POLITECNICO DI TORINO

Master of Science course in

Automotive Engineering

Numerical-experimental procedure to scan and measure the deformation patterns of honeycomb made barriers used in vehicle crash tests

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1. Introduction

This thesis has been developed in the FCA Safety Centre in Orbassano (TO). In this document a new test of Euro NCAP will be presented. The test is the Mobile Progressive Deformable Barrier one, in which a new progressive deformable barrier is utilized. The reason why a new barrier will be used will be explained in the following. The reason why this test will be introduced in the rating of the new cars from the year 2020 is the compatibility between vehicles in case of impact. It will be explained in the following.

Some projects have been developed during the years about the compatibility topic. They will be explained in this document. They started in the 1996 with the EEVC WG 15, continued with the VC-COMPAT and finished in the 2012 with the FIMCAR project. These projects were financed by the European Committee in order to find a test for the evaluation of the compatibility in each vehicle. The scope has been reached with the last project.

The practical purpose of this thesis is to develop a numerical-experimental procedure in order to evaluate the deformation pattern of the new honeycomb progressive barrier. The procedure will be useful in order to give a score of the test. The procedure should be implemented by using the available tools. The tools already available in the Safety Centre office are a 3D scanner ATOS Core 500 and the relative software ATOS Professional 2016, produced by GOM (Gesellschaft fűr Optische Messtechnik mbH). They will be better explained in the following.
The procedure, ones implemented, it must be tested on physical barrier and, if possible, it must be validated by using a comparison with other results obtained in external laboratories with other methods. It can be validated also by using other type of methods.

The results obtained from the scansion and the procedure utilized for the evaluation will be discussed at the end of the document.

2. EURO NCAP

The European New Car Assessment Programme (Euro NCAP) is a voluntary vehicle rating testing system created by the Swedish Road Administration, the Fédération Internationale de l'automobile and International Consumer Research & Testing, and backed by the European Commission, seven European governments, and motoring and consumer organisation in every EU country.

It is important to make a distinction between homologation and rating test. The first is a typology of test that is mandatory and it is required by the law in order to sell the vehicle. The result of this kind of test is passed or failed. Rating test is a test not mandatory by law but made in order to give a rating. Euro NCAP deals with rating test and the evaluation is on a scale of maximum 5 stars. The scope of the Euro NCAP is to evaluate the safety of a new vehicle model that is on the European market, so already homologated, and spur the car makers to project always a safer vehicle.

Since the test of this program are not mandatory, the severity of the tests is higher with respect to the homologation tests.

The actual set of tests performed by Euro NCAP includes four different categories:

- the occupant protection (that comprise driver and passengers);
- the child occupant protection;
- the vulnerable road user protection (which includes pedestrian and cyclists);
- and the safety assist (with the evaluation of driver-assistance and crash-avoidance technologies).

Each category includes some tests. In the occupant protection area the tests that are performed are the offset deformable barrier (in which the offset is of 40% of the vehicle width), the full width rigid barrier, the side mobile barrier, the side pole, the whiplash and the Autonomous Emergency Braking (AEB) city.

In the area of child occupant protection, the tests include the Child Restraint System (CRS) Performance, the vehicle provision and the CRS installation check.

In the vulnerable road user protection category, the tests included are the head impact, the upper leg impact, the lower leg impact, the AEB pedestrian and the AEB cyclist.

In the last area, the one of the safety assist, the technologies tested are the Electronic Stability Control, the Seatbelt Reminders, the Speed Assistance, the AEB Interurban and the Lane Support.

2.1. History of Euro NCAP

The Euro NCAP, from its birth till today, has increased the difficulty in reaching five stars of evaluation. In this way, a carmaker that want to reach the maximum rating has to increase the safety of the vehicle.

In FIGURE 1 a road map from the birth of Euro NCAP till today is represented with all the steps.

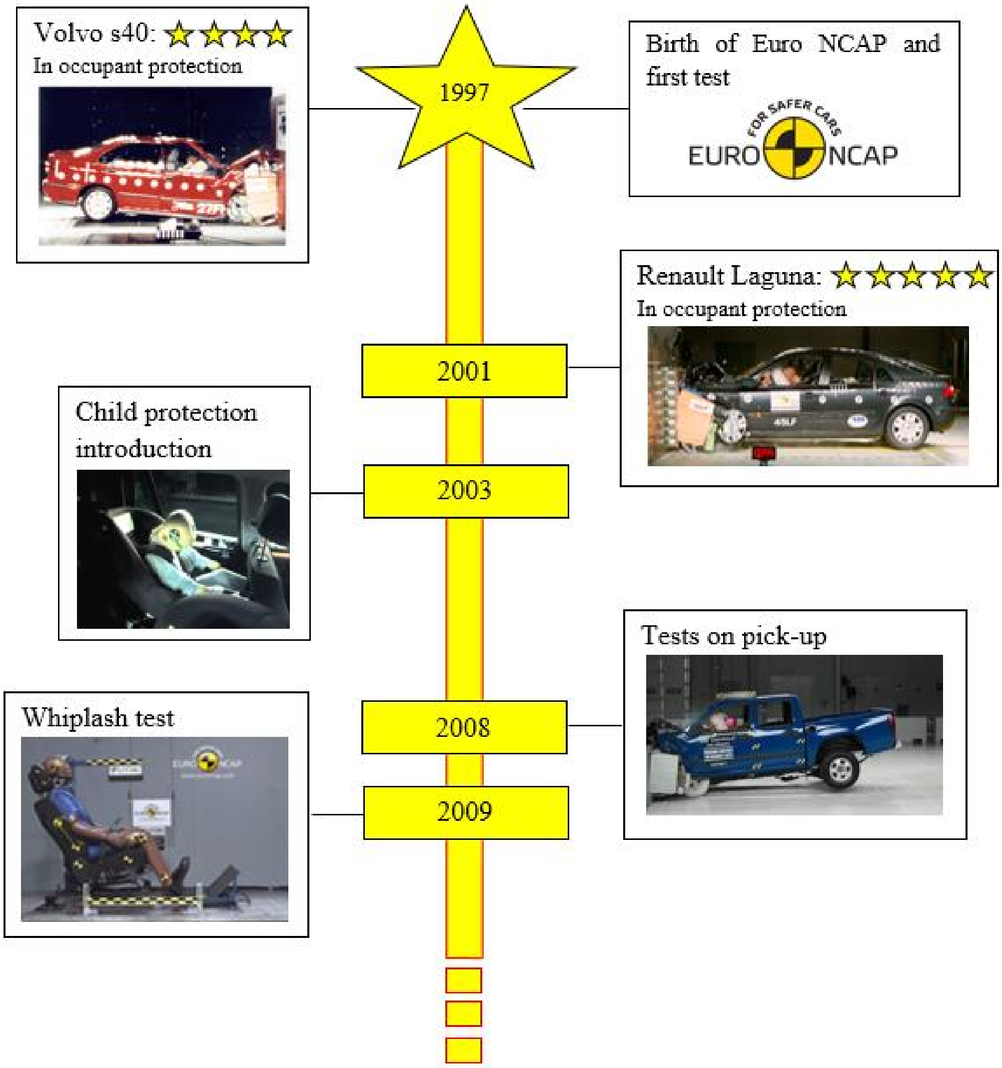


FIGURE 1 - Road map of Euro NCAP 1997-2009

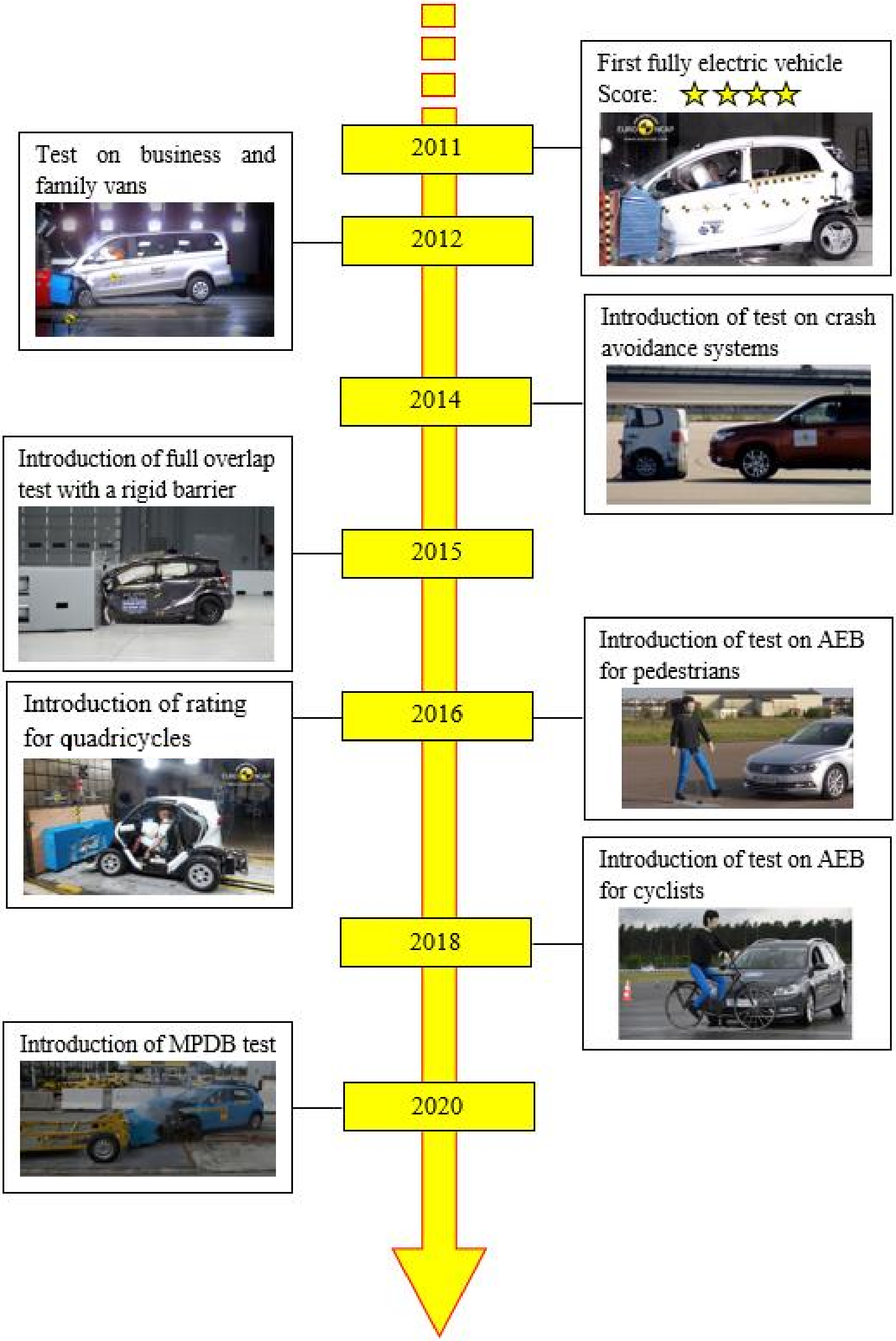


FIGURE 2 - Road map of Euro NCAP 2009-2020

Starting from the 1970s the group of Euro NCAP has begun to form and in 1997 the first tests have been made. The tests included the category of adult occupant protection and of pedestrian protection. The first result was that the tests are so severe that no car can reach four stars in the occupant protection. Always in 1997 a second phase of tests are published and the first car to reach four stars in occupant protection was the Volvo s40, and other cars to follow. A moment of the frontal impact crash test of the Volvo s40 is represented on left side of FIGURE 3. For what regard the pedestrian protection, the improvements were slower.
In 2001 the first five stars were reached by the Renault Laguna, represented during a phase of the test on the right side of FIGURE 3. Since this year, standards have risen so that it is more common to achieve five stars, always in occupant protection, so many car manufacturers set this rating as the target for their new vehicle models.

FIGURE 3 - Volvo s40 on left and Renault Laguna on right

From 2003 a new rating is introduced, the one regarding the child protection, because survey shown that more than the 60% of the child restrain was not used correctly. The rating is based on the evaluation of the child restraints recommended from the manufacturer for an 18-month infant and a 3-years old child. Small dummies representative of the children are used, as shown in FIGURE 4.

FIGURE 4 - Child dummy in Child Restraint System

In 2008 Euro NCAP starts to test also pick-up, a category of vehicle that is born to carry goods and becomes then a family vehicle with the twin cabin. The results of the first pick-ups tested was that no one reached more than four stars, one of them is represented in FIGURE 5.

FIGURE 5 - Frontal impact of a pick-up

In 2009 a new test was introduced, the whiplash one. It represents the rear impact and it is performed using a seat mounted on a sled test and subjected to low, moderate and high test severities. The dummy positioned on the seat, mounted on the sled is reported in FIGURE 6, while in FIGURE 7 the virtual phases of the test are represented.

FIGURE 6 - Whiplash test

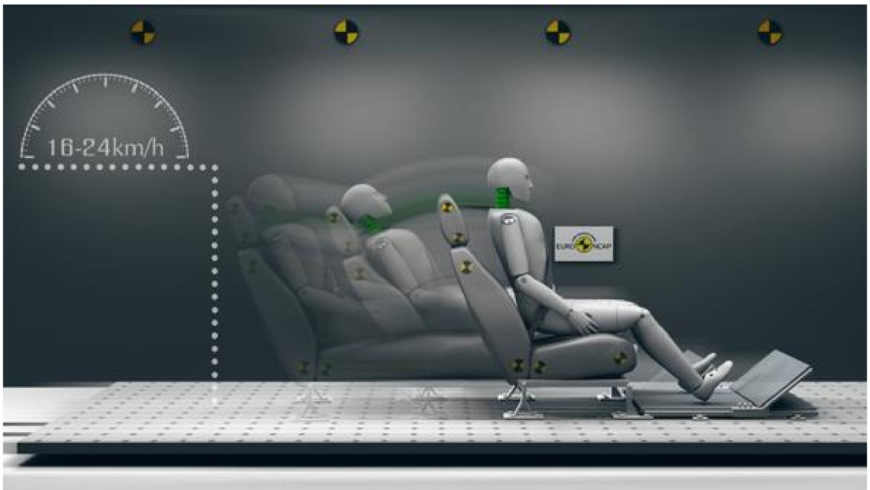


FIGURE 7 - Phases of the whiplash test

In the same year a new rating scheme was introduced because, even if a greater part of the vehicle models shows optimal results in adult occupant protection, more than half reach less than two stars in the pedestrian protection. For this reason, the new rating system will reward the overall safety of the vehicle. The maximum score remains five stars.

In 2011 the first fully electric vehicle was tested and the result of four stars shown that safety does not need to be compromised in zero-emissions vehicles.

In 2012 the testing is extended also to business and family vans, represented in FIGURE 8, by using protocols that are more true-to-life than the legal test for van-based vehicles.

FIGURE 8 - Family van frontal impact

In 2014 a new rating is introduced on tests of crash avoidance systems, for example the Autonomous Emergency Braking (AEB) or the Lane Keep Assist. The decision to reward collision avoidance technologies on new cars aimed at encouraging more widespread fitment and further improve the safety of all road users. In FIGURE 9 an example of AEB test.

FIGURE 9 - AEB test

In 2015 Euro NCAP introduced a new test: a full overlap test with a rigid barrier at a speed of 50 km/h, represented in FIGURE 10. The dummy utilized in this test are small female type both in driver position and in rear passenger side seat. In recent years, the structure of the car become stiffer and reduces lower leg and head injuries because passenger compartment is less prone to collapse.

FIGURE 10 - Full overlap test with rigid barrier

In 2016 the rating was expanded also to the Autonomous Emergency Braking in order to protect also the vulnerable users of the road, such as pedestrians, cyclists and motorcyclists. Vulnerable users of the road are half of the Europe's total road deaths, with AEB system a fifth of the deaths are reduced. AEB works with lasers, radar or cameras to detect the imminent collision in order to perform an emergency braking to stop the vehicle or to reduce the impact speed. Euro NCAP, with its test, helps also the customer to identify which is the best technology for this purpose. This kind of test is represented in FIGURE 11.

FIGURE 11 - AEB test with a pedestrian

In 2016 a two stars rating is introduced for quadricycles, they were tested two years before and the results was very poor and some of them have shown serious risks of life threatening injuries. In these two years there were little improvement in safety and there are still fundamental problems with this sector. An example of front and side impacts are reported in FIGURE 12.

FIGURE 12 - Quadricycle's test, frontal impact on left and side impact on right

In 2018 there was the debut of cyclist test for the first time in the world, by broadened the AEB test. Cyclist belong to the vulnerable road user category. An example of AEB test for cyclists is reported in FIGURE 13.

FIGURE 13 - AEB test for cyclist

In 2020 will be inserted in the rating a new frontal impact with a Mobile Progressive Deformable Barrier (MPDB). This test is a car-to-car test and it is reported in FIGURE 14; it will be useful in order to calculate the aggressivity of the tested vehicle toward other vehicles.

FIGURE 14 - MPDB test

As it is possible to see from the innovations among the years, Euro NCAP is introducing new tests in the fields where there are safety deficiencies, in order to encourage the car makers to focus and solve these problems. In other cases, when the test is no longer representative of the real case, the tests are reviewed and modified. The analysis of the last new test is the scope of this thesis, and it will be described in CHAPTER 4.

2.2. Frontal impact

Frontal impacts are crash along X direction, so they include frontal offset deformable barrier, full width rigid barrier and the last Mobile Progressive Deformable Barrier.
It is important to analyse the passage from the Offset Deformable Barrier (ODB) test to the Mobile Progressive Deformable Barrier (MPDB) test and the reasons of the decision.
The ODB test is performed at a speed of 64 km/h and with an overlap of 40 percent into a deformable barrier. The conditions are representative of a car-to-car impact, both travelling at the speed of 50 km/h.
In the new MPDB test, instead a mobile progressive deformable barrier and the vehicle are both travelling at 50 km/h and the overlap of the barrier is of 50 percent. In FIGURE 15 the two typologies of test are compared.

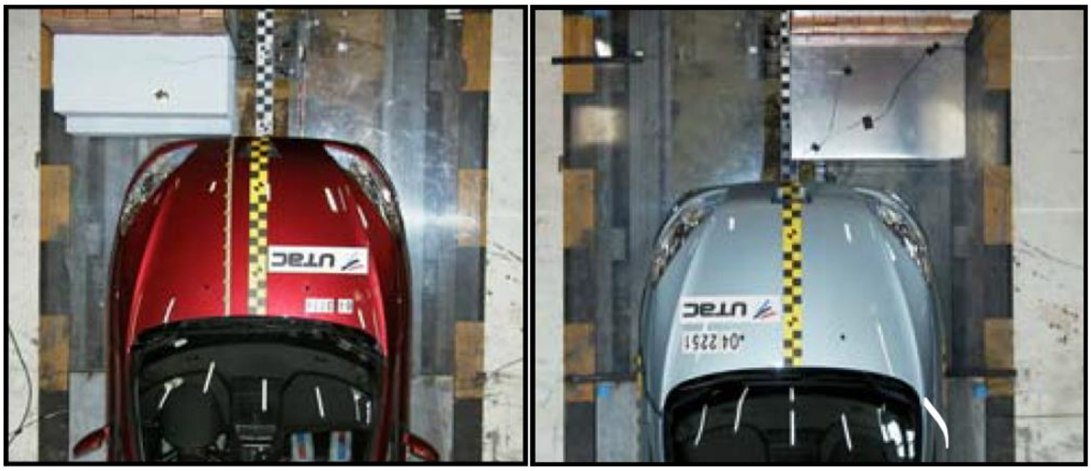


FIGURE 15 - ODB on left and MPDB on right

The two principal changes are in the type of barrier and in the overlap zone.

2.2.1. Barrier type

The deformable barrier used in the ODB test was designed in the 90s on the base of the vehicles present at that time and so less stiff than today vehicles. During the years, vehicles have become stiffer due to the increasing severity of the tests.

Two are the reasons for the change of the barrier typology: instability and bottoming out.

Instability means that the test is not reproducible because with the same vehicle the barrier can behave in different way. Sometimes the barrier absorbs energy and sometimes not. An example is shown in FIGURE 16, in which the two barriers comes from two different tests with identical vehicle and same setting.

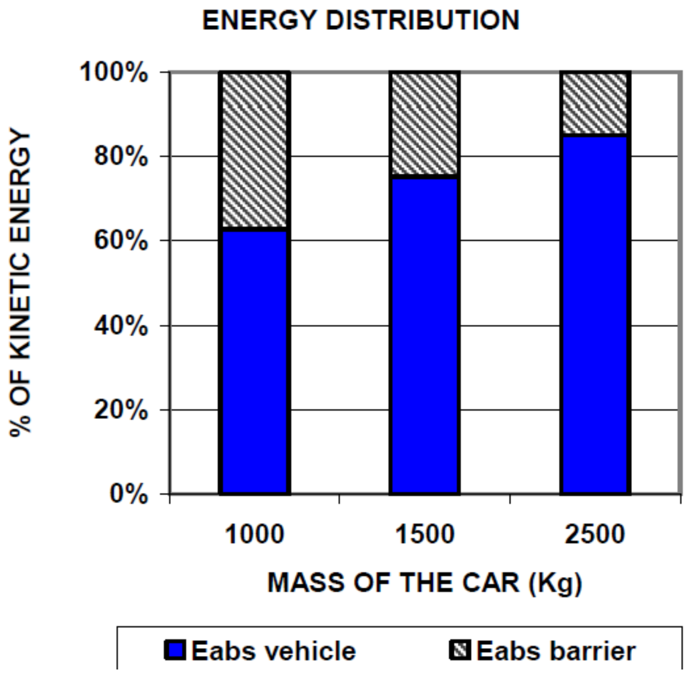
FIGURE 16 - Two crashed barrier of the same vehicle test

As it is possible to see, the two barriers have a completely different shape.
The second reason for which the old barrier is no more representative of real world is the bottoming out. Each new vehicle, since they are stiffer than older ones, bottoms out the barrier. The phenomenon is clearly visible in the FIGURE 17.

FIGURE 17 - Bottoming out of the barriers

This phenomenon leads to the fact that the barrier absorbs the same amount of energy. Since all vehicles bottoms out, the energy absorbed by the barrier is always the same.

So, equal energy absorbed by the barrier for different vehicle mass. Since the energy that must be dissipated from a heavier vehicle is higher than the energy that must be dissipated from a lighter one, the percentage of energy absorbed by the barrier with respect to the total amount of energy is different. In percentage, the energy absorbed by the barrier is smaller for heavier vehicles than for lighter ones. The percentage of energy absorbed by the barrier does not depend on the vehicle mass. The remaining energy, that is absorbed by the vehicle, is higher (in percentage) for heavier vehicles than lighter vehicles. So, the severity of the test increases with the increasing of the vehicle mass. In the GRAPH 1 it is possible to see that. The quantity of energy absorbed by the barrier is always the same, but the percentage of this energy is higher for lighter vehicles and lower for heavier vehicles. So, the severity of the impact is higher for heavier vehicles because the energy that remains to dissipate (the energy that is not absorbed by the barrier) is higher with respect to lighter vehicles. So, there is no more proportionality between a test on a light vehicle and a test on a heavy vehicle.



GRAPH 1 - Percentage of energy absorbed by the barriers and by the vehicles

The new type of barrier, the Mobile Progressive Deformable Barrier, would solve the problem of bottoming out. In FIGURE 18 the comparison between the new barrier (on left) and the old one (on right) is present. With the same colour are represented the blocks with the same stiffness characteristics.

The dimensions of the overall barrier are increased and a block (Block B) with a progressive stiffness, from 0.616 MPa to 1.090 MPa, is introduced. The new barrier will be better explained in the following, in paragraph 4.1.1.

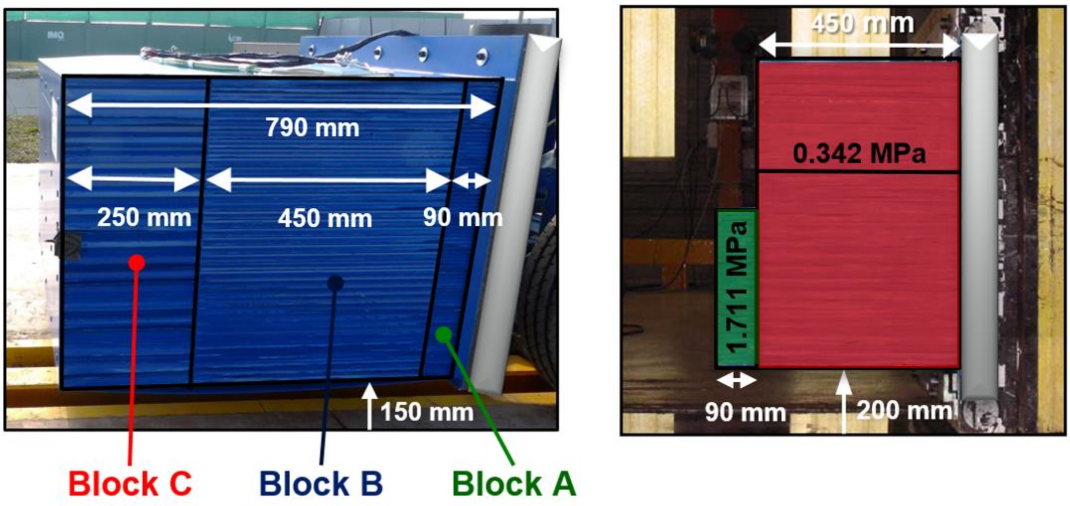


FIGURE 18 - Comparison between MPDB and ODB

From the FIGURE 18 it is possible to see that the most rigid block is present in the front part in the ODB while it is in the back position in the MPDB. The reason of the position in the two barriers is different. In the MPDB, the block A is useful in order to avoid the bottoming out for today vehicles. Instead, in the ODB the front rigid bumper was inserted on the base of some test done with different typologies of barrier. This kind of barrier had resulted the most representative for the vehicles of that time. The barriers that was tested, without the rigid bumper or with a rigid block behind, were both too severe.

2.2.2. Overlap

A new overlap is required in order to better approximate the overlap of real accident. Moreover, checking half of the front end is needed for partner protection assessment in the future.

3. Vehicle compatibility

Vehicle incompatibility (or vehicle compatibility) is a term used in the field of automotive safety. It refers to the tendency of a vehicle to cause damage to another vehicle during a crash and the probability that these damages can lead to the death of the driver. If a vehicle is compatible, the tendency to cause damage is reduced while, in an incompatible vehicle the probability of a fatal crash, in case it happens, is higher. So, as defined by Schoeneburg in 1996 'the goal of compatibility is to enhance partner protection without decreasing occupant protection or to optimize occupant protection in such a manner that the overall safety of the vehicle is maximized'.

The compatibility of a vehicle can be considered good if two vehicles in car-to-car crash have the same death ratio and low number of fatalities at the same time.

The compatibility is a subject that has been widely studied in Europe in order to develop a test that evaluate the aggressivity of a vehicle. In FIGURE 19 are represented the most important studies about that.

FIGURE 19 - Studies about compatibility

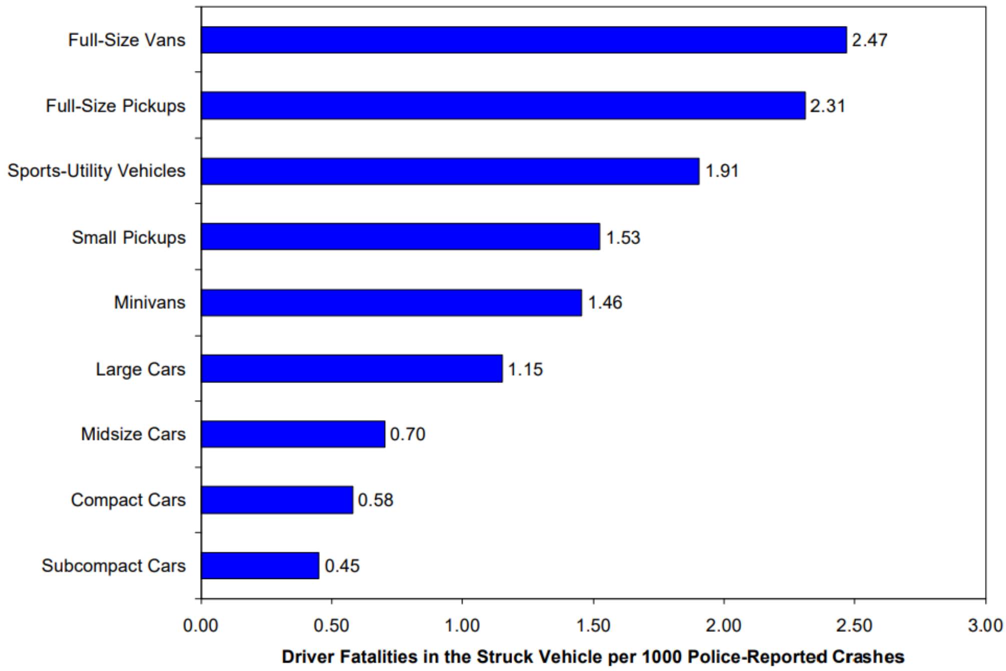
It is possible to divide the abovementioned studies in project developed over time:

- EEVC WG15 project from 1996 to 2006;
- VC-COMPAT project from 2003 to 2006;
- FIMCAR project from 2009 to 2012.

3.1. General studies about compatibility

The National Highway Traffic Safety Administration (NHTSA) is a U.S. government agency and one of its purpose is to enforce Federal Motor Vehicle Safety Standard. NHTSA defines a sort of unit of measurement to define the aggressivity (more a vehicle is aggressive and less it is compatible), it is the aggressivity metric (AM) and it is defined as the ratio between driver fatalities in collision partner and the number of crashes of subject vehicle. The NHTSA, with the AM, ranks all passenger vehicle and Light Trucks and Vans (LTVs) by using 1991-94 FARS[1] and GES[2]. LTVs are divided in five categories: sports utility vehicles, full-sized pickups, small pickups, minivans, and full-sized vans; while passenger cars are divided in four categories: large, midsize, compact, and subcompact.

From GRAPH 2 it is possible to see that the most aggressive category of vehicle is the full-sized vans with an AM of 2.47, while minivans category is the least aggressive of LTVs group with AM of 1.46. The group of passenger cars is, in general less aggressive than LTVs; the most aggressive of this group are large cars with AM of 1.15 (lower than the least aggressive of LTVs) and the least aggressive of all categories are the subcompact cars with an AM of 0.45.



GRAPH 2 - Aggressivity Metric for different categories of vehicles

[1] **Fatality Analysis Reporting System** became operational in 1975, it contains data on a census of fatal traffic crashes within the 50 States, the District of Columbia, and Puerto Rico.

[2] Data in the **General Estimates System** (GES) are obtained from a nationally representative probability sample selected from all police-reported crashes. The system began operation in 1988. To be eligible for the GES sample, a police accident report (PAR) must be completed for the crash, and the crash must involve at least one motor vehicle traveling on a traffic way and result in property damage, injury, or death.

Vehicle weight is not the only factor that affect the aggressivity because, midsize cars can have about the same weight of some small pickups but the aggressivity metric is the double for the minivan with respect to the midsize car. So, other parameters affect the AM, even if the weight has a strong influence.
The conservation of momentum in a collision places smaller cars at a fundamental disadvantage when the collision partner is a heavier vehicle.
Another important factor that influences the AM measure is the age of the driver and of the occupants of the vehicle because this measure is based on the number of fatal impact but, young people behaves different from older ones. Younger people are more injury tolerant and so less likely to die from their injuries, while older people are less injury tolerant and so more likely to die from their injuries.
Another important factor to be considered is the typology of impact, if it is a frontal impact the probability that it is fatal is lower with respect to a side impact. The reason of that comes from the amount of protection provided from the vehicle on the front with respect to the one in the side part.
In FIGURE 20 it is possible to see the higher value of fatal incident for cars with respect to bigger vehicle and the relative lower values that are present in the frontal impact.

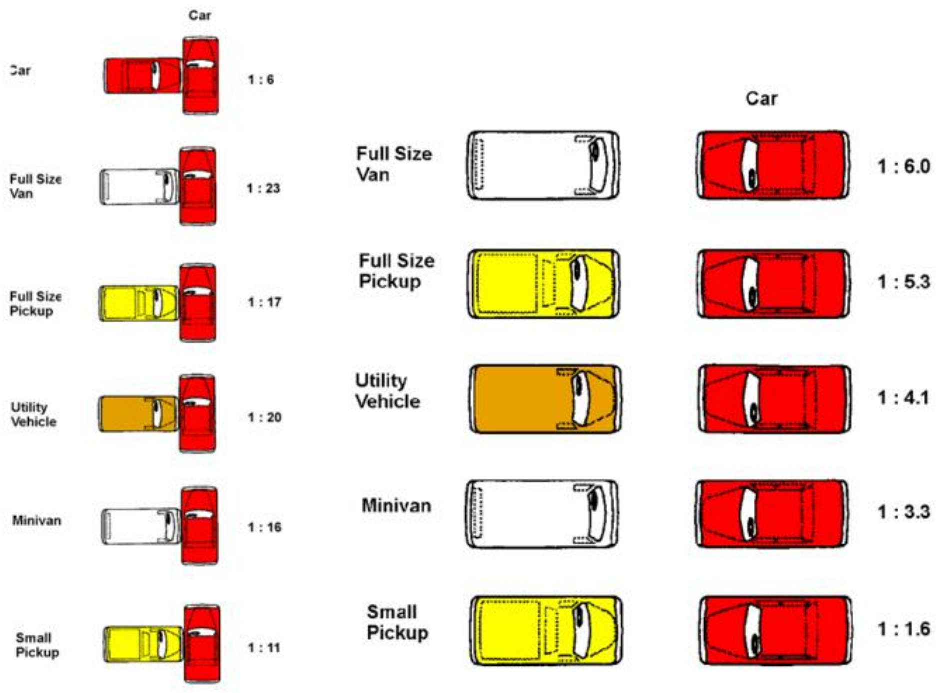


FIGURE 20 - Side impact and frontal impact with the relative AM

Important is to notice that the study is of some years ago, when the majority of the vehicle are without the presence of airbag or other safety devices. If only the model year after 1990 are considered, the values of AM are reduced for all the categories, but the ranking remains always the same. So, with or without safety system integrated, the LTVs remains the category most aggressive.

3.1.1. Statistical analysis

The studies on a statistical base lead to the results that the incompatibility of a vehicle is due to three main factors that are:

- Mass incompatibility;
- Stiffness incompatibility;
- Geometric incompatibility.

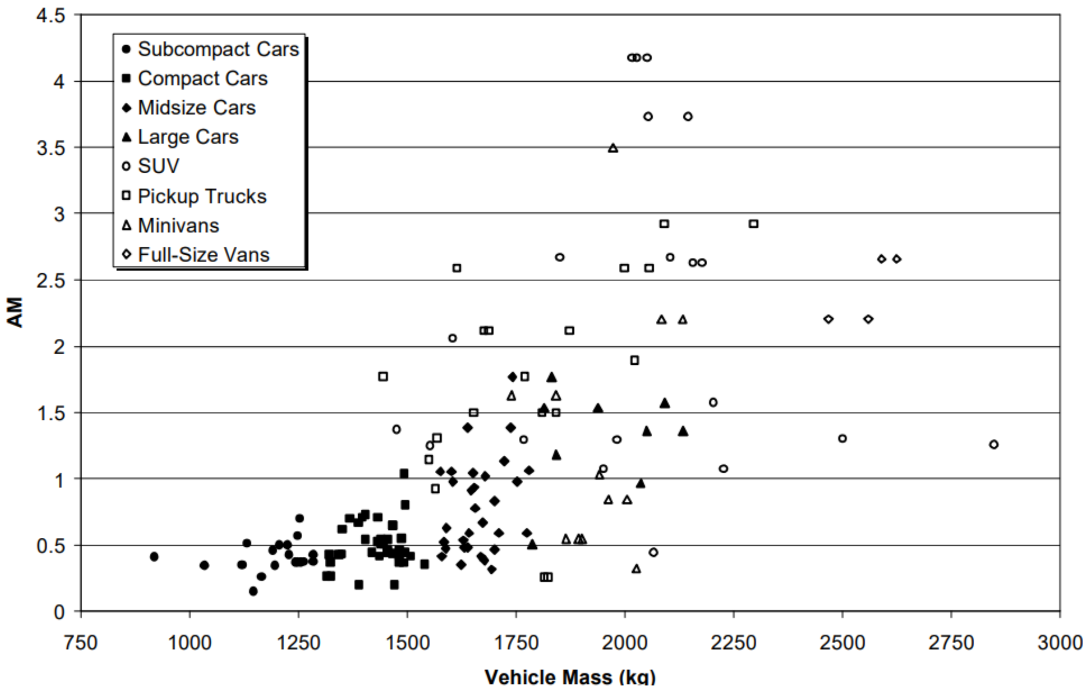
They are singularly analysed in the following.

Mass incompatibility

The mass of the two different categories, LTVs and passenger car, are different and in general LTVs are heavier of about 400 kg. When a collision between two vehicles from these two categories occurs, the small car is placed in a disadvantageous situation because of the momentum conservation: a small and light car will always experience higher velocity changes.

When a collision occurs between two vehicles of the same weight, fatalities per crash accident are minimized and they have the best compatibility conditions due to the same death ratio and minimum fatalities.

From GRAPH 3 it is possible to see that, in general, the higher is the vehicle mass and higher is the Aggressivity Metric value. However, as said before, it is possible to have a vehicle with high mass but with an AM value relatively low.



GRAPH 3 - AM as a function of vehicle mass for different categories

Evans and Fricks in 1993 studied the importance of the vehicle mass in the incompatibility field. They studied data of two-vehicle crashes and they determined a law on the base of a statistical analysis. They found the relative risk, R, of a driver fatality in the lighter of two cars compared to the risk in the heavier car as a function of the ratio, μ, of the mass of the heavier to that of the lighter.

The relationship found is:

$$R = A\mu^{u}$$

The value that assumes u in this relation is 2.75 ± 0.11, while A is a proportionality coefficient.

All the parameters such as safety belt presence, model year, absolute mass of the involved vehicle, impact dynamics and driver factors are taken into account in the analysis. Evans and Frick conclusions are that the vehicle mass is the dominant factor on relative driver fatality risk when two vehicles of different mass crash into each other, in accordance to other researches.

The influence of vehicle mass can be expressed in two laws, published by Evans:

- The lighter is the vehicle, the less is the risk to other road users.
- The heavier is the vehicle, the less is risk to its occupants.

In FIGURE 21, these two laws are represented on the base of the weight of the vehicle, the data present in the graph are obtained always in statistical analysis.

Vehicles are divided in three categories on the base of the mass: the first category comprise vehicle with mass lower than 800 kg, the second category the vehicle with mass between 801 and 1000 kg and the last with mass higher than 1000 kg.

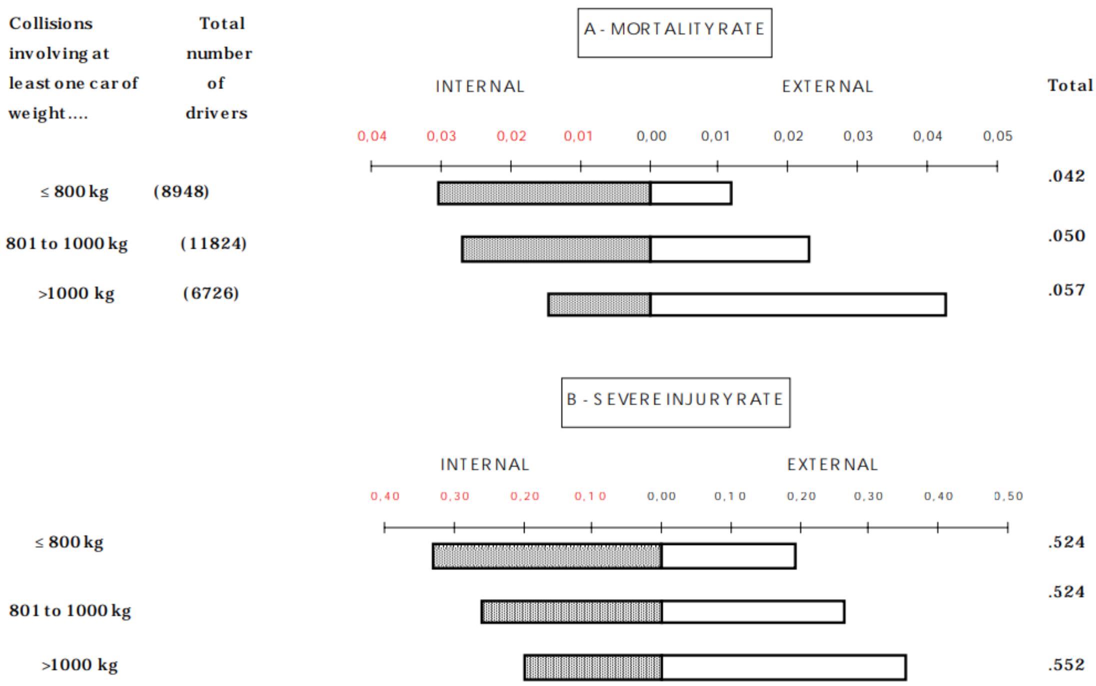


FIGURE 21 - Mortality and severity injury rate on base of vehicle weight

Both for mortality and for sever injury, the trend is the same and follow the law stated by Evans. If the protection of the occupant is indicated as internal safety, while the protection of the occupant of the other impacted vehicle is indicated as external safety, it is possible to see that for lighter vehicle the internal safety is low and the external safety is high. The internal safety increases with the increase of the mass, while external safety decreases with the increase of the mass.

Always from the same figure it is possible to see that the external mortality rate increases more than how the internal mortality rate decreases with the increases of the vehicle weight. For what regard the injury instead, the quantity of increase or decrease of mortality rate in the different categories is about the same.

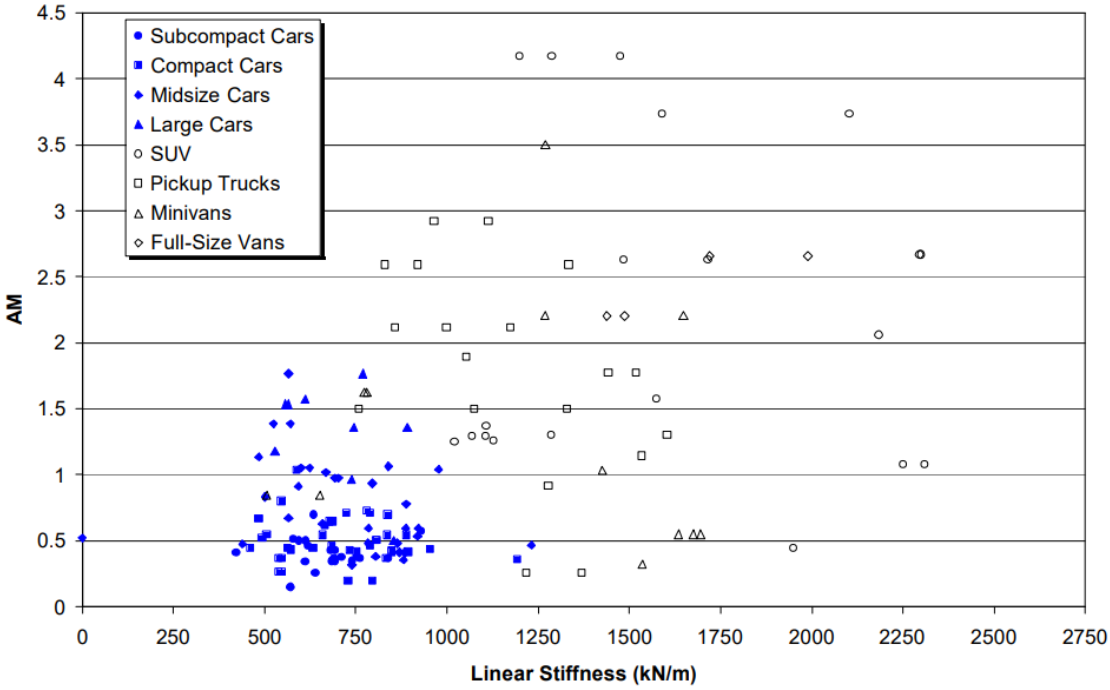
Stiffness incompatibility

The stiffness of the frontal structure plays a smaller role with respect to the mass, but also this factor is related to the aggressivity of the vehicle. In general, the group of the LTVs are stiffer than passenger cars, and a higher stiffness means higher AM value.

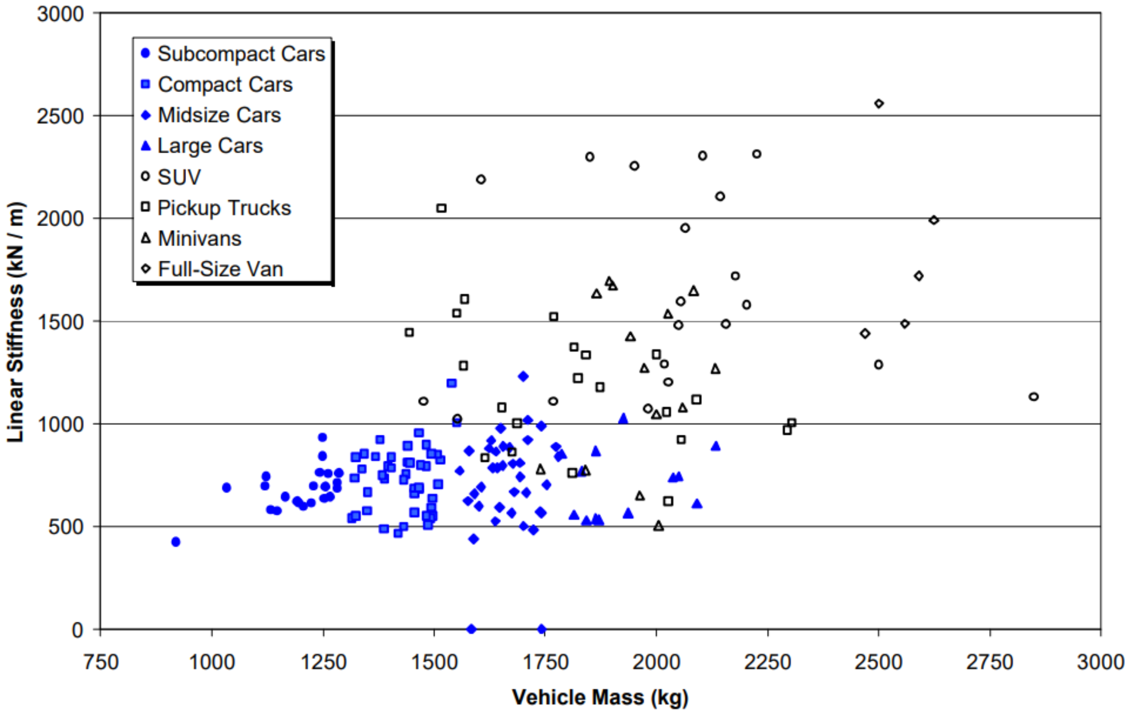
In general, the small and light cars have the tendency to have a lower stiffness and small crush space, and large deformations in case of crash accident with heavier vehicle.

Higher is the stiffness of a vehicle and higher is the aggressivity but also the occupant protection is higher, on contrary lower the stiffness, lower the aggressivity and worst is the protection of the occupant. Occupant protection and partner's protection are going in opposite directions.

From GRAPH 4 it is possible to see that the higher is the linear stiffness of the vehicle and the higher is the value of its aggressivity. The behaviour is similar to the one of the mass, in fact stiffness and mass of a vehicle can be related. In GRAPH 5 it is observable this relation: the trend is almost proportional, higher the mass and higher the stiffness. The stiffness depends linearly on the mass and quadratically on the displacement and on the speed. It is also possible to see that for any given mass, there is a wide distribution of linear stiffness values.



GRAPH 4 - AM as a function of vehicle stiffness for different categories



GRAPH 5 - Relationship between mass and stiffness of the vehicle

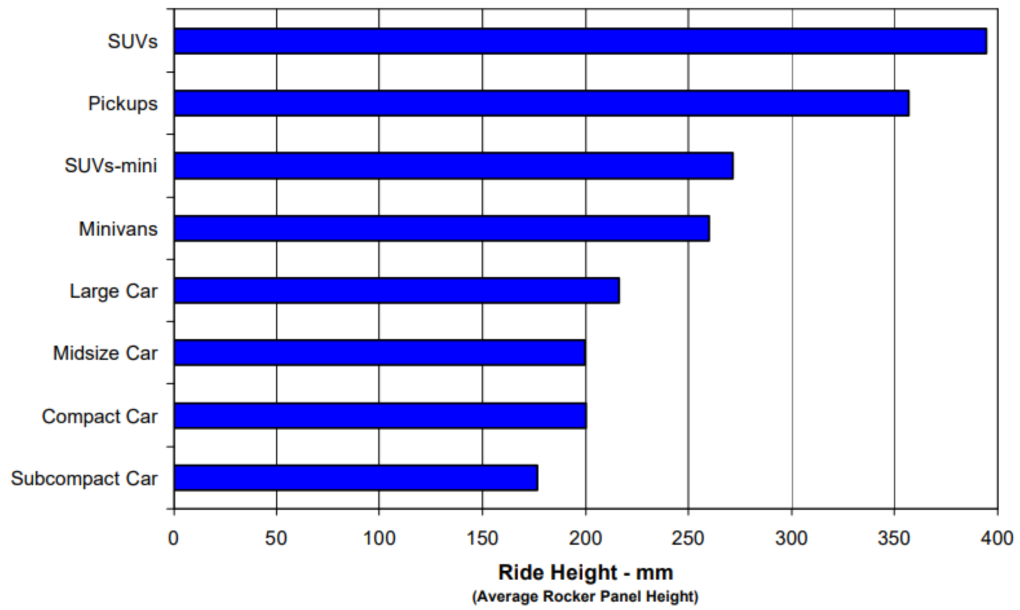
As it is possible to see also from FIGURE 22, the post-crash deformation is considerably stronger in the small vehicle, on left, than in the more rigid large vehicle, on the right.

FIGURE 22 - Comparison of small vehicle (on left) and heavier vehicle (on right) after a frontal crash

Geometric incompatibility

In general, LTVs group ride higher with respect to passenger cars. This difference creates a mismatch in the structural load paths in frontal impacts and it may prevent proper interaction of the two vehicle structures in a collision. Also in side impacts the situation for the less high vehicle (passenger car) is disadvantageous with respect to a higher one (LTV) because the LTV structure can override the car door sill, and contributes to the intrusion of the side-impacted vehicle.

In GRAPH 6 are represented the average height of different categories of vehicle and it is possible to notice the higher values for the LTVs categories.



GRAPH 6 - Ride height of different vehicle categories

In FIGURE 23 it is possible to see the geometric incompatibility between a vehicle of LTVs group and a vehicle of passenger cars group.

FIGURE 23 - Geometric incompatibility

Evans and Frick also studied the influence of vehicle size on the compatibility. Instead of ride height, they considered the wheelbase of the vehicle.

The risk relationship obtained for this parameter is:

$$R = \upsilon^{u}$$

Where υ is the ratio of the wheelbase of the two impacting vehicle and it is always greater than one; while u has a value of 6.76 ± 0.24.

The much stronger relationship by wheelbase ratio than by mass ratio, as indicated by an exponent of 6.8 compared with 2.75, should not be interpreted to imply that wheelbase is a better explainer of fatality because the relationship between fatality ratio and wheelbase ratio follows directly from the relationship between mass and wheelbase. In fact, also for Evans and Frick the mass has a greater importance with respect to wheelbase in the compatibility, in order to support this thesis they made an analysis and they conclude that the mass is the most important factor.

3.1.2. Mechanical analysis

All the parameters just analysed, the mass, the stiffness and the geometry, are studied on a statistic base. The same phenomenon can also be analysed from a mechanical point of view, as interaction between two bodies.

If the Newtonian mechanics is considered, a central impact is the collision of two non-rotating bodies that collide in a point in the connecting line between their centres of gravity.

As it is represented in FIGURE 24, the impact sequence of two bodies with different masses, starts with the two bodies that are proceeding at different speeds. Then the bodies enter in contact and starts the approach period, till the maximum deformation. The restitution period starts and lasts up to the separation of the bodies.

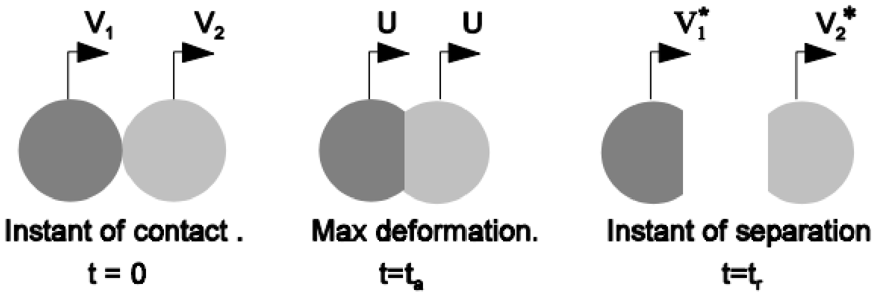


FIGURE 24 - Impact sequence

During the first period, both the bodies deform. The deformation can be perfectly plastic, perfectly elastic or partially plastic and partially elastic. In FIGURE 25 the deformation of the different behaviour of the body are represented.

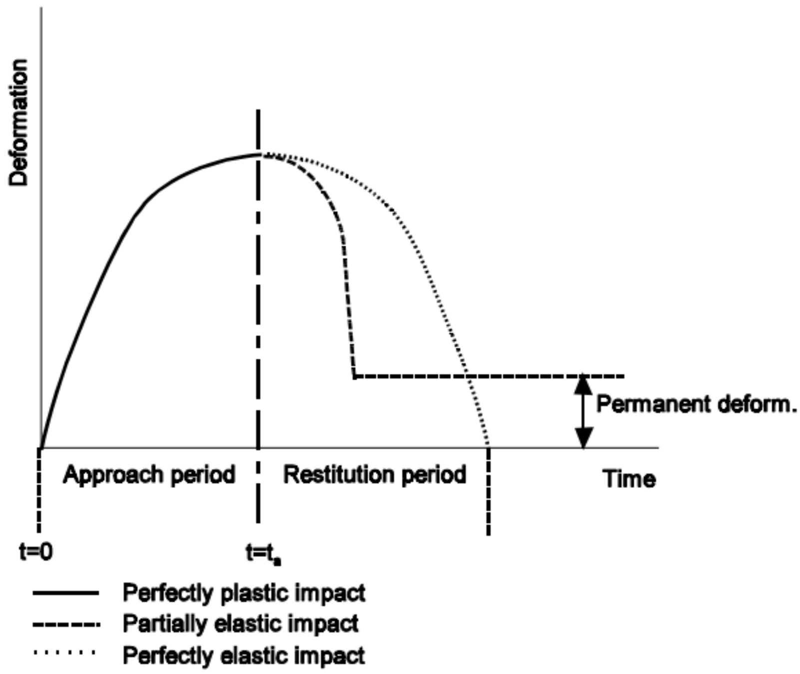


FIGURE 25 - Different behaviour of the body deformation over time

During the restitution period the deformation is recovered in the case of perfectly elastic behaviour, it is partially recovered in the case of partially elastic impact and it is not recovered in case of plastic impact.
It is possible to define a coefficient of restitution, k, on the base of the deformation recovered, it is defined as the ratio of the relative final velocity over the relative initial velocity. It is in the range between 0 and 1. The coefficient of restitution equal to 1 corresponds to the perfectly elastic impact, while the other extreme (k=0) corresponds to the perfectly elastic impact.
The impulse momentum law is expressed as

$$\int_0^t F(t)dt = m_i\,(v_i^* - v_i)$$

Where F is the force applied in the impact, m is the mass of the body, v^* and v are respectively the final and the initial velocity of the body.
The equation can be applied in the two distinct period, in which forces and velocities are different.

$$\int_0^{t_a} F_a(t)dt = m_1v_1 - m_1u = m_2u - m_2v_2$$

$$\int_{t_a}^{t_r} F_r(t)dt = m_1u - m_1v_1^* = m_2v_2^* - m_2u$$

Where F_a and F_r are the two forces applied during the two different period of the impact and u is the common speed at the end of the approach phase.
On the base of these equations, the force that is applied on each body depends on the mass and the speed of both the bodies. The deformation in the body that results depends also on the stiffness on the body.

3.2. EEVC WG15

EEVC WG15 stands for Enhanced European Vehicle-safety Committee Working Group 15. It was established in 1996 to work on improving car crash compatibility and frontal impact, and it works till the 2006. The scope of the project was ‘to develop a technical proposal for regulatory application to improve a vehicle’s frontal impact and compatibility performance’. The test to be established could be a review of the just

present frontal impact tests (the full overlap with a rigid barrier or the Offset Deformable Barrier) or a new test.
The symbol of the working project is the one depicted in FIGURE 26.

FIGURE 26 - EEVC symbol

The first part of the project was dedicated to the research and the investigation of the car compatibility. While the second part of this project was dedicated to establish a test in order to evaluate the compatibility. From 2003 the project was developed in collaboration to the VC-COMPAT, another project, explained in the next paragraph 3.3.
The studies about the accidents were useful in order to identify the problems that generate incompatibility, and so the cause in which it is important to intervene in order to decrease the injuries or the severity of them.
Both experimentally car-to-car crash and mathematical modelling were used, the first in order to identify the major problems that leads to incompatibility while the second in order to study the effect of changing the effective stiffness and mass of the two impacting vehicles.
One of the scopes of the project was to improve compatibility, this can be obtained by increasing the structural interaction, so by improving the stiffness homogeneity of the front-end of the vehicle that leads to a more uniform force distribution between the two colliding vehicles. But this can lead also to a change in crash load-paths into the occupant compartment, and then intrusion in the cockpit.
Since the assessment of the homogeneity is needed, the knowledge of the force-time history is required. In order to have this information, a Load Cell Wall was introduced in the studies of the project.

It was found that the main criteria that should be analysed in order to assess the compatibility in a car-to-car impact are the structural interaction, the strength of the passenger compartment and the strength of the car front end. So, in order to assess the compatibility, some tests are proposed and analysed:

- Full width frontal impact on a load sensing wall (with or without honeycomb), to assess the homogeneity of the force distribution of the car front end and so assess its structural interaction capability. It was not discovered if the homogeneity is an adequate indicator of the structural interaction capability;
- Euro NCAP Offset Deformable Barrier test with force sensing wall, to measure frontal stiffness;
- Overload test to measure passenger compartment strength before collapse (if this level has not been reached in Euro NCAP ODB test);
- Progressive Deformable Barrier test (PDB) with partial overlap to generate vertical and lateral shear forces within the front end of the vehicle. The shear is generated thanks to the design of the barrier since it is made of progressive honeycombs designed to have the global behavior of a car with its non-uniform stiffness distribution). This test should assess the structural interaction capability and the frontal stiffness. It was not known if the energy absorption capacity of the barrier could be counterproductive, so if a carmaker could take advantage of this energy in order to reduce the energy to be absorbed by the vehicle.

The level of force accepted for the compatibility in these tests was not decided because it must be objective and depends on the kind of test chosen.

There are some basic principles that are in agreement also with the general studies on the compatibility described before. There is the necessity to improve compatibility but this must be achieved without compromising the self-protection; in order to achieve good compatibility, the structural interaction is a key requisite; and the bulkhead concept, so the need to prevent or minimize the compartment intrusion as long as there is energy dissipation capacity in the vehicle front end.

The planning drafted at the starting of the project included also to make first attempts to assess potential benefit of compatible passenger cars. During the project it was found that it is not possible to do this work because the factors that influence incompatibility, except the mass, could not been clearly correlated to the severity of the injuries.

3.3. VC-COMPAT project

The Improvement of Vehicle Crash Compatibility Through the Development of Crash Test Procedures (VC - COMPAT) is a project coordinated by the TRL Limited[3] and financed by the European Community. It starts the 27th March 2003 and last till 30th November 2006. The symbol of the project is depicted in FIGURE 27.

FIGURE 27 - VC-COMPAT symbol

This project has been started in order to support the project EEVC WG15 already in development.

From the point of view of the project participants, the compatibility can be studied by dividing that in three subtopics, as was decided also in the previous project:

- *Structure interaction* (SI) that is the description of the interaction between vehicles during an impact. If SI is poor, it can lead to a compartment intrusion at a severity lower than the designed one.
- *Frontal force level* that is a function of vehicle mass and crush zone length. All vehicles today have more or less the same crush zone length, of about 600-700 mm, so lighter vehicles have lower force level than heavier ones.

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[3] **TRL Limited** is known as Transport Research Laboratory and it is a fully independent private company that offers transport consultancy and research service. It is established in 1933 by the UK Government and privatised in 1996.

- *Compartment strength* that is related to the frontal force level. The compartment strength must be sufficiently high in order to resist to a collapse of the compartment in the case in which the front end does not absorb the amount of energy that it is designed for.

So, the test to be implemented for the evaluation of the compatibility must consider all these aspects. Despite that, the members focalised on the structure interaction and only limited activities was dedicated to compartment strength and force level. So, at the end of the project no procedures to evaluate these two aspects of compatibility was presented.

As suggested from the International Harmonised Research Activity group for frontal impact, the VC-COMPAT group chose two final tests in order to assess compatibility: the Full Width Deformable Barrier (FWDB) and the Progressive Deformable Barrier (PDB). The choice of almost two tests (an offset and a full overlap test) is due to encourage the carmaker to do not design the structure of the vehicle optimized for one crash configuration.

Even if, the procedure to evaluate the force level and the cockpit intrusion was not explained in the project, from FIGURE 28 it is possible to see that the PDB test can give information about all aspect of compatibility. This is possible by evaluating different part of the test, with different instrument. In order to evaluate the structural interaction, an analysis on the barrier can be made, by measure the deformation. For what concern the force level a signal coming from the load cell wall (LCW) can be used. While for the evaluation of the compartment strength, the information coming from the dummies can be utilized.

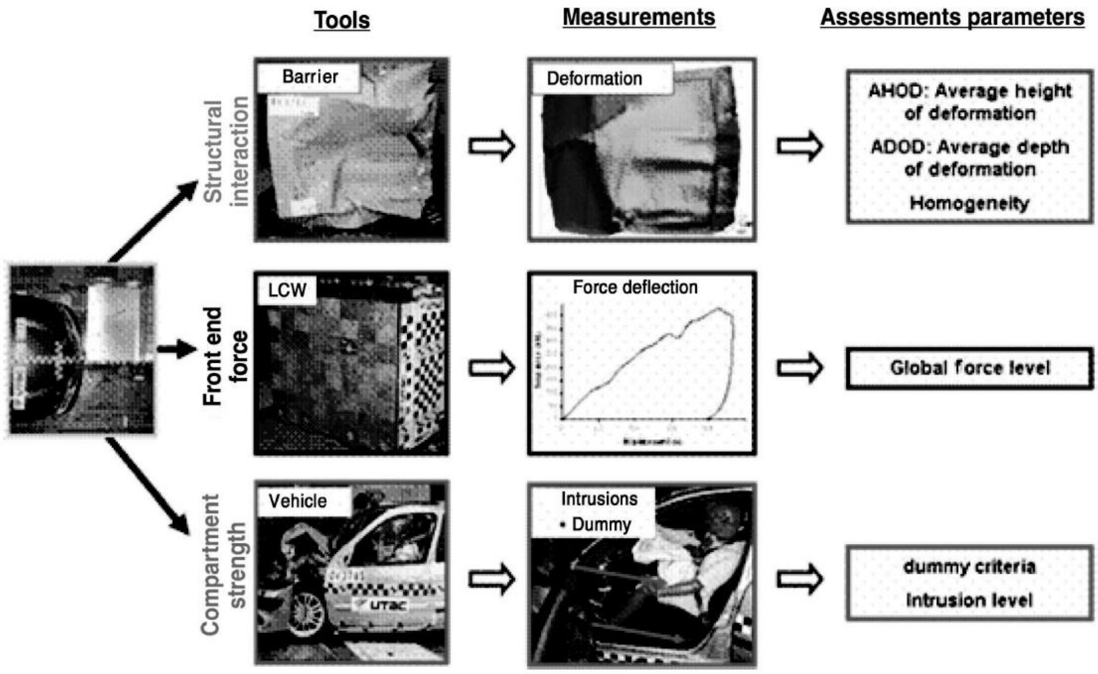


FIGURE 28 - PDB test

In the studies, both car-to-car test and car-to-barrier test have been carried out. The first kind of test were used to evaluate the different structural design and to discover the critical parameter in which attention must be put in order to improve compatibility. The second one in order to see the performance of the test with different type of vehicles.

In the mathematical modelling field, there were three different tasks that are:

- Finite Element barrier modelling in order to support the development of the crash test procedure and it's validation, all combination of different overlap and different speed are simulated;
- Multibody modelling methodology in order to develop a fleet model and analyse the benefit and the effect of the improved compatibility in different crash configurations;
- Multibody simulation of vehicle force level in order to verify the matching between vehicles with different weight.

With different assumption, different results of the simulation was found. With the assumption that all vehicles had the same deformation zone of about 700 mm, smaller vehicles can be made stiff enough in order to provide suitable safety levels in high-mass ratio impact. While with a different assumption that larger vehicles had a 50 mm longer deformation zone, the acceleration levels in the smaller vehicles are similar to the previous case but the force levels of small vehicles should be increased above the levels present at that time.

An analysis was also made in order to detect the most appropriate test area by evaluating the position of the absorbing elements. The result was that a good assessment area includes a vertical range between 180 and 650 mm in order to contain all the subframe, the main rail, the upper rail and wheel sill load paths. While in horizontal direction, a good area is half of the vehicle width but excluding 150 mm adjacent to the barrier, as reported in the barrier depicted in front view in FIGURE 29.

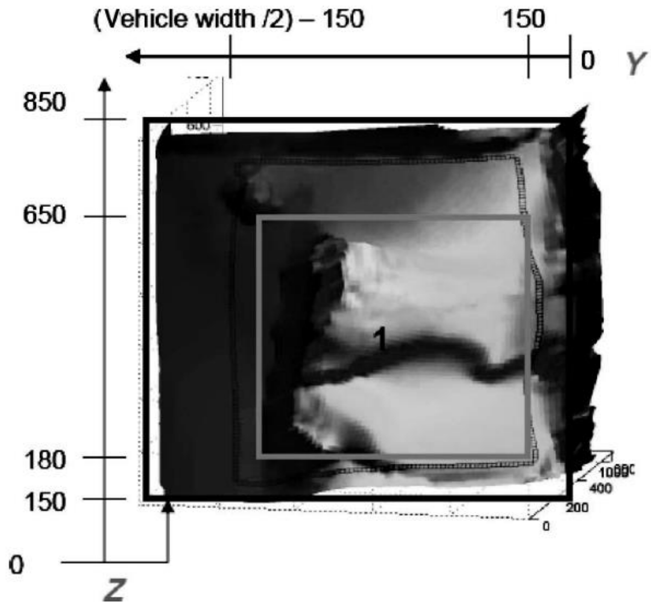


FIGURE 29 - Front view of the barrier with dimensions

From results obtained with the car-to-car test, it is possible to assert that the two-level load paths vehicles are better than one-level load path vehicles in terms of structural interaction performances. The presence of the lower load path in a small car is particularly beneficial for what regard the impact against a SUV which also has a lower load path.

For what regard the VC-COMPAT project, both the full width frontal impact on a load sensing wall and the Progressive Deformable Barrier test proposed by the EEVC WG 15 are valid tests in order to evaluate the compatibility. What is yet to be established is a threshold from which a vehicle pass from be incompatible vehicle to be a compatible one.

3.4.FIMCAR project

FIMCAR stands for Frontal Impact and Compatibility Assessment Research and it is a project coordinated by the Technische Universität of Berlin and financed by the European Community. It starts the 1st October 2009 and last till 30th September 2012; the scope of this project is to propose a frontal impact assessment approach for the evaluation of the self and partner protection. The project is based on the previous research program about compatibility and on data analysis of modern car accident.
In FIGURE 30 is represented the symbol of the project.

FIGURE 30 - FIMCAR symbol

During the development of the project, the attention is focused in the frontal car-to-car impact, but also other kind of impact are considered, such as side impact or cat-to-Heavy Good Vehicle impact.
In particular, the project was created in order to give an answer to the open questions that was remained from the previous project, for example to understand the advantages and disadvantages of force based metrics and barrier deformation based metrics or to confirm the presence of specific compatibility issues such as structural interaction or investigation of force matching. The other scope of the project was to define the procedure of the test that will be able to evaluate the compatibility.
An important data that is considered in this study is that the major cause of death in European Union is caused by road accidents and more than 50% of the dead are car occupant. It is also important to investigate in the nature of the occupant injuries.
Two frontal impact are made in rating or homologation and they are the ones discussed above in paragraph 2.2. With the introduction of these tests, in the years the safety performances of the vehicle are improved. Even if the vehicles behave well in these kinds of tests, it could be possible that the same behavior is not representative of the car-to-car crash, in which the result is worst, because of the car incompatibility.

Compatibility is a compromise between self and partner protection, and it is important to do not sacrifice one for the other.
Various test method to evaluate the compatibility are studied in different country, especially Japan, America and Europe and the result is that both off set and full width test are needed in order to evaluate compatibility and frontal protection performance. This is a result that was found also in the previous European projects.
In this project the combination of different frontal impact test is studied in order to create a test for the compatibility evaluation. The tests are the Full Width Rigid Barrier (FWRB), the Full Width Deformable Barrier (FWDB), the Offset Deformable Barrier (ODB), the Progressive Deformable Barrier (PDB) and the Mobile Deformable Barrier (MDB).
In the analysis of car-to-car impacts a relationship between mass ratio and driver injury severity was found. The mass ratio is defined as partner mass over self-mass. Higher is this value, so higher is the partner mass and higher is the severity of the driver injury. Instead, the relation between intrusion and severity of injury was not found and so the compartment strength is not a primary contributor to the injury severity. However, compartment strength is an important problem in crash between cars and HGVs.
The results of this analysis are influenced by the age of the vehicle, in fact newer vehicles have better integrity of the cockpit; and it is influenced also by the age of the occupant, due to the injury tolerance as found in the previous years.
Since that affirmation, only the newer vehicles are considered in the analysis, in order to make a review that is consistent with the actual situation.
The participants at this project agree on some points from the previous studies:

- Compatibility includes self and partner protection;
- Improving compatibility will reduce the injury risks of occupants in single and multiple vehicle impacts;
- Compatible vehicles will deform in a stable manner, by allowing the deformation zones to be exploited also in cases in which different vehicle sizes and masses are involved.

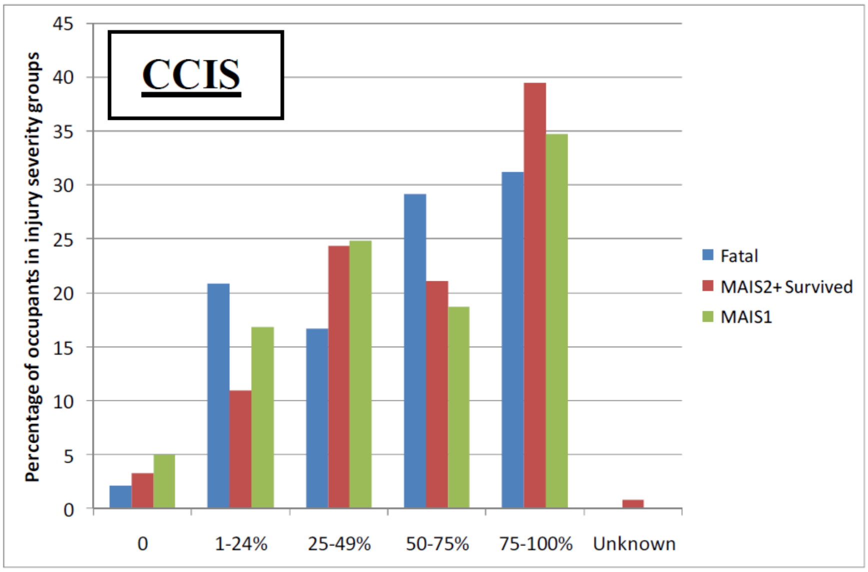
In the project is useful to identify if the compatibility issues identified in the previous projects are still valid in the actual vehicles, such as the structural interaction, the frontal force matching or the compartment strength.

The first part of the project consists in the analysis of the accident. The data that was considered are from UK Cooperative Crash Injury Study (CCIS) and German In-Depth Accident Survey (GIDAS). Only significant front impact was considered and only impacts which involve vehicles that have no more than seven years. The injured people that were taken into account are adult occupant that are seated on the front row (for adult it is intended a person over 12 years old).
In TABLE 1 are reported the data from the CCIS and GIDAS. The MAIS acronym stands for Maximum Abbreviated Injury Score, where the scale goes from zero with 0% of death probability to 6 with 100% of death probability.
In the table Fatal corresponds to MAIS 6, MAIS 1 corresponds to minor and moderate injuries while MAIS 2+ includes values of the scale from 2 to 5, so from serious to critical injuries.

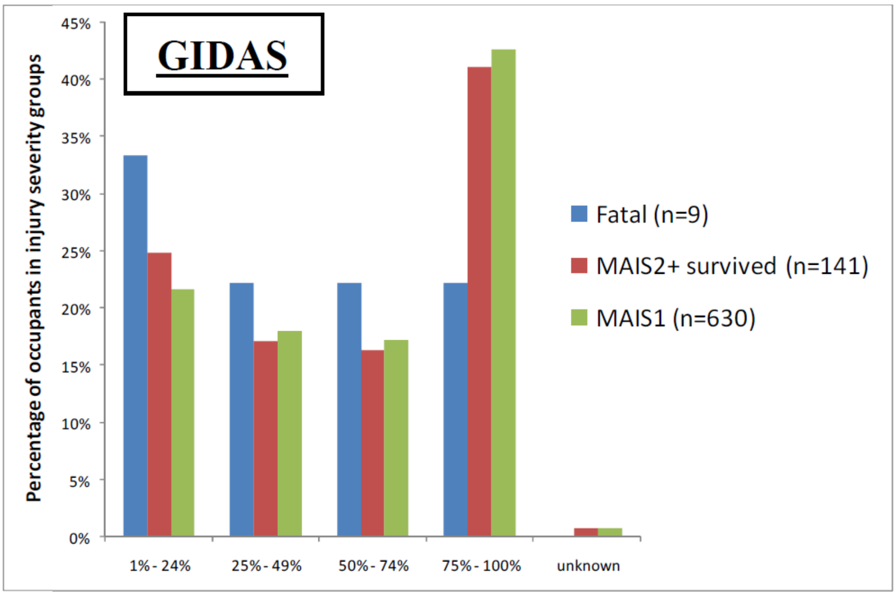
TABLE 1 - Data from CCIS and GIDAS

Database	Fatal	MAIS2+ Survived	MAIS 1
CCIS	83	466	1236
GIDAS	16	155	701

It is immediately evident that the data reported are very different, the higher number of cases in data from CCIS is due to the typology of sampling procedure in which the fatal or serious injuries are favorites.
What was found from these data is a high proportion of FATAL and MAIS 2+ injury in accident with an overlap higher than 75 % in both the sets of data. In the following diagram the distribution of injuries with respect to the overlap of the accident is reported, in GRAPH 7 with CCIS data while in GRAPH 8 with GIDAS data.
While in the first case the impacts with small area object, like poles or trees, are separated and shown in the column with 0% overlap, in the second case these type of accident are included in the category from 1 to 24 % of overlap.



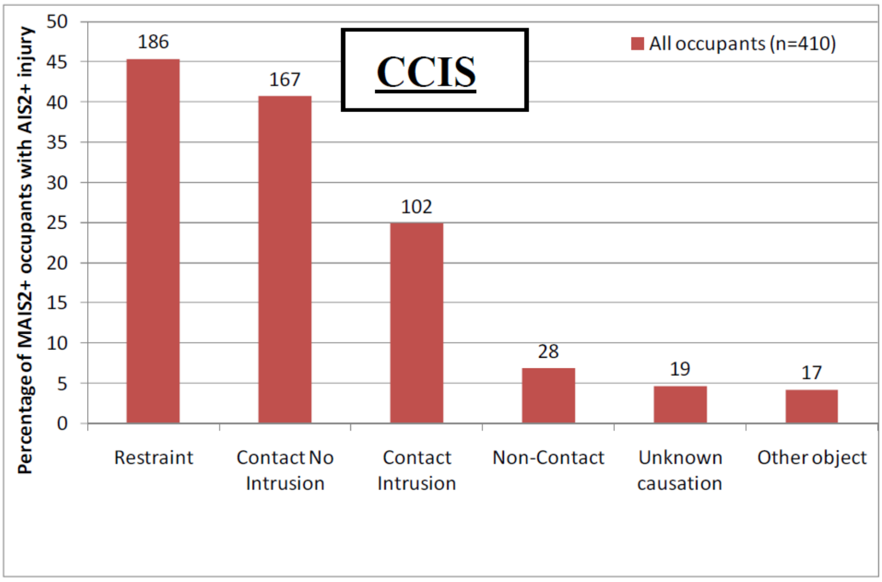
GRAPH 7 - Injuries distribution as a function of overlap accident for CCIS data



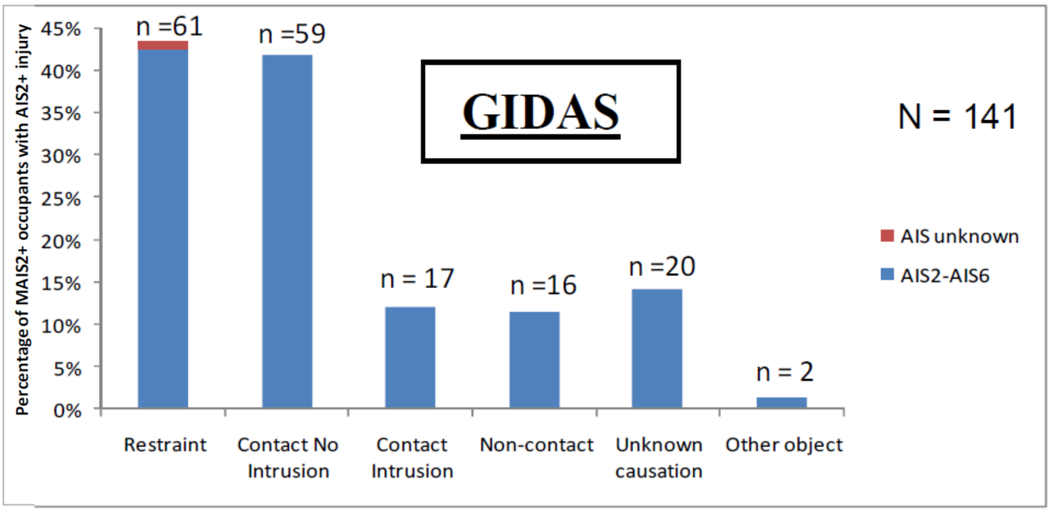
GRAPH 8 - Injuries distribution as a function of overlap accident for GIDAS data

Then the causes of the injuries are investigated and at each injury is associated a code. For example, a fracture of ribs can be correlated to the seatbelt and so a certain code is assigned to that injury. The code are divided in six categories that are: *restraint*, *contact no intrusion* (in which the injury is due to the contact with a component of the cockpit compartment that is not intruded), *contact with intrusion* (in which the injury is due to the contact with a component of the cockpit compartment that is intruded), *non-contact* (for example a whiplash in which no contact happens), *other object* (injuries due to the contact with object not belonging to the vehicle, for example not restrained load) and *unknown*.

The injuries divided per category are shown in GRAPH 9 for the CCIS data and in GRAPH 10 for the GIDAS data.



GRAPH 9 - Number of injuries divided in categories for CCIS data



GRAPH 10 - Number of injuries divided in categories for GIDAS data

The distribution of the injuries is more or less equal for both the sets of data, the most spread injury typology is due to the restrain system. Another information that can be catch out from these graphs is the size of the compartment strength that is inversely proportional to the injuries cause by '*contact with intrusion*'. The percentage of this cause of typology is of 25 % for CCIS data and of 12 % for GIDAS data. If the intrusion of less than 10 cm are classified in '*no intrusion*' category the percentage of CCIS data reduced to 16 %.

Other information that were found from the analysis of these two set of data are that with the increase of the overlap of the accident, also the injuries caused by the '*restrain system*' increase but decreases the number of injuries caused by the '*contact with intrusion*'.

As found also in the previous project, the age of the occupants is an important factor, in fact the over 60 years old have a higher risk of injuries with respect to younger people.

The last information that was found in this analysis but also in previous project is regarding the typology of vehicle, the fatal or critical injuries are higher in case of heavy good vehicle and car impact with respect to a car-to-car impact.

In the following figures are reported the subdivision of the total injury case in presence or not of intrusion, in order to individuate the issue of compatibility. In the FIGURE 31 and FIGURE 32 are shown the data for fatal injuries and MAIS 2+ injuries, respectively.

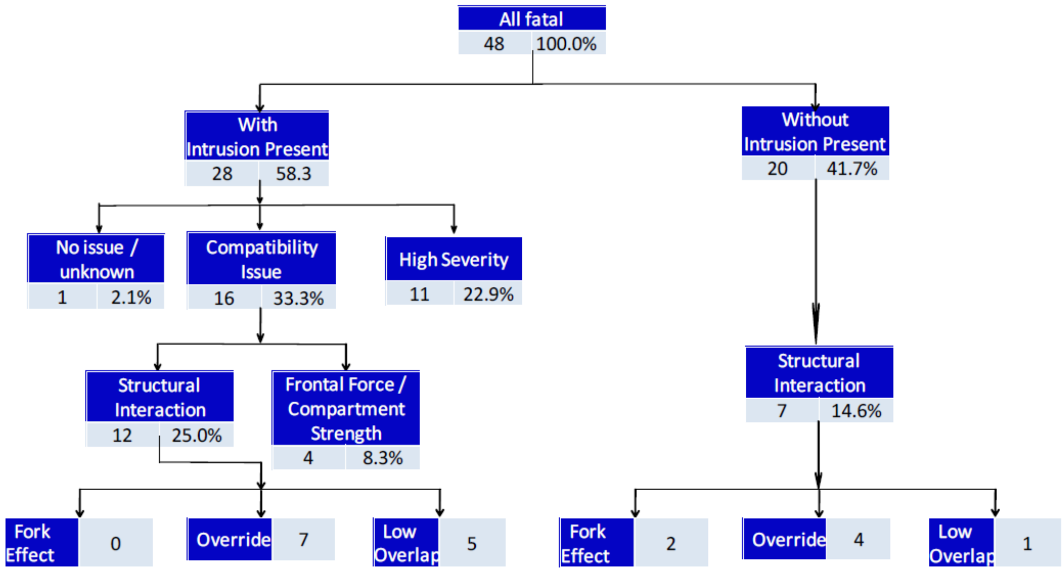


FIGURE 31 - Compatibility issue for fatal case of CCIS data

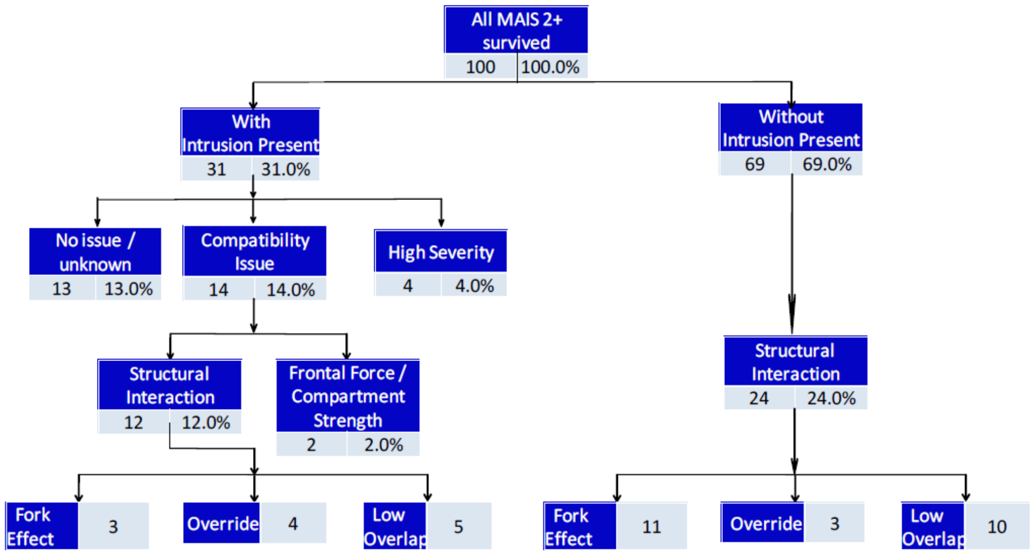


FIGURE 32 - Compatibility issue for MAIS 2+ case of CCIS data

What comes out is that the structural interaction is still a major problem, while the frontal force and compartment strength is a minor problem. It is important to note that the poor structural interaction may mask the second, minor problem. The main case of structural interaction problems are the override and the low overlap.

In the second part of the project, the development of a new procedure to evaluate the compatibility of each vehicle is carried out. The ideas of the previous project VC-COMPAT of using a full overlap and an off-set test procedure is shared.
Since for the structural interaction the override and the overlap are a problem, the structural alignment in the test is considered an important parameter.

Full overlap test

The reason why the full overlap test is needed is because it can control a vehicle's structure alignment and because it provides a severe deceleration pulse in order to test the restraint system.
Two type of this test are present: the Full Width Rigid Barrier (FWRB) test and the Full Width Deformable Barrier (FWDB) test. In both test the structural interaction characteristics can be investigated by measure the force distribution through a Load Cell Wall (LCW). The LCW is composed of 125 mm square elements with the bottom row mounted at a distance of 80 mm from the ground. It is possible to see a scheme in FIGURE 33.

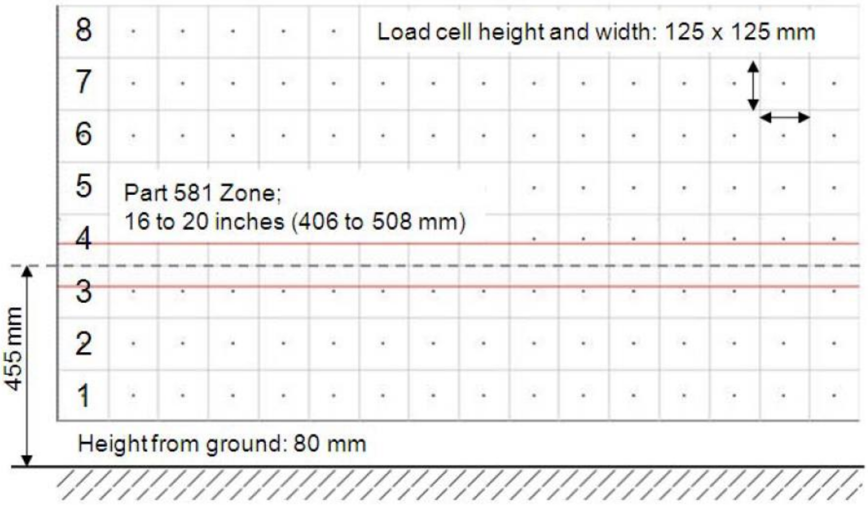


FIGURE 33 - Scheme of a LCW

The ‘Part 581 Zone’ indicated in the figure is a common interaction zone defined as a zone from 16 to 20 inches (so from 406 to 508 mm) measured from the ground. This area represents a good interaction with cars.

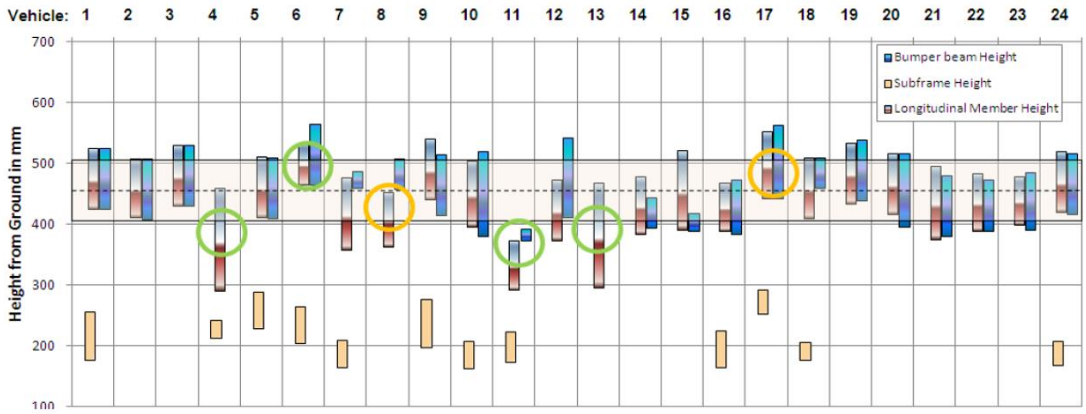
Both the test, FWRB and FWDB, have some advantages with respect to the other test. The FWRB is an already present test, while the FWDB is used only for research purposes.

One of the advantages of the FWRB is that the LCW can measure directly the force, but the most important one is that this test is already used for the homologation in some countries.

While the advantages of the FWDB are that it is more representative of the real impacts, the engine dump loading is attenuated and so it is easier to see the behaviour of the structure, and the presence of the deformable layer can help to detect the Secondary Energy Absorbing Structure and asses them. In this case it is possible a load spreading due to the deformable face presence.

A metric in order to evaluate the test must also be proposed by the participant of the FIMCAR project. Fifty-four crashed vehicle at a speed of 56 km/h were analysed and a portion of twenty-four vehicle analysis is depicted in FIGURE 34.

In the upper part of the table, an analysis of the position of the structure is made. It is represented the position of the bumper beam, the one of the subframe and of the longitudinal member. It is depicted also the ‘Part 581 Zone’, so it is possible to see which vehicles have the structure in the good area and which not. This can be considered a geometric evaluation.



F3+F4>100	167	147	155	87	149	167	138	155	153	176	73	157	86	148	126	143	97	130	151	168	160	149	152	155
F4/(F3+F4)	,54	,51	,77	,31	,57	,93	,3	,38	,71	,52	,25	,31	,25	,59	,47	,31	,7	,52	,65	,64	,46	,37	,24	,47
1. Metric	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	0	1	1	1	1	1	1	1

FIGURE 34 - Assessment of 24 different vehicles

The metrics is based on the force detected with the LCW, and the results are present in the following row of FIGURE 34.

The rule used in order to evaluate if a vehicle is compatible or not is a comparison of values: the sum of the force detected in row 3 and 4 of the LCW shall exceed 100 kN before the time when the total LCW force reach 200 kN (it is the third row from the bottom in FIGURE 34). The second rule is that the force at row 4 divided for the sum of forces in row 3 and 4 shall be between the values 0.2 and 0.8 (it is the second row from the bottom in FIGURE 34).

Apart from vehicle number 8 and 17, it is possible to note that there is an agreement between the geometric assessment and the metric assessment.

In conclusion, a metric in order to evaluate the test is present but it is still to be decided the vehicle test speed and the use of the barrier (rigid or deformable barrier).

Off-set test

The off-set test is useful in order to evaluate the structural alignment, the load spreading, the compartment integrity and the restrain system. Two possible barriers for this kind of test are available, the barrier used for the homologation and the Progressive Deformable Barrier (PDB) as was discussed in the previous projects. The

severity of the test must be chosen by taking into account the compartment strength requirements. One way to set the severity can be by using the deformation energy expressed as Energy Equivalent Speed (EES) and the values of EES should be similar to the one used for the test for the homologation or for the rating.
The speed chosen for the test is of 60 km/h, while the overlap is of 50%.
In FIGURE 35 it is possible to see a comparison between the barrier used for the actual test and the PDB with the interaction area with the vehicle.

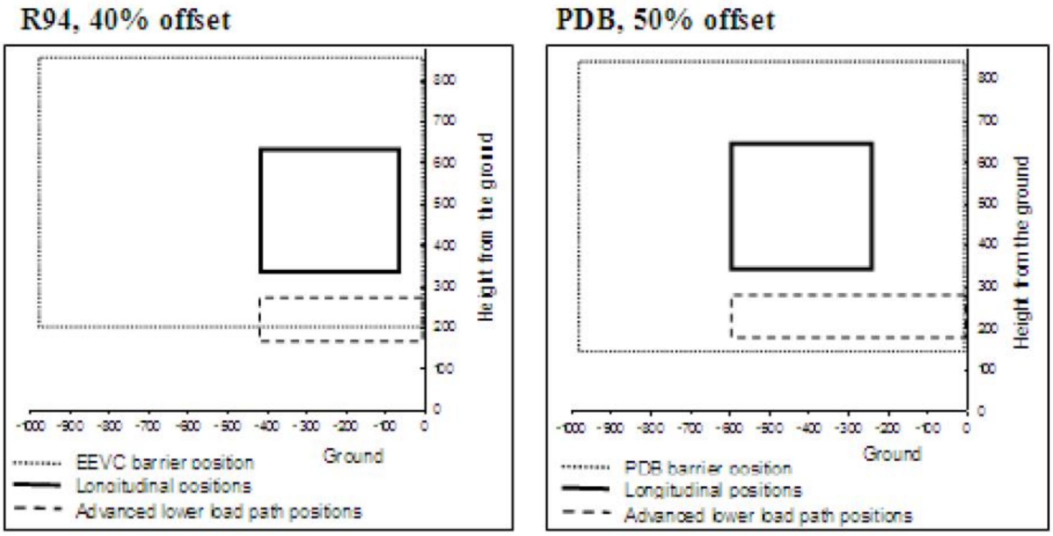


FIGURE 35 - Comparison between actual barrier and PDB

The PDB stiffness increases with depth and has upper and lower lad levels in order to be the more as possible similar to the real case, so to another vehicle. The EES is designed in order to be independent on the vehicle's mass.
The particularity of this test is that the barrier is also used as evaluation of the test. From a 3D scansion of the barrier, the deformation pattern and the depth can be evaluated. Two parameters are evaluated in the barrier, the homogeneity and the longitudinal deformation.
In FIGURE 36 it is possible to see a £D representation of the barrier developed during the project.

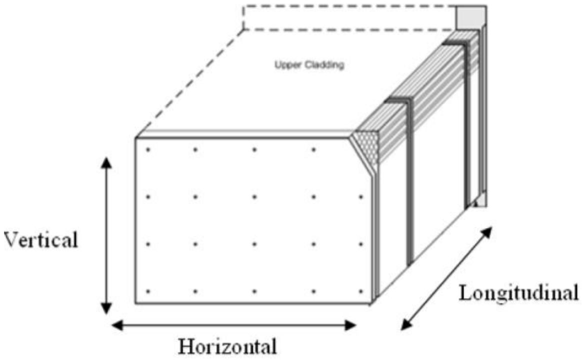


FIGURE 36 - PDB barrier

Also in this case, ones the test is defined, a metric in order to evaluate it must be determined. With this kind of test are analysed 37 impacted barrier and, in a first stage, they were divided in three categories: barrier that show good compatibility, barrier that show a bad compatibility and barrier in between.
In a second stage, in each category the barrier are classified from the best to the worst, so in this case a subjective criteria was used.
The classification in used in order to develop the metric. The metric defined takes into account the homogeneity (H) and the longitudinal deformation (d) of three different zones defined in FIGURE 37:

- Upper zone (U): from 600 to 820 mm from the ground;
- Middle zone (M): from 350 to 600 mm from the ground;
- Lower zone (L): from 180 to 350 mm from the ground.

$$S = f(d_U, d_M, H_M, d_L, H_L)$$

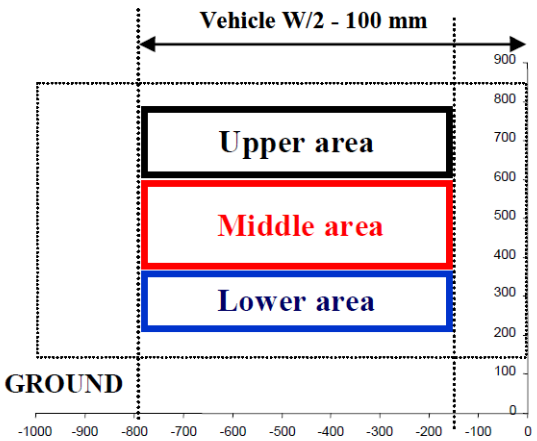


FIGURE 37 - Zones of the barrier

The values determined in the three zones have not the same importance, so the function found in order to give a score of the barrier has different weight for each zone.
In FIGURE 38 it is possible to see the subdivision of the score, while in the following it is present the formula used to evaluate the barrier.

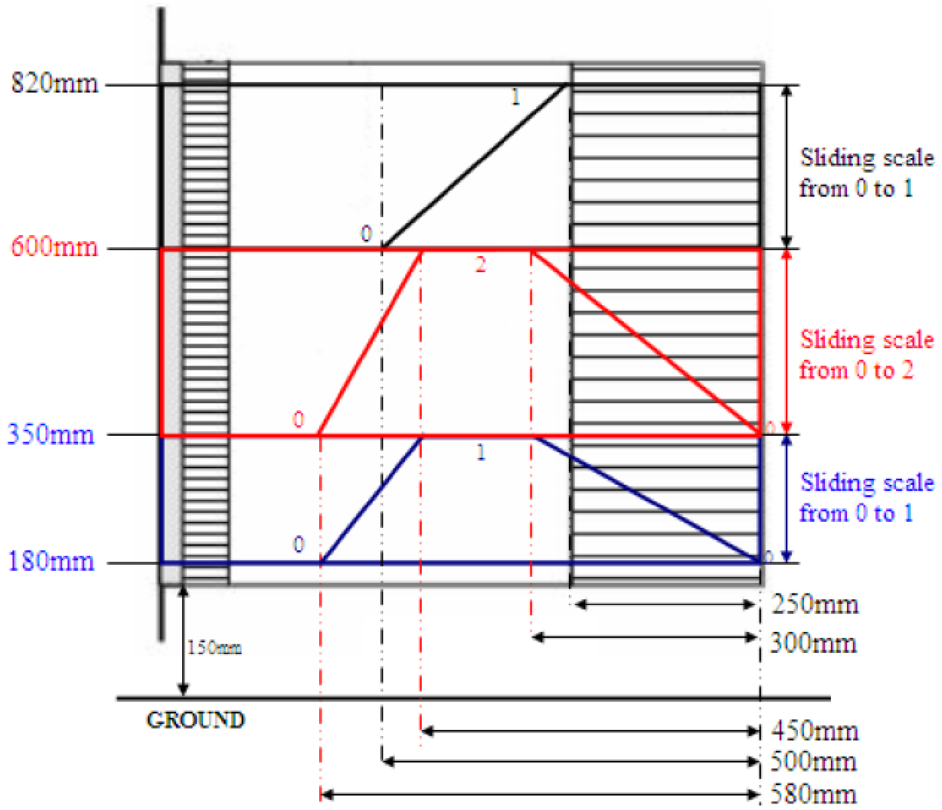


FIGURE 38 - Score for each zone

In middle zone the range for the score goes from 0 to 2, while for both the upper and lower zone the score goes from 0 to 1.

$$S = d_U + d_M + H_M + d_L + H_L$$

The maximum score of this metric is 7 points and the score of the middle zone (d and H) participates to the total score as 57%, the lower zone as the 29% and the upper zone as 14%.
The decision of the FIMCAR project was to develop a Mobile Progressive Deformable Barrier (MPDB) test. This kind of test is exactly equal to the one discussed above, the

PDB test. The only difference is the severity of the test due to the mass of the trolley that conduct the barrier.

The test developed can be seen in FIGURE 39.

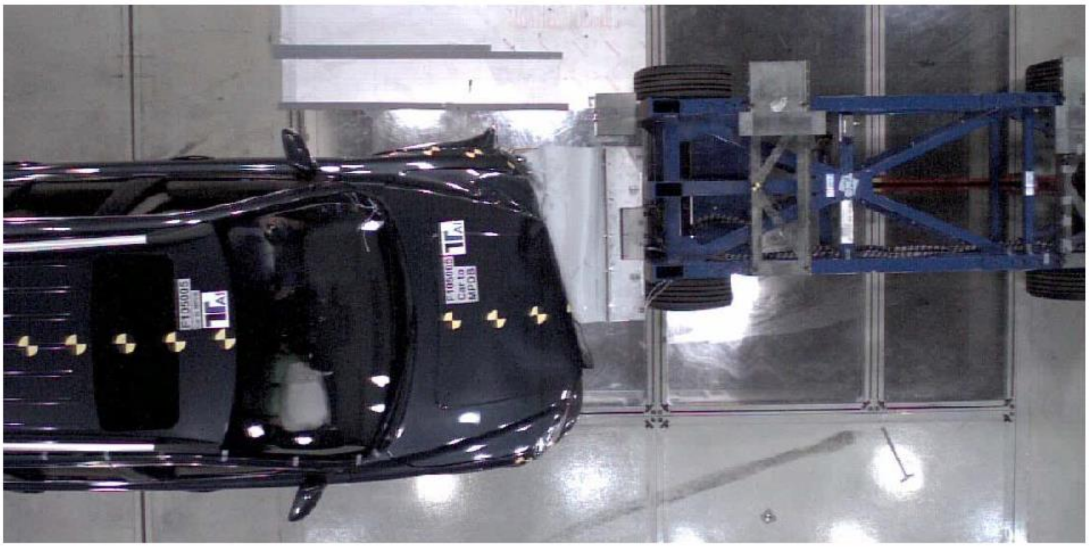


FIGURE 39 - MPDB test

The development of the test goes to the 2018 in which a protocol of Euro NCAP was published and it is described in the next chapter.

4. MPDB frontal impact testing

The European New Car Assessment Programme (Euro NCAP) establishes a new test starting from the 1st January 2020. The test is a frontal impact with 50% of overlap. A Mobile Progressive Deformable Barrier (MPDB) is used. It should be fitted in a trolley that must run at the target speed of 50 km/h against the vehicle that has the same opposite speed. The tolerance on the speed is of ± 1 km/h and it must be measured as near as possible to the point of impact for both the trolley and the test vehicle. The target impact angle is 0 degrees ± 2 degrees for both the test vehicle and the trolley, also in this case the measurement must be effectuated as near as possible to the point of impact. The target overlap is 50% ± 25 mm while the target vertical alignment is ± 25 mm. In order to verify the overlap and the alignment, a small rivet should be tape as near as possible to the edge of the deformable barrier which is to be struck, and a mark should be placed on the bumper of the test vehicle where the pin would strike if an exact overlap of 50 % of the vehicle width is achieved. To acquire data an on-board data acquisition unit is used, it must be triggered by a contact plate at the point of first contact (t=0) and the digital information are recorded at a sample rate of 20 kHz (or 10 kHz).

A braking system can be used only after the conclusion of the first impact, braking must not begin until 100 ms after the vehicle velocity reaches zero.

For what concern the reference load of the vehicle, the fuel tank must be filled with the 90% of the fuel tank capacity mass; driver and passenger occupants are represented with a mass of 80 kg each, the luggage compartment must be filled with a mass of 50 kg evenly spread, and for the second row seats child restrains must be used with dummies of masses 23 kg and 36 kg. For vehicle with two seats, only front masses must be used.

After the test, all doors must be able to be opened. The force that must be applied to the door handle in order to unlatch and to open it at 45° must be less than 500 kN. The force can be measured with a spring-pull attached to the external handle.

The dummies must be removed, if possible, without move the seats. If this is not possible, move the seats and then remove dummies or cut out of the vehicle the seats and then remove dummies.

The evaluation of the test is based on three parameters that are determined using the results of the MPDB to car impact. The parameters are:

- The standard deviation of the post-test barrier face measurements;
- The Occupant Load Criterion;
- The presence of bottoming out of the MPDB face.

A sequence of an example of test carried out can be show in the FIGURE 40.

FIGURE 40 – MPDB frontal impact test sequence

4.1. Trolley and barrier

The trolley is fitted with the Progressive Deformable Barrier (PDB) and together they form the Mobile Progressive Deformable Barrier (MPDB). The total mass of the MPDB must be 1400 kg ± 20 kg. The position of the centre of gravity of the MPDB is defined with a certain tolerance and also some dimensions of the trolley are specified, as shown in the FIGURE 41. The interface plate between the trolley and the barrier should be 1700 mm wide and 650 mm high.

The trolley may be fitted with an emergency abort system, but this is not mandatory. Tyres of the trolley must be inflated at the same pressure and the weight must be evenly distributed as possible left to right.

The trolley construction should be such that there are no structures above the barrier face upper mounting flange that are likely to be contacted by the vehicle.

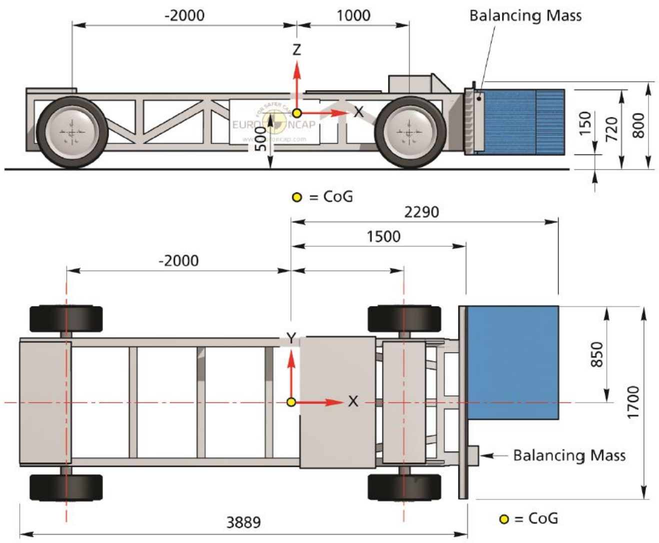


FIGURE 41 - MPDB trolley

4.1.1. Barrier

The barrier consists of three stacked aluminium honeycomb blocks. The blocks have different characteristics. The front (A block) and the rear (C block) blocks offer constant levels of force with deflection. The middle block (B block) has a progressively increasing level of force with increasing deflection.
The different blocks are visible in

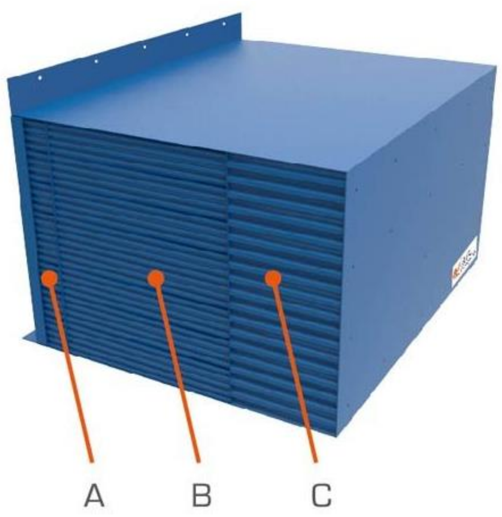
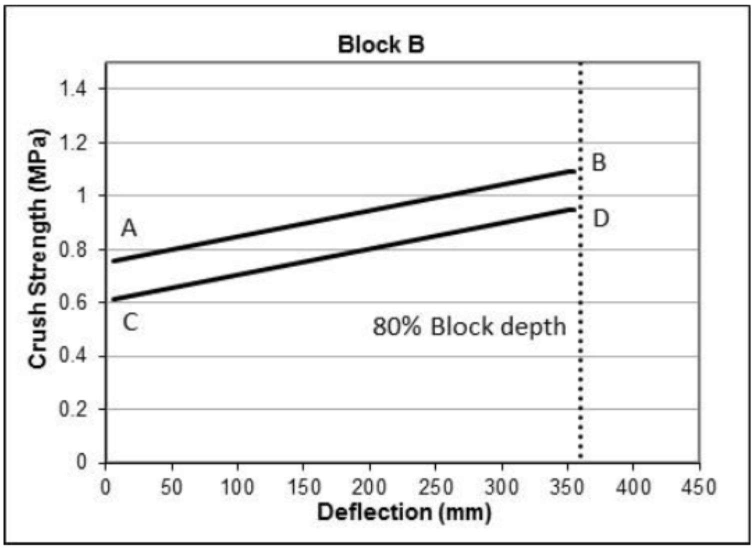


FIGURE 42 - MPDB with A,B and C blocks

Each block must satisfy statically and dynamic requirements.

Static test

The strength of A block should be 1.54 MPa to 1.71 MPa when statically crushed while for the C block a strength of 0.308 MPa to 0.342 MPa is requested. For what concerns block B, the crush strength characteristic should lie within the corridor shown in FIGURE 43. The test to be done in order to verify if the characteristic of the block stays in that range is made on a sample 250 mm x 250 mm x 450 mm of size and it is compressed between two parallel loading plates which are at least 20 mm larger than the block cross section. The compression speed is 100 mm/min ± 10% while the data acquisition is sampled at a minimum 5 Hz. The static test should continue till a height of 355 mm of the sample.



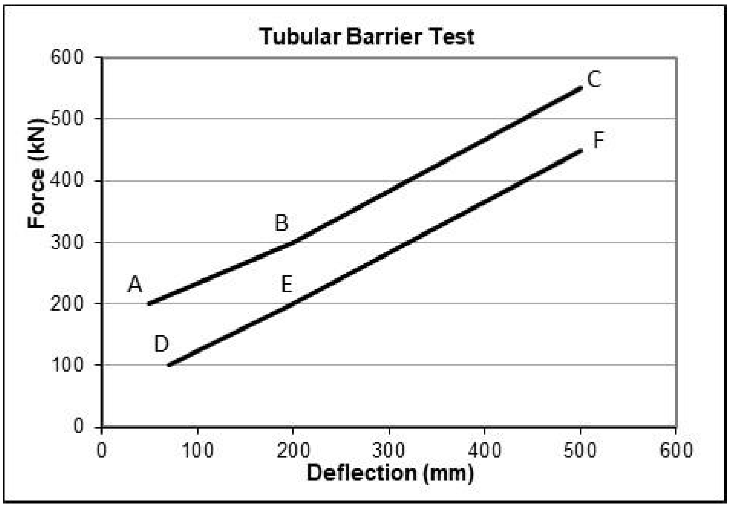
	Crush	Deflection
A	0.756MPa	6mm
B	1.090MPa	350mm
C	0.616MPa	6mm
D	0.950MPa	350mm

FIGURE 43 - Block B crush strength characteristic

Dynamic test

The test for dynamic requirements consists in a barrier firmly attached to the rigid wall and a tubular design impactor made in steel attached to a trolley with no relative displacement during the test. The speed of the impactor must be 60 km/h -0/+1 km/h at the moment of impact; with 0 degrees ± 2 degrees of inclination with respect to the longitudinal axis. The overlap is 800 mm ± 20 mm in Y axis.

The force deflection curves of the deformable barrier tested shall lie within the force corridors defined in FIGURE 44.



	Force	Deflection
A	200kN	50mm
B	300kN	200mm
C	550kN	500mm
D	100kN	70mm
E	200kN	200mm
F	450kN	500mm

FIGURE 44 - Tubular impactor corridors

In FIGURE 45 it is possible to see the impactor and the alignment of the test.

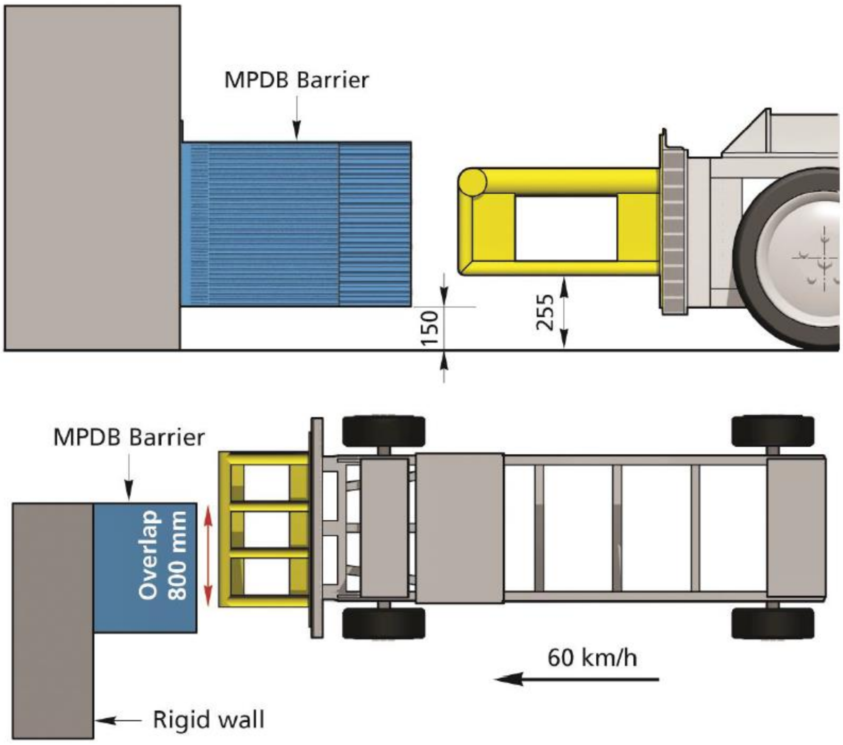


FIGURE 45 - Impactor and alignment

The rear block is bonded to an aluminium back plate which is also used for mounting the impactor. The blocks are bonded to three aluminium sheets and the entire impactor is covered by an aluminium skin (cladding) riveted to the front face.

The principal dimension of the whole barrier are 1000 ± 2.5 mm width and 568 ± 5 mm height, while the thickness of each block are 90 ± 1 mm, 450 ± 1 mm, 250 ± 1 mm, respectively of block A, B and C.

In FIGURE 46 it is possible to see an exploded view of all components of the barrier, while in FIGURE 47 the main quotes are represented.

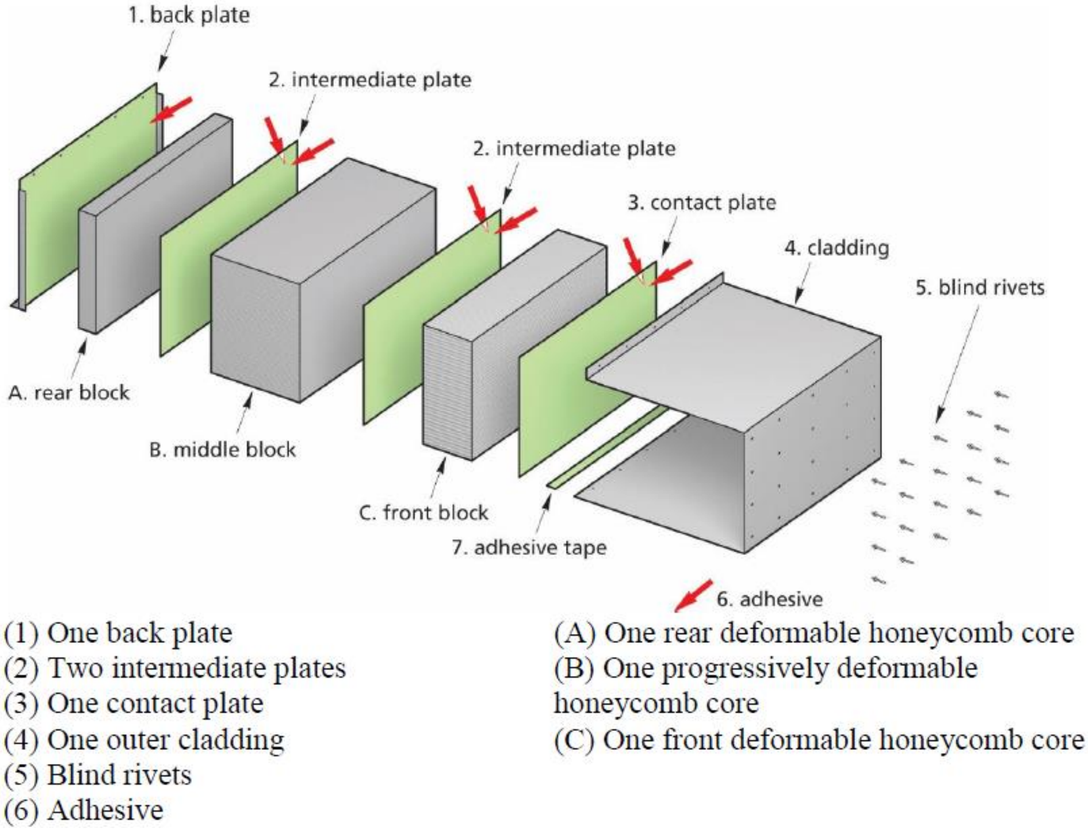


FIGURE 46 - Exploded view of the impactor

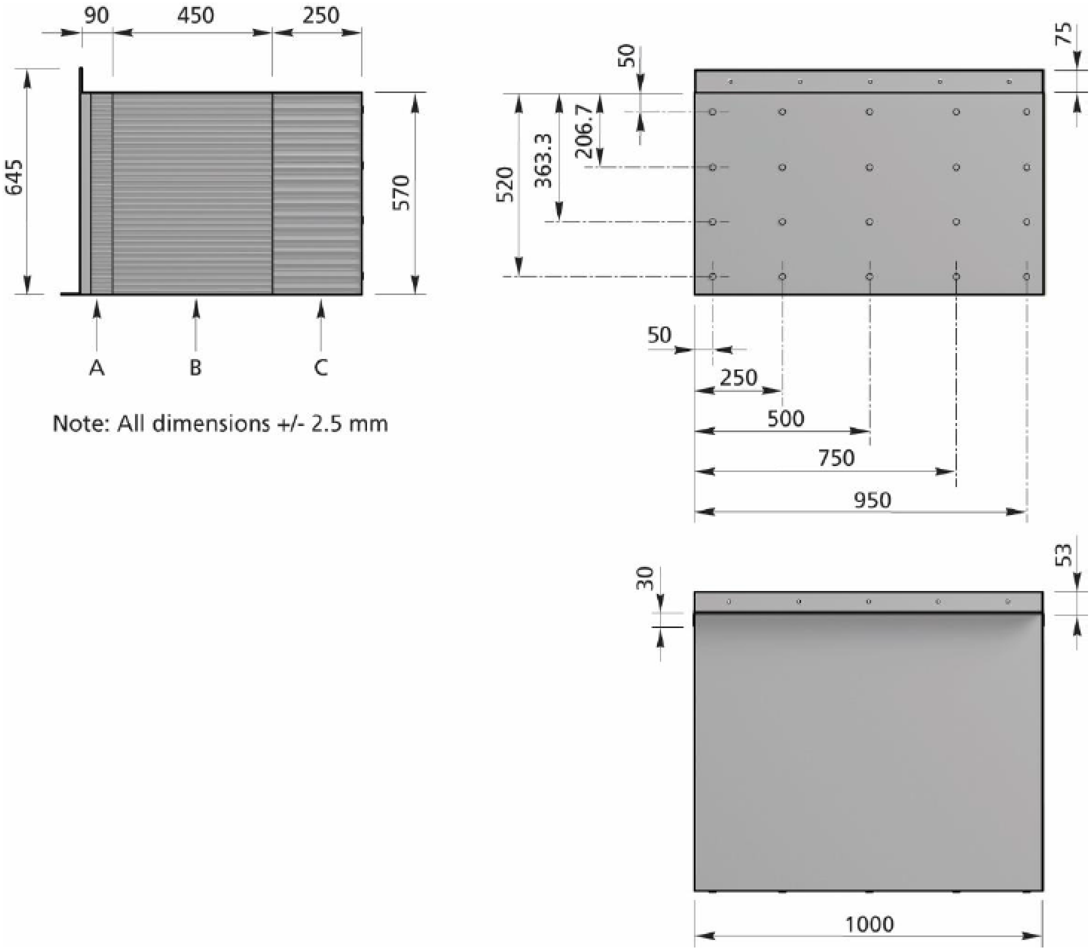


FIGURE 47 - Barrier dimensions

The dimensions of the honeycomb cells are different in each block and are 6.3 mm for the A block, 9.5 mm for the B block and 19.1 mm for the C block, all with a tolerance of 10 % as it is possible to see in FIGURE 48.

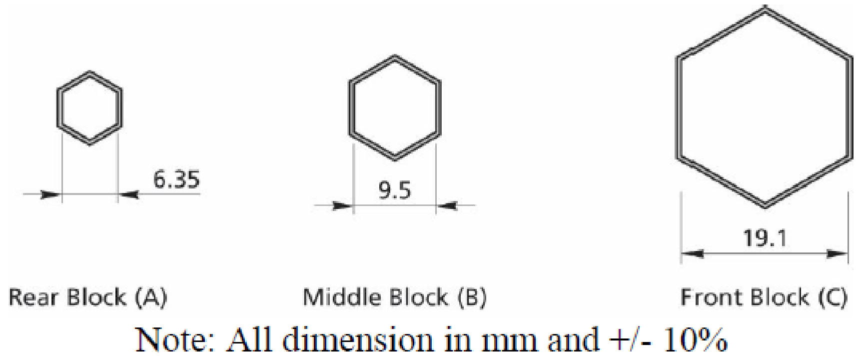


FIGURE 48 - Honeycomb cell dimensions

The upper flange of the barrier is vertical while the lower one is bent of 90 degrees; it is possible to see that in the side view of the projection in FIGURE 47.
The cladding plate is connected to the contact plate through twenty aluminium or steel blind rivets, as shown in FIGURE 46 and FIGURE 47.
Honeycomb blocks are connected to the plate and each other through adhesive that is a two-part polyurethane or equivalent. A maximum of 0.5 kg/m^2 is evenly applied, while the thickness is maximum 0.5 mm.

4.2. Barrier face measurement

A well-defined reference system should be used, it is represented in FIGURE 49. The origin is placed in the lower right corner (seen from the direction of motion of the trolley), Y vector is from the left lower corner point (indicated in violet in figure) to the right lower corner point (green in figure) and the YZ plane is the best-fit plane from all four corner points.

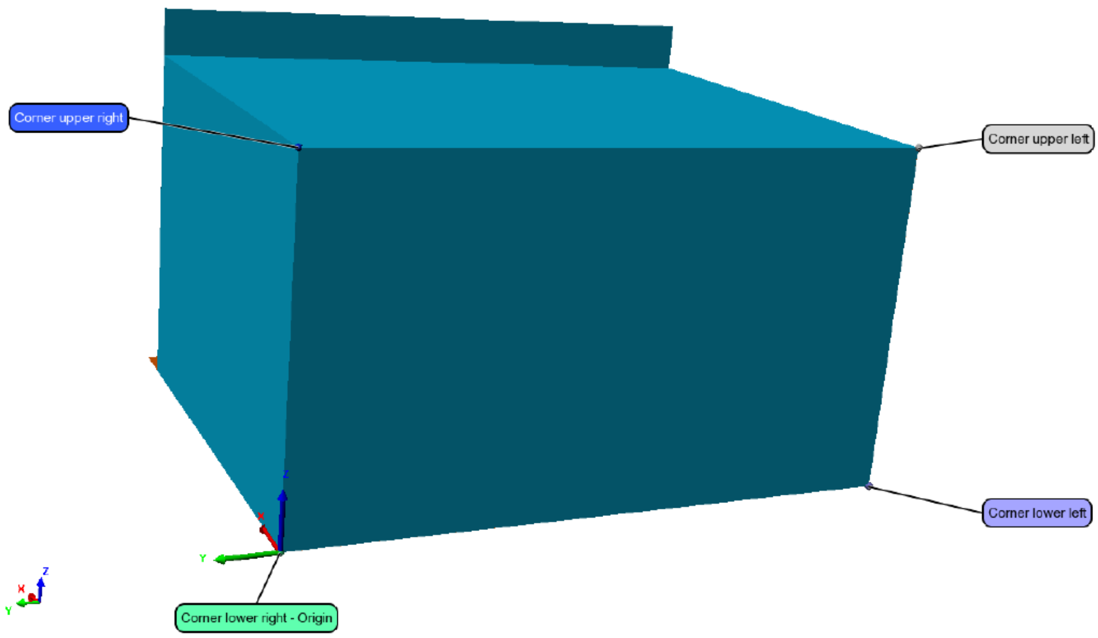


FIGURE 49 – Barrier reference system

A 3D measurement system must be used (scanner) in order to scan the barrier before and after the test, the maximum tolerance that this system should have is of ± 1 mm. At least four point in each side of the barrier back plate must be taken (in the stiff border as shown in FIGURE 50) in order to realign the barrier measurement after the crash.

FIGURE 50 - Reference points positioned in the side back plate

After the crash a new measurement must be done. In the case in which the face of the barrier and the vehicle are still connected, care must be taken to separate the two with the minimal deformation of the honeycomb. If the two cannot be separated, the rule of the protocol must be applied. The barrier surface must be cleaned, and mechanical artefacts must be removed. Cracks that are obviously not caused by intrusion must be filled with clay before scanning. From the scansion a mesh of the after-test barrier should be created with a maximum edge length of 10 mm.
A grid of 1400 points must be used in order to calculate the deformation of the barrier in each point. The points of the grid have an equal distance of 20 mm and the grid is centred in the undeformed barrier. The points must be numbered and positioned as in FIGURE 51.

Grid1 X=0 Y=10 Z=10	Grid2 X=0 Y=30 Z=10	……..	Grid50 X=0 Y=990 Z=10
Grid51 X=0 Y=10 Z=30	Grid52 X=0 Y=30 Z=30	……..	Grid100 X=0 Y=990 Z=30
……..	……..	……..	……..
……..	……..	……..	……..
Grid1351 X=0 Y=10 Z=550	Grid1352 X=0 Y=30 Z=550	……..	Grid1400 X=0 Y=990 Z=550

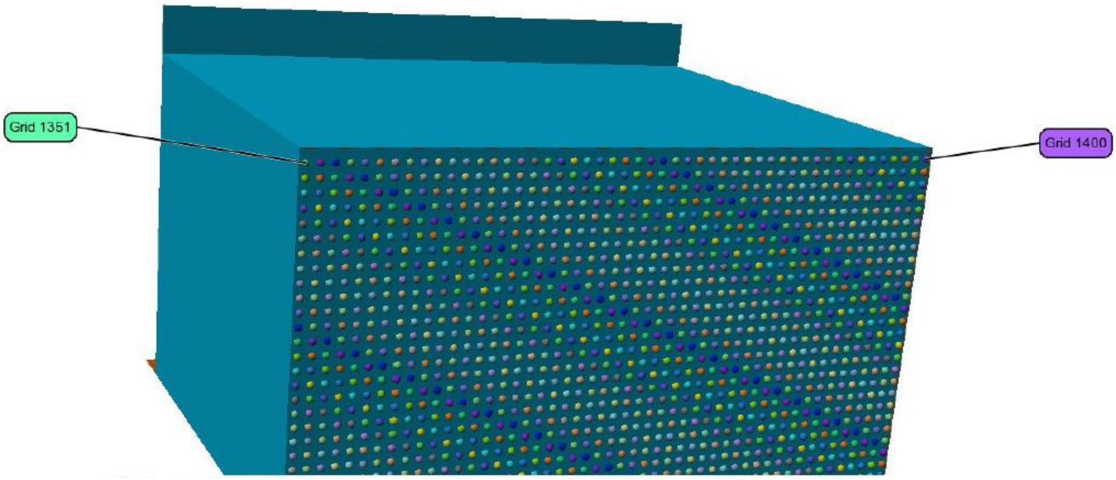


FIGURE 51 - Grid of points centred in undeformed barrier

The grid of points should be projected on the mesh of the deformed barrier along the X axis, as shown in FIGURE 52. If some points do not hit the mesh, because of the presence of some holes in the mesh, points should be placed as close as possible to the desired position by considering the X value of the neighbouring grid points or the surrounding mesh surface. The values of each point must be exported in the assessment file provided by Euro NCAP.

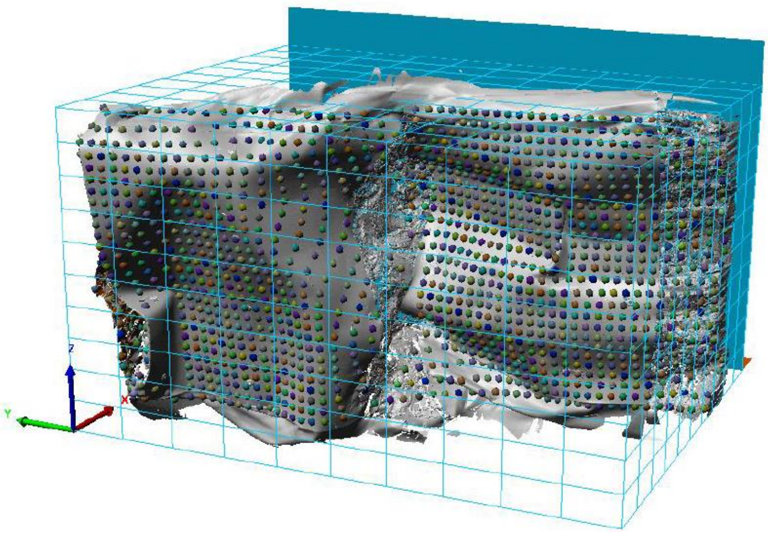


FIGURE 52 - Projection of grid in the deformed barrier mesh

4.3. Evaluation

As previously mentioned, the evaluation of the Euro NCAP test is based on three categories: the standard deviation (SD) of the post-test barrier face measurements, the occupant load criterion (OLC) and whether the vehicle has bottomed out (BO) the MPDB face.
The score, starting from the 1st January 2022, will be a penalty applied to the overall test score. The penalty will go from 0 to 8 points. In the introduction years, 2020 and 2021, the penalty will be halved.
The penalty for standard deviation and occupant load criterion is based on two interlinked sliding scales that cover the full range. While bottoming out is an additional 2 points penalty that is added to the modifier calculated from the combination of SD and OLC; in any case the maximum compatibility assessment will not exceed 8 points.

4.3.1. Barrier deformation standard deviation

The homogeneity of the vehicle is based on the standard deviation of the intrusion depth of the barrier face. The standard deviation is defined as the spread around the mean intrusion that covers 68.2% of all measured intrusion points. The bigger is the standard deviation and the bigger is the spread of the measured points and the higher is the aggressivity of the vehicle (so lower compatibility).
The area in which the evaluation is based on, depends from the vehicle. The height is independent from the vehicle sizes, while the width depends on it. The lower border is at a distance of 250 mm from the ground level and the upper border is at a 650 mm from the ground. For a left-hand drive vehicle, the right border of the area is located at 200 mm from the right-hand edge of the barrier face. The left border is the one that depends on the width of the test vehicle, it is located at 45% of the overall width of the vehicle from the right-hand edge of the MPDB face. The dimension described are visible in FIGURE 53.

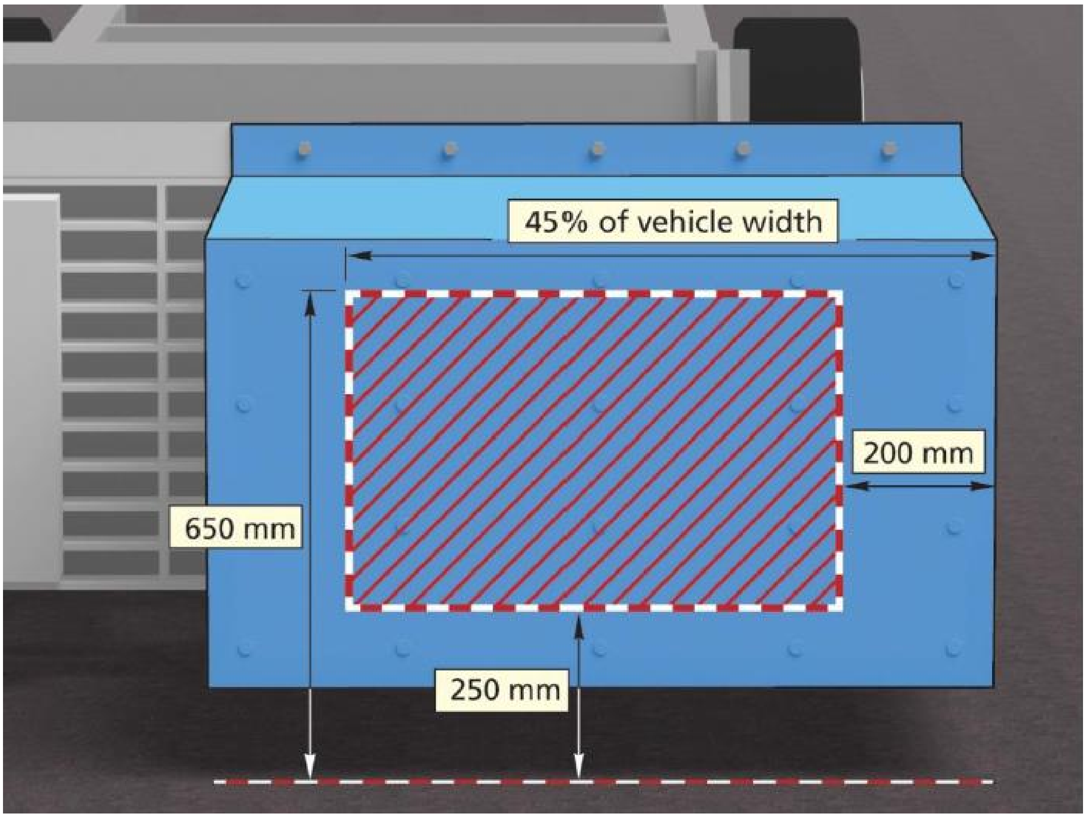


FIGURE 53 - Evaluation area

4.3.2. Occupant Load Criterion

The Occupant Load Criterion is based on the X-acceleration acquired in the centre of gravity of the MPDB, it is evaluated using a sliding scale between 25g and 40g.

In order to obtain the acceleration for the evaluation of this criterion, the following equation must be used. First of all, the velocity course of the barrier should be calculated by integration of the acceleration, then the $OLC_{SI-unit}$ in the International System (SI) units can be derived.

$$V_t = \int A_X(t)\, dt + V_0$$

$$\begin{cases} \int_{t=0}^{t=t_1} V_0 dt - \int_{t=0}^{t=t_1} V(t)dt = 0.065 \\ \int_{t=t_1}^{t=t_2} (V_0 - OLC_{SI-unit} \times (t - t_1))dt - \int_{t=t_1}^{t=t_2} V(t)dt = 0.235 \\ V_0 - OLC_{SI-unit} \times (t - t_1) = V(t_2) \end{cases}$$

Where:

- V_0 is the initial velocity of the barrier at $t = 0s$;

- t_1 is the end of the free-flight-phase of a virtual dummy on the barrier along a displacement of 0.065 m;
- t_2 is the end of the restraining-phase of a virtual dummy on the barrier along a displacement of 0.235 m after the free-fight-phase.

OLC should be converted from SI unit into g (standard gravity) with the conversion factor of $1\ g = 9.81\ \frac{m}{s^2}$.

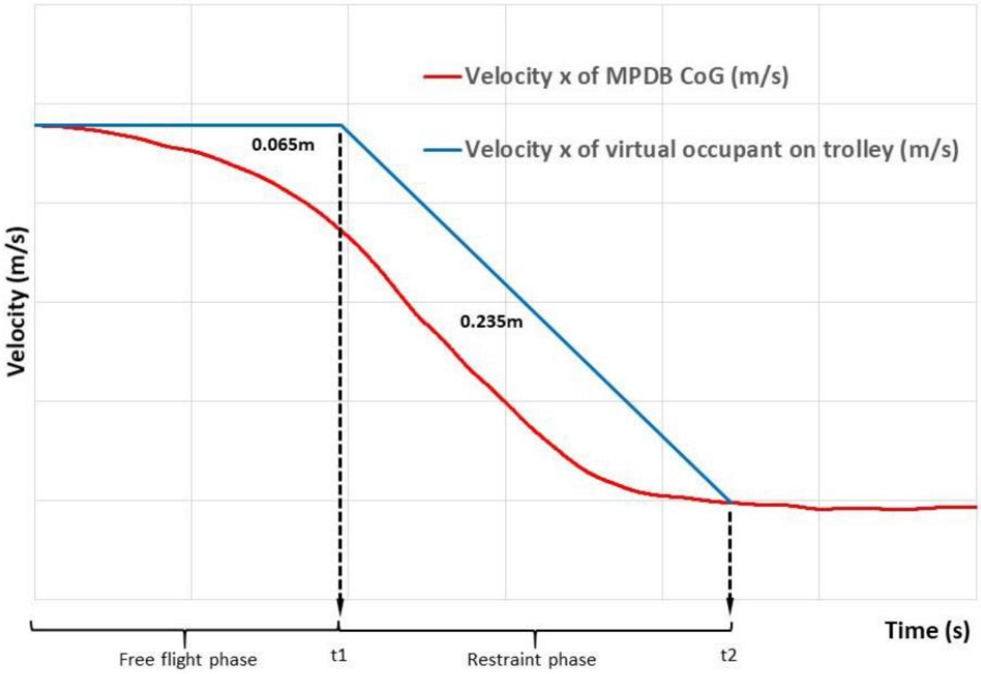


FIGURE 54 - OLC evaluation

In FIGURE 54 it is possible to see the first part of free-flight of the dummy, from t=0s till the time t_1, at constant speed of the occupant. The restraining phase till t_2 at decreasing speed of the occupant. In red is represented the speed of the centre of gravity of the MPDB while in blue it is represented the speed of a virtual occupant on the trolley.

4.3.3. Bottoming out

Bottoming out is defined as an area of the barrier that has been penetrated by 630 mm or more, that has an area at least of 40 mm x 40 mm.

The presence of bottoming out is determined from a physical examination of the barrier face and vehicle. This will be evaluated by the Inspector during the vehicle inspection and be based upon the barrier scanning results.

4.3.4. Calculation

As previously mentioned, the evaluation is based on SD and OLC and an additional penalty for BO is added:

for SD<50mm, OLC<25g and no BO there will be no penalty;

for SD<50mm, OLC<25g and BO there will be a penalty of -2;

for SD>150mm, OLC>40g and no BO there will be a penalty of -8;

for SD>150mm, OLC>40g and BO there will be a penalty of -8;

When the SD and the OLC are between these limits, the following percentage are used:

Performance limits	0%	20%	40%	60%	80%	100%
Standard deviation	50mm	70mm	90mm	110mm	130mm	150mm
OLC MPDB	25g	28g	31g	34g	37g	40g

By interpolate the value obtained with the ones of the range, both for SD and OLC the effective penalization is calculated, it is possible to see it in the graph represented in FIGURE 55.

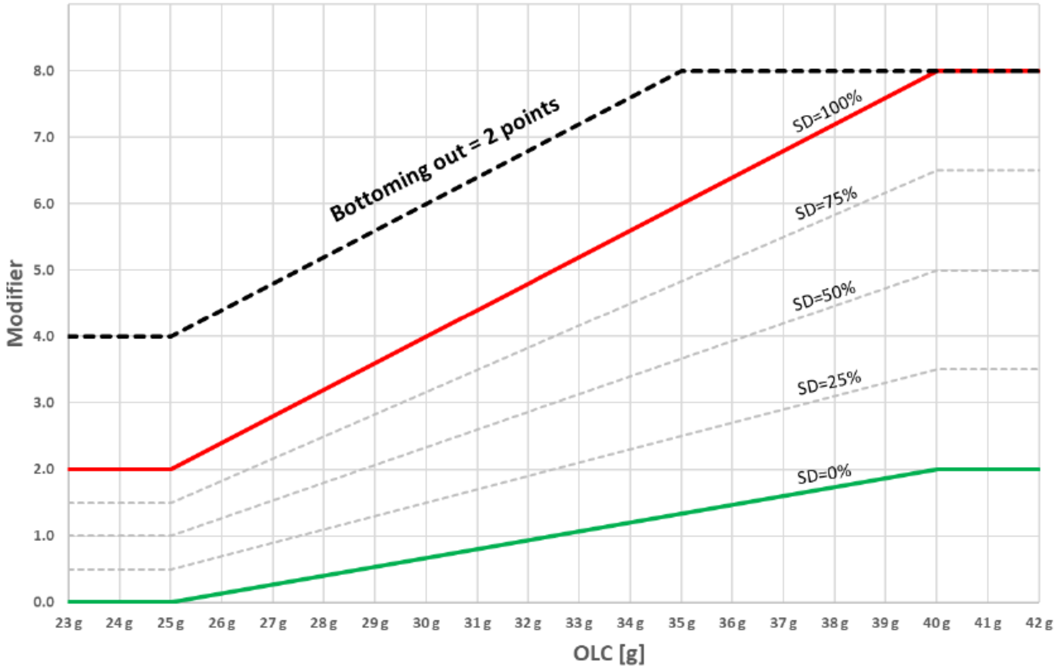


FIGURE 55 - OLC and SD graph

5. Tools

The tools used are the 3D scanner ATOS CORE 500 for the acquisition of the barrier and the relative software ATOS Professional 2016.

5.1. Scanner

ATOS Core 500 is a high resolution, optical digitizer that delivers rapid and precise three-dimensional measuring data for the optimization of design processes, thereby improving industrial production processes. The Scanner is composed of two stereoscopic cameras and a blue light emitter LED with a wavelength of 400-500 nm. Since the sensor works with narrow-band blue light, the interfering ambient light can be filtered during image acquisition. It is possible to see the tool in FIGURE 56.

FIGURE 56 - Scanner ATOS Core 500

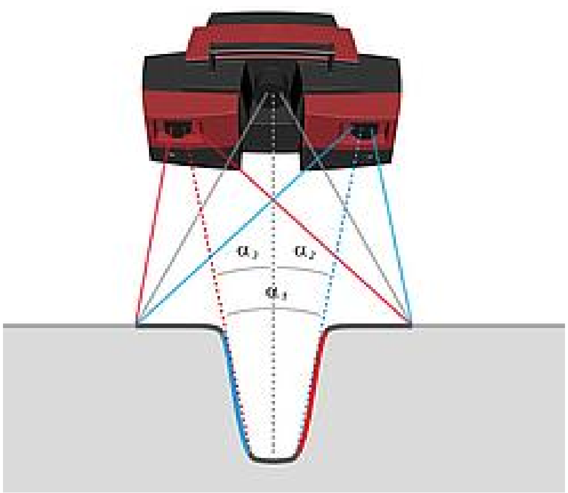


FIGURE 57 -Triple Scan technology

The scanner uses the Triple Scan technology patented by GOM (Gesellschaft fűr Optische Messtechnik mbH). During the measurement, precise fringe patterns are projected onto the surface of the object and are recorded by two cameras. This automatic principle offers advantages in measuring reflective surfaces or objects with complex indentations. The functioning of the measuring system can be seen in FIGURE 57.

The simulated measurement uncertainty is less than 0.0010 mm. So it is in accordance with the required tolerance of the protocol, in which the minimum tolerance accepted for the scansion of the barrier is ± 1 mm, as mentioned in paragraph 4.2.

For big or complex shape object, more than one scansion are needed. The scanner is able to position the acquired image in the space thanks to some markers that must be placed in the object to be scan. Markers can be magnetic or adhesive and are black and white concentric circles in order to create an elevate contrast and permit to the acquisition system to recognize them. The external circle of the marker is black while the internal one is white For each scansion a minimum number of three saved markers must be visible at the cameras of the scanner in order to align the successive scansion to the previous done.

In order to acquire a complete or big object, multiple scansion must be done. The tool can be positioned in a movable support in which the position and orientation of the scanner can be done in order to scan surfaces that are not acquired yet. Every scansion generates a cloud of points and more scansions generate the complete object.

During the use, the scanner must be connected to the computer and it works with its software ATOS Professional 2016.

Before using the tool, the sensor must be initialized. It takes about 20 minutes and this time is needed in order to adapt it to the environmental temperature.

The scan has also a touch probe, a sensor that can evaluate the position in region that are not optically accessible. This tool is not useful for the scope of this thesis.

5.2.Software

The software is ATOS Professional 2016 and it can work with the scanner. The software works in different environment on the bases of the operation that must be done. The environments are:

- SCAN: it is the environment used to acquire data, to digitalize the object;
- MESH EDIT: it is the environment in which the mesh can be modified;
- ANALYSIS: it is the ambient used to analyse the object scanned or compare it with an imported CAD;
- LIVE: it is the environment used to acquire data of the movement of some selected point or acquire information about positions by using the touch probe. This ambient is not useful for the scope of this thesis, so it is not discussed.

The ambient that will be utilized for this project are the firsts three, in order to acquire object (that will be the barriers), repair the mesh and then analyse it.

The SCAN ambient permits to visualize in the computer monitor, before the scansion, the surface that it will acquire. In the preview it is possible to see also the relative markers that are present and that the software is able to distinguish. The markers that the system is able to recognize are visualized with a green cross, if the marker is just acquired in previous scansion an identification number is associated to it and it is displayed near the green cross. The cross can appear also red if the contrast is not appropriate or the distance of the marker is not in the acquisition range. Two parameters are adjustable in the cameras for each scan: the contrast level and the exposition time.

When more scansions are done, the cloud of points are visualized together in the page and the already scanned object is constantly displayed with the actual position of the scanner. The software gives a feedback of the scansion done, based on some parameters such as the temperature of the sensor, the alignment of the scansion with respect to the previous, the external movement and the luminous variation; the evaluations are indicated with an arrow and a colour:

- Good quality if the arrow points upward and the colour is green;
- Not optimal quality if the arrow points toward the right and the colour is yellow;

- The measurement is not been transformed if the arrow points downward and the colour is red;
- Unknown quality if the question mark on white background is present.

The evaluation of the scan is done both for each single scansion (each frame) and for the overall scansion.

In the same ambient it is possible to polygonalizing the object obtained and so transform the clouds of points of all the scansions in a mesh composed of not overlapped triangles. The density of the triangles is different from one area to another, depending on the curvature of the object. The mesh obtained has some defect due to the acquisition procedure and to the shape of the object, especially some halls are present.

In the second ambient, the MESH EDIT, it is possible to modify the mesh generated from the polygonalization. If the acquired object has a too complex shape, it can happen that the scansion cannot be done completely and so the final mesh has some holes or parts of the surface that are missing. In these cases, the reconstruction of the mesh can be done.

Other operations on the mesh are available, such as repair, smooth or lighten.

The last ambient that is described is the ANALYSIS in which the analysis of the mesh is possible. In this section the comparison with another surface is possible, one surface is the one that is acquired, while the other one can be a CAD model or a second scansion. In the first case the comparison with a theoretical model is done while in the second case it is possible to compare an object before and after a deformation in order to analyse the differences. The second case is the one that is the main object of this thesis.

6. Procedure to measure the deformation of the MPDB

As mentioned in the second chapter, the barrier deformation after the impact has to be measured in order to do a rating of the crash. To do that, a scansion of the barrier before and after the crash is needed. Two procedures are implemented, one for the evaluation of the barrier coming from the internal laboratory. The other procedure is for the evaluation of barriers coming from external laboratories in which the tests are done, so only the crashed barrier is available. The procedures are illustrated by steps in the following.

6.1. Procedure for barrier coming from the internal laboratory

Since the barrier is coming from the internal laboratory, where the test is performed, the pre-test is available and so the scansion can be done before and after the test. In this way the measurement is precise.

6.1.1. STEP 1: Positioning of the undeformed barrier

The barrier must be acquired before and after the impact in order to have some reference points that are coinciding in the pre-test and after-test scansions, i.e. some points that remain in an undeformed area of the barrier. The Euro NCAP protocol suggest to take these points on the back plate layer, on the side part, as shown in FIGURE 58.

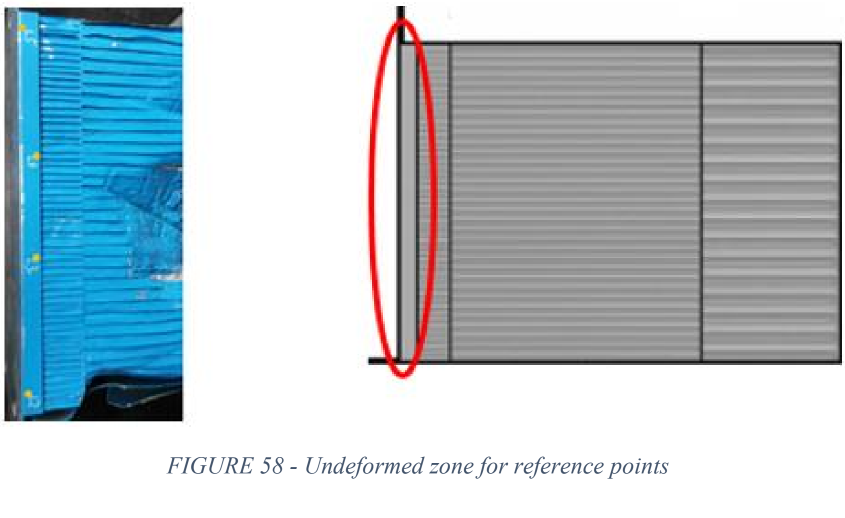


FIGURE 58 - Undeformed zone for reference points

Even if the dimension of the barrier are standard, the tolerance is about ± 2.5 mm in all dimensions as written in the protocol (paragraph 4.1.1). Since these relative high tolerances, it is better to make the scansion before and after the crash.
The barrier is mounted on the trolley in order to make the scansion. The reference points can be taken in the barrier, as explained in the protocol, but same other can be taken also on the trolley in order to be sure that at least three reference points are in the undeformed zone.
A barrier mounted on the trolley is shown in FIGURE 59.

FIGURE 59 - Barrier mounted in a trolley

In the right picture of FIGURE 59 it is possible to see the reference points positioned in the back plate and also on the plate of the trolley.

6.1.2. STEP 2: Acquisition of the undeformed barrier

The acquisition phase of the undeformed barrier takes into account the scansion and the polygonalization.
First of all, the scanner ATOS Core 500 must be installed on the movable support. The movable support permits to adjust the position and the orientation of the scanner. The position can be modified by acting on the height, movement toward the right or the left, depth and rotation of the scanner itself. So that, by keeping fix the support and move only the adjustable position, multiple scansion are possible in a relatively small amount of time. To acquire the barrier, the scanner must be powered by current and connected to the computer in which the correlated software ATOS Professional 2016 is installed. By running the software, the sensor of the scanner must be initialized and

then a waiting of about 20 minutes is necessary in order to permit to the sensor to adapt itself to the ambient conditions. If this passage is skipped, the scansion done with the sensor not properly wormed will have a not optimal quality. Ones the software has been started, to initialize the sensor, from the SCAN ambient, the *initialize/close sensor* button ( ) in the upper right must be press.
During the waiting for the sensor, the markers can be applied on the barrier and on the metal plate of the trolley. For this application adhesive markers of 6.0 mm diameter are used. In FIGURE 60 is shown how markers looks like.

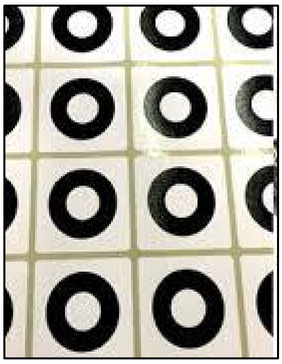


FIGURE 60 - Markers

The markers must be positioned randomly on the barrier, it is important to don't follow a specific alignment in order to facilitate the system to position the object in the space. An excessive number of markers is not useful, especially in this acquisition because of the simple geometry of the object (substantially the barrier is a box whit almost flat surfaces).
When the sensor is ready, the *light on* button ( ) becomes red. Now a *new series of measurement* can be started from the button in the upper left ( ). The image of what the cameras see appears in the screen. The scanner can be positioned in the best way according to what is represented in the screen, the contrast and the exposition can be adjusted directly under the image.
For the first scan it is important to frame at least three green cross, that are the markers that will receive the ID number. Higher is the number of green cross that the system see and better it is for the follow-on of the scansion. Attention must be kept instead for the successive scan, in which the scansion must be done always when at least three markers whit their ID number are present, in order to permit the software to position the scansion in the space and align it with the others.

From each scansion and the next, the position of the scanner must be changed in order to frame always a new portion of the surface or a different angulation of the same surface.
In this phase, attention must be kept also to remember to scan the reference point on the back plate and on the trolley, if positioned. These element will be useful for the alignment of the scansion of the post test barrier in the following steps.
After the scansion, the cloud of points that is acquired must be transformed in a mesh through the polygonization. To do that, the *polygonization and recalculation button* ( ) must be pressed. This operation requires some time.
In this case it is not important that the mesh is well finished but it is enough that it is complete, even if whit some holes.
Anyway edge of the frontal face (seen from the direction of motion of the vehicle), should be complete in order to correctly position the barrier in the reference frame, in the STEP 5: Alignment of the undeformed barrier. Also the side back plate and the edge of the upper or lower face should be well finished for the same reason.
This barrier is useful only for the alignment with the reference system and the alignment with the deformed barrier, so good finishing is not requested.
After this operation, two elements are present: the scansion and the mesh of the barrier. The scansion must be kept and not discard because it will be useful for the alignment of the deformed barrier scansion, since the reference points are only present in the scansion and not in the mesh element.
In FIGURE 61 it is possible to see the scansion of an undeformed barrier, all the green points visible on the surface are the markers positioned on the barrier surface.

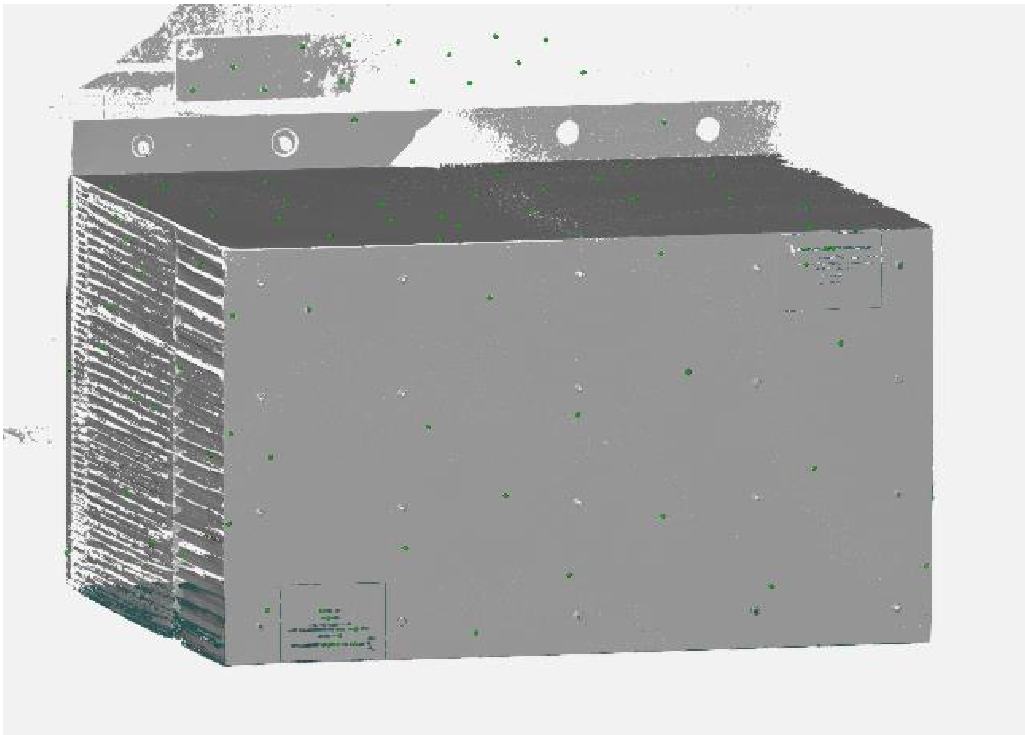


FIGURE 61 - Scansion of the new barrier

6.1.3. STEP 3: Scansion of the deformed barrier

The scansion of the post-test barrier must be done in the same file where the scansion and the mesh of the pre-test barrier is present.

The scansion of the crashed barrier must be done when the barrier is still mounted on the trolley in order to avoid any deformation after the end of the test. As described by the protocol, any piece of the vehicle that remain attached to the barrier must be removed, if possible. The removal of these part must be done carefully and without deform the barrier.

The post-test barrier, at contrary of the pre-test one, can have some parts of the aluminium honeycomb that are reflective and so an anti-reflective spray should be applied on these areas.

Some markers can be added in the surface because some of them may have been detached during the impact and other may have been added because of the rupture of the cladding and so new surface to be scanned.

As in the previous scan, the scanner must be set and to start a new scansion the button *new series of measurements* in the SCAN ambient should be press and so a new scansion is displayed in the folder '*effective elem*ents' in the left side of the screen.

All the accoutrements used for the scansion of the pre deformed barrier, such as position of the scanner and time for the worm up of the sensor are still valid.

Also in this case, attention must be kept in order to include the reference markers in the scansion (the ones on the side back plate and on the plate of the trolley).

In the post test barrier, the deformation can include the rupture of the cladding plate or not. The case in which the cladding plate is broken the scansion is more difficult due to the different facets of the honeycomb layers deformed. If this happens, the scansion takes more time and it must be done carefully, with many scansions in different position, in order to capture the different faces of the honeycomb. In this situation it is practically impossible to have a complete surface without holes. Anyway, more scansions are done, more the surface will be complete and more the final evaluation will be precise. The most important area that should be complete is the one of the rating; in the external part of the barrier, even if the surface is not complete it is not a problem for the rating.

If the cladding plate remains intact, the scansion will be faster and the surface will be easily complete, without holes.

An example of scansion of a barrier in the first case in which the cladding is broken is shown in FIGURE 62 while a case in which it remain almost intact is shown in FIGURE 63. In both figures on the right is present the frontal view (seen from the car side) while in the left part of the figures are present a rotated view in order to better understand the shape of the cladding plate.

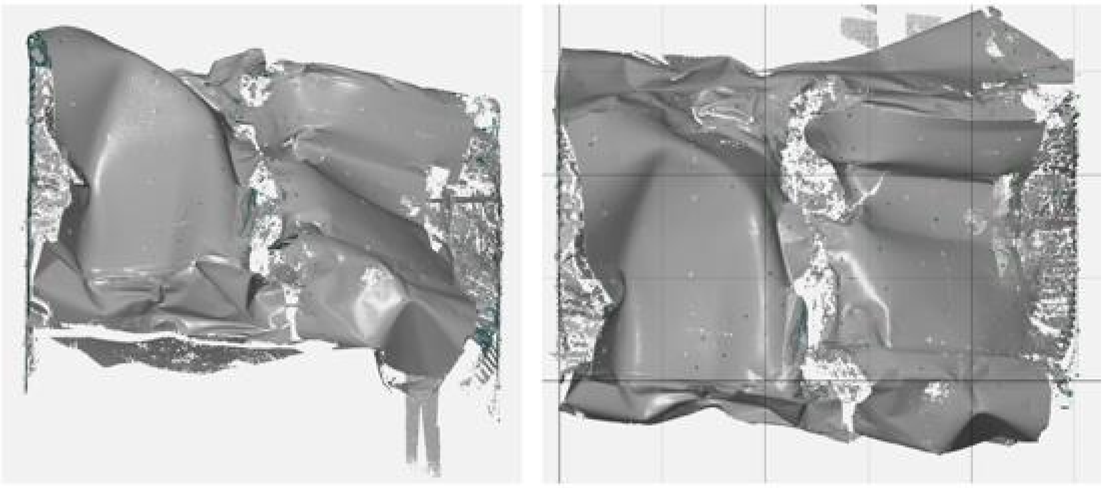


FIGURE 62 - Barrier with broken cladding. Axonometric view on left ad frontal view on right

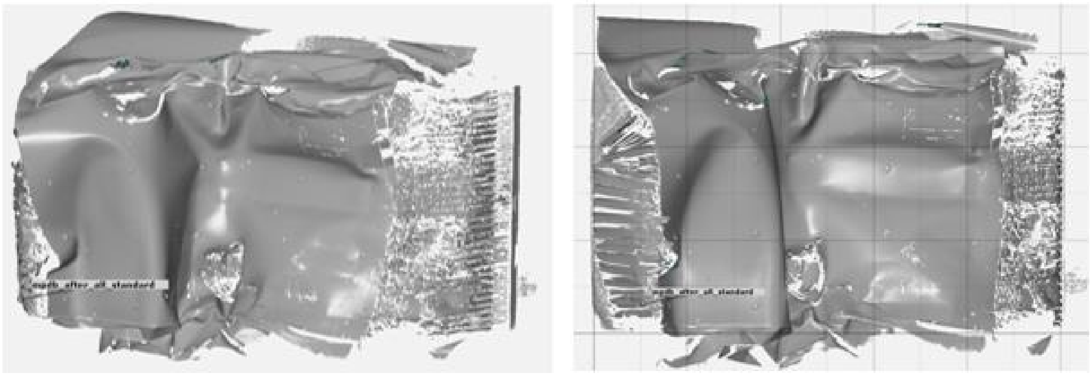


FIGURE 63 - Barrier with almost complete cladding. Axonometric view on left ad frontal view on right

Sometimes it can happen that the cladding is broken, and the deformation is too deep that the scanner is not able to reach the surface of the deformation. In these cases, a procedure in which a layer of honeycomb is removed can be applied. Deeper is the deformation and higher is the number of layers that could be removed or, instead a thicker layer could be removed.

This was done in a characterization test in which the deformation was too deep and three scansions are done in order to reach the bottom of the deformation. The depth of the deformation in this test was so high because a strut with a small contact surface was used. In FIGURE 64 it is possible to see the deformation of the barrier while in FIGURE 65 the three different scansions are visible. The scansion for different layer can be done in separate scansions and then polygonized together.

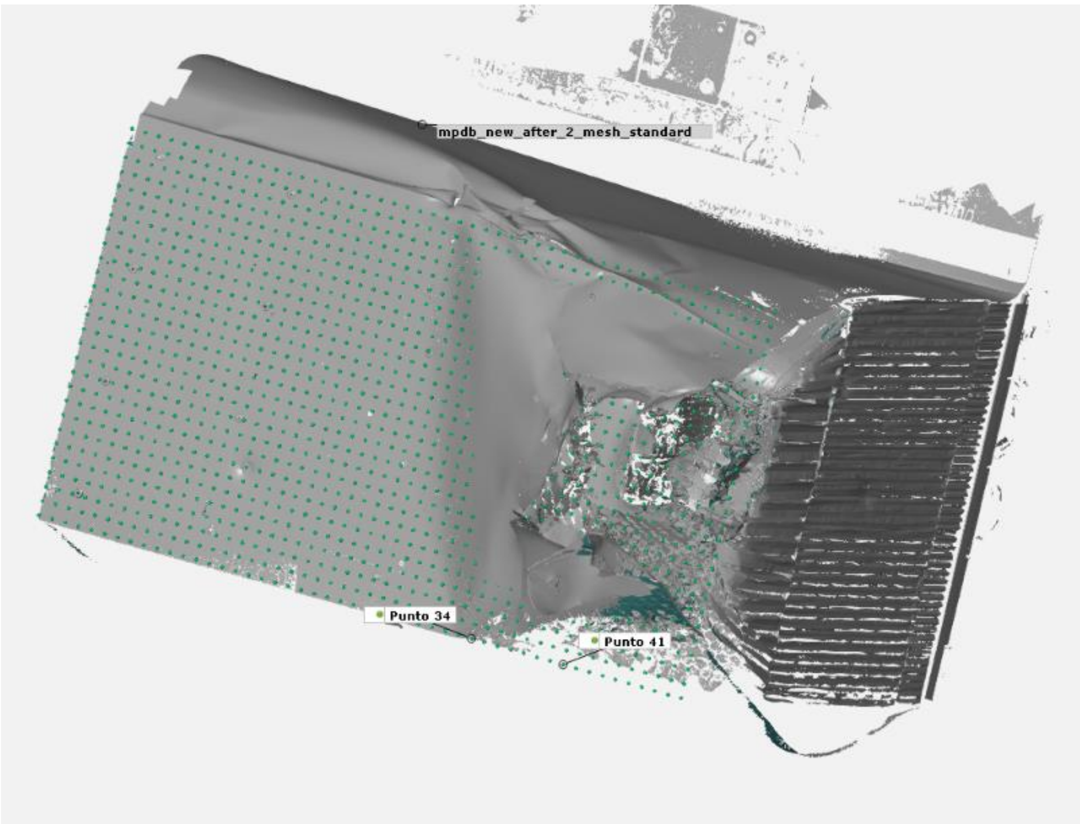


FIGURE 64 - Deformation of the barrier

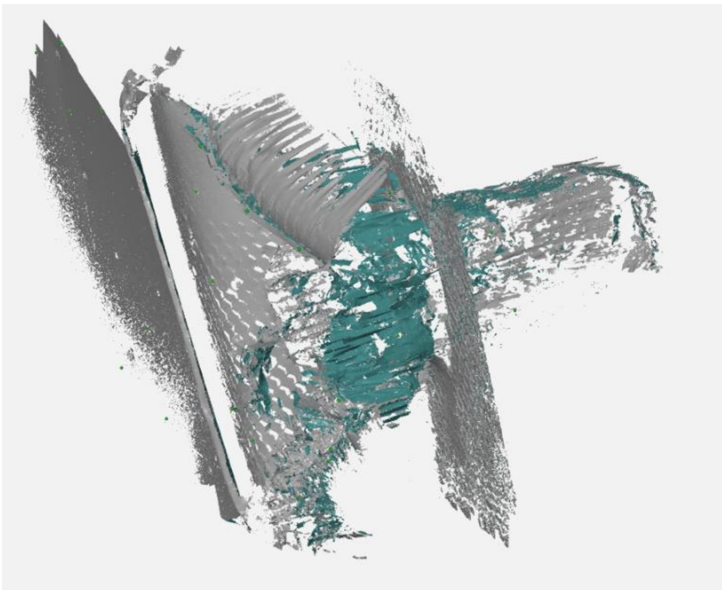


FIGURE 65 - Different layer of scansions

As it is possible to see from FIGURE 64 the classing plate is deformed in the opposite direction: the deformation has negative values of X. This is due to the removal of the strut. In this case it is not important for the scope of the test that was only to see the maximum sinking and the scansion of deep deformed barrier.

6.1.4. STEP 4: Alignment and polygonization of deformed barrier

Before the transformation in mesh, the scansion of the deformed barrier has to be aligned with the scansion of the undeformed barrier. To do this operation the reference points on the side back plate and on the trolley are needed.

For the alignment the path to be followed is: in the SCAN ambient, *align points for common references* ( ), then select three points of the metal plate and verify that the preview of the alignment is the one desired. Sometimes problems can arise from the fact that the markers are placed too near or with a similar geometry in different zones, so can happen that the point selected gives an alignment that is not the one expected. To avoid this problem, it is better to choose points on the side back plate or on the trolley that are as distant as possible. Another important accoutrement is the selection of points that are present on both the scansions, the pre and post-test one.

After the alignment of the two scansion, the polygonization of the second scan must be done. In order to do that the scansion of the post-test barrier only must be selected. The polygonization can be done in the same manner as before, as described in paragraph 6.1.2.

In FIGURE 66 the alignment of the two mesh of the barrier is shown. The crashed barrier is almost completely hidden from the newer one, but it is possible to hide an element (the new barrier in this case) in order to work better.

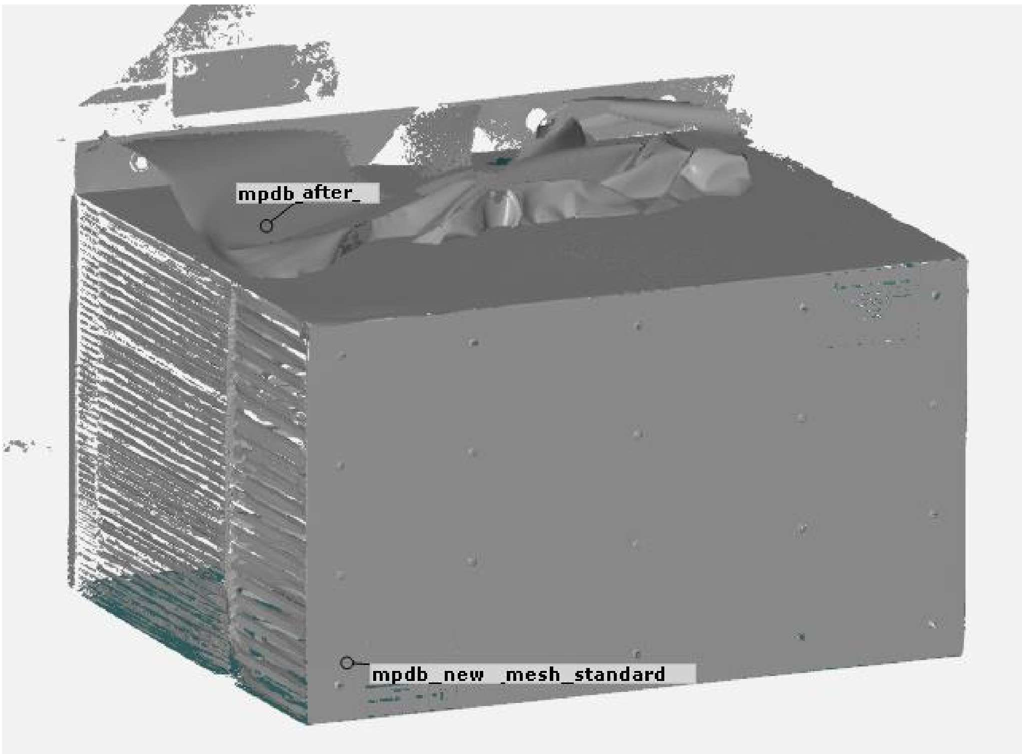


FIGURE 66 - New and after crash scansion aligned

6.1.5. STEP 5: Alignment of the undeformed barrier

The mesh of the undeformed barrier must now be aligned with the reference system presented in the Euro NCAP protocol, described in paragraph 4.2 and shown in FIGURE 49.

The software presents different option for the alignment of the object, but the best and faster way that is founded is composed of only one function.

For the alignment the following path must be followed: *operation*, *alignment*, *initial alignment*, *3-2-1*, then some points must be inserted. As the name suggest, the points that must be selected are 3, 2 and 1: three points to individuate a plane, two points to individuate the second plane perpendicular to the first and one point to individuate the third plane perpendicular to the firsts two. The scheme to be followed is the one represented in FIGURE 67.

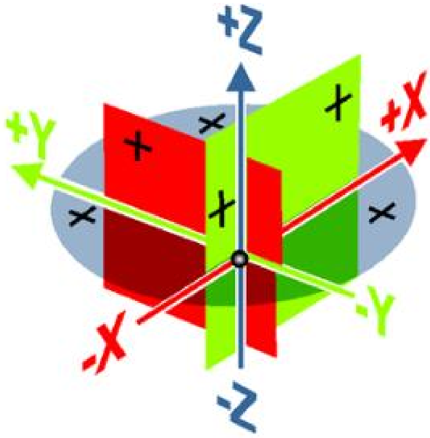


FIGURE 67 - Function 3-2-1

In the function it is possible to change the order of the plane. The one showed in FIGURE 67 is ZZZ-YY-X, so three points on plane perpendicular to the axis Z, two points on the plane perpendicular to the axis Y and one point in the plane perpendicular to the axis X. The best solution for the alignment of the barrier is XXX-YY-Z.
So, in order to have the reference system according to the one of Euro NCAP, the first three points must be selected on the frontal surface (the one on which the vehicle will impact frontally); it is important to select the *positive plane* option. The second two points must be selected on the bottom face of the barrier by deselecting the *positive line* option, if possible, or on the top face if the bottom is not present. In the case in which only the top surface is available, the point should be selected in this face and a value of 570.00 mm of offset should be chosen in both the value of Z plane. The third point of the set has to be selected on the left side (seen from the vehicle), in the side back plate, because it is the only part of the face that is flat and perpendicular to the other faces.
So done, the reference system will be not exactly aligned with the barrier faces because of irregularity of the barrier surface acquired from the scanner. The error of this operation will be small, and it is compensated from the robustness of the method for the evaluation stated by Euro NCAP.
In FIGURE 68 it is possible to see the mesh of the barrier aligned with the reference system indicated in the protocol.

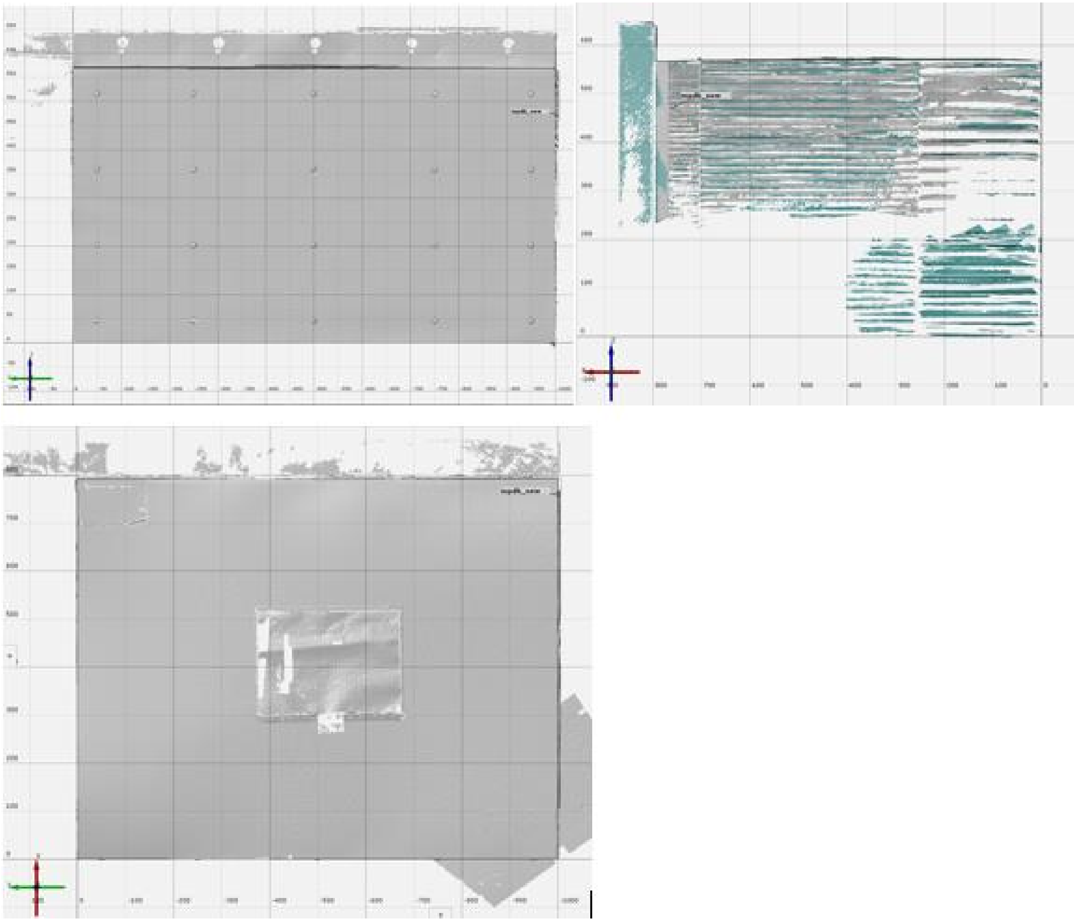


FIGURE 68 - Alignment of the barrier in the Euro NCAP reference frame

6.1.6.STEP 8: Mesh reconstruction

The mesh just transformed can have some holes because of the different facets of the surface, some parts that are not reachable from the scanner cameras or some reflective areas, such as glossy paint or aluminium. In the protocol is mentioned the possibility to rebuild the mesh if the mesh dimension is not bigger than 10 mm.

In these cases, the mesh can be reconstructed in two different ways.

The first method is used when holes are present, the holes must be not too big otherwise the function does not work. To close a hole, the path to be followed is: in the MESH EDIT ambient, *close holes*, *interactive mode…*, and then the hole must be selected. It is possible to close the big holes by using a sub-function of that. The function to be used is the *partial closure of the hole,* which can be activated before selecting the hole. With this function it is possible to choose the limit of the hole to be filled by giving to the software the two extremes of the segment that separate the big hole and the portion to be filled. In FIGURE 69 are shown some holes that are present on the surface, while in FIGURE 70 the holes are closed by using the just described function.

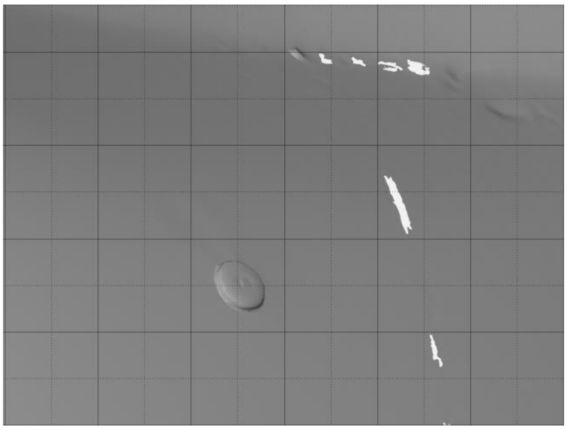


FIGURE 69 - Holes on the surface

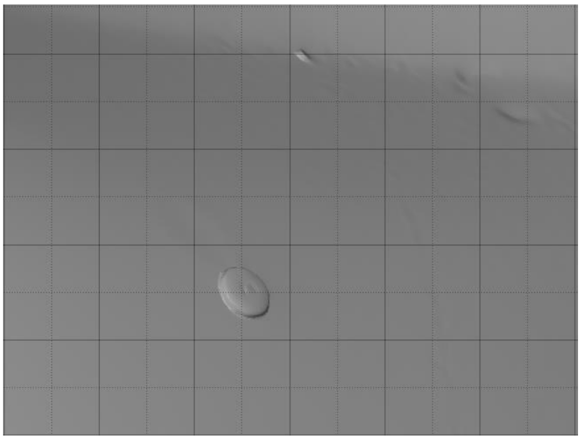


FIGURE 70 - Holes closed on the surface

The other method is the one useful to close the surface when there are discontinuities between the surfaces. This method is composed of two steps, in the first step, one or more bridge must be created in order to connect the surfaces. The second step is useful to close the hole that was created in the first one.

To create the bridge, the button to be pressed is in the ambient MESH EDIT and it is *create mesh bridge* (). When the function has been opened, the two side of the bridge have to be selected and then the bridge of mesh is created. Important is the length of the bridge that should not exceed 10 mm. It is possible to check the length of the bridge, only if there is the daub that it can exceed, by create a distance: in the

ANALYSIS ambient, *create, distance, distance 2 points…* and then select the two extremities of the bridge.
If the length of the bridge overcomes the maximum length of 10 mm the bridge cannot be constructed and, if possible, a near point should be chosen.
One or more bridge should be created in order to form a closed boundary. In this way the first method can be used to fill the hole.
A representation of the mesh bridge is depicted in the FIGURE 71.

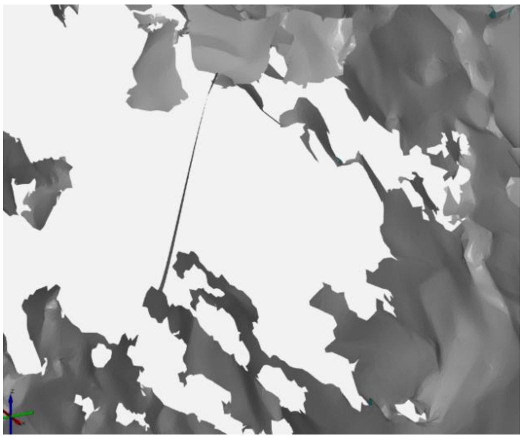


FIGURE 71 - Mesh bridge

Attention must be taken in the reconstruction of the mesh by the use of bridge of mesh, it is important to select the point on the positive side of the surface. The mesh surface has a positive side, coloured in grey, and a negative side, coloured in green. If a mesh bridge is connected to a point on positive surface on one side and on a point on negative surface on the other side, the bridge that will be constructed will be twisted. Then, when the hole will be closed an error can arise. A twisted mesh bridge is depicted in FIGURE 72.

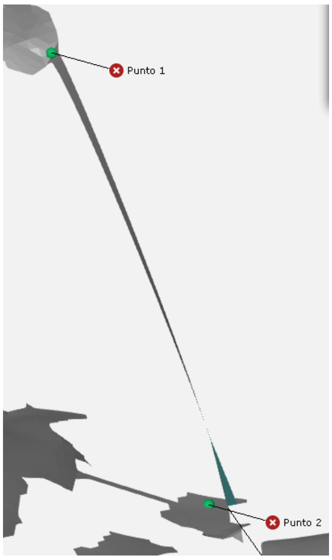


FIGURE 72 - twisted mesh bridge

Both the method are approximations because the software does not know the surface and it estimates that on the base of the curvature of the nearby present surfaces. So, smaller is the hole to be filled (created with the bridge of mesh or just present) and more precise will be the reconstruction of the surface.

In this step it is important to cover all the surface, from the frontal view, in the X direction. The most important part that must be complete is the area of rating.

A full completion of the surface (also in parts that are not in sight from the frontal view) it is not necessary for the rating, as explained also in the protocol, and so some time can be saved. On the other side, the completion of the surface in the rating area is mandatory because in the absence of surface under the projection of some points, it is not possible to calculate the distance in that points and so a high value of depth (633 mm) is attributed by default. The value that will be attributed to the missing value is so high that can be a bottoming out. Even if all the conditions for the presence of the bottoming out do not occur, a so high value in the rating area can increase the mean and the standard deviation by negatively contributing to the final score.

The phase of the mesh reconstruction is one of the longest but it is mandatory, especially when a too holed surface is present, in order to do not have a high penalization on the score.

6.1.7. STEP 7: Grid creation and import

As descripted in the paragraph 4.2, the deformation is measured in 1400 different points, equally spaced. Since the software permits to create also some geometrical elements, such as point, lines and planes, the points can be created directly in the software used for the scansion. The grid of points is obtained by intersection of planes, equally spaced of 20 mm except the first planes, of the column and of the row, that are spaced of 10 mm from the origin. Another plane in YZ position is created in order to have the third plane for the intersection. In fact, the points are created as the intersection of three planes. Also this is a quite long phase but it is done only ones.
The grid as created, visible in FIGURE 73, is imported in the file with the mesh of the pre-test barrier and of the post-test one. The path to be followed is: *file*, *import*, *file* and then select the file in which the grid is saved.

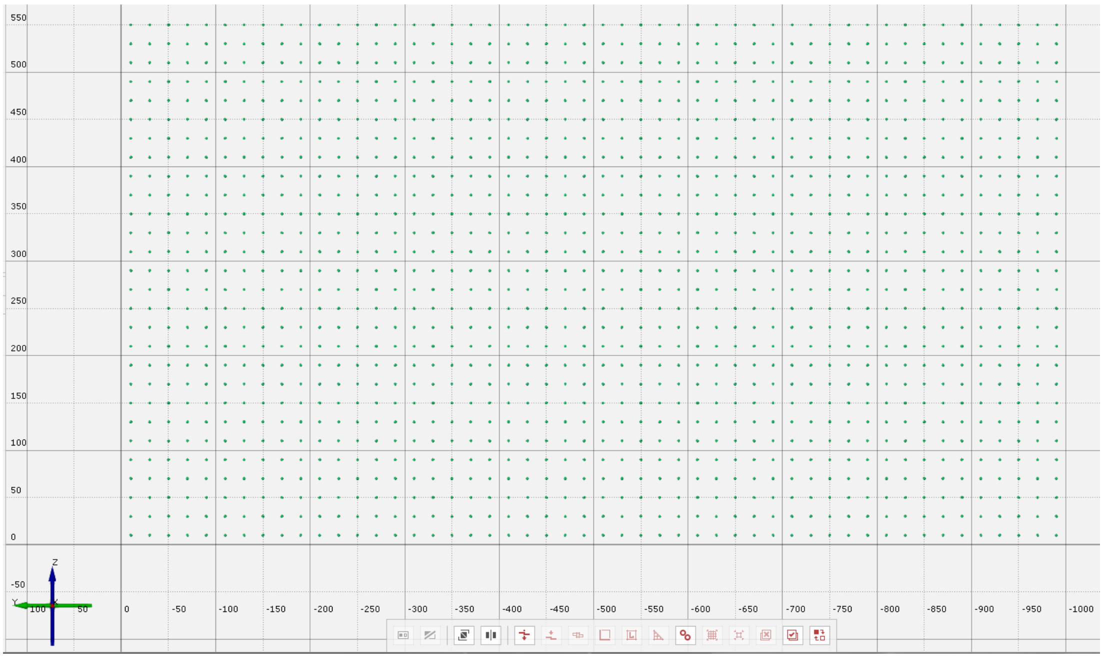


FIGURE 73 - Grid of points

6.1.8. STEP 8: Creation of the distance and the principle of measurement

In this step the creation of a principle of measurement to calculate the deformation in each of the 1400 points is done.

The first passage is to create a measure that will become the reference measurement, in this case the reference measure is a distance in the X direction (the projection of a point in the X direction), so the depth. It is very easy to create a distance and it is possible to do that in a random point.

The path to be followed is: *create*, *distance*, *distance point-direction,* then the point, the direction and the surface of end distance must be selected. For the point it is not important which one is selected (one at random in the grid), for the direction the X must be selected, while for the surface the mesh of the deformed barrier must be selected.

Ones the distance is created, the principle of measurement can be derived. To create it, the path to be followed is: select the point on which the distance is created, *analysis*, *define measurement principle defined by user…*, then a name must be given to that principle.

In FIGURE 74 it is represented the creation of one distance in a random point of the grid, in this case the point 6.

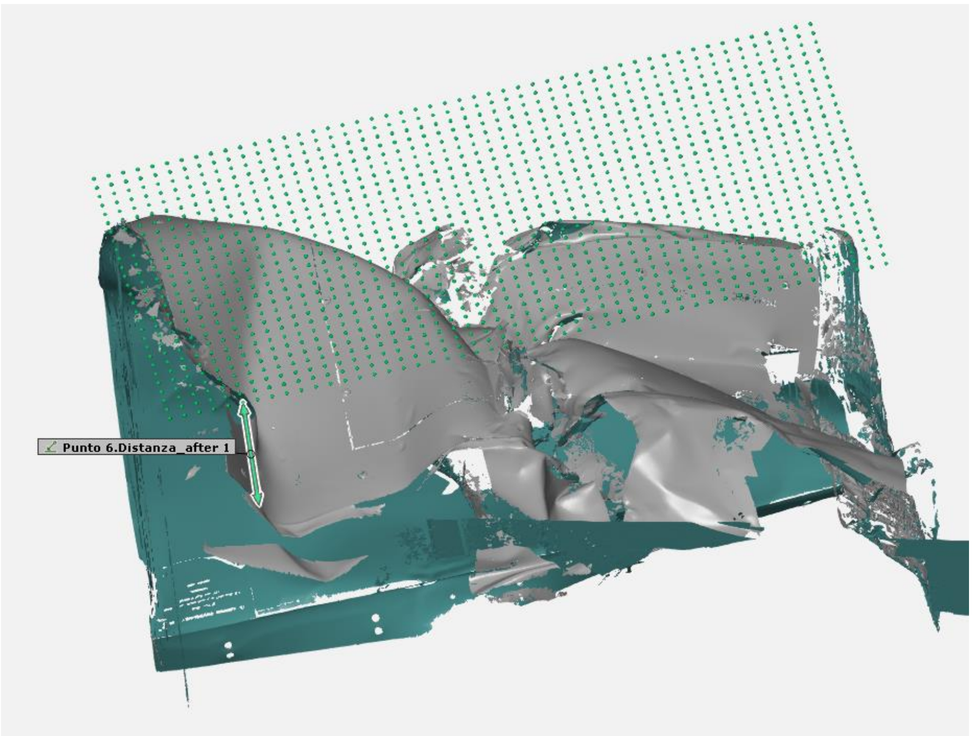


FIGURE 74 - Creation of one distance

6.1.9. STEP 9: Application of the measurement principle

Once the surface is completely reconstructed in the rating area, all the distances of the 1400 points of the grid can be calculated. Thanks to the measurement principle crated before, the distance can be easily calculated in each point.

To create the distances in all the points, the path to be followed is: in the ANALYSIS ambient, select all the points of the grid, press the right mouse button and the CTRL key on any part of the background, press the button *analysis principle defined by the user* in the windows that is appeared ( ), then select the name of the principle that has been created in the STEP 8: Creation of the distance and the principle of measurement.

In this way the distance of all the points of the grid on the surface in the X direction has been created. An image of what appears on the screen after this passage is visible in FIGURE 75.

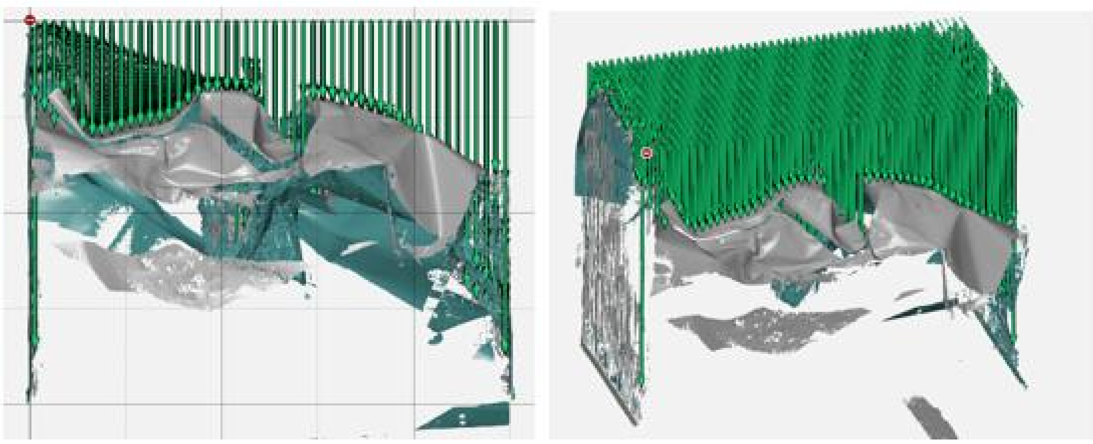


FIGURE 75 - Distances in all points of grid. Side view on left, axonometric view on right

Not all the points have a distance because, where the projection of the point does not encounter the surface, the distance is not created. This is not so important if the point is outside of the rating area.

The distances so created are vectors; in order to export them in a table a scalar value is requested. To transform the distances from vector to scalar the next passage must be followed: in ANALISYS ambient, select the folder 'dimensions' in the left part of the screen (inside the 'effective element' folder), from the window used before to apply the measurement principle, select *check* ( ) and then *distance*.

The distances are now converted in scalar values and are ready to be exported.

6.1.10. STEP 10: Distances export and import on spreadsheet

The scalar values of the distances are represented in a table on the software. The only passage that should be done is select the *table* button in the menu of the ANALYSIS ambient. In FIGURE 76 how the table is presented is shown.

Name	Datum	Property	Criterion	Type	Nominal	Actual	Tol -	Tol +	Dev
Punto 1.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+164.853			-216
Punto 2.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+191.003			-190
Punto 3.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+222.928			-158
Punto 4.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+153.489			-227
Punto 5.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+188.201			-193
Punto 6.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+231.886			-149
Punto 7.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+244.113			-137
Punto 8.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+244.365			-137
Punto 9.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+238.103			-143
Punto 10.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+232.101			-149
Punto 11.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+226.386			-155
Punto 12.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+222.362			-159
Punto 13.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+219.615			-161
Punto 14.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+215.904			-165
Punto 15.Distanza_after 1		L		inspection_dimension_scalar	+381.408	+209.309			-172

FIGURE 76 - Table

The column of interest is the one with the title 'Actual', in which there are the values of the distances.

It is important to use the 'Details' template in order to have all the distances ordered from the point 1 to the point 1400, including the distances that have not value because of the missing of surface in the projection area. They are indicated as a series of question marks. Remember that some distances without value can be present in the area outside of the rating one, without affecting the final score.

To export the data in a text file, the *export table content* button should be pressed. The software permits to choose some details of the exported file properties. The constraint is to select the comma as decimal separator, otherwise when the values are imported in the spreadsheet, they are wrong of some order of magnitude.

A representation of a portion of the exported text file is shown in FIGURE 77.

```
Element                 Datum Property   Nominal    Actual     Tol -
      Tol  +Dev   Check Out
 Punto 1.Distanza_after 1        L      381,408    164,853
      -216,555
 Punto 2.Distanza_after 1        L      381,408    191,003
      -190,405
 Punto 3.Distanza_after 1        L      381,408    222,928
      -158,480
 Punto 4.Distanza_after 1        L      381,408    153,489
      -227,919
 Punto 5.Distanza_after 1        L      381,408    188,201
      -193,207
 Punto 6.Distanza_after 1        L      381,408    231,886
      -149,522
 Punto 7.Distanza_after 1        L      381,408    244,113
      -137,295
 Punto 8.Distanza_after 1        L      381,408    244,365
      -137,043
 Punto 9.Distanza_after 1        L      381,408    238,103
      -143,305
 Punto 10.Distanza_after 1       L      381,408    232,101
      -149,307
```

FIGURE 77 - Text file

In order to do a rating of the test, the values must be inserted in a spreadsheet. The spreadsheet is precompiled by Euro NCAP, so the order in which the values must be inserted is just decided.

The values are exported in the text file as a unique column, so when they are imported in the spreadsheet it is necessary to transpose them in rows, as the numeration of the points in the grid is in rows. A model in which the values are automatically inserted in the precompiled spreadsheet is created.

The order of the values is in columns of the grid, as shown in FIGURE 78.

		Location	Type	x-coordinate	y-coordinate	z-coordinate
		Name	Type	Coordinate (x)	Coordinate (y)	Coordinate (z)
Row 1		MP 1351	Vergleichspunkt1351	181,283	-10,000	550,000
		MP 1301	Vergleichspunkt1301	133,800	-10,000	530,000
		MP 1251	Vergleichspunkt1251	84,695	-10,000	510,000
		MP 1201	Vergleichspunkt1201	59,027	-10,000	490,000
		MP 1151	Vergleichspunkt1151	48,037	-10,000	470,000
		MP 1101	Vergleichspunkt1101	???	-10,000	450,000
		MP 1051	Vergleichspunkt1051	???	-10,000	430,000
		MP 1001	Vergleichspunkt1001	7,605	-10,000	410,000
		MP 951	Vergleichspunkt951	8,663	-10,000	390,000
		MP 901	Vergleichspunkt901	???	-10,000	370,000
		MP 851	Vergleichspunkt851	29,055	-10,000	350,000
		MP 801	Vergleichspunkt801	34,246	-10,000	330,000
		MP 751	Vergleichspunkt751	34,625	-10,000	310,000
		MP 701	Vergleichspunkt701	29,575	-10,000	290,000
		MP 651	Vergleichspunkt651	24,011	-10,000	270,000
		MP 601	Vergleichspunkt601	???	-10,000	250,000
		MP 551	Vergleichspunkt551	36,644	-10,000	230,000
		MP 501	Vergleichspunkt501	34,501	-10,000	210,000
		MP 451	Vergleichspunkt451	???	-10,000	190,000
		MP 401	Vergleichspunkt401	???	-10,000	170,000
		MP 351	Vergleichspunkt351	79,056	-10,000	150,000
		MP 301	Vergleichspunkt301	129,838	-10,000	130,000
		MP 251	Vergleichspunkt251	130,411	-10,000	110,000
		MP 201	Vergleichspunkt201	134,751	-10,000	90,000
		MP 151	Vergleichspunkt151	687,627	-10,000	70,000
		MP 101	Vergleichspunkt101	124,235	-10,000	50,000
		MP 51	Vergleichspunkt51	???	-10,000	30,000
		MP 1	Vergleichspunkt1	164,853	-10,000	10,000

FIGURE 78 - Values inserted in the precompiled spreadsheet

6.1.11. STEP 11: Evaluation

For what concern the evaluation of the standard deviation, the other data that must be inserted in the spreadsheet are the vehicle width and the handle driving (left or right) in order to define the dimension of the area of the rating, as explained in paragraph 4.3.1.

From these data inserted, it is also possible to evaluate the presence or absence of the bottoming out while, for the evaluation of the Occupant Load Criterion the data of the accelerometer positioned in the centre of gravity of the barrier must be inserted in the proper sheet with the real speed of impact. The interval between each value of acceleration that must be inserted is 50μs.

The OLC and the SD are calculated automatically and the value of the penalization is shown in the rating sheet.

For the Standard deviation and the bottoming out, a map that represents the barrier is also shown with different colours that represent different ranges of sinking distances. A graph with different depth is represented in order to simulate a 3D representation of the barrier, also in this case the ranges are represented in different colours. The image of the 3D reconstruction is present both for the whole barrier and for the rating area only. An example of the pattern and the 3D representation are shown in FIGURE 79 and in FIGURE 80, respectively. In the coloured map it is possible to see a framed area that is the rating one.

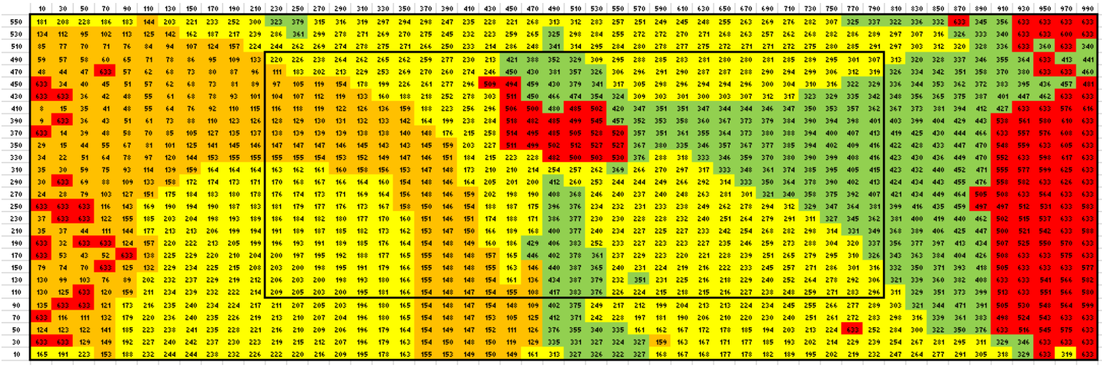


FIGURE 79 - Coloured map

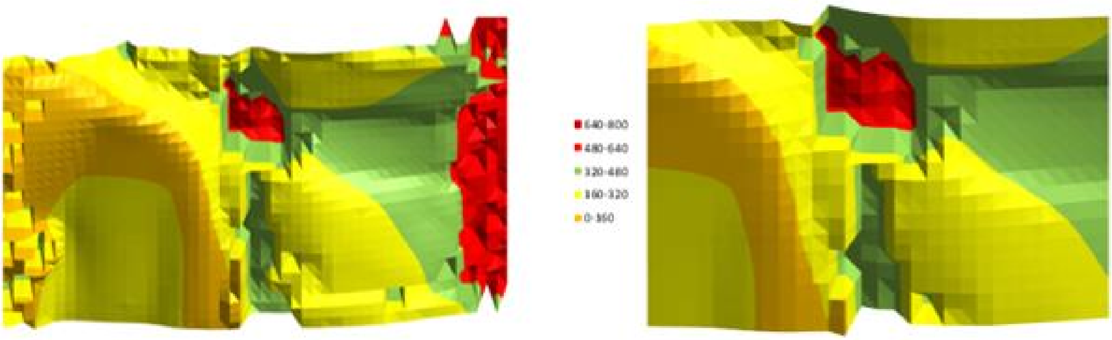


FIGURE 80 - 3D representation of the MPDB. Whole barrier on left, rating area on right.

6.2.Procedure for barrier coming from external laboratories

A second procedure is implemented. It is useful in order to evaluate the barriers that arrive in the laboratory after the test. For example because they are commissioned to external laboratories. In this case, the procedure that must be ensued in the preparation of the vehicle cannot be followed personally by the laboratory's members. So the pre-test barrier is not available. A trick, in order to bypass this problem, is used. The crashed barrier that comes in the laboratory is positioned in a station. Also a scansion of a new barrier, of the same model, is scanned in the same station. This make possible the comparison through common points in the station.

The procedure adopted for the evaluation of the deformed barrier in the case in which only the physical barrier and the data of the test are available is a little bit different. The virtual phases, so the passages done with the software ATOS Professional are identical. What changes is the scanning process and how it is managed.
Since in this case, only the post-test is available, a unique pre-test must be considered. The results of the deformation in this case will be less precise with respect the other procedure because two barriers that are not the same are compared.
Only the steps that change from the other procedure are discussed in the following.

6.2.1. STEP 1: Positioning and acquisition of the undeformed barrier

Even if the suggestion of the Euro NCAP is to take as reference points the ones in the side back plate, in this case it is not possible because the pre-test barrier is not available.
A unique scansion of the pre-test barrier can be done and so, the barriers (both the pre-test barrier and the post-test barriers) must be able to be mounted in a unique way and the reference points must be taken in a zone that does not belong to the barrier. So a station is created in which the barriers can be mounted, since the barrier comes from an external laboratory and so the trolley is not available.
The holes present on the barriers for the fixing on the trolley can be exploited in order to uniquely mount it on the structure of the station. Both the pre and post-test barrier can be fixed on it.
For what concerns the reference points, they can be taken directly on the station or on a metal plate that is screwed in the station if the station is used also for other purposes, as in this case. The markers for the reference points are then applied on the plate, a minimum of three markers are needed in order to align two different scansion. The positioning of more than three markers is advisable in order to be sure that, even if some markers are removed due to wear and tear, at least three markers are always present. The metal plate should be positioned near the barrier, in the case showed in FIGURE 81 it is positioned above the barrier.

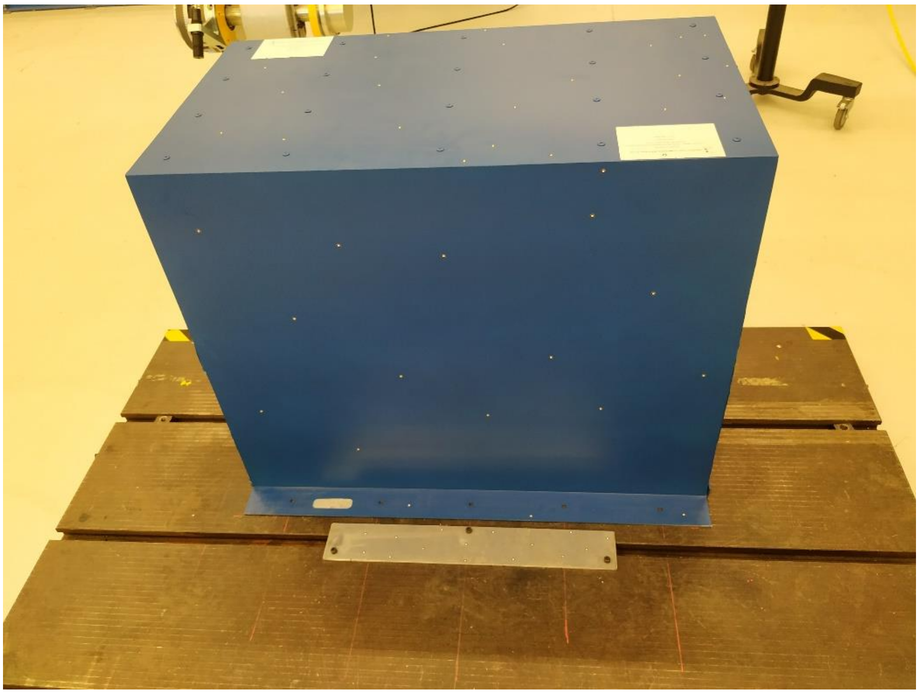


FIGURE 81 - Station of the barrier

Attention must be kept in order to acquire the reference point positioned in the metal plate.

The unique scansion of the pre-test barrier must be done whit the barrier that is carefully fastened to the station and the file with the scansion must be saved in a safe place. For each test, a copy of the file of this scansion must be used.

For what concern the markers, in the metal plate of reference, a number higher than three markers is advisable. As described before, also in this case it is better to do not align them whit a precise order.

The operation of acquisition and polygonization are exactly equal to the one described in paragraph 6.1.2 (STEP 2: Acquisition of the undeformed barrier)

6.2.2. STEP 2: Positioning and acquisition of the deformed barrier

In order to scan the deformed barrier, it must be mounted on the station by means of the fasteners used for the fixing of the undeformed barrier. Since the station is created in a way that the position of the mounted barrier is unique, the deformed barrier will be coincident with the pre-test barrier in the undeformed zones.

The barrier after the crash has internal residual stresses and so when it is dismounted from the trolley, some of them are exploited, especially in the zone of fasteners. This deformation does not influence too much the final evaluation of the deformation because they are restricted to that zone. The problem that can derive from that is the new fixing to the station because of the deformation of the fastened region. At least three out of ten screw should be fixed in order to have a unique position. More screws are fastened and better it is. There is no other choice because the trolley with the barrier mounted on is not available.

The markers should be applied on the surface before the scansion, and then the acquisition and polygonization are made always in the same way.

Also in this case, the reference points in the plate must be acquired.

6.2.3. STEP 3: Alignment of deformed barrier to the undeformed one

The undeformed barrier can be scanned and saved in a different file with respect to the deformed one or it can be saved in the same file. If the two scansion are located in two different files, one of them must be imported in the other.

It is convenient to import the undeformed scansion in the deformed one. In this way the file containing the undeformed barrier, that must be conserved, remain unchanged. To import the file the following procedure must be done: *file*, *import*, *file* and then select the file.

Then the alignment between the two scansion can be performed as explained in the STEP 4: Alignment and polygonization of deformed barrier. In this case the points that should be selected for the alignment are the ones present in the metal plate of reference.

For what concerns the next steps, they are equal to the procedure of internal laboratory test.

6.3. Problems

Some problems arose during the implementation of the procedure. The two majors problems encountered are related to the scansion and to the barrier holes position for the fixing on the trolley. These two problems are now explained and analysed.

For what regard the first problem, the scansion of the crashed barrier, it was noted some difficulties in the acquisition of the honeycomb part when the cladding plate breaks. Even with multiple acquisition, with small variation of position and inclination, in the zone of rupture the scansion was never completed. The worst barrier at this purpose is the one shown in FIGURE 82. As it is possible to see the surface is not well completed.

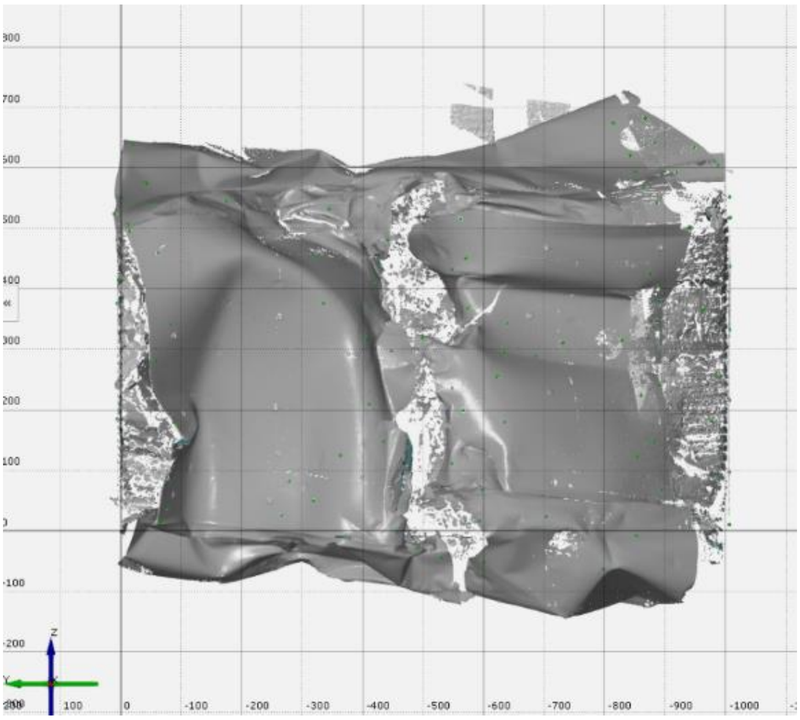


FIGURE 82 - Worst barrier surface

It has been taken into consideration another scanner, in order to see if the problem comes from the scanner utilized or if it is a physical impediment that does not permit the complete scansion.
The second scanner that was taken into account is a scanner head of the headlight arm of Kreon 3D.
The same barrier is scanned by both the scanner and the comparison can be seen in FIGURE 83.

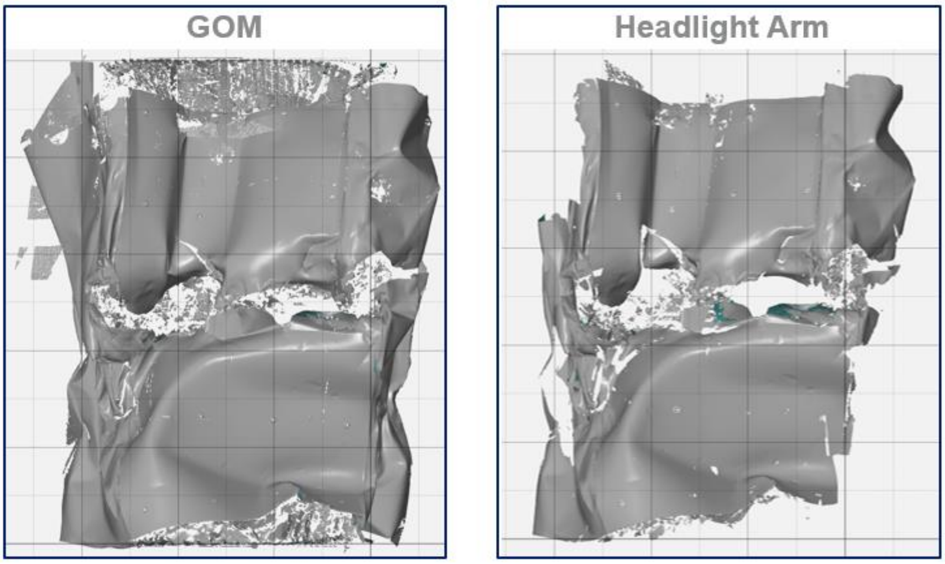


FIGURE 83 - Comparison between GOM and Headlight arm

The second scanner is faster than GOM but, as it can be seen from the figure the scansion in the honeycomb zone is worst. This is due to the combination of large dimension of the scanner and a short focus distance of the scanner on the headlight arm. For the second reason it is necessary to keep the scanner close to the object during the scanning. Unfortunately, the dimension of the scanner are too big in order to stay close to the honeycomb surface. So, the combination of these two characteristics of the Kreon scanner leads to the scansion depicted on the right of FIGURE 83.
The longer distance of focus of the scanner GOM reduce in part this problem, in the sense that the scansion is more complete. The incompleteness that remain is due to some shaded areas that cannot be reach by the blue light of the scanner.
The conclusion of this problem is that the scanner GOM is not perfect for this type of work but even with other type of scanner some problems are present. Since with the GOM scanner all barrier scansion made till today had such a quality that they could be reconstructed within the limits imposed by the protocol.
The second problem encountered is about the position of the holes. Since the tolerance of all the barrier's dimension specified by Euro NCAP are of ± 2.5 mm, also the position of the holes has this tolerance. This is not a big problem in the procedure in which the barrier is mounted on the trolley and the scansions of the pre and post-test are done always in the same barrier, positioned in the same way. So, even if for the fixing on the trolley it is necessary to slot the holes, the position of the barrier is the same before and after the test. The problem arises when the scansion is made on the

station. When the scansion must be done on a crashed barrier, it is already been slotted. When the barrier is new, not always it can be mounted on the holes done on the station, as it can be seen from FIGURE 84 and FIGURE 85

Only one new barrier must be scanned for this procedure, so a barrier able to mount on the holes is found and the scansion was made.

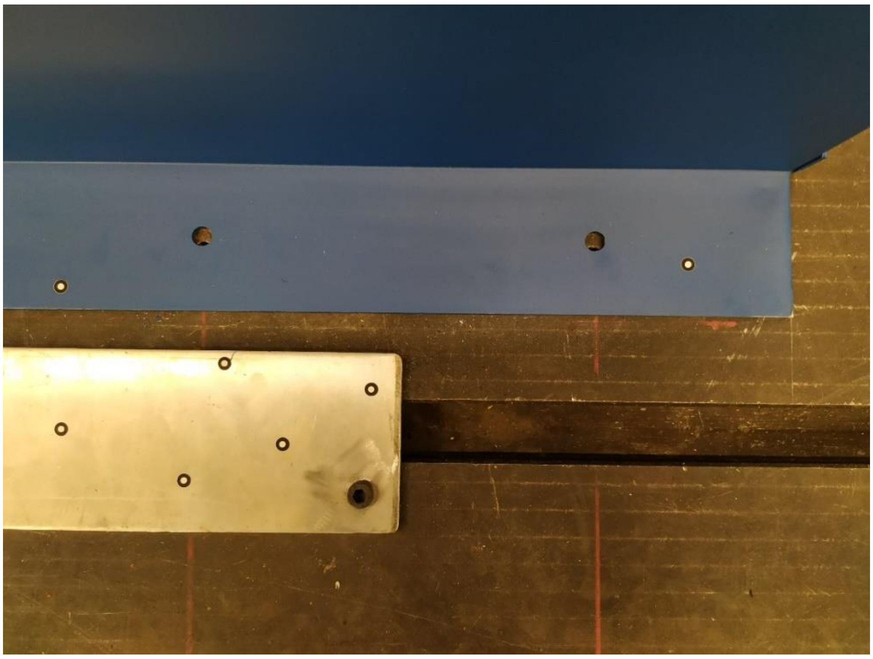


FIGURE 84 - Holes of the barrier that does not coincide with the hole of the station in the upper part

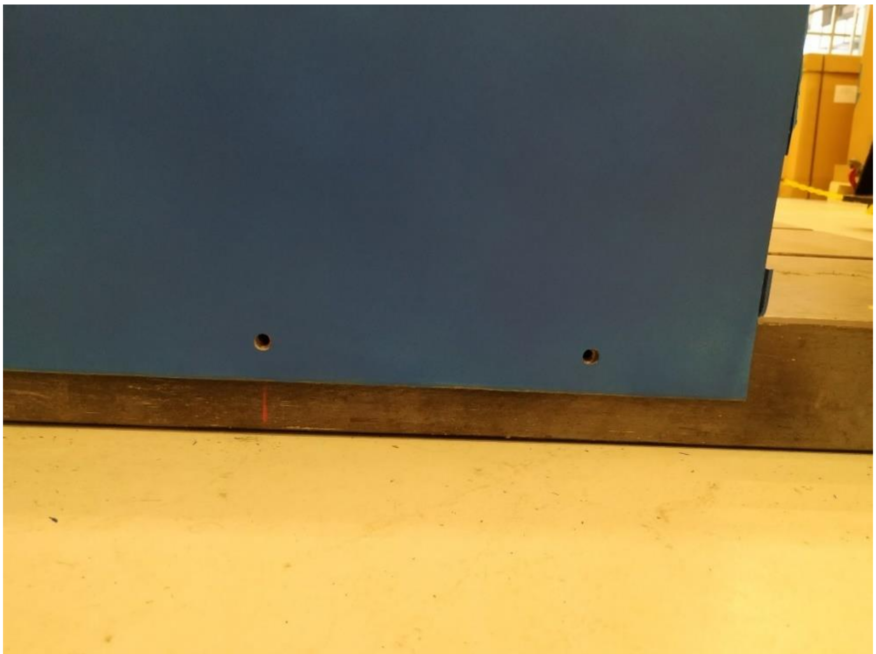


FIGURE 85 - Holes of the barrier that does not coincide with the hole of the station in the lower part

7. Results, analysis and validation

In order to validate the procedures implemented, some application are done, both in the tests made internally in the laboratory of FCA Safety Centre and on barrier coming from external laboratories.

7.1. Application of procedure to external laboratory's tests

A comparison of results between the method just explained and an external measurement is done.
The comparison is made with a barrier of a test carried out by an external laboratory.
In order to make the comparison, the second procedure is used (Procedure for barrier coming from external laboratories) because only the crashed barrier is available.
The barrier is the one shown in FIGURE 86 and the whole procedure is applied to that.

FIGURE 86 - Crashed barrier

In FIGURE 87 the scansion made on the barrier is represented.

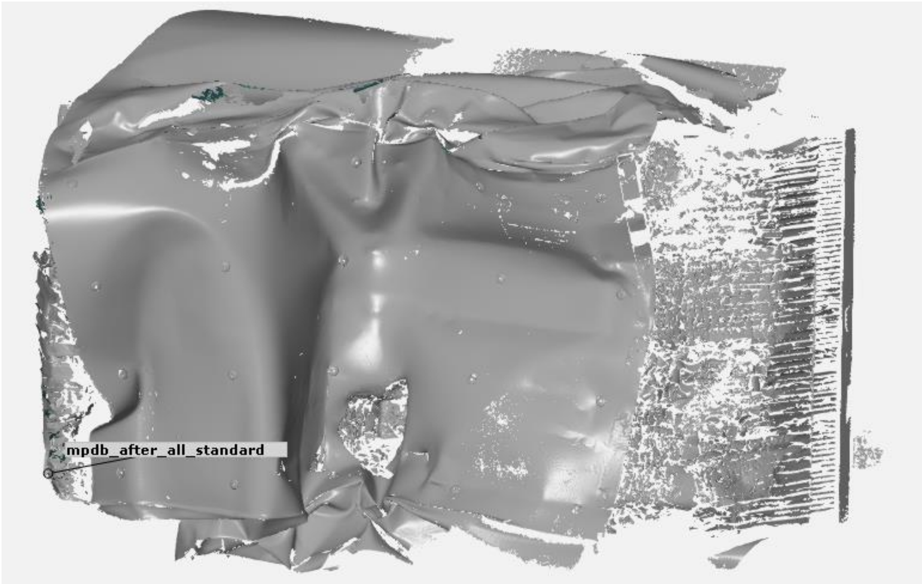


FIGURE 87 - Scansion of the barrier

The surface of the barrier is reconstructed in the missing parts that, in this case, they are not too big holes and so the reconstruction will be a small approximation. The surface reconstructed is shown in FIGURE 88.

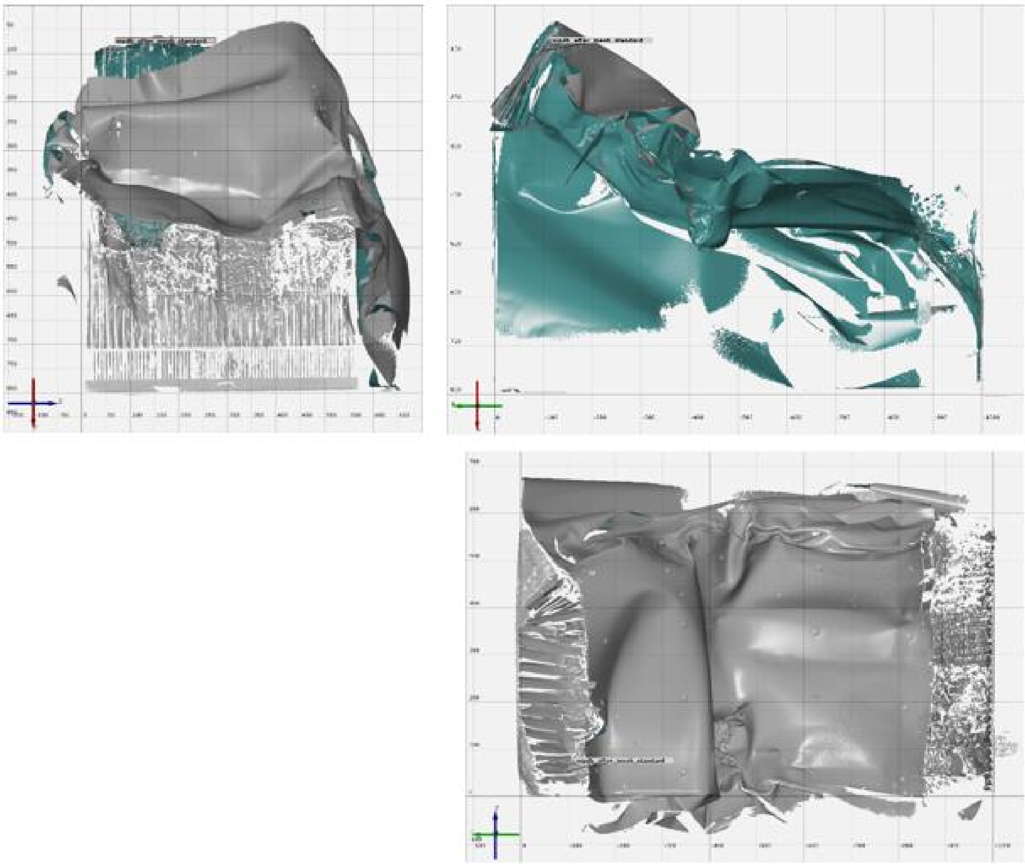


FIGURE 88 - Reconstruction of the barrier

Then the next steps are performed, so the distances of all points are calculated as shown in FIGURE 89 and imported in the spreadsheet.

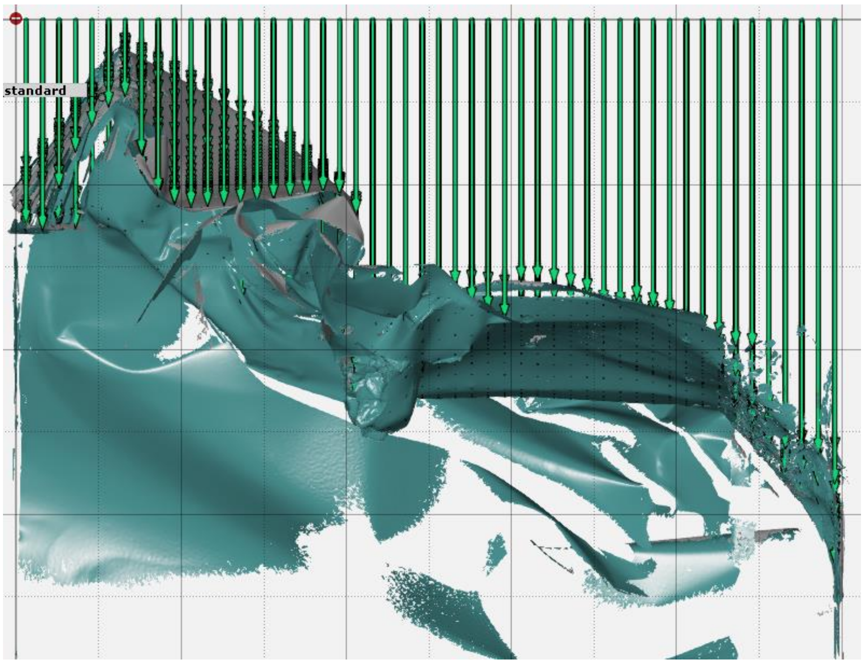


FIGURE 89 - Distances

The results obtained are that the values of the distance in each point are not exactly equal between the two laboratories; but the colored diagram shown in the spreadsheet is quite similar. It is possible to see the comparison in next figures. In FIGURE 91 is present the diagram obtained from the external company's results, while in FIGURE 92 the results obtained with the just described method are shown. The ranges of the different colors are shown in the legend in FIGURE 90.

FIGURE 90 – Legend – measures are in mm

Mean:	367 mm
Standard deviation:	101 mm

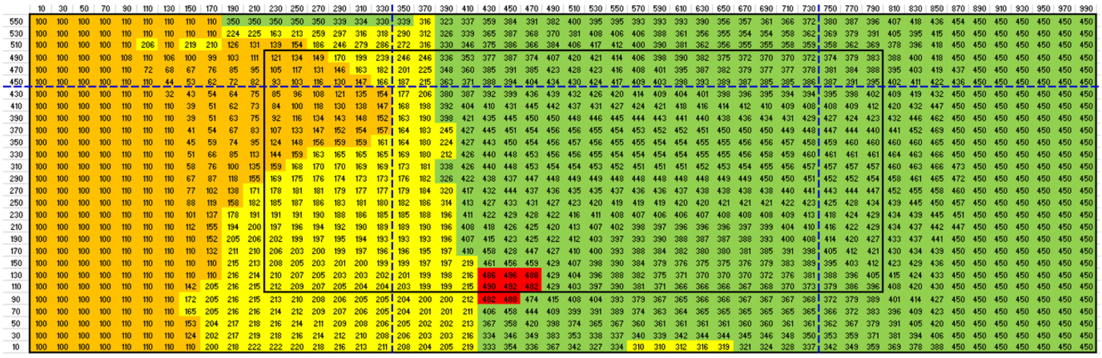


FIGURE 91 - Colored diagram obtained from the external measurement

Mean:	373 mm
Standard deviation:	101 mm

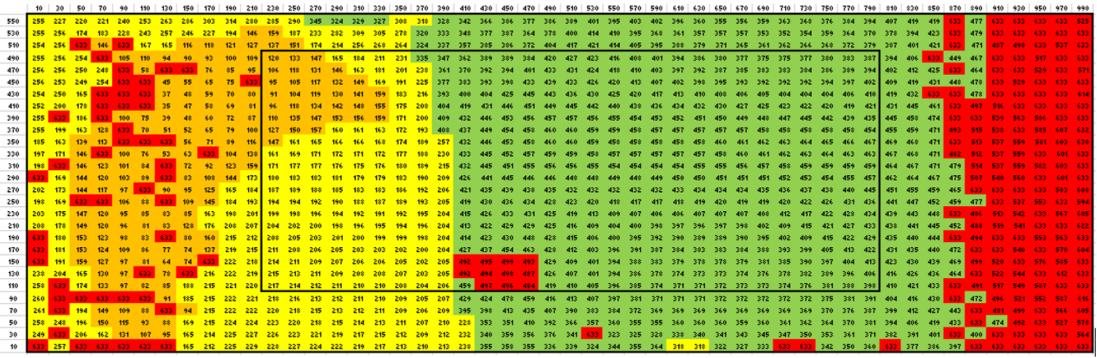


FIGURE 92 - Colored diagram obtained from the method described

From the results it is possible to make some notes. First of all, the trend of the barrier, by observing the colours, is similar. Then it is possible to notice that in the second diagram the red squares are largely present in the non-rating area while they are not present in the first one, this is only because the reconstruction in the second case is not done completely and the default value of 633 mm is assigned to those points that have not the value of distance. The area outside of the rating area, as mentioned before, it is not important and so some time is saved by skipping this long phase.

The difference in colours can also be due to the fact that some data are around the value of changing colour, so even if they are close values, they can have different colours.

The important result is the standard deviation of the rating area that in both cases is exactly equal.

7.2. Application of procedure to external laboratory's tests and comparison between three laboratories' results

A second comparison is made, always in a test done in an external laboratory. This time the comparison is made between three laboratories; one of them is the FCA Safety Centre, with the procedure described above.
The physical object is shown in FIGURE 93 while the scansion carried out with the ATOS Core 500 is depicted in FIGURE 94.

FIGURE 93 - Crashed barrier on the trolley

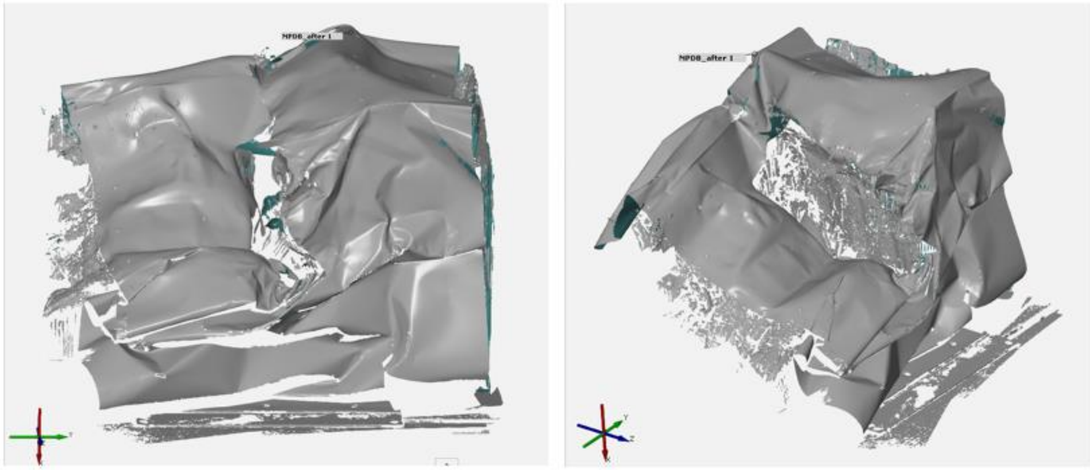


FIGURE 94 - Scansion of the barrier in two different view

The results coming from the two external laboratories are too different, about 7 mm of difference in the value of standard deviation. Since this discrepancy is present, two different results are compared also from the FCA Safety Centre: one with only the surface acquired without reconstruction and the other with the reconstruction of the surface.

In FIGURE 95 are compared the two cases, with and without reconstruction viewed from the front (see from the vehicle).

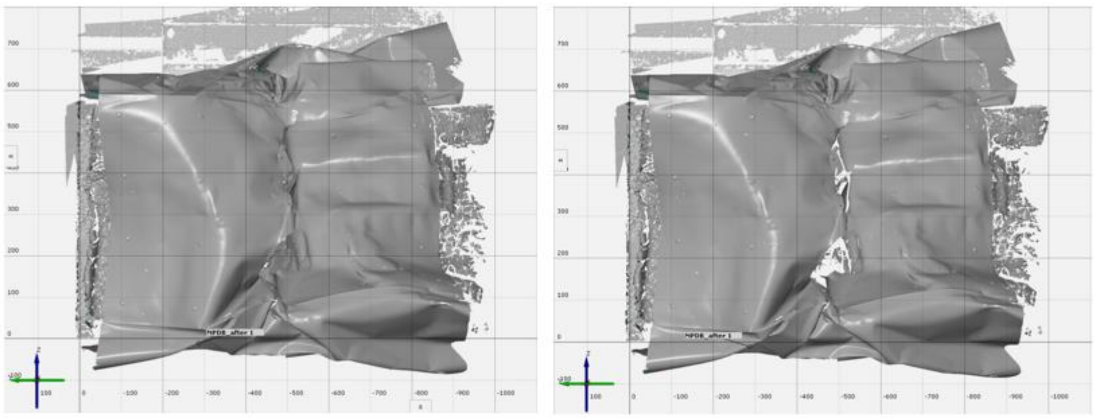


FIGURE 95 - Comparison of reconstructed and not reconstructed scansion

The results obtained in the two cases are reported in the next figures, in order: the two external laboratories (FIGURE 96 and FIGURE 97), the results obtained with the procedure described, before the non-reconstructed case (FIGURE 98) and then the reconstructed one (FIGURE 99).

Mean:	244 mm
Standard deviation:	156 mm

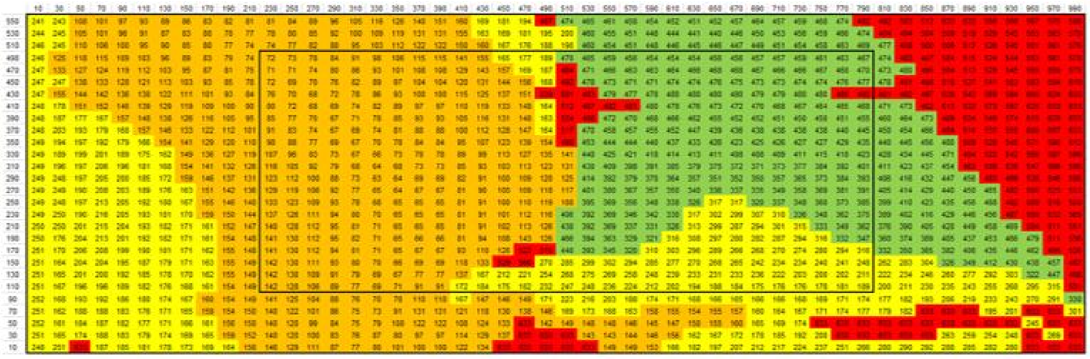


FIGURE 96 - Result of laboratory 1

Mean:	250 mm
Standard deviation:	162 mm

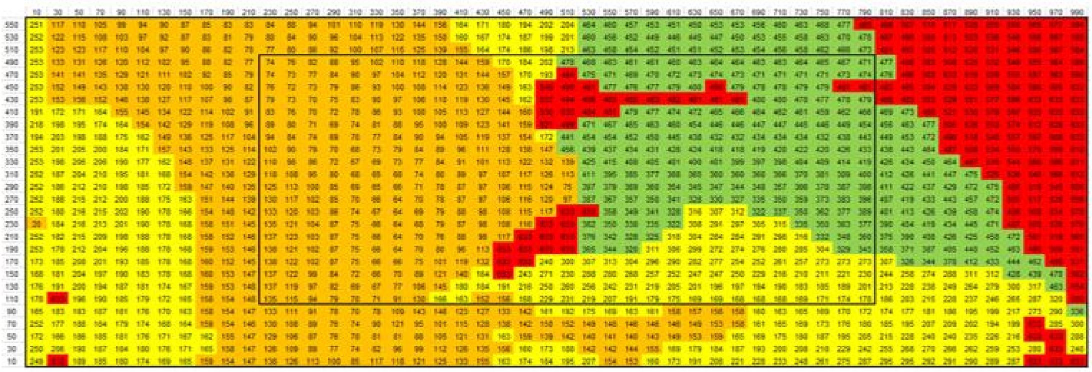


FIGURE 97 - Result laboratory 2

Mean:	249 mm
Standard deviation:	161 mm

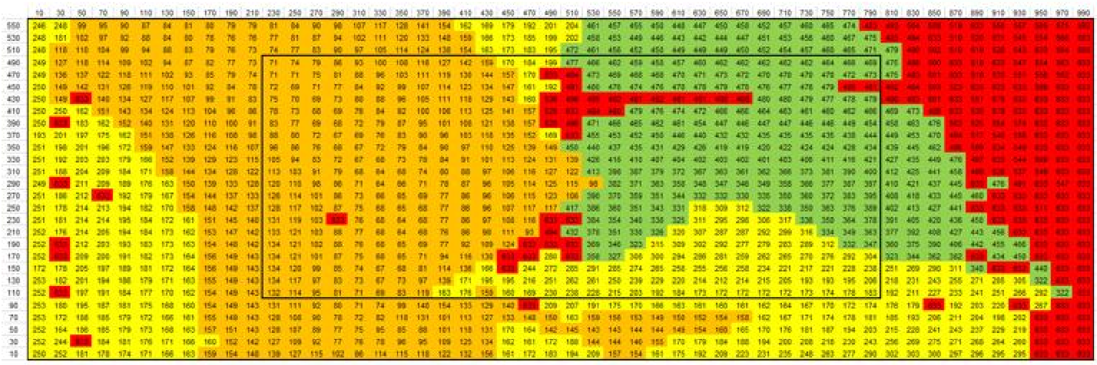


FIGURE 98 - Result with the non-reconstructed scansion – FCA laboratory

Mean:	246 mm
Standard deviation:	155 mm

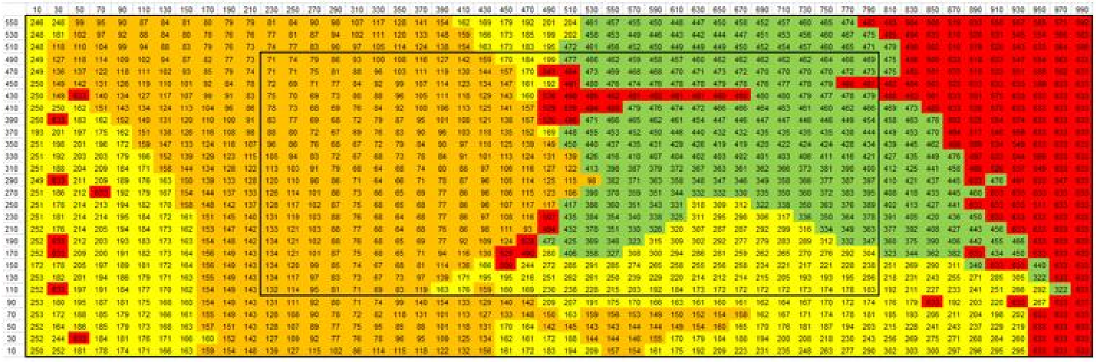


FIGURE 99 - Result with the reconstructed scansion – FCA laboratory

From the comparison of the showed results, it is possible to see that both standard deviation and mean value of the case without reconstruction correspond more or less to the result of the laboratory 2 while the result of the case with the reconstruction of the surface is more similar to the one of laboratory 1.

In this case the reconstruction was simple, in the sense that the missing surface was more or less vertical. It was not possible to acquire the surface due to a physical impediment due to the height of the other half of the barrier. So a really small error may have been done due to the reconstruction of the missing surface.

Result in the case of reconstruction of the surface is more truthful. The higher value of standard deviation in the other case is due to the missing surface under the projection of the point.

In both cases of FCA laboratory the bottoming out is not present, not even for the laboratory 1. While for the result of laboratory 2 the bottoming out is present.

A slight difference can be noted between the laboratory 1 and the others in the zone indicated in FIGURE 100. The difference is only in the colour, it is due to the fact that the cell formatting is made on the base of the legend previously shown in FIGURE 90, so two cell with the same number can have different colour due to the approximation. For example, if a cell has a value of 479.6 mm and the other a value of 480.1, the difference is only of 0.5 mm but the first cell has the colour green while the other is red and both are approximated at 480 mm.

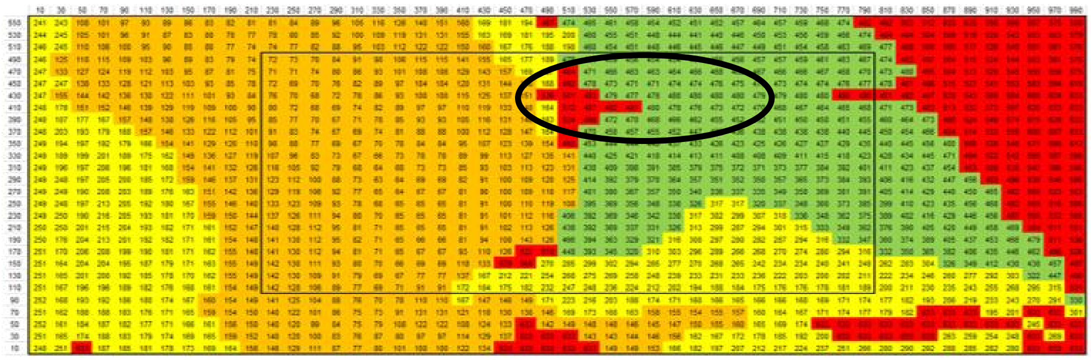


FIGURE 100 - Zone of laboratory 1

7.3. Application of procedure to an internal laboratory's tests

The procedure in which the pre-test barrier is available is applied to a test done inside the FCA laboratory. Even if a comparison of the result is not available, the procedure is applied. The physical crashed barrier is shown below, in FIGURE 101.

FIGURE 101 - Crashed barrier

The scansion of the barrier just after the test is shown in FIGURE 102 while the reconstructed surface is present in FIGURE 103. In both figures the view is the frontal one (see from the vehicle).

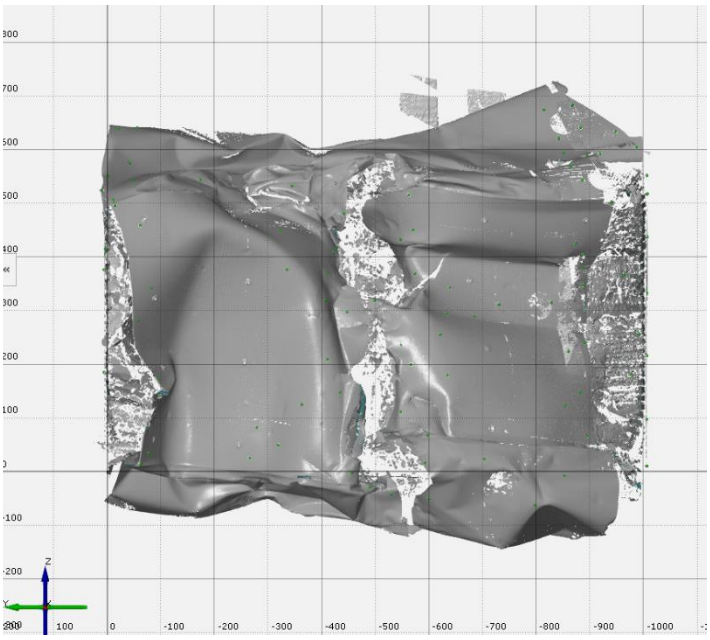


FIGURE 102 - Scansion of the barrier after the test

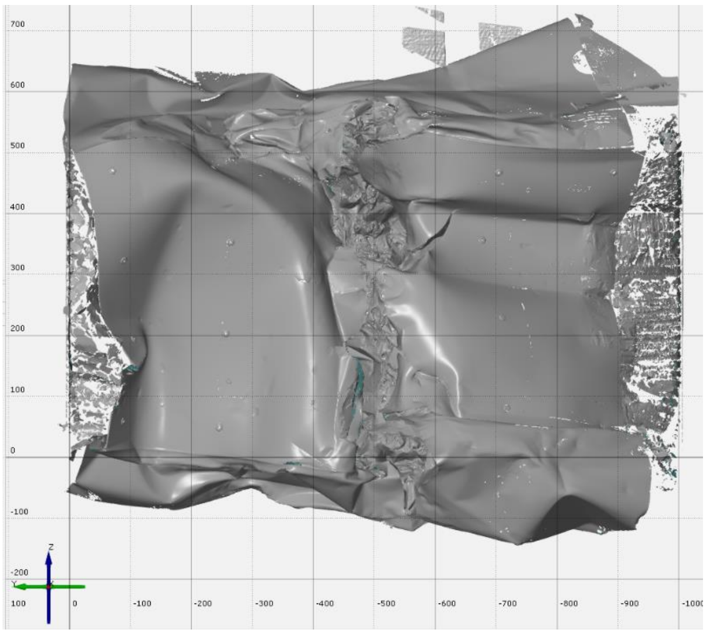


FIGURE 103 - Mesh with reconstructed surface

The first figure and also the comparison between the two gives the possibility to note the quantity of rupture of the cladding plate. The reconstruction in this case was more complex but in any case, the dimension of the reconstructed mesh is in the tolerance required from the protocol.

In this case, even if the calculation of the result is not so useful in terms of validation, because no other result to compare are available, the scansion of this barrier was useful to test part of the procedure. The barrier represented in FIGURE 104 is the same shown before (in FIGURE 102) but in this case the cladding plate is removed. The cut of part of the cladding plate comes from the inspection of the barrier in which emerged that a certain distance, not negligible, is present between the pressed honeycomb and the cladding plate.

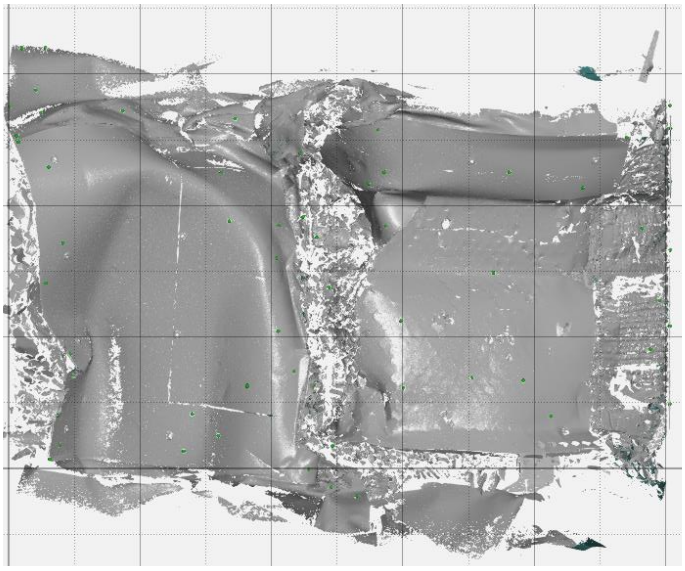


FIGURE 104 - Scansion of the barrier with the cut of cladding plate

The removal of the cladding plate allowed also to better scan the honeycomb part of the barrier, as it is possible to see in the central zone of the FIGURE 104 in comparison with the one in FIGURE 102.

The evaluation of the deformation in each point is calculated in both cases and a difference has been found.

In FIGURE 105 are present the results of the scansion and reconstruction of the surface of the barrier with the cladding plate, so as the situation just after the crash. In FIGURE 106 are present the results of the scansion and reconstruction of the surface of the barrier after the cut of the cladding plate.

Mean:	276 mm
Standard deviation:	101 mm

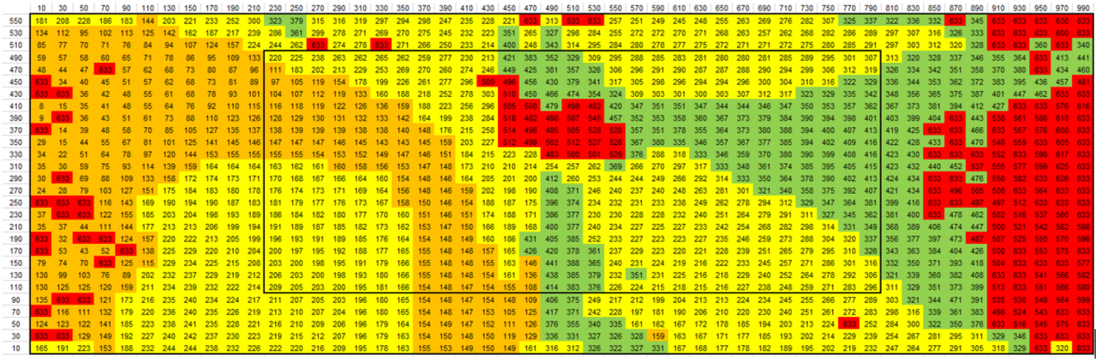


FIGURE 105 - Result of the barrier with cladding plate

Mean	316 mm
Standard deviation:	114 mm

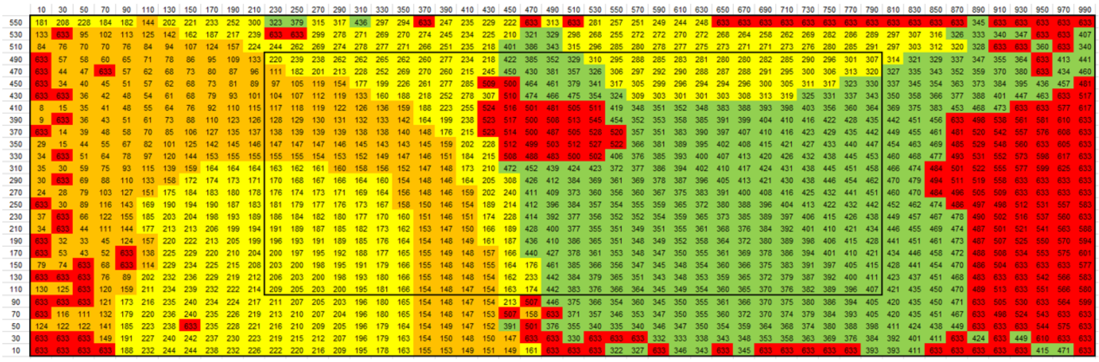


FIGURE 106 - Result of the barrier with cut of cladding plate

It is possible to see a difference between the two results only by observing the colours of the cells. Also the mean of the values present in the rating area and the standard deviation of them are different. The standard deviation, that is the important value for the purposing of the score, has a difference of 13 mm.

The conclusion is that the most truthful result is the second, the one in which the cladding plate is removed. The reason of this affirmation is that the real deformation is the one of the honeycomb, while the position of the cladding plate is due to a partially elastic behaviour of the element (due to the spring back of the cladding plate). Another difference that is possible to note is the dimension of the red area in the rating zone: it is bigger in the case in which the cladding plate has been removed. This is due to the fact that, by removing the cladding plate, the visual of the scanner was better and so it has been done a smaller error in the reconstruction of the mesh.

Both the differences discussed lead to conclude that the second result is the most reliable.

Another test was made in the FCA's laboratory and the implemented procedure was applied to the barrier. Also in this case a comparison of result is not available but a test made with the same vehicle is available.
In this case the vehicle is a right drive one, so the most deformed zone is on the left side of the barrier, if it is seen from the vehicle view. Bigger deformation is in the opposite side with respect to all other barrier that were showed.
In the crashed barrier is shown, while in FIGURE 108 the scansion of it is present.

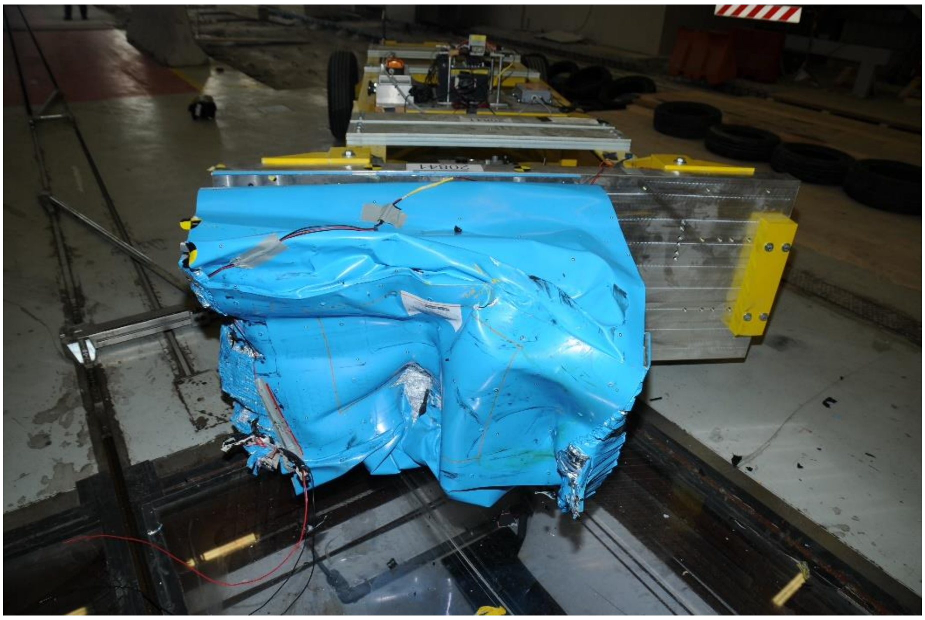


FIGURE 107 - Crashed barrier on the trolley

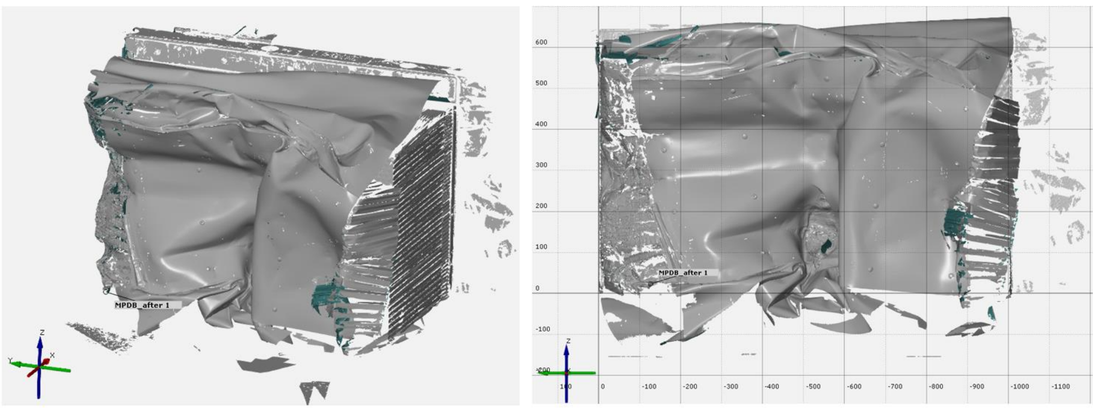


FIGURE 108 - Different view of scansion of crashed barrier

The scansion showed in the picture is the one already reconstructed. In this case the shape of the cladding plate is simple for the acquisition step. Only a small rupture of the cladding plate happens. So the reconstruction is fast and with small approximation. Also in this case, the procedure for the test done in the internal laboratory is applied.
In FIGURE 109 are reported the results of the rating. Even if a comparison with other laboratories is not available, the standard deviation is in line with other results made with the same model of vehicle. So, the results are reliable.

Mean:	366 mm
Standard deviation:	100 mm

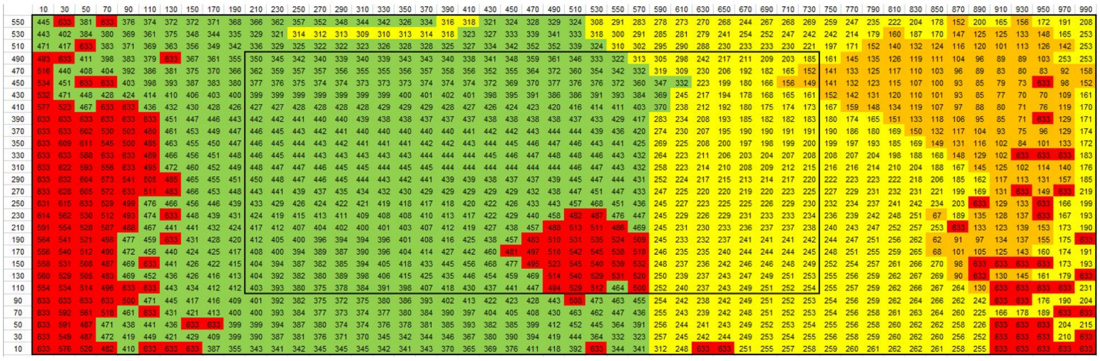


FIGURE 109 – Results of the barrier scansion

8. Conclusion and future works

In conclusion, in this thesis a description of Euro NCAP and its principal activities has been made. It was mentioned also the history of the institute with a list of crash tests which were introduced from its birth in 1997 till today, and the motivation of the introduction or change of a test.
The topic of compatibility between vehicles has also been treated. A definition of compatibility has been given. It is possible to resume it as the measure of how much a vehicle can be dangerous with respect to another in case of accident. The studies about this topic were also explained and the projects made about that. The projects were, starting from the 1996 with the EEVC WG15, continuing with the VC-COMPAT and finishing with FIMCAR in 2012. All these projects were financed by the European Union with the scope of implementing a test able to evaluate the compatibility in all different vehicles.
The series of project brought to the decision to define the test that was published in a Euro NCAP protocol in November 2018. The test will enter in the official list of tests for the Euro NCAP rating starting from the 2020. In this thesis the protocol was explained with the description, in particular, of the new Mobile Progressive Deformable Barrier and the measurement of the deformation pattern on it. It has also been explained the evaluation of the test that is composed by the sum of three score: one due to the barrier face measurement, one to the occupant load criterion and the last due to the bottoming out in the barrier.
The scope of the thesis, that was to implement a procedure to scan and measure the deformation pattern of a honeycomb made barrier, has been reached. The request was to create this procedure in accordance with the Euro NCAP protocol about the MPDB test. The protocol suggests a method in order to evaluate the deformation of the barrier. Some tools were already available in the FCA laboratory. The scanner used is the ATOS Core 500, produced by GOM and the relative software ATOS Professional 2016.
Some attempts were made before of the final procedure described in this thesis. At the end, the decision was to implement two separate procedure for two different evaluation type. One procedure is created in order to evaluate the barriers that come from the

internal laboratory. In this case all passages of the test can be followed personally by the members of the laboratory. So, during the preparation of the test, also the scansion of the new, pre-test barrier can be made. Then, after the test, the scansion of the post-test barrier is effectuated. In the comparison of the pre and post-test scansion, the points on the barrier's surface that have not been deformed match perfectly.
A second procedure is implemented. It is useful in order to evaluate the barriers that arrive in the laboratory after the test. The crashed barrier that comes in the laboratory is positioned in a station. Also a scansion of a new barrier, of the same model, is scanned in the same station. Common points positioned on the station permit to align the pre test barrier with the post-test barrier.
The method for the evaluation of the deformation, after the scansion, is the same.
Both the procedures were tested, and some results come out. The positive comparison with the data obtained from external laboratories can be considered an initial validation of the procedure.
During the development of the procedure different attempts were made and also some problems have come up. For example, the positioning of the barrier in the station due to some big tolerances in the location of the holes, or the difficulty in scanning too depth surfaces.

A future work that can be done is the validation of the procedure in terms of ISO 17025, which is a quality norm. Since the FCA Safety Centre laboratory is accredited with this quality norm, a more in-depth study on the procedure and how accredit it can be done.

9. Bibliography

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