Vehicle Occupant Impact Severity in Relation to Real World Impact Conditions

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SYNOPSIS

Longitudinal safety barriers are tested in order to assess the safety barriers containment capacity and the vehicle occupant impact severity. In the EN standards, the occupant impact severity is evaluated with the same test (TB11) for all the classes of barrier: a 900 kg car colliding with impact speed equal to 100 Km/h and impact angle equal to 20°. Considering that real world impact conditions may be substantially different, at least two questions arise:

1. Which is the distribution of passenger cars kinetic impact energy for different type of roads and which is the relative position of the conventional test?
2. Are the values of Acceleration Severity Index (ASI), Theoretical Head Impact Velocity (THIV) and Post-impact Head Deceleration (PHD) obtained in the conventional test TB11 representative for real world impact conditions?

The "correct" answer to these questions requires a very expensive research program. This because a huge number of accident reports has to be collected and each accident event has to be reconstructed, furthermore many computer crash simulations have to be performed. In order to get a "preliminary" problem assessment, a study has been carried out performing an accident analysis and many crash simulation in different impacting conditions.
The accident analysis has been carried out by the examination of 160 police run off the road accident reports on a rural dual carriageway road, integrated with the inspection of accident sites. Many accident parameters have been evaluated and distribution probabilities of impact velocity, impact angle and vehicle mass have been drawn. The real world impact conditions obtained have been used as input for the crash simulation of a passenger car against a longitudinal safety barrier. Impact simulations have been carried out by non-linear dynamic finite element analysis performed with the software LS-Dyna. The finite element model used for the vehicle is the result of an extensive modeling activity and is very capable to represent the crash dynamics and consequences.
Collision outcomes in terms of THIV, PHD and ASI have been evaluated for each impact condition and, by combining the impact condition distributions with these results, the distributions of the impact severity indices have been assessed. The study carried out show that the probability of outcomes greater than the ones of the TB 11 are equal to 26% for ASI, and 34% for THIV and PHD.
According to the results of the study, passenger cars crash test conditions more representative of real world impacts, on motorways and on rural dual carriageway roads, would be:

- Impact speed = 130 km/h;
- Impact angle = 20 degrees;
- Vehicle mass = 1500 kg.

Such impact conditions would represent the ninetieth percentile of cars kinetic transversal impact energy. Moreover, with reference to the rigid wall fixed to the ground used in the simulations, they give rise to ASI, THIV and PHD values more severe than eighty-five percent of real world run off the road accidents.
The previous results show that the conditions proposed by the standard could be not conservative in Italy. They have to be intended, however, as preliminaries and stressing the need of a more in depth, and public funded, research program.

INTRODUCTION

Longitudinal safety barriers are tested in order to assess the safety barriers containment capacity and the vehicle occupant impact severity. According EN standards (CEN, 1998a, 1998b), the occupant impact severity is evaluated by performing the TB11 test for all the safety barriers classes: a 900 kg car colliding with impact speed equal to 100 Km/h and impact angle equal to 20°. Considering that real world impact conditions may substantially differ from the test conditions, at least two questions arise:

1. Which is the distribution of passenger cars kinetic impact energy for different type of roads and which is the relative position of the conventional test?
2. Are the values of Acceleration Severity Index (ASI), Theoretical Head Impact Velocity (THIV) and Post-impact Head Deceleration (PHD) obtained in the conventional test TB11 representative for real world impact conditions?

The “correct” answer to these questions requires a very expensive research program. This because a huge number of accident reports has to be collected and each accident event has to be reconstructed, furthermore many computer crash simulations have to be performed. The present study is aimed to provide a first contribution to answer these questions. It has been carried out performing an accident analysis on a rural dual carriageway road and many crash simulation in different impacting conditions.
The results obtained have to be intended, however, as preliminaries and stressing the need of a more in depth research program. Anyhow, the study is in progress at the University of Naples “Federico II” and at the Second University of Naples

REAL WORLD IMPACT CONDITIONS

Review of Literature

To date, few studies on impact conditions in run off the road accidents have been carried out, although these studies would be helpful for the selection of appropriate safety countermeasures and the upgrading of the standard crash test conditions.
Mak performed an analysis of real-world impact conditions basing on in–depth investigation and reconstruction of over than 500 accidents in USA (Mak and Mason, 1980, Mak and Calcote, 1983, Mak, et al., 1986). Impact speed and angle distributions for five different functional classes, including freeways, rural arterials, rural collectors/local roads, urban arterials, and urban collectors/local roads, were developed by fitting gamma functions to the crash data. Impact angle and speed distributions were found to be independent. Most of the data used to generate the impact speed and angle distributions were from utility pole crashes. Since these crashes have relatively high reporting rates, the effects of unreported crashes on the speed and angle distributions should be relatively low. Since the present study is focused on motorways and rural dual carriageway roads, impact speed and angle distributions of freeways have been used as comparison data.
US impact speed distributions are expected to be quite different from EU distributions, since of different speed limits, speed management systems and users behavior. Basing on the observation that crash data do not reflect any significant speed variation within the first 6 m from the edge of the pavement (Mak, et al., 1986, Perchonok, et al., 1978), impact speed distribution for motorways and rural dual carriageway roads has been estimated by using the passenger cars free flow operating speed distribution measured on the Motorway A3 Salerno-Reggio Calabria (De Luca, 2003) and by modifying the operating speed in relation to the analysis of braking marks measured in the analysis of 160 run off the road accidents on the rural dual carriageway road R09 Salerno-Avellino.
Although US impact angle distributions might be similar to EU impact angle distributions, an investigation of run off the road accidents has been carried out in order to obtain data which more reflect EU conditions.

Accident Analysis

Accident data on the road R09 Salerno – Avellino, section located in Province of Avellino - Italy, have been analyzed. Reference period was 1998-2002. Investigation has been carried out by the analysis of complete police accident reports. The road is a rural dual carriageway, with two lanes for each carriageway, 21.6 km long. Total Average Annual Daily Traffic (AADT) is equal to 48,000 vehicles/day and passenger cars account for 81% of the total traffic volume.
Total number of accidents is equal to 339 (see table 1), 164 accidents caused injuries and the most frequent accident type is single vehicle run off the road (160 accidents, 1 fatality, 113 injuries).
Main focus of the accident analysis has been to study impact conditions of passenger cars in single vehicle run off the road accidents.
Passenger cars have been divided in two categories: 1) vehicles with mass equal to 900 kg, 2) vehicles with mass equal to 1500 kg. Vehicles have been sorted in relation to the characteristics cited in the Police accident reports. Sixty vehicles (43%) were in the first category, eighty vehicles (57%) were in the second category.

Table 1 Aggregate accident data (passenger cars and heavy vehicles)

	Accidents		Fatalities		Injuries	
	N	%	N	%	N	%
Head on	**0**	**0,00%**	**0**	**0,00%**	**0**	**0,00%**
Right angle/turning	**3**	**0,88%**	**1**	**16,67%**	**6**	**2,16%**
Side swipe	**31**	**9,14%**	**1**	**16,67%**	**29**	**10,43%**
Rear end	**97**	**28,61%**	**3**	**50,00%**	**117**	**42,09%**
Hit pedestrian	**0**	**0,00%**	**0**	**0,00%**	**0**	**0,00%**
Hit stopped vehicle	**8**	**2,36%**	**0**	**0,00%**	**7**	**2,52%**
Hit parked vehicle	**3**	**0,88%**	**0**	**0,00%**	**3**	**1,08%**
Hit obstacle in carriageway	**37**	**10,91%**	**0**	**0,00%**	**3**	**1,08%**
Collision with train	**0**	**0,00%**	**0**	**0,00%**	**0**	**0,00%**
Run off the road	**160**	**47,20%**	**1**	**16,67%**	**113**	**40,65%**
Sudden braking	**0**	**0,00%**	**0**	**0,00%**	**0**	**0,00%**
Falling from a vehicle	**0**	**0,00%**	**0**	**0,00%**	**0**	**0,00%**
Total	339	100,00%	6	100,00%	278	100,00%

Impact angle distribution has been estimated trough an in depth examination of the braking marks in the carriageway and in the verge. In the police accident reports, only 34 braking marks (length and direction) have recorded. These marks were used as reference population since information on impact angles in other accidents are not available.
A number of theoretical distributions, such as normal, exponential, and negative binomial, have been fitted to the data and it has been found that a gamma function provides the best fit for the impact angle distribution. The gamma function is uniquely defined by the two coefficients α and $\Beta$. The coefficient values (α = 1.566; $\Beta$ = 7.554) have been calibrated by maximizing the log likelihood function. Impact angle distribution differs from Mak's distribution (see figure 1) since the study's distribution is characterized by lower values of impact angles. Fifty percentile of the distribution is equal to 9.4 degrees whereas it is equal to 13.5 degrees in the Mak's distribution; eighty-five percentile is equal to 20.8 degrees while it is equal to 25.0 degrees in the Mak's distribution.
According to the impact angle distribution estimated in the study, on motorways and on rural dual carriageway roads sixteen percent of passenger cars run off the road accidents have impact angle greater than the impact angle of the TB 11 crash test (20 degrees).

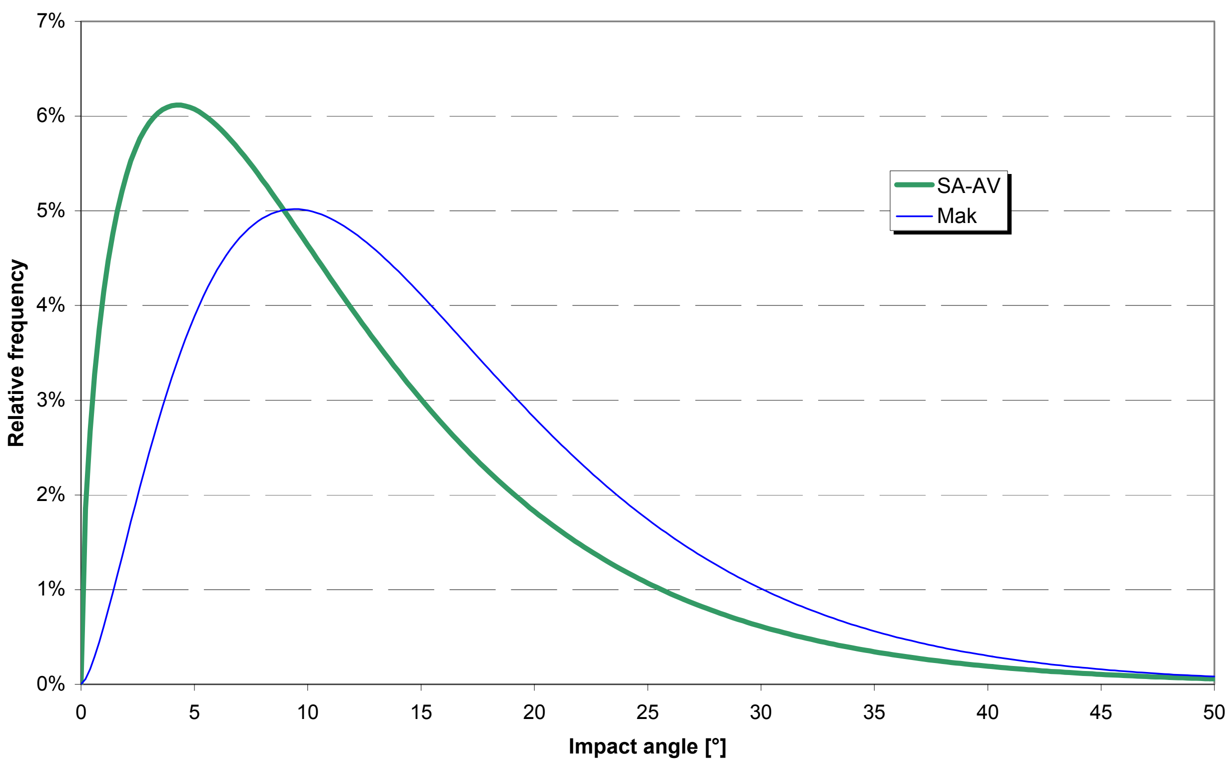

Figure 1 Impact angle distribution

Impact speed distribution for motorways and rural dual carriageway roads has been estimated by modifying the passenger cars free flow operating speed distribution measured on the Motorway A3 Salerno-Reggio (De Luca, 2003) in relation to the analysis of braking marks in 160 run off the road accidents on the road R09 Salerno-Avellino. These marks should be representative of the driver efforts to reduce the speed before the impact. Passenger vehicles speed distribution on A3 is normal, with mean equal to 126.5 km/h and standard deviation equal to 23.2 km/h. Basing on hypothesis of independence between speed and length of braking marks, a probability matrix 7X7 has been constructed. Each cell of the matrix represents the probability of given initial speed, equal to the average value of the cell interval, and length of braking maneuver, equal to the average value of the cell interval. For each combination of initial speed and braking markings length, impact speed has been computed by the formula:

$$v_f = \sqrt{v_i^{\,2} - 2 \times g \times f \times s} \qquad (1)$$

where:
v_f = impact speed (m/s);
v_i = Initial speed (m/s);
g = gravity acceleration;
f = friction coefficient, assumed equal to 0.8;
s = length of braking mark (m).

Resulting impact speed follows a normal distribution with mean equal to 120.2 km/h and standard deviation equal to 25.2 km/h. Mak's impact speed distribution (Gamma function, α = 5.879, B = 7.787) is substantially different from the study's distribution (see figure 2), since of the lower operating speeds in USA.
According to the impact speed distribution estimated in the study, on motorways and rural dual carriageway roads seventy-nine percent of passenger cars run off the road accidents have impact speed greater than the impact speed of the TB 11 crash test (100 km/h).

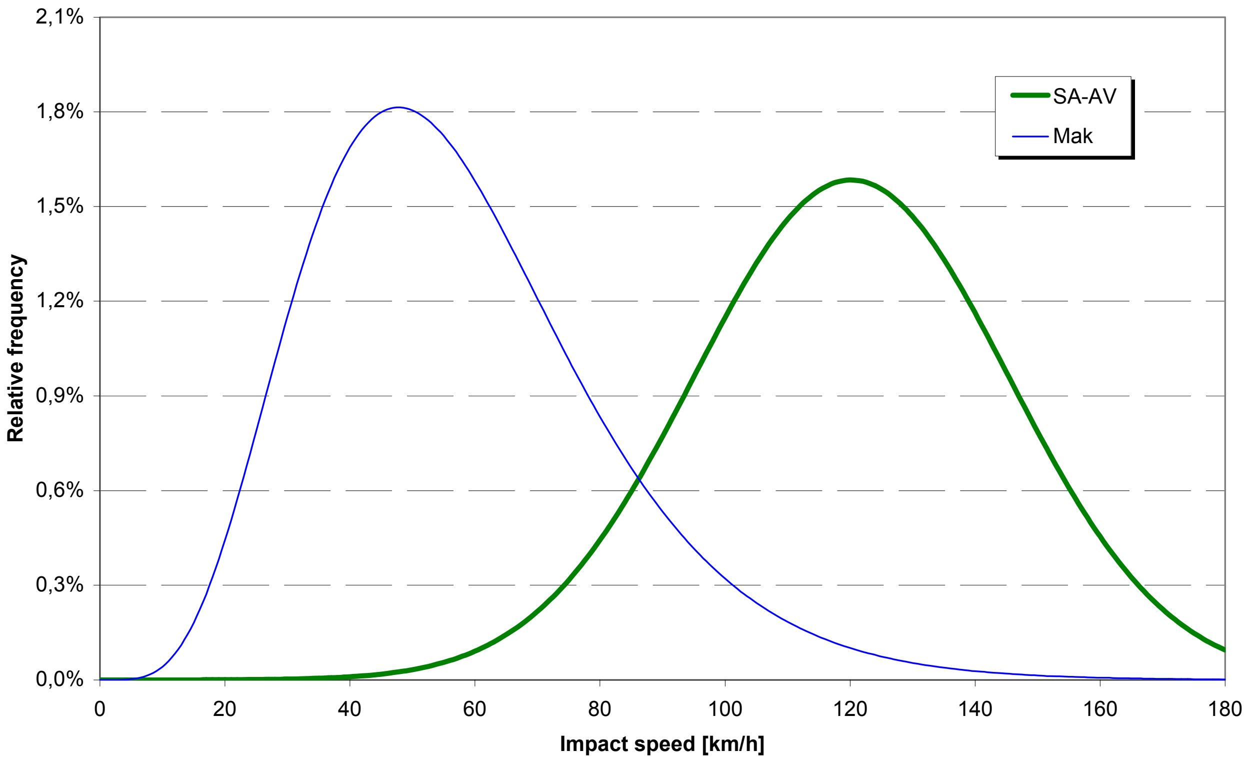

Figure 2 Impact speed distribution

Given the above reported impact speed and angle distribution, and passenger cars mass distribution, the kinetic transversal impact energy distribution for passenger cars has been calculated. Distribution arising from data of the study has been compared with distribution arising from Mak's data (see figure 3). Both distributions show that transversal impact energy of the crash test TB 11 does not represent the worst impact conditions on motorway and rural dual carriageway roads. Indeed, TB 11 impact energy (41 kJ) is exceeded in 30% of the passenger cars run off the road accidents. Using Mak's impact conditions distribution, TB 11 impact energy is exceeded in 45% of the run off the road accidents, due to the greater impact angles arising from this distribution.

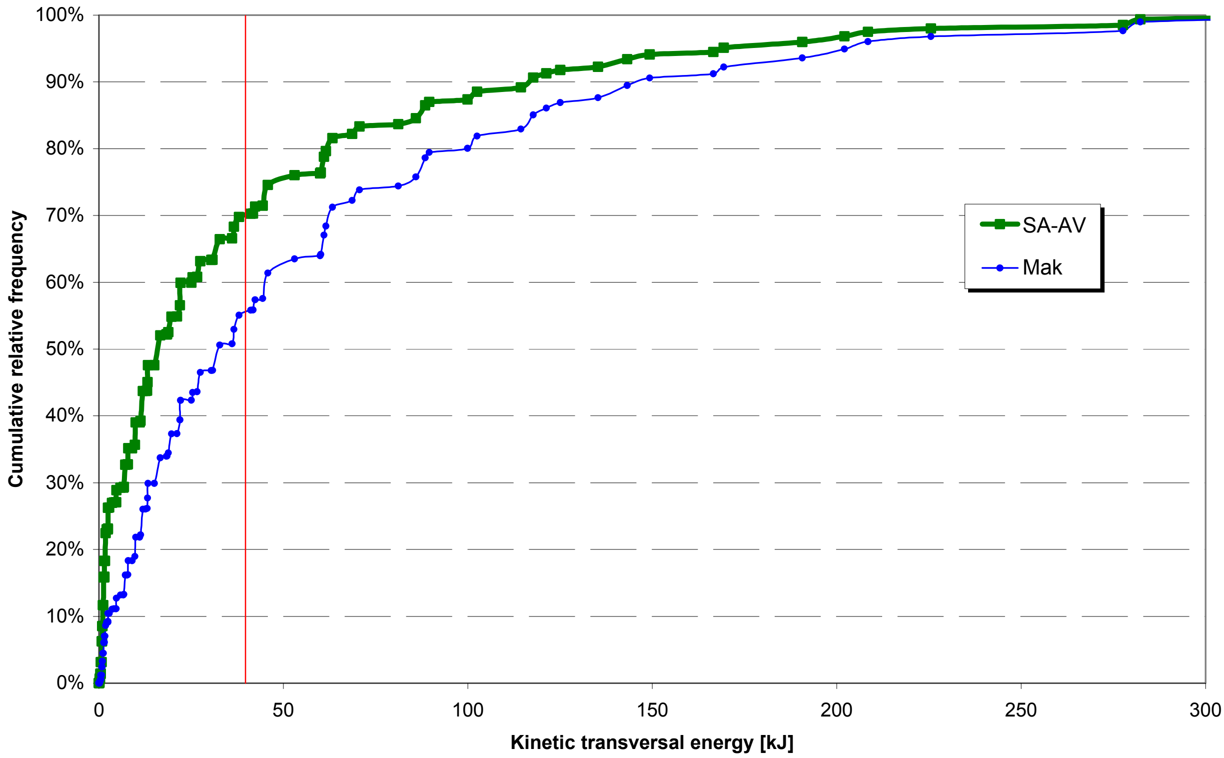

Figure 3 Kinetic transversal impact energy distribution

CRASH SIMULATIONS

Crash test simulations have been carried out by using the simulation code LS-DYNA 960. This software is a general purpose, nonlinear, explicit finite element code that was originally developed by Lawrence Livermore National Laboratory and has since been enhanced for automotive crash analysis by Livermore Software Technology Corporation (LSTC). Potential advantages of using sophisticated, state-of-the-art tools such as LS-DYNA 960 in roadside safety research include design modification, optimization, and performance prediction. Several roadside safety appurtenances currently being installed in USA can be directly linked to the use of nonlinear finite element analysis using LS-DYNA (Reid, et. al., 2003; Reid, 2004).

Vehicle Model

The vehicle used in the simulations is the Geometro 60 General Motors. The use of such vehicle was suggested by the need to have a finite element model that correctly represents the real geometry of the coachwork. The finite element models of the vehicles employed in the European tests TB11 have not yet been developed because they need a huge amount of human and economical resources. The model used arises from a finite element model downloaded from the web site of the National Crash Analysis Centre (NCAC). This original model has been modified for the present study in order to solve some weakness which could strongly affect the simulation results. A similar task has been carried out at the Worcester Polytechnic Institute (WPI) and at the University of Nebraska-Lincoln (UNL), where the original model of the 2000-kg pickup truck has been improved (Reid and Marzougui, 2002; Tiso, et. al., 2002). The tests performed to detect the needed improvements in the pickup truck and the modification carried out were very useful to define the imperfections of our car model. The defects of the Geometro were pointed out analyzing the behavior in some preliminary crashes against safety barriers and when running on road with bumps or in sideslip motion.
The identified unusual vehicle behavior resulted from:

1. the vehicle weight did not act on the suspensions but on rigid links between wheels and vehicle body;
2. forces between coachwork parts were transmitted only through few nodes.

The first problem made the vehicle suspensions inexistent and did not allow the wheel steering. This defect modified substantially the vehicle behavior, especially when the wheels climbed a New Jersey safety barrier. The rear suspensions in the same way were locked. In addition the vehicle didn't include any torsion bar, which is useful to moderate rolling. These problems have been solved by modifying the geometry and the mechanical characteristics of the suspension system and by changing the links between wheels and vehicle coachwork. The Fiat Uno suspensions scheme and characteristics were used as reference. The changes introduced made the suspensions system working and the wheels steering. In figure 4 the developed suspensions system is shown.

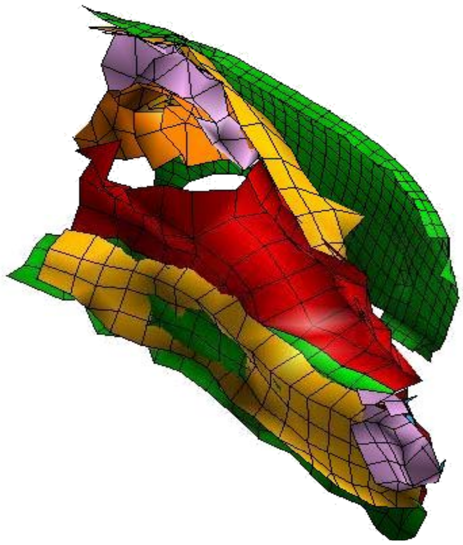

Figure 4 Suspensions system

The problems due to the connections between the different parts of the coachwork would made completely ineffective the simulations. In figure 5 it is possible to see an image of the vehicle's deformations where there is division between parts without the stresses attained the magnitude to produce the detachment. Such behavior modification required an huge amount of simulations, which were aimed also at obtaining the best result in terms of mesh density and time analysis. In figure 6 an image of the same deformed part following the re-meshing process is presented. The unusual behavior of the original model is not present.
Both the vehicles with different mass (900 and 1500 kg) had the same shape and were obtained by changing the materials density. This has been done because at the moment of the study a good finite model (as geo metro is) of a 1500 car was not available, there were only very rough finite models. A mass positioned in the center of gravity attached to the structure was used to gather speeds and accelerations during the impact.

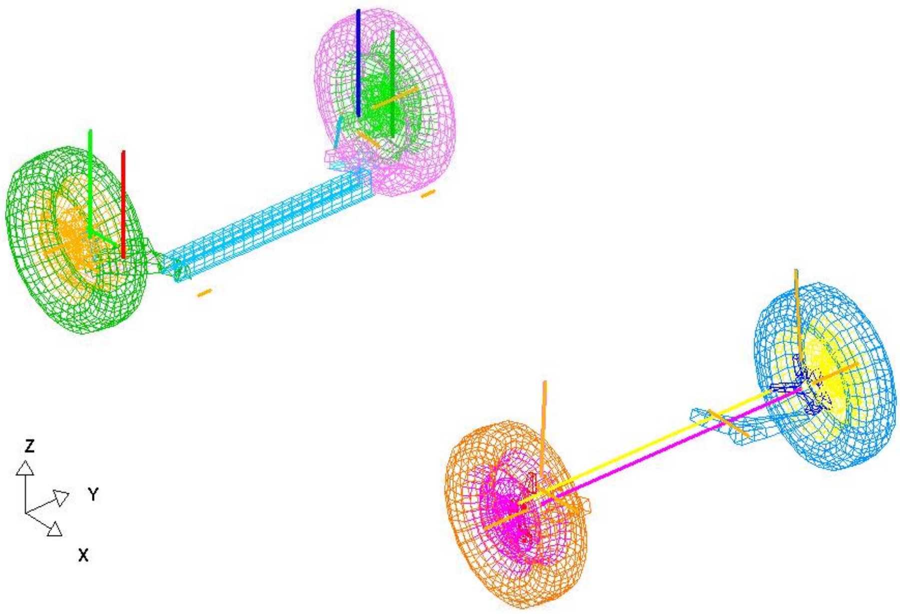

Figure 5 Parts detachment after the impact in the original model

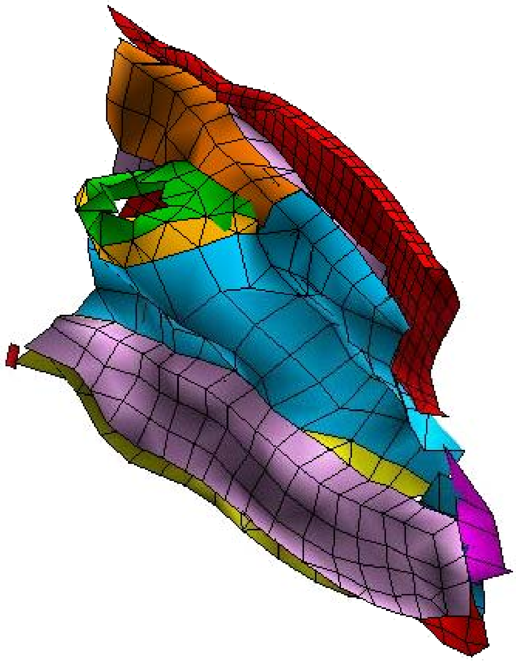

Figure 6 Deformations in the improved model

Barrier Model

The occupant severity indices depend on the barrier type. Deformable barriers usually give lower values of severity indices than the rigid ones. In order to give less significance to the simulated barrier, a rigid wall fixed to the ground has been used in the simulations. Such decision was also made in order to reproduce the crash tests performed in a research involving many European crash tests laboratory and aimed at evaluating their data acquisition procedure and elaboration. This Round Robin was organized by the Task Group 1 of the CEN TC 226/WG1. The vehicle used in the real tests was the Peugeot 106 and the barrier was made up by a prefabricated concrete wall fixed to the ground.

Occupant Severity Indices

The occupant impact severity was assessed by the indices included in the standard EN 1317: Acceleration Severity Index (ASI), Theoretical Head Impact Velocity (THIV) and Post-Impact Head Deceleration (PHD).
The Acceleration Severity Index ASI is the maximum of a time function:

$$ASI = \max \sqrt{\left(ax_{med}(t)/12\right)^2 + \left(ay_{med}(t)/9\right)^2 + \left(az_{med}(t)/10\right)^2} \qquad (2)$$

Where ax_{med}, ay_{med} and az_{med}, are the acceleration values in g averaged on a 50 ms moving window.

The Theoretical Head Impact Velocity (THIV) concept has been developed for assessing occupant impact severity for vehicles involved in collisions with road restraint systems. The occupant is considered to be a freely moving object (head) that, as the vehicle changes its speed during contact with the restraint system, continues moving until it strikes a surface within the interior of the vehicle. The magnitude of the velocity of the theoretical head impact is considered to be a measure of the impact severity.
The head is presumed to remain in contact with the surface during the remainder of the impact period. In so doing, it experiences the same levels of acceleration as the vehicle during the remaining contact period (Post Impact Head Deceleration - PHD). The PHD is computed with the following equation:

$$PHD = \max \sqrt{\left(ax_{med}(t)\right)^2 + \left(ay_{med}(t)\right)^2} \qquad (3)$$

Where ax_{med} and ay_{med} are the acceleration values in g averaged on a 10 ms moving window, and the time t is computed after the head contact.

A recent study on the severity indices evaluation (Anghileri, 2004) showed that the mechanical noise affecting acceleration measures, which has neither physical meaning nor effect on the real severity, should be removed for their evaluation. Moving average shows a not reliable behavior modifying signals canceling some frequencies but maintaining others. A modification has been proposed substituting the moving average, in the procedure to compute ASI and PHD, with an appropriate low-pass filtering.
The simulation results in term of ASI, THIV e PHD have been compared with results of the round robin test (see table 2). Values of ASI and PHD in the simulation and in test are very close, whilst there is a slightly greater difference (about 18%) in the THIV value.

Table 2 Comparison between round robin test and simulation

Index	Simulation result	Round robin test result
ASI	**1.8**	**1.9**
THIV [km/h]	**27**	**33**
PHD [g]	**16**	**14**

General Behavior During the Crash Test Simulation

The impact of the vehicle against the barrier can be split in four steps (see figures 7, 8 and 9 where the results of the 100 km/h and 20° simulation are reported):

1. the impact of the front corner, which causes a strong transversal force and in addition a considerable moment on yaw axis which lead to a reduction of the impact angle (the impact in the given simulation started at time 0 and ended after about 0.06 s);
2. the lateral scraping of the vehicle, where the interaction between vehicle and barrier is reduced (in the given simulation it started at 0.06 and ended at 0.13 s);
3. the impact of the rear corner, which causes the end of the yaw motion induced in the first step (in the given simulation it started at 0.13 and ended at 0.16 s);
4. the end of the impact.

The ASI (t) diagram (see figure 7) shows that the vehicle-barrier interaction was significant especially in the first step. The PHD (t) diagram (see figure 8) instead shows that the maximum acceleration for the head in contact with the vehicle cabin was reached in the third step. This happens because the impact between the point representing the driver head and the cabin occurs in the second step, as shown in the THIV plot (see figure 9). Increasing the impact velocity, the head impact occurs in the first step and the maximum PHD value is very high. In the simulations carried out such condition occurs when impact speed reaches about 130 km/h.

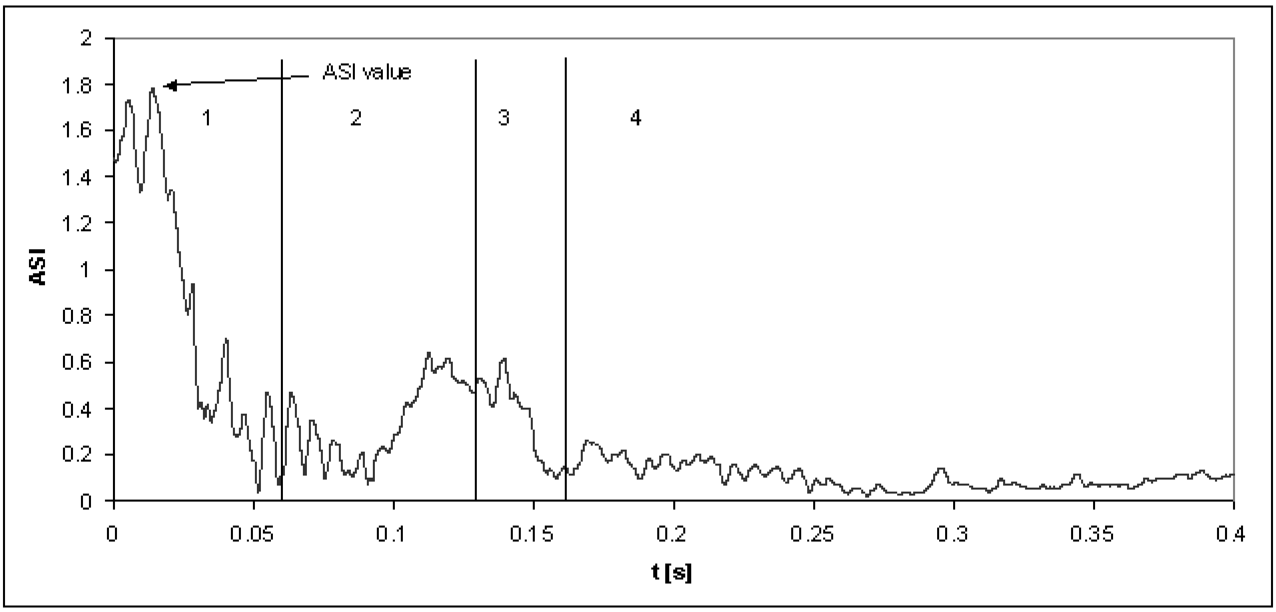

Figure 7 ASI(t) diagram

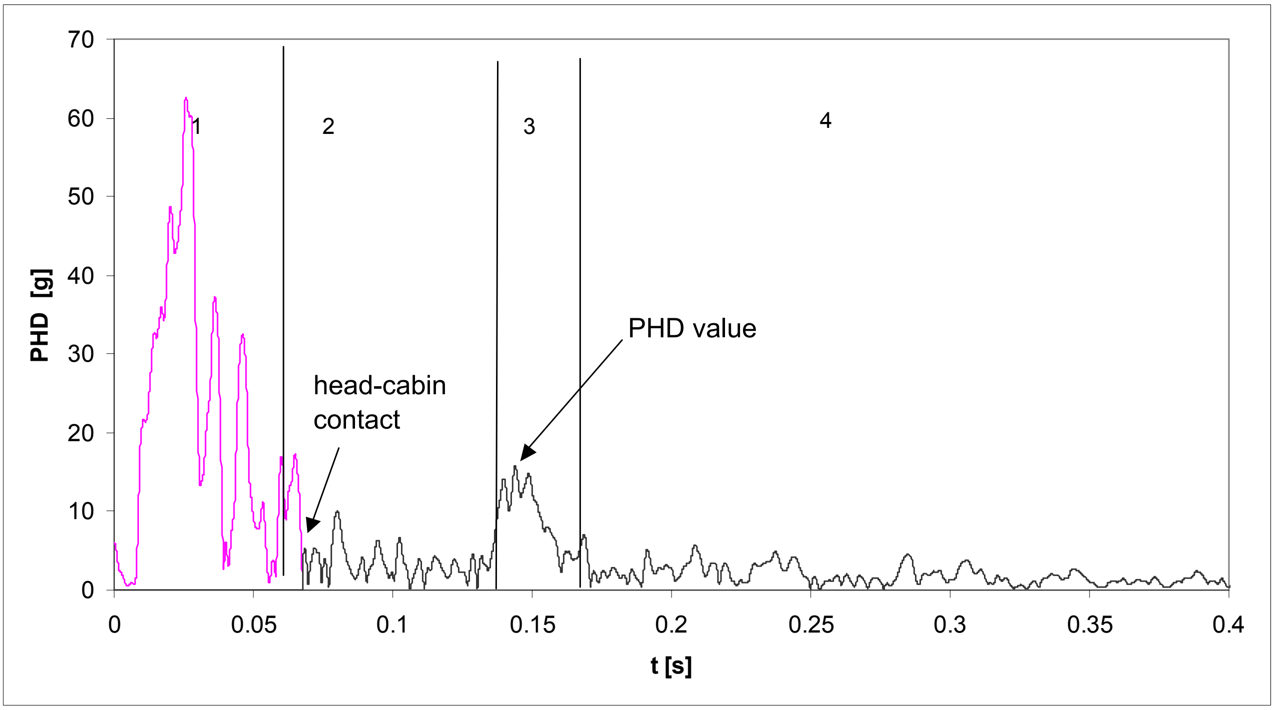

Figure 8 PHD (t) diagram

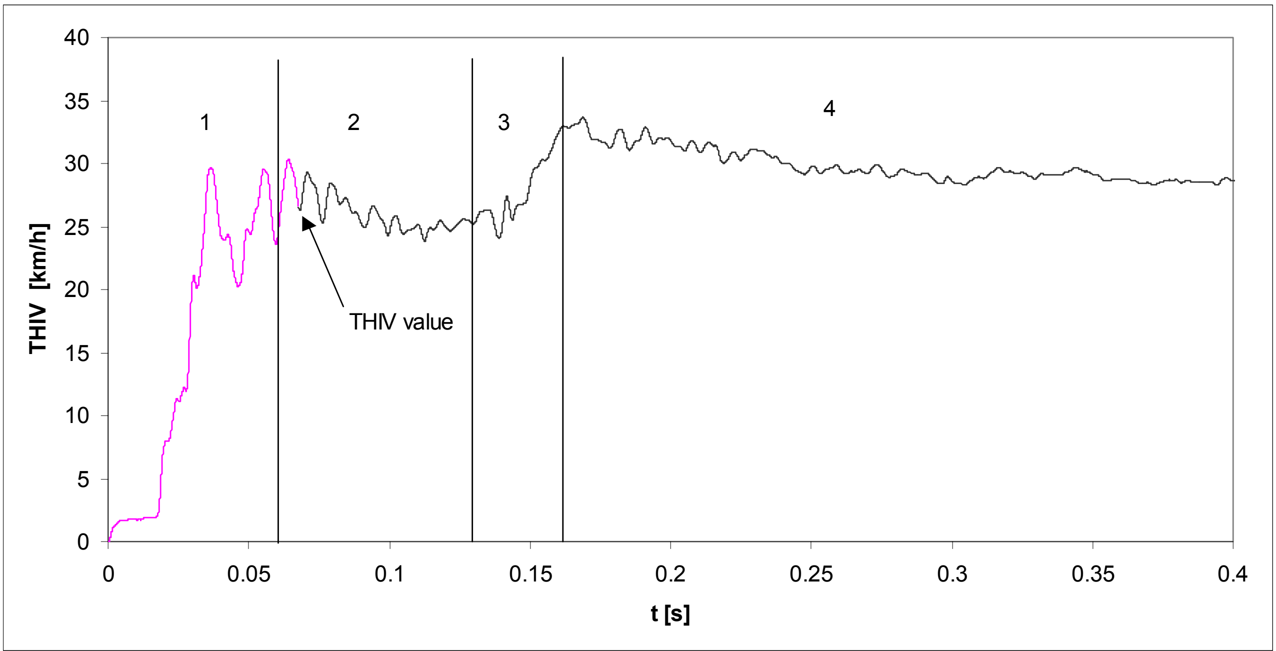

Figure 9 THIV (t) diagram

Simulation Results

Sixty simulations have been carried out (see tables 3 and 4). As above said, the barrier was a rigid wall fixed to the ground ant test vehicles were Geometro 60 with mass equal to 900 and 1500 kg. Impact angles were equal to 2.5, 7.5, 12.5, 20.0, 25.0 and 30.0 degrees. Impact speed were equal to 50, 80, 100, 130 and 150 km/h.

ASI, THIV and PHD values resulting from all the simulations can be compared with the values resulting from the simulation of the TB11 test (ASI = 1.8, THIV = 27 km/h, PHD = 16 g). Results exceeding the ones of the TB11 test are highlighted in tables 3 and 4. They refer to the following impact conditions:

- Impact speed equal to 80 km/h and impact angle grater than 25° (20° as far as THIV is concerned);
- Impact speed equal to 100 km/h and impact angle grater than 20°;
- Impact speed equal to 130 km/h and impact angle grater than 12.5° (7.5° as far as THIV and PHD is concerned);
- Impact speed equal to 150 km/h and impact angle grater than 7.5°.

It is worthwhile to note that the PHD index reaches very high values for high speed and impact angle. This happens because the contact of the "head" with the vehicle cabin occurs in the first phase of the collision, when the deceleration is very elevated.
The maximum value of the ASI was about three times the value obtained in the simulation reproducing the TB11 crash test. The maximum value of the THIV was twice and the PHD reached values up to six times the reference ones.

Table 3 Simulation results (m = 900 kg)

Impact speed [km/h]	ASI						THIV [km/h]						PHD [g]					
	Impact angle [°]						Impact angle [°]						Impact angle [°]					
	2.5	7.5	12.5	20.0	25.0	30.0	2.5	7.5	12.5	20.0	25.0	30.0	2.5	7.5	12.5	20.0	25.0	30.0
50	0.2	0.3	0.6	0.8	1.0	1.2	1	5	10	13	21	25	1	2	5	7	9	12
80	0.3	0.7	1.1	1.4	1.7	**2.0**	3	11	17	21	**29**	**35**	2	8	11	13	16	**20**
100	0.3	0.9	1.4	**1.8**	**2.3**	**2.8**	5	13	21	**27**	**36**	**40**	2	10	13	**16**	**25**	**38**
130	0.3	1.1	1.8	**2.3**	**3.4**	**4.7**	7	16	**28**	**34**	**47**	**51**	2	11	**23**	**63**	**81**	**97**
150	0.4	1.2	**1.9**	**3.0**	**4.0**	**5.4**	9	19	**32**	**40**	**52**	**56**	3	15	**31**	**82**	**109**	**130**

Table 4 Simulation results (m = 1500 kg)

Impact speed [km/h]	ASI						THIV [km/h]						PHD [g]					
	Impact angle [°]						Impact angle [°]						Impact angle [°]					
	2.5	7.5	12.5	20.0	25.0	30.0	2.5	7.5	12.5	20.0	25.0	30.0	2.5	7.5	12.5	20.0	25.0	30.0
50	0.1	0.5	0.7	0.9	1.1	1.4	1	3	9	14	17	22	1	2	4	7	8	10
80	0.2	0.8	1.1	1.4	1.6	**1.9**	3	11	16	22	26	**32**	1	6	10	11	12	14
100	0.3	1.0	1.3	**1.9**	**2.1**	**2.6**	4	13	20	**29**	**32**	**41**	2	9	15	**17**	**19**	**22**
130	0.4	1.1	1.8	**2.5**	**3.3**	**3.9**	6	17	**28**	**40**	**43**	**55**	3	12	**24**	**30**	**36**	**40**
150	0.4	1.2	**2.0**	**3.0**	**4.0**	**4.9**	8	18	**32**	**47**	**52**	**67**	4	14	**28**	**36**	**44**	**52**

DISCUSSION

The previous results show that the TB 11 crash test impact conditions could be not conservative in Italy. Even if the magnitude is different, US accident analysis studies confirm these results. According the impact distributions estimated in the study, TB11 impact energy is exceeded in 30% of the passenger cars run off the road accidents, impact speed is exceeded in 79% of ROR accidents, and impact angle is exceeded in 16% of ROR accidents.
Analysis of ROR accidents on motorways and rural dual carriageway roads in Regione Campania during the period 1995-2002 (3'171 accidents) shows that passenger cars accident represent 85 % of total run off the road accidents. Therefore, according to the present study results, TB 11 impact energy could be exceeded in about 25 % of the total accidents (percentage of impact energy greater than TB11 x presence of car in run off the road accidents).
As a matter of fact, it means that more severe impact conditions of passenger cars would be accepted in a percentage that is greater than the global presence of commercial vehicles in run off the road accidents (which accounts for 8 %).
Therefore it seems correct to assume more severe passenger car test condition for barriers to be installed on motorways and rural dual carriageway roads. For roads with lower operating speeds, TB11 test could be representative of real world car impacts.
Analytical crash test simulations have quantified the effects of the impact conditions defined by the accident analysis in terms of occupant severity indices. By combining the impact conditions results with the occurrence probability of these conditions, cumulative distributions of ASI, THIV and PHD have been calculated (see figures 10, 11 and 12). Probability of severity indices outcomes greater than the ones of the TB 11 are equal to 26% for ASI, 34% for THIV and PHD.
Moreover, the increase in the occupant severity indices with the impact energy could be higher for barriers conceived as "deformable" only for impact energy levels corresponding to the ones of the TB11 test. Therefore, stiffness is constant with energy.
According to the results of the study, passenger cars crash test conditions more representative of real world impacts, on motorways and rural dual carriageway roads, would be:

- Impact speed = 130 km/h;
- Impact angle = 20 degrees;
- Vehicle mass = 1500 kg.

Such impact conditions would represent the ninetieth percentile of cars kinetic transversal impact energy. Furthermore, with reference to the rigid wall fixed to the ground used in the simulations, they give rise to ASI,

THIV and PHD values more severe than eighty-five percent of real world run off the road accidents on motorways and on rural dual carriageway roads.
As said before the results obtained show that the TB 11 crash test impact conditions could be not conservative in Italy. They have to be intended, however, as preliminaries and stressing the need of a more in depth research program. Anyhow, the study is in progress at the University of Naples "Federico II" and at the Second University of Naples.

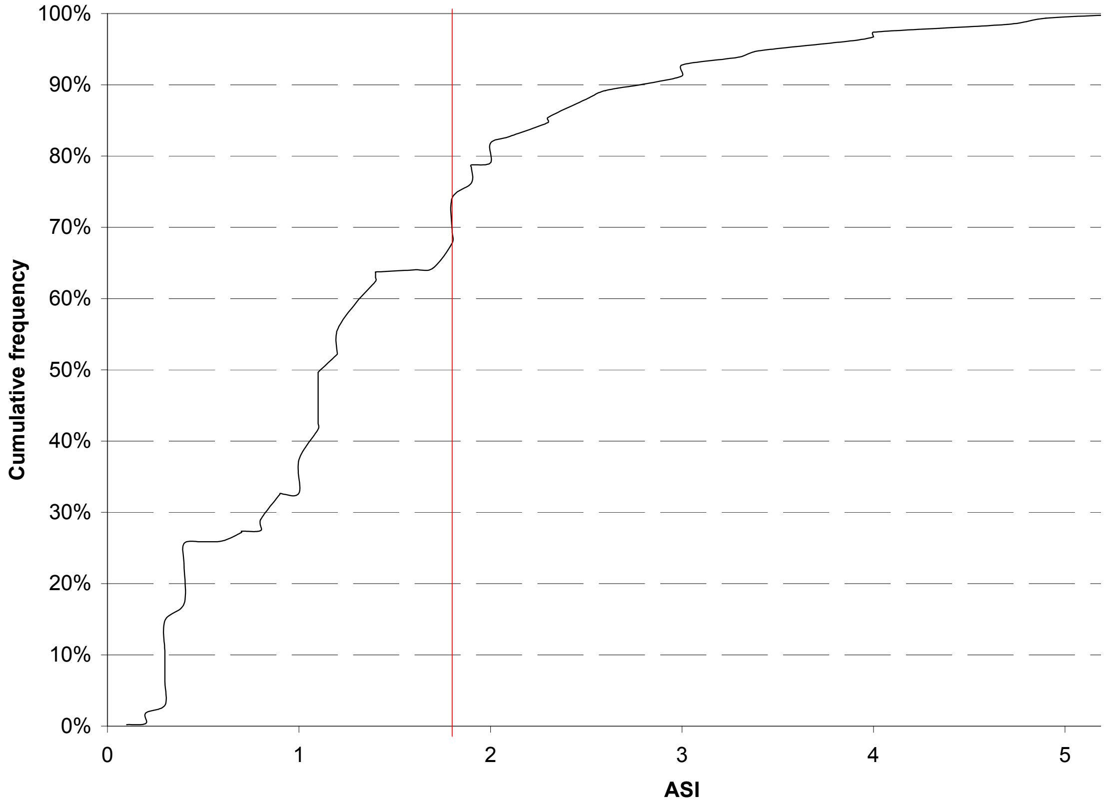

Figure 10 Cumulative distribution of ASI

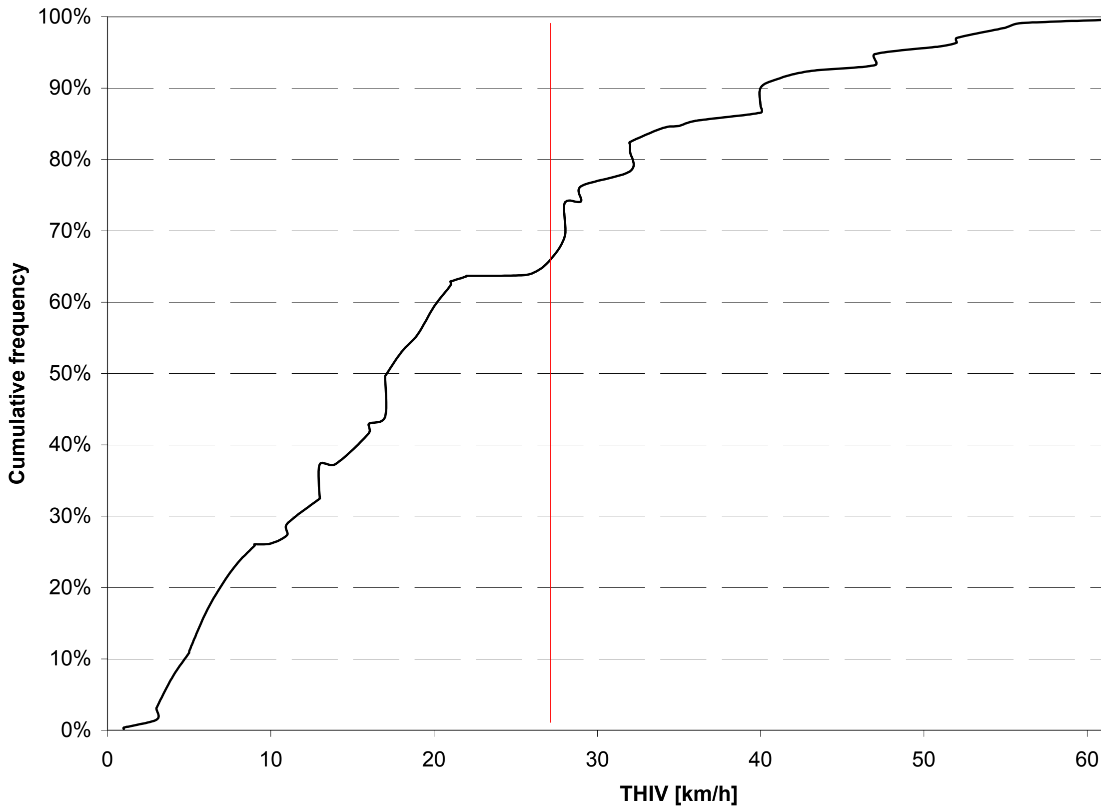

Figure 11 Cumulative distribution of THIV

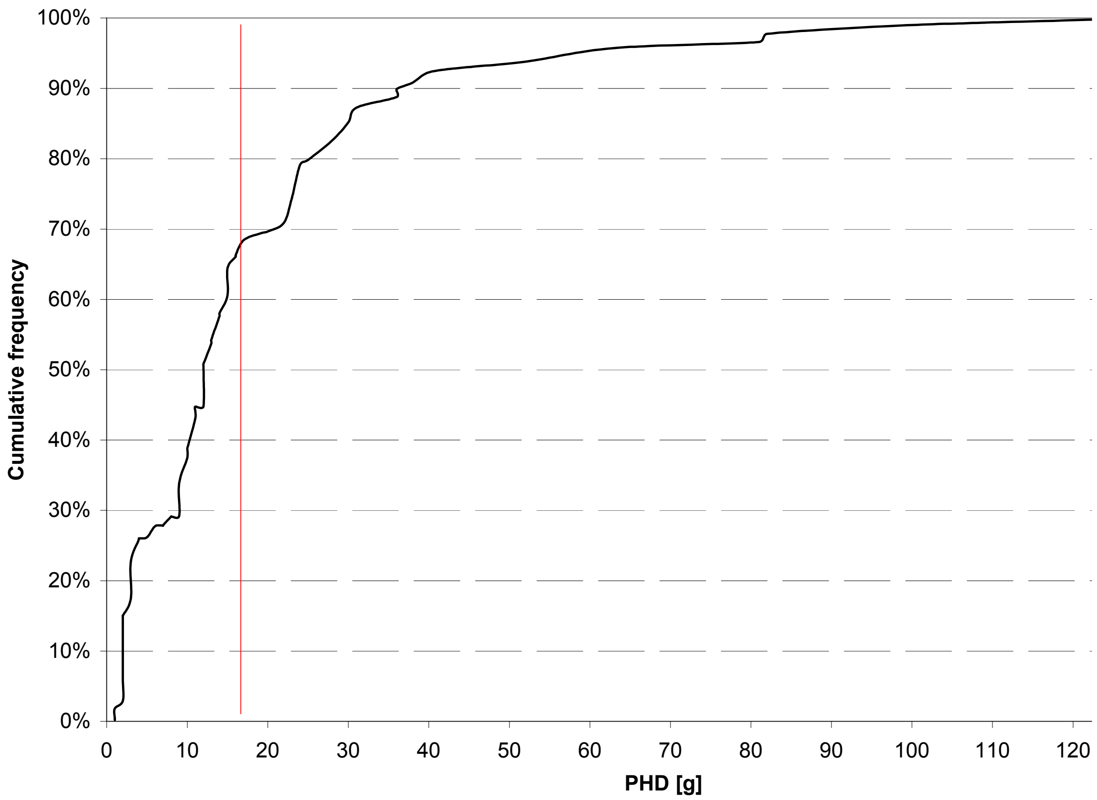

Figure 12 Cumulative distribution of PHD

CONCLUSIONS

The impact condition of TB11 test appears to be not completely representative of real word run off the road accidents on motorways and rural dual carriageway roads. According to the results of this study, concerning the road R09 Salerno – Avellino (a rural dual carriageway road), the impact energy is exceeded in 30% of run off the road accidents, whilst impact speed is exceeded in 79% of accidents and impact angle is exceeded in 16% of accidents.

The comparison of occupant severity indices ASI, THIV and PHD, evaluated by finite element simulation, for many impact conditions defined in the accident analysis with the same indices evaluated for the TB11 test conditions shows that the probability of outcomes greater than the ones of the TB 11 are equal to 26% for ASI, and 34% for THIV and PHD.

According to the results of the study, passenger cars crash test conditions more representative of real world impacts, on motorways and on rural dual carriageway roads, would be: impact speed = 130 km/h; impact angle = 20 degrees; vehicle mass = 1500 kg.

Such impact conditions would represent the ninetieth percentile of cars kinetic transversal impact energy. Furthermore, with reference to the rigid wall fixed to the ground used in the simulations, they give rise to ASI, THIV and PHD values more severe than eighty-five percent of real world run off the road accidents on motorways and rural dual carriageway roads.

The previous results have to be intended, however, as preliminaries and stressing the need of a more in depth, and public funded, research program,. Anyhow, the study is in progress at the University of Naples “Federico II” and at the Second University of Naples

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