

Road Restraint Systems in Abaqus

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Abstract: Road restraint systems (RRS) play a key role in the consequences of many road accidents, yet such systems have only undergone minor improvements over recent decades.

As a result of this, the UNE EN-1317 European regulation has been implemented in order to qualify RRS in terms of safety and performance. Virtual development of the new UNE EN-1317-compliant RRS brings challenges to regular crash test analysis. When a vehicle crashes into an RRS, some of the poles sustaining the guardrail collapse, usually a few centimeters under the surface of the soil, after that, some of the preloaded bolts connecting the guardrail to pole fail, freeing the guardrail from the pole, and finally, the guardrail has to withstand the remaining vehicle energy and conveniently redirect it into the road again.

In this paper, a correlation between simulation and a full crash test is presented. In order to achieve good agreement in the correlation, several Abaqus analysis techniques are evaluated. First of all, the soil mesh undergoes important distortion, so we need to go beyond the regular Lagrangian mesh and evaluate other approaches such as Arbitrary Lagrangian-Eulerian (ALE) and Coupled Eulerian-Lagrangian (CEL). Secondly, an implicit-explicit scheme is necessary in order to take into account the bolt-preloading, which has proven to be critical in the overall behavior of the system. Finally, subcycling is adopted in order not to penalize the global time increment due to the detailed bolt assemblies.

Keywords: Bolt Loading, CEL, ALE, Subcycling, Damage, Failure, Safety, Soils, Tires

1. Introduction

This study was done with the final objective of improving the results between test and simulation of RRS in order to be able to develop this kind of system in a reliable manner.

As a reference, a real test was used. The test was carried out according to European regulation EN-1317. The specific test is of the type TB32 where a medium sized car (1500 kg) is crashed against the barrier at 110 km/h with an angle of 20° between the car trajectory and the barrier.

RRS present a number of challenges that require using advanced features of the simulation software. Such capabilities are not always available in some of the most common software used in the automotive industry, so research is necessary to validate the suitability of this software.

Some of the main factors to take into account are:

- Capability of Implicit and Explicit Analysis and their ability to transfer the results between them
- Availability of soil material laws
- The regular features required in any automotive Explicit crash analysis, such as progressive damage and failure of materials, robust behavior of the contact interactions and reliable modeling of parts such as tires

The study is divided into phases, from soil testing to the final correlation of the whole crash test:

- Pull-out test of a pole inserted into the soil
- Soil material parameters adjustment and validation against the pull-out test
- Whole crash test correlation
- Conclusions of the study

2. Pull-out test of the pole

The soil used with RRS is a mixture of gravel with coarse sand. The behavior of this kind of material presents challenges when modeled using finite elements, as it is a relatively soft material that is able to undergo high deformations.

Our goal is to obtain a reasonably good agreement in a specific test: the pull-out test.



Figure 1. Configuration of a pole pull-out test

In this test a pole is inserted into the soil and is pulled up to a certain force. Both, displacement and force are measured for correlation proposals.

3. Soil modeling

Several approaches can be used to achieve a good correlation between simulation and test, these include:

- Using standard FE elements and a material law with progressive damage and failure
- Arbitrary Lagrangian Eulerian (ALE) adaptive meshing
- Coupled Eulerian-Lagrangian (CEL)

3.1 Using standard FE elements and a material law with progressive damage and failure

This approach could be accurate enough in several scenarios, although, its behavior is not physically realistic compared with the test. In the test the material flows around the pole, such behavior is not achieved using a material with progressive damage and failure, where the elements are eliminated once a certain threshold is reached.

3.2 Arbitrary Lagrangian Eulerian (ALE) adaptive meshing

The ALE allows a FE mesh to undergo high values of strain. This approach is much more suitable for our objective.

In this paper, this analysis technique is tested and correlated with a real pull-out test.

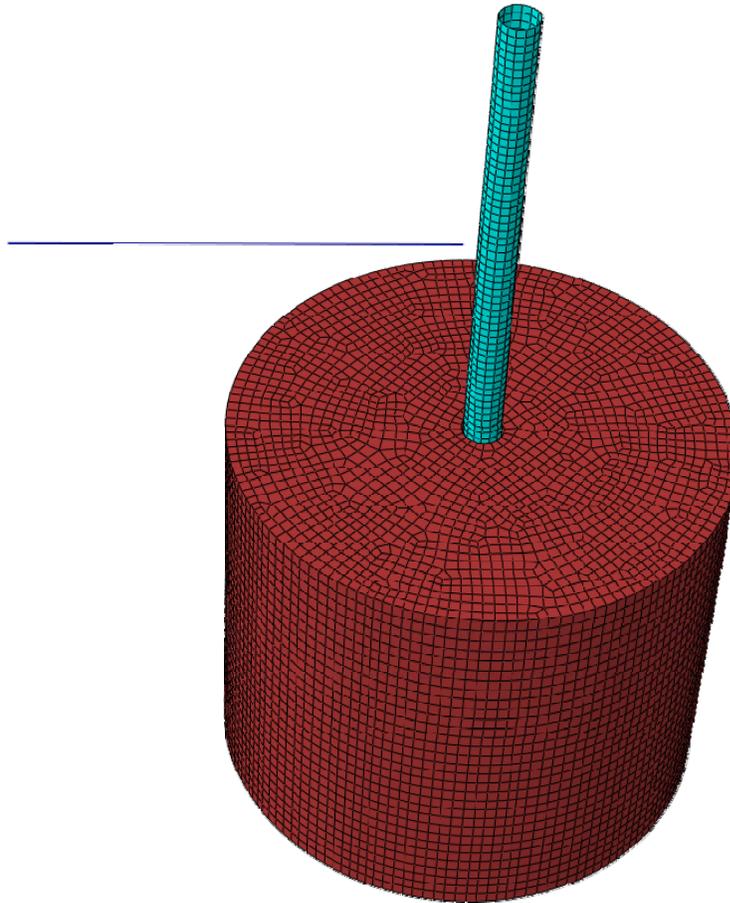


Figure 2. Mesh model

The soil is meshed with solid elements and the pole with regular shell elements.

Definition of the ALE domain is quite simple, and is done through the keyword:

```
*ADAPTIVE MESH,ELSET=elset_name,FREQUENCY=freq,MESH SWEEPS=sweeps
```

In order to keep a good performance during the calculation some attention is needed when defining parameters **FREQUENCY** and **MESH SWEEPS**. They are the key to achieving a good balance between accuracy and performance in the calculation.

Regarding the soil material, a Drucker-Prager material law was used.

Drucker-Prager model is suitable for granular-like soils materials with pressure-dependent yield and that are sensitive to the rate of straining.

Correlating a Drucker-Prager material law was a hard work with a lot of iterations. Even though, most of the mechanical properties of the soils are available in the literature, some tuning is necessary to achieve a good correlation.

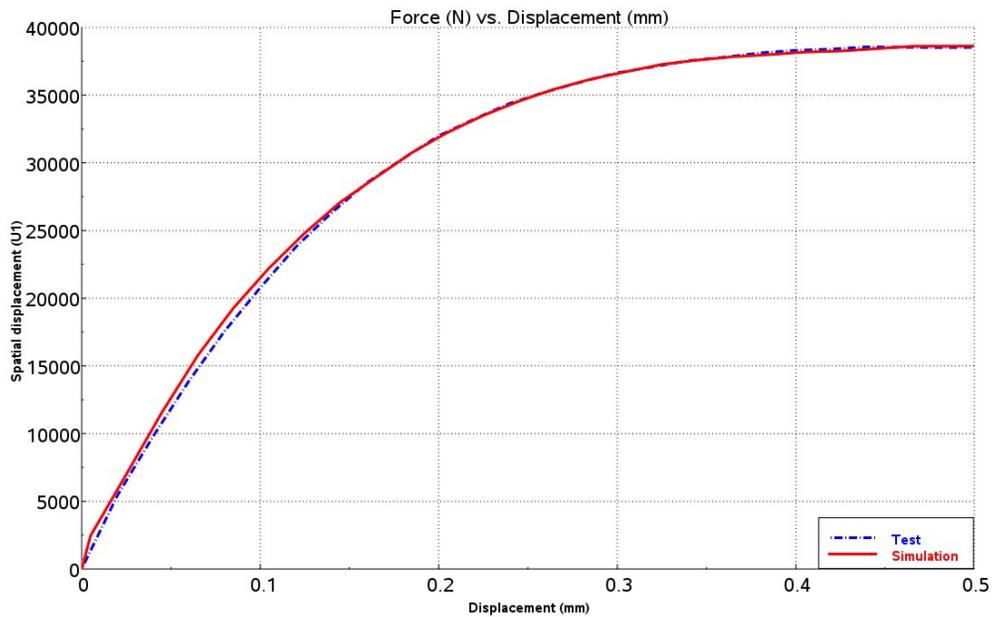


Figure 3. Force (N) vs. displacement (mm)

3.3 Coupled Eulerian-Lagrangian (CEL)

Not all the countries in the European Community use the same kind of gravel. A few countries use a mixture of sand to support their barriers which allows the poles to be dragged out of the soil when a crash happens.

In these cases, we have an extreme deformation of the soil, more like a flow of material than a deformation itself. In this scenario, even the ALE technique has its limitations.

When involving a flow behavior an analysis technique like CEL could be much more appropriate.

CEL analysis allows the material flow through the Eulerian mesh. Additionally, Eulerian materials can interact with a Lagrangian mesh through contact interactions.

In our study, the soil is in an Eulerian domain filled with soil plus void (part of the Eulerian domain without material, but that could be filled with soil if required). On the other hand, the pole is the Lagrangian domain and the interaction between both domains is done using a contact interaction.

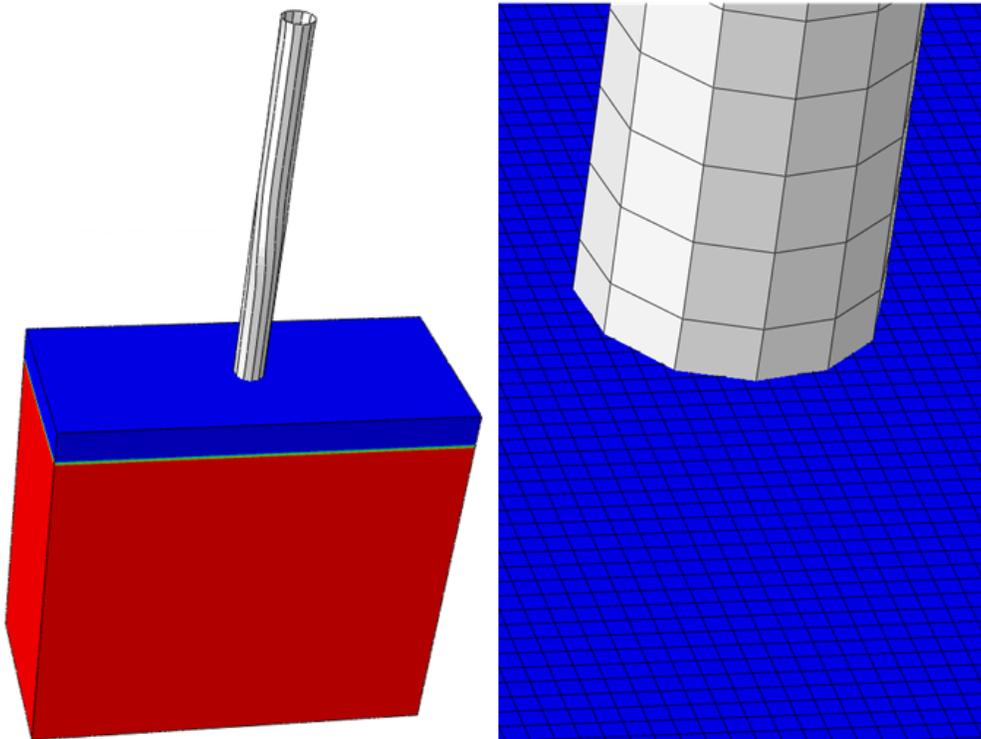


Figure 4. On the left, material assignment. On the right, detailed view of the mesh

As can be seen in the picture above, the Lagrangian mesh of the pole is inside the Eulerian mesh. Some of the Eulerian elements are filled with a soil material, so it is necessary to indicate to Abaqus which part of the volume of such elements is shared by a Lagrangian mesh.

This action can be performed using the Volume Fraction tool included in Abaqus/CAE. The Volume Fraction tool creates a set of initial conditions that will be used at the beginning of the analysis:

```
*INITIAL CONDITIONS,TYPE=VOLUME FRACTION
```

Another advantage of using CEL is its capability of using a wide range of material laws. Among these materials there is Drucker-Prager as well, so we could use the same parameters found when calibrating the ALE model.

However, in this case we have not correlated the material behavior because what we would like to do is to study the possibility of using CEL when the pole is buried in sand.

To do that, we used sand material parameters obtained in bibliography and we carried out the pull-out test with this new soft material.

The calculations done show that CEL is a very good solution for this kind of problem, although some considerations had to be taken into account to carry out a full crash test analysis, these being:

- There is no need to create a new mesh for the soil each time we change the profile of the pole, but we have to use the Volume Fraction tool in Abaqus/CAE in order to generate the initial conditions for the calculation.
- The contact interaction between an Eulerian domain and the Lagrangian mesh needs to have between 3 and 5 Eulerian elements for each face element at the Lagrangian domain. This means that if we have a Lagrangian element with a side length of 12 mm we will need to create a Lagrangian domain of 4 mm or less in the area where the contact could take place. The consequence of this is a fine Eulerian mesh which needs a large calculation time.

The results show that the CEL analysis is able to undergo extreme deformations without any problem.

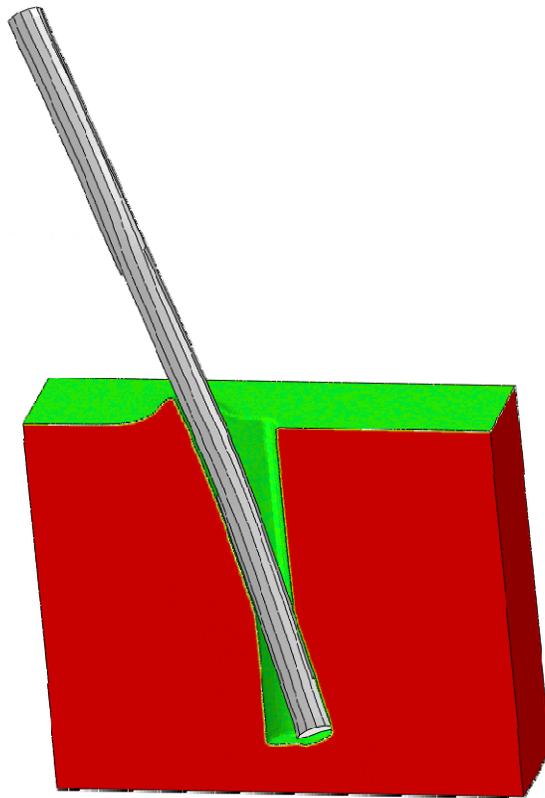


Figure 5. Deformed plot of the CEL calculation

4. Complete vehicle crash correlation

The complete model calculation is a sequence of calculations. First of all, an Implicit calculation is carried out including only the poles and the bolts. This first assembly is used to obtain the stresses in the bolts and the nearby areas.

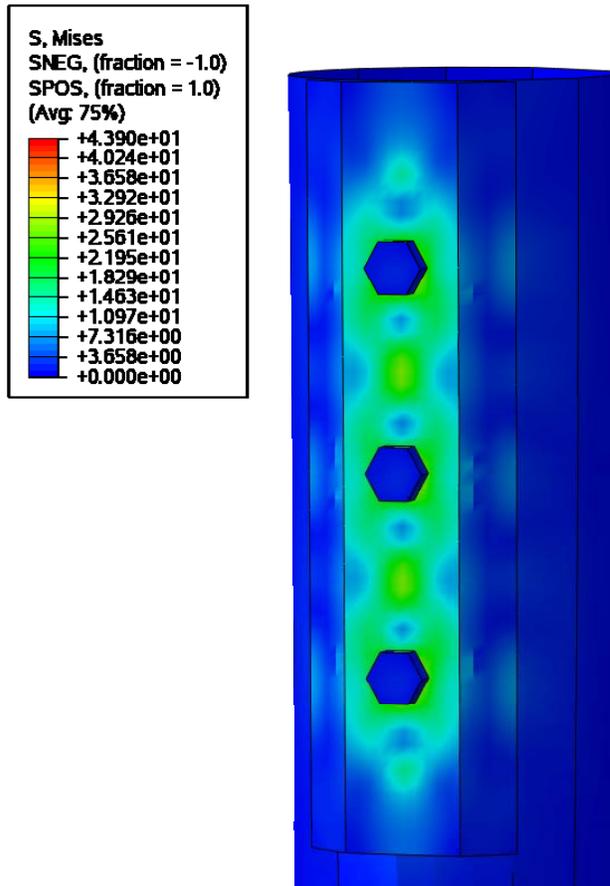


Figure 6. Stresses (MPa) due to the bolt pretension

Secondly, the remaining model is added to this initial Implicit calculation. The soil model, the barrier and the car are now included in the complete model.

The first task performed at the Explicit calculation is to import the Implicit model and its stresses and strains. This is done using the keywords:

```
*IMPORT, STATE=YES, UPDATE=NO
List of element sets that are to be imported,
*IMPORT ELSET
List of element set names for which the element set definitions are to be imported,
*IMPORT NSET
List of node set names for which the node set definitions are to be imported,
```

The next step is to redefine all the entities from the Implicit analysis that we want to use in our Explicit analysis, among others, the surfaces that will be used in the contact interactions:

```
*SURFACE, NAME=surface_name, TYPE=ELEMENT
```

After that, we can continue with the standard definition of the model (*NODE, *ELEMENT, etc.). Once, the Explicit model is defined we should define the subcycling areas:

```
*SUBCYCLING, ELSET=elset_name
```

The following action is to define the History Data, that is the *STEP

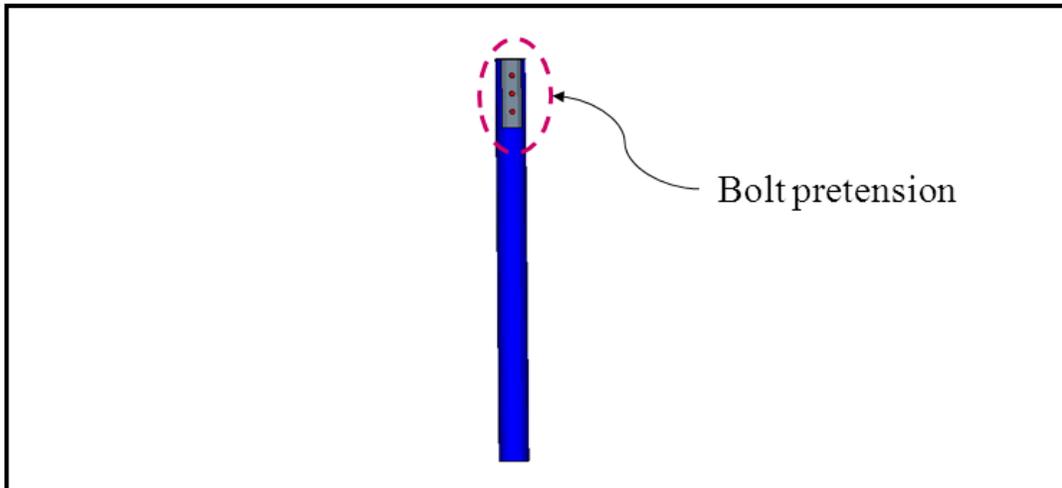
Inside this section we have to include the definition of the adaptive mesh domain used in the soil:

```
*ADAPTIVE MESH, ELSET=elset_name, FREQUENCY=freq, MESH SWEEPS=sweeps, CONTROLS=controls
```

Regarding the contact interactions we have to take into account the following considerations:

- It is not a good practice to include in the same surface elements included in the subcycling domain and elements of the global domain.
- Elements involved in adaptive domain should interact with other elements using Contact Pairs
- Regarding the other contact interactions in the model, General Contact definition can be used without any special restriction

Implicit calculation



Explicit calculation

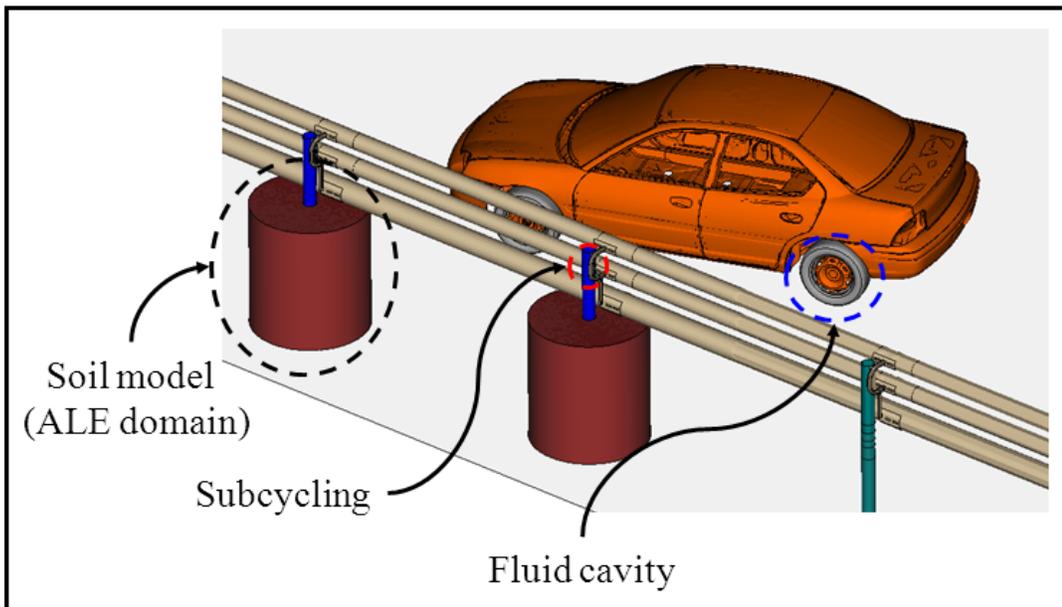


Figure 7. Sequence of the calculations

Looking at the results, one of the first things we checked was the failure of the bolted connections. As explained before, they can be the difference between a successful test and a failed one. Another point to take into account is the high deformation at the soil material. The deformation of the soil and the pole was very realistic and matched very well the behavior observed in this kind of test.

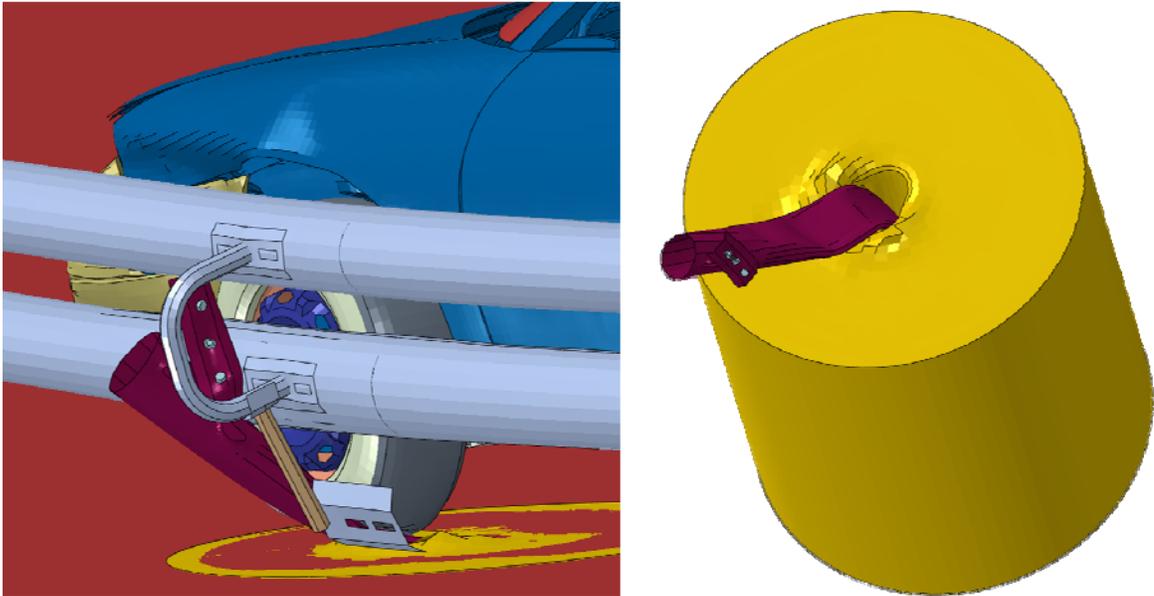


Figure 8. Failure of the bolts and soil deformation

Finally, the shape and the total value of the deformation on the barrier were measured. Both values and deformed shape were compared, with good agreement.



Figure 9. Maximum deflection during the test and simulation

5. Conclusions

The presented work is the result of the aim of improving the agreement between test and the simulation of RRS. A methodology was defined and tested, so it can be used in future projects with confidence.

The key factors that could determine the result of the test had been included in the simulation, such as failure of bolt assemblies with pretension, reliable soil behavior and a complete car model including relevant features such as detailed definition of tires or material failure.

6. References

1. Abaqus User's Manual, Version 6.11, Simulia
2. National Crash Analysis Center (NCAC), Dodge Neon car model, <http://www.ncac.gwu.edu/vml/models.html>