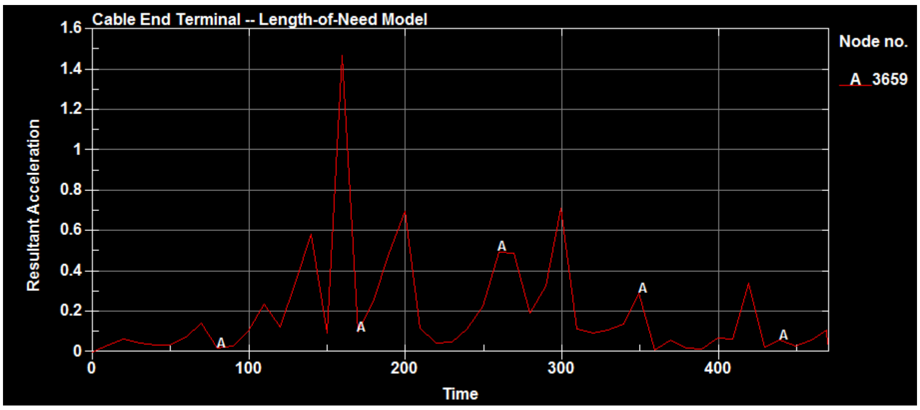


Figure 22. Plot Resultant Acceleration (Time (ms) / Acceleration (mm/ms^2)).

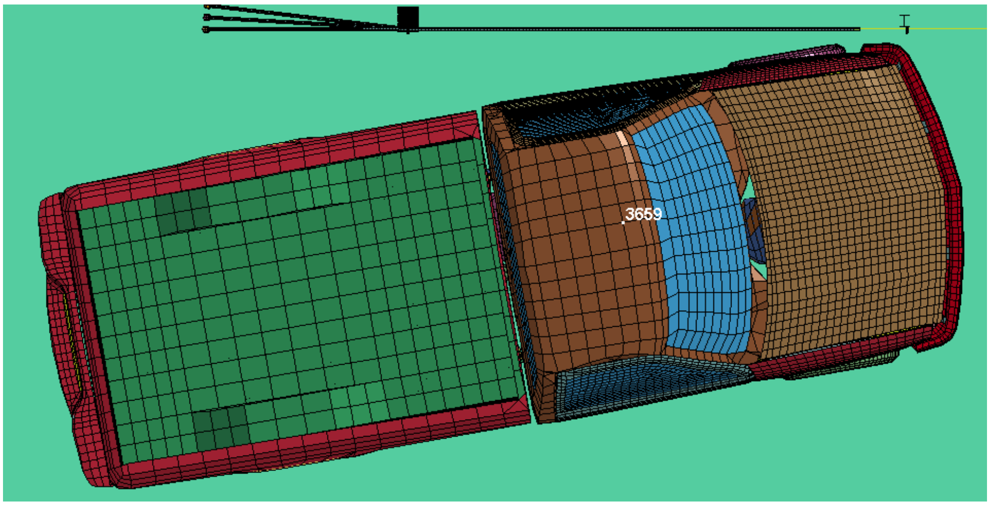


Figure 23. Node where we study the acceleration.

4.2 CASE 2

VELOCITY (km/h)	ANGLE (°)
70	40

Table 4. Values of the case 2.

Here we have the sequence of images of the case of 40° and 70 km/h. This file cannot be fully run so we only have few frames.

Concerning the second case, as we can see in the images displayed on the page (X), occurs a small break of one of the hooks of the barrier. Studying according to the first case, in which we have not seen any break, we can conclude that not only an increased the speed influences the outcome of the clash, but an increased of the angle is important.

The following figure it shows us the view of the vehicle position. The rectangular shape represents the area where we have based our images.

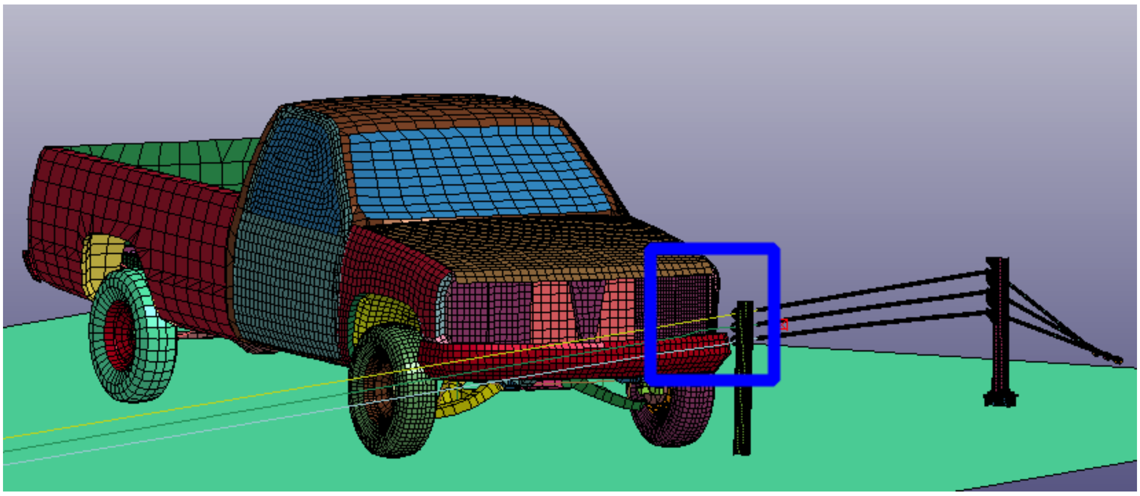


Figure 24. Vehicle view.

The time corresponding to each sequence is:

- Sequence 1 (20ms)
- Sequence 2 (30ms)
- Sequence 3 (40ms)

As in the first study, the chosen images we have used represent the base of the pole, view from two different sides.
The image, which represents the values of this stress, is expressed in MPa.

Firstly we show a general view of the crash. The frames where we can figure out how the materials are deformed.
And secondly the Von Misses stresses in the base of the pole.

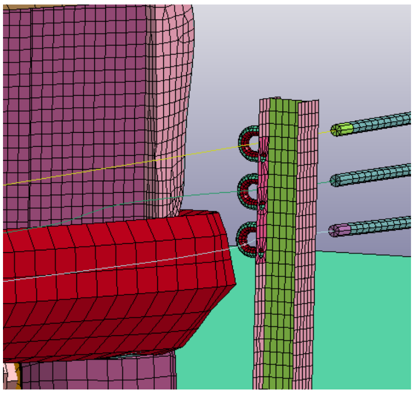


Figure 25. Sequence 1

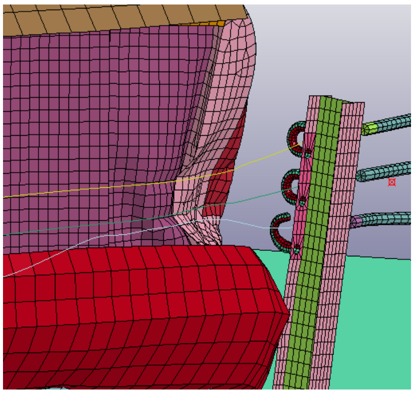


Figure 26. Sequence 2

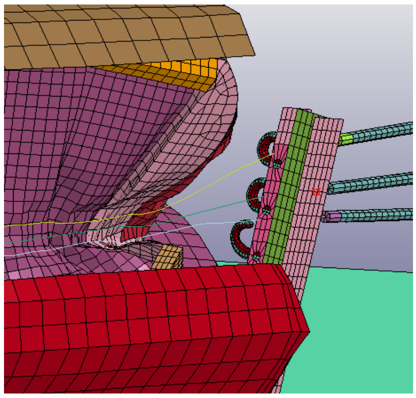


Figure 27. Sequence 3

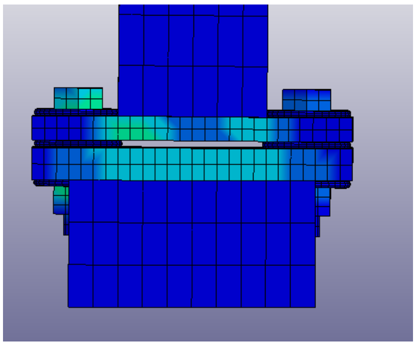


Figure 28. Sequence 1

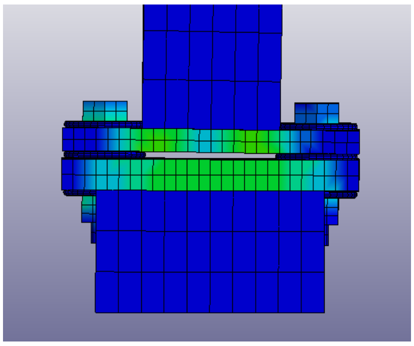


Figure 29. Sequence 2

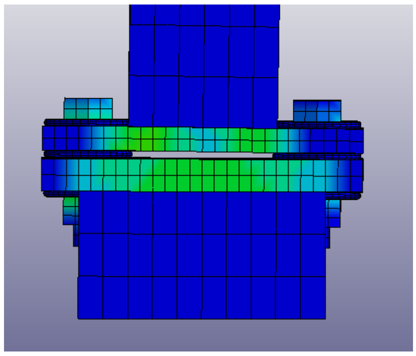


Figure 30. Sequence 3

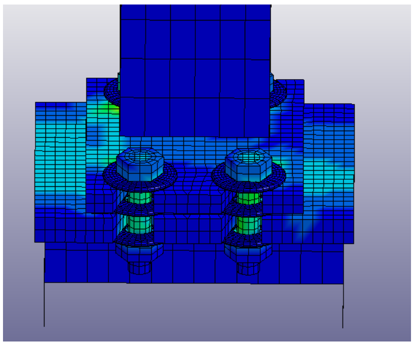


Figure 31. Sequence 1

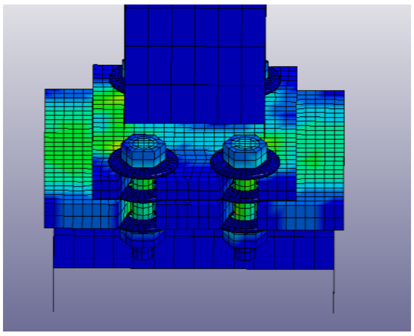


Figure 32. Sequence 2

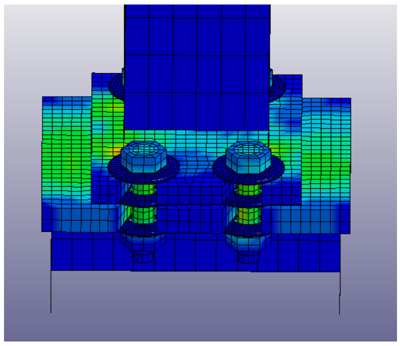
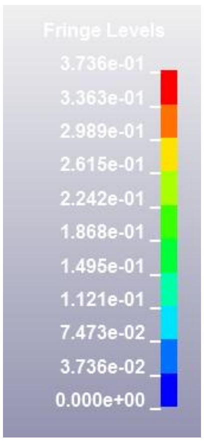
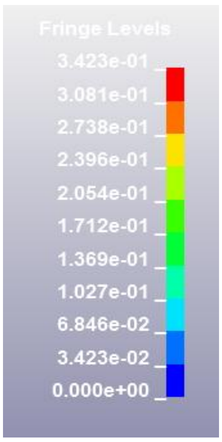


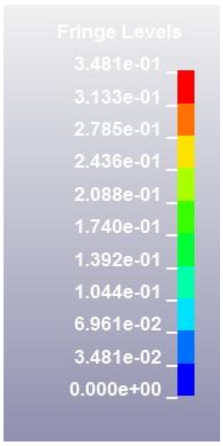
Figure 33. Sequence 3



4



5



6

4.3 CASE 3

VELOCITY (km/h)	ANGLE (°)
90	40

Table 5. Values of the case 3.

The last case we analyse, third case, is the one where the pole is completely destroyed just before Ls-Dyna crashes. If we increase the velocity to 90 km/h and the angle is 40° the pole will not resist the crash at all.

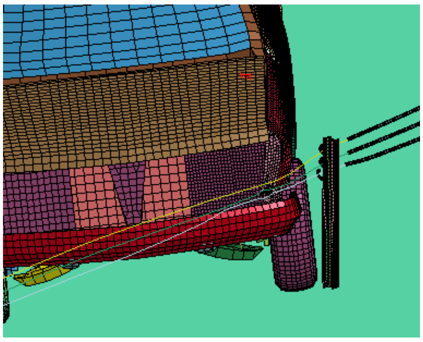


Figure 34. Sequence 1

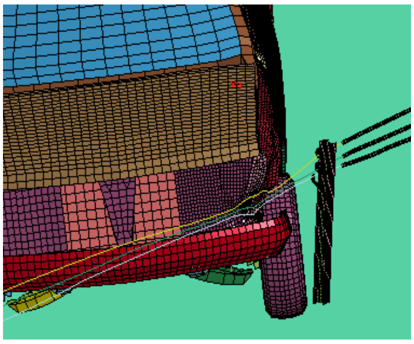


Figure 35. Sequence 2

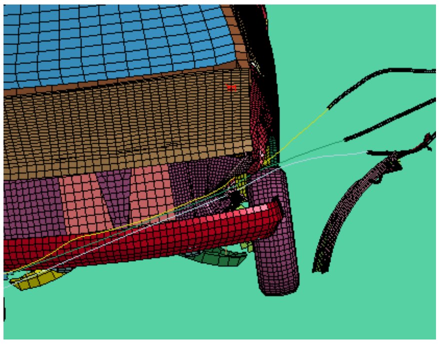


Figure 36. Sequence

4.4 CASE 4

Almost any file is run properly due to finite elements errors. We are just able to get good results from the 10° cases.

So we analyse and compare the different values obtained in these cases. In the other cases we just make a brief comment using a series of images that can show what happen until the program collapses.

All data is showed from the following table.

		MAX. ACELERATION		MAX. STRESS		ENERGY ABSORTION
		VALUE (G)	TIME (ms)	VALUE (MPa)	TIME (ms)	VALUE (kJ)
VELOCITY	50 km/h(*)	60	350	860	480	30.000
	70 km/h(**)	28	250	370	250	>30.000
	90 km/h	62	440	400	340	45.000
	120 km/h	148	160	500	340	50.000

Table 7. Analysis different values.

(*) The vehicle hits the post violently and a strange phenomenon occur, the total energy increases, which has no sense, it is also produced a high acceleration and great stresses.

(**) Only half of the analysis is completed so we cannot ensure that values of acceleration, stresses and energies are the maximums ones.

Logically, the higher is the crash velocity the higher are the stresses, accelerations and absorbed energies. There are only a few strange results that are not logical due to finite elements errors.

We can say that all crash has quite high accelerations comparing with these values.

SOME TYPICAL VALUES OF G-FORCE	
DESCRIPTION	**VALUE**
Death or serious injury likely	25G
Maximum for human on rocket sled	46,2G
Brief human exposure survived in crash	100G
Highest recorded g-force ever survived (Kenny Bräck, 2003)	214G

Table 8. Some typical values of G-force. [11]

There is a considerable variation among individuals referring to G-force tolerance. But G-force also depends on many different factors, especially the time. The longer the G-force is acting, the worse will be the consequences and damage.
As we can see in the table, race car drivers have survived instantaneous accelerations of up to 214 g during accidents.

In some degree, G-tolerance can be trainable, and there is also considerable variation in innate ability between individuals. In addition, some illnesses, particularly cardiovascular problems, reduce g-tolerance.

The following graphics show the possible errors that could be made in the program analysis.

As we can see, when kinetic energy begins to be stable, an unexpected phenomenon occurs that makes this energy rise with no reasonable cause.

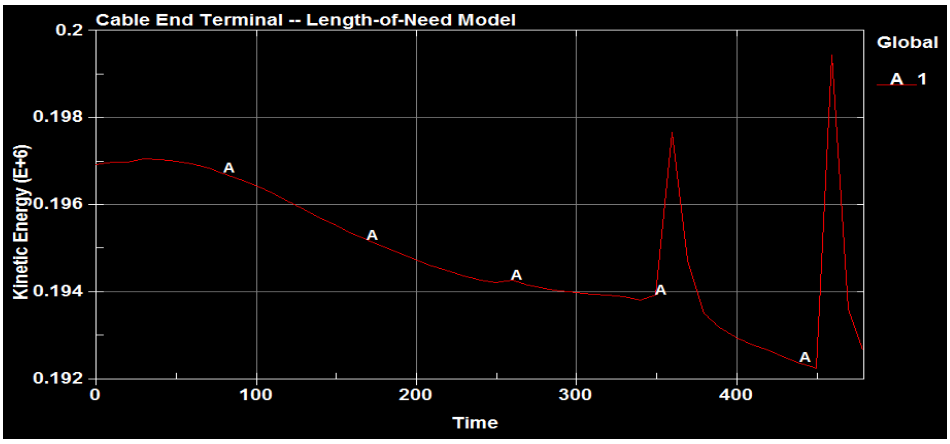


Figure 37. Plot Kinematic Energy for 50 km/h (Time (ms) / Energy (J)).

When the internal energy seems to reach its maximum value, an unexpected increase occurs.

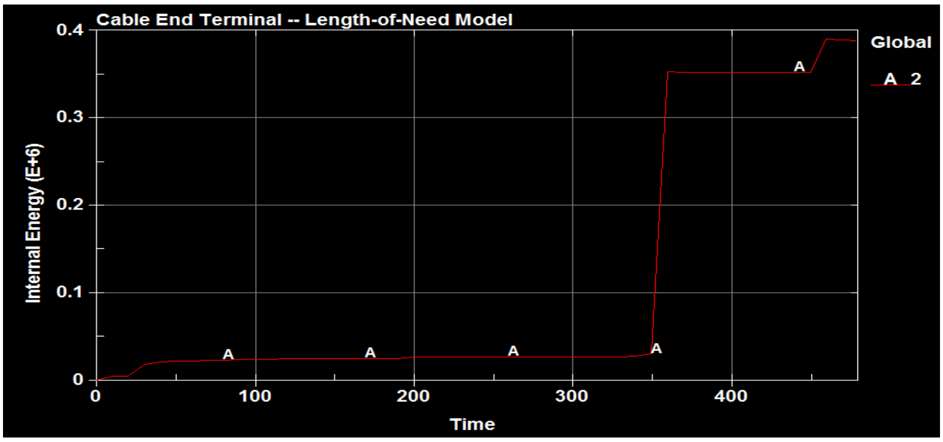


Figure 38. Plot Internal Energy for 50 km/h (Time (ms) / Energy (J)).

In this plot where the value of total energy varies abruptly, it is proven that the analysis is invalid.

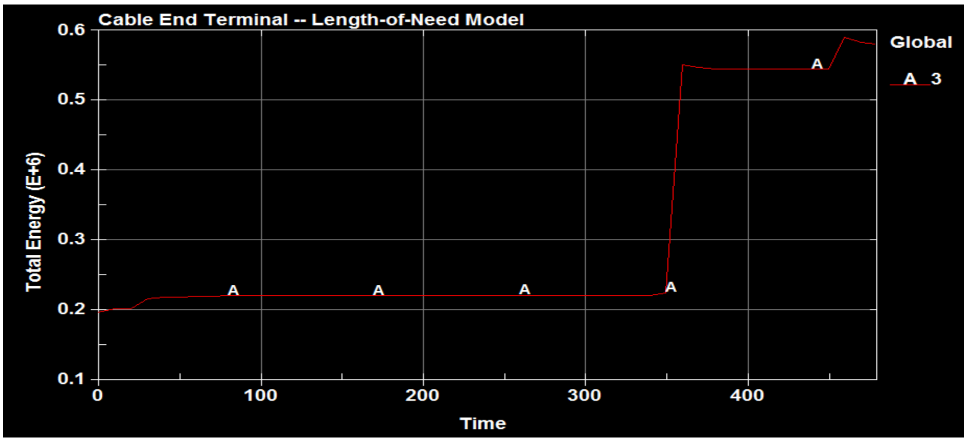


Figure 39. Plot Total Energy for 50 km/h (Time (ms) / Energy (J)).

5 CONCLUSION

Nowadays the passenger and pedestrian security is one of the most important concerns in the automotive sector. This industry is changing rapidly to address the stringent requirements for safety and security of the vehicle. Requirements are not only coming from customers, but regulatory authorities are also pressuring for greater safety and security in vehicles. This is one of the main reason why we have chosen this project.

Carrying out real simulations is expensive and takes a long time. For this reason, such research like this we make can be very useful.

Firstly, to make this study we learn concepts such as energy absorption, material properties and types of barriers. Once we get this basic knowledge we have to decide which cases are going to be studied. For instace, in our case, we come to the conclusion that it is not worth studying crash angles over 55 degrees due to the unlikelihood of such an impact. When we exactly know the models to be studied we create them on the computer program with all their respective parameters and run them. We can spend a few hours until we get the results as the numerical simulations are very complex. After all we get the results and we draw the conclusions that we have exposed.

It is a fact that finite elements method is not exactly real and sometimes, actually in most of the cases, we do not get any results or the results we get are not logical. However, these computer programs such as Ls-Dyna and Ls-Prepost have improved exponentially reaching accuracies we did not even dream few years ago.

Finally, we could say that we can get quite interesting and relevance data if the analysis is carried out carefully and people have a deep knowledge about finite elements method.

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