

DEVELOPMENT OF A NEW CRASH-CUSHION CONCEPT FOR COMPATIBILITY PURPOSES OF RIGID OBSTACLES NEAR THE ROAD

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Paper Number 98-S3-O-11

ABSTRACT

This paper describes the development of a new, easy to handle and economic crash cushion for rigid obstacles to reduce occupant loads and injury risk during the impact.

Out of different concepts and experimental crash tests of energy absorbing barriers a mixture of concrete and granulated plastics ('Styroporbeton') has led to the best results regarding car deceleration and intrusions.

The improvement of occupant safety of this system is documented on the one side by comparing car deformation and acceleration behavior of crash tests with and without a crash cushion in front of a rigid barrier and on the other side by comparing the impact velocities of crash tests with and without crash cushion, causing similar car deformation.

For instance the car deformation of a 95 km/h crash against the crash cushion can be compared with a crash against a rigid barrier with an impact velocity of 52 kph.

GENERAL

There is an increasing demand for mobility within the whole world. The number of vehicle registrations is growing, producing greater traffic densities. However, there has not been a corresponding increase in the available traffic infrastructure. This introduces major problems for the society. Greater mobility will reduce traffic safety if there are no safety improvement strategies to address the changing traffic situation.

The confined traffic space and the narrowness of obstacles or danger zones near the road are responsible for many accidents and injuries. Annually, many people suffer from injuries due to a crash into these objects. Enormous economic and societal costs for the society are produced by this accident type. Therefore, the development and mounting of crash barriers was a logical step.

Active (primary) and passive (secondary) safety are two different aspects in traffic safety, whereby the active safety contains measures to avoid accidents and the passive safety contains the token measures to reduce the accident severity. Although great efforts and improvements in active safety have been achieved many accidents caused by different circumstances occur. Current compatibility research and development are mainly focused on car to car and car to truck crashes. A significant part of accidents with severe and fatal injuries of the occupants results from car collisions against rigid obstacles (like tunnel portals) near the road with impact speeds on a relative high level which are often higher as the specified crash test standards and therefore intrusions and high acceleration forces endanger the occupants.

Usually car structures are optimized to fit the safety standard (crash tests) for occupants. If the energy from high velocity impact can be reduced to levels similar the standard crash tests by energy absorbing objects around rigid obstacles the injury risk will decrease.

The ideal solution for safe road conditions is to remove all barriers near the road and to provide enough space to decelerate a vehicle in dangerous situations. But this is an impractical request and therefore the most effective method is an adequate design of obstacles in such a way that barriers also dissipate energy.

Optimal conditions could be achieved by absorbing energy not only by the car structure as also by an energy absorbing cushion in a way, that intrusions to the passenger safety cell are avoided as well as the acceleration pulse is on a tolerable level.

The loads to the vehicle occupants during a crash depends on the mass of the occupant and the decelerations affecting this mass. The deceleration depends on the velocity change, the deformation distance and the restraint system of the occupants. The masses of the occupants and the change of velocity or the impact velocity are given values and so the only parameter to influence the occupants safety is the distance for the velocity change. This is on the one hand the deformation

distance and on the other hand the possible movement of occupants, provided by the restraint system.

There is a clear correlation between deceleration and deformation distance. If the impact is totally plastic the deceleration depends only on the deformation distance (for a given impact velocity), but the structural load is proportional to the vehicle mass.

The crash configuration is optimal if the kinetic energy is dissipated by the deformation of the vehicle's front and no intrusion into the passenger compartment occurs.

Typical values for the crash against a rigid wall are: about 25% of the kinetic energy dissipated by the deformation of one longitudinal beam and 50% by the displacement of the engine. If there is no rigid barrier the frontal parts of the vehicle can not deform optimal and therefore other parts of the vehicle are loaded. Accident investigations have shown that there is a higher risk to be injured by intrusions than by accelerations or belt loads. Therefore the main goal should be to avoid intrusions into the passenger compartment.

The acceleration loads increase with increasing overlap, in opposite the possibility of intrusions increase with decreasing overlap (caused by the increasing deformation).

By means of crash cushions the deformation distance will increase and the deceleration will be reduced. Because the vehicles are optimized for different crash tests (especially the frontal impact against a rigid barrier with an impact velocity higher than 50 kph) the restraint systems are designed for such crashes. If the use of crash cushions leads to similar occupant loads the injury risk for the occupants will be reduced.

METHODOLOGY

In a first step different materials and concepts were tested on a crash sled. Out of this experiments different crash cushions were designed and tested in a crash facility designed for such tests under similar crash conditions. The crash vehicles were accelerated towards a concrete block with a mass of 24.000 kg, using two fixed pretensioned ropes for leading the crash car and a towing rope for the acceleration. Few meters before the barrier the vehicle and the ropes were released by a special mechanism and the car crashed without external influence against the cushion, which was fixed in front of the concrete block (Figure 1.).

The longitudinal and lateral accelerations of the cars during the impact were measured by means of an accident data recorder (UDS™ Unfalldatenspeicher by VDO-Kienzle®) fitted in the trunk of the vehicle. The

crashes were also documented with a high speed video camera using a frame rate of 1000 pictures per second. After the impact the vehicle deformations were documented with detailed photos and measurements.

Also simulations for the estimation of the occupant loads using the MADYMO (MATHematical DYNAMIC MODEL; multibody and FEM computer package) tool of PC-CRASH (program for the simulation of motor vehicle accidents) were executed.

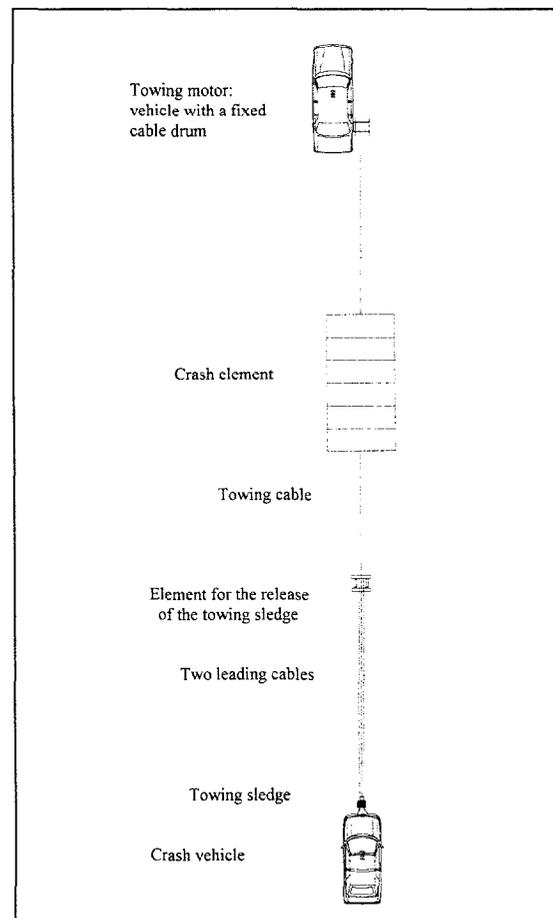


Figure 1. Crash Facility.

CASE 1: TMA

The first crash was a Ford Escort against a so called TMA-element (Truck Mounted Attenuator) from Energy Absorption Systems, Inc., a construction which was designed to reduce severity of collisions with work vehicles. It consists of a Durashell Nose for low speed impacts and an aluminum construction for dissipating energy by impacts on higher speed levels. This element is used in some countries and the effectiveness has been proofed. The dimension of the tested TMA was 2,21 x

2,39 x 0,66 [m] and it was fixed 0,2 m above the ground (see Figure 2).

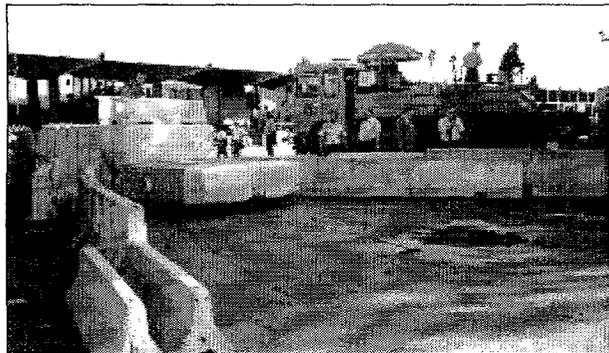


Figure 2. TMA.

The impact velocity was 89 kph, the angle of impact was 0° with 100% overlap. The mean deceleration during a crash time of 200 ms was 136 m/s^2 with a maximum of 29 g. There were no intrusions into the passenger compartment and the doors opened without restriction. The pedals were displaced minor, the deformations of the vehicle front reached the front axle, the base plate, the A-pillar and the top were not damaged.

The deceleration diagram (see Appendix) shows two peak values, the first 20 ms after the impact when the engine hits the element and the second peak value occurs after 80 ms when the wheels come into contact with the car-body. The elastic part of the crash is minor, remarkable is the break of the whole vehicle front into the cushion without major deformation.

CASE 2: STYRODUR

Crash against an element consisting of 25 pasted plates of Styrodur and a 2 mm sheet-metal at the front.

The element was installed 0,20 m above the ground (dimension 1,02 x 1,88 x 0,60 [m]) and impacted by a Ford Escort with 100% overlap and an impact speed of 89 kph, the angle of impact was 0° . The mean deceleration during ca. 100 ms was 171 m/s^2 with a peak value of 33 g (see Appendix).

The passenger compartment was damaged, the dashboard twisted, the base-plate deformed and the seats had an inclination to the front, the pedals were displaced into the foot room, the steering wheel displaced vertical. The car-body had immense deformations and the roof had a dent near the B-pillar.

15 ms after the impact the engine hood started to deform, after 35 ms the wheels reached the barrier and the first cracking occurred, 50 ms after the impact the

elements disintegrated and the vehicle had large deformations. The front axle went back and 60 ms after the impact the axis reached the A-pillar, the element was smashed and the windshield was dropped, the rear axle lost the contact to the ground. The vehicle went up about 40° and rotated left (about 15°), after 950 ms it stood still.

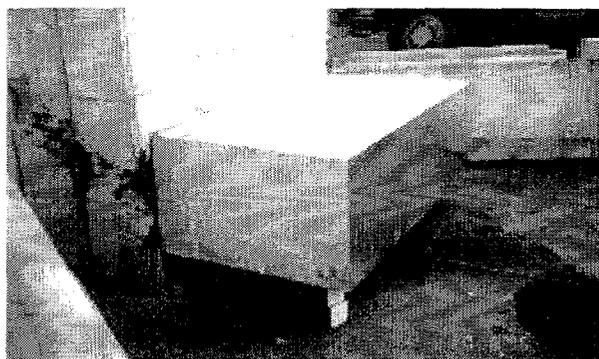


Figure 3. Styrodur-element.

CASE 3: TIRE PILE

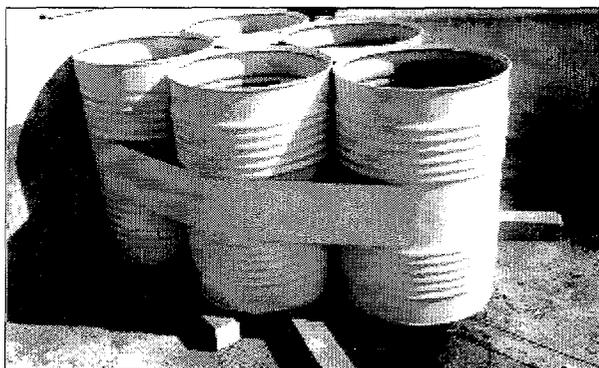


Figure 4. Tire pile.

The crash element contained tires which were stored in metal barrels (see Figure 4.). The element with the dimension 1,70 x 1,15 x 1,05 [m] was impacted by a Ford Escort with an impact speed of 93 km/h and 100% overlap. The mean deceleration was 125 m/s^2 , the peak value about 35g. The deceleration pulse showed three sections with peak values after 20, 50 and 110 ms (see Appendix).

The passenger cell was deformed, the base plate buckled slightly and therefore the seats inclined. The firewall also showed deformations, the pedals and the steering wheel were displaced, the roof had a small dent near the B-pillar and the front door could not be opened.

15 ms after the impact the hood deformed and the first barrel was destroyed. After 90 ms the vehicle

reached the wall behind the barrel element and therefore immense deformations appeared, the front axle was brought to the A-pillar, the wind screen dropped. The rest position of the vehicle was 1,5 m in front of the crashed barrier.

CASE 4: HONEYCOMB STRUCTURE

This element was built of 0,36 mm tinplate, which was buckled and welded to a honeycomb structure (see Figure 5.).

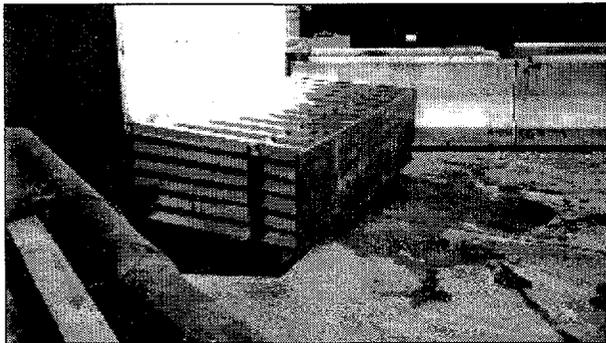


Figure 5. Honeycomb-element.

On the front a 4mm sheet-metal was fixed. The element was installed 0,20 m above the ground (dimension 1,10 x 2,08 x 0,59 [m]) and impacted by a Ford Escort with an impact speed of 88 km/h with 100% overlap. The mean deceleration during 120 ms was 229 m/s² with a peak value of 43 g (see Appendix).

There were immense deformations into the passenger compartment, the A-pillar was cracked, the base plate deformed, the pedals and the steering wheel were displaced into the passenger cell. The roof was deformed on a wide area and the front axle went back to the A-pillar. The opening of the front doors was impossible.

30 ms after the impact the tires contacted the crash element, the first part of the cushion deformed with fold bumps, but this effect ended and the vehicle deformed. The front axle and the front structure had extensive deformations, after 80 ms the vehicle was damaged and the rear axle went up.

CASE 5: EEVC

The crash element was built out of two EEVC (European Experimental Vehicle Committee) side impact elements built by the company Fritzmeier. This element is used for side impact crash tests in Europe. It consists of 6 PU-foam pieces with defined properties and a sheet-metal in front (see Figure 6.).

The element (dimension 0,94 x 1,50 x 0,50 [m]) was impacted by a Ford Escort with an impact speed of 80 km/h. The mean deceleration was 166 m/s² with a peak value of 32 g (see Appendix).

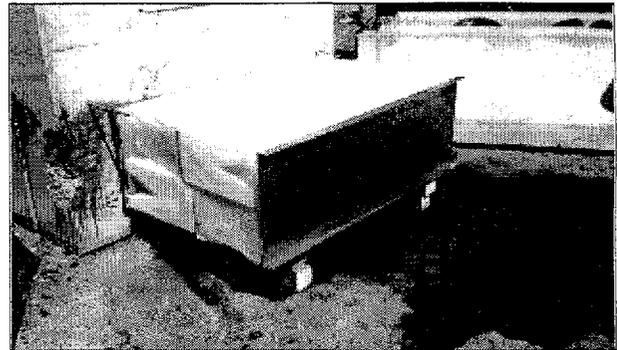


Figure 6. EEVC-element.

The steering wheel and the pedals were displaced, the dashboard twisted, also the base plate was deformed and the seats had a frontal inclination. A dent on the roof near the B-pillar and front axle deformations could be observed and the front door opened only by large forces.

The first element was deformed without remarkable vehicle damage but when the second part of the element was reached after 50 ms the front axle contacted with the car-body and the vehicle deformed.

CASE 6: 'Styroporbeton'

A mixture of concrete and granulated plastic (Protteolith®) was used for this element (see Figure 7.).

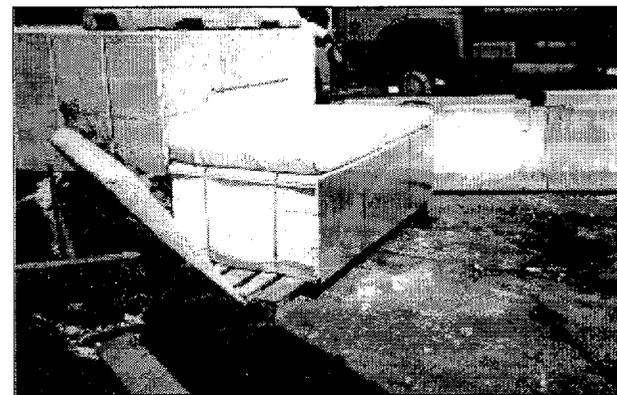


Figure 7. 'Styroporbeton'-element.

The element was installed 0,20 m above the ground (dimension 1,00 x 2,00 x 0,60 [m]) and impacted by a Ford Escort with an impact speed of 80 km/h and 100% overlap. The mean deceleration during 120 ms was 187 m/s² with a peak value of 31 g (see Appendix).

During the first 20 ms no vehicle deformation could be observed, after that time the tires contacted with the element, the vehicle burst into the element and 90 ms after the first contact the element was demolished.

The passenger cell was not destroyed remarkably, the roof, the base plate and the seats were deformed minor, the firewall was without deformation and the front axle went back.

CASE 7: RIGID WALL

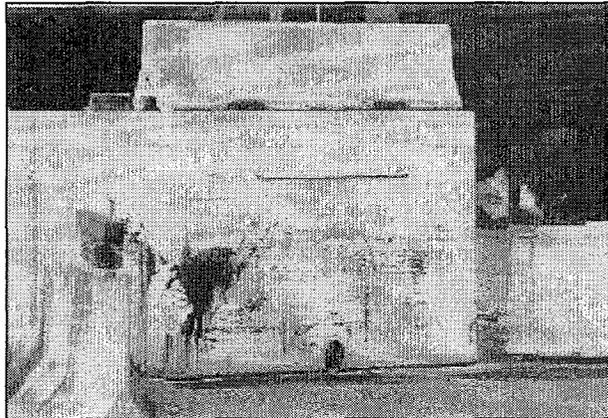


Figure 8. Rigid wall.

Crash against the concrete block with a impact speed of 89 km/h and 100% overlap. The mean deceleration during 120 ms was 217 m/s² with a peak value of 43 g.

The whole passenger compartment was destroyed, the pedals contacted with the seat and the headrests contacted with the roof. The dashboard, the base plate, the firewall, the roof and the A-pillar were damaged extremely.

FINDINGS OF THE FIRST TESTING SERIES

The best results were shown by the TMA barrier and by the 'Styroporbeton'-element, also the tire-element brought acceptable results but modifications to this element would have been too complicated. Therefore the decision was made to optimize the 'Styroporbeton'-element because of the great potential which could be seen in the first test series.

- easy to handle
- inflammable
- lower costs
- recycled material and the possibility to recycle the element after the impact
- flexibility

For the next series the element was modified regarding dimensions and structure. The length of the

element was enlarged to 1,60 m, the mixture rate of the 'Styroporbeton' was changed and different densities were combined to test the effect of different mixtures and to get to a progressive force trend. Also an offset crash with a high impact speed was done.

- case 8: 1,80 x 0,80 x 1,60 [m], two pieces (1,80 x 0,80 x 0,80 [m]) with different densities (170 kg/m³ and 280 kg/m³) combined to one element.
- case 9: 1,80 x 0,80 x 1,60 [m], with constant density (190 kg/m³).
- case 10: 1,80 x 0,80 x 1,60 [m], two densities combined. (190 kg/m³ and 330 kg/m³)

CASE 8: STYROPORBETON (170/280)

The element was installed 0,20 m above the ground (dimension 1,80 x 0,80 x 1,60 [m]) and impacted by a Ford Escort with an impact speed of 81 kph and 100% overlap. The middle deceleration was 168 m/s² during a period of 140 ms, with a maximum value of 30 g (see Appendix).

The vehicle front was shortened approx. 20 cm, the deformations reached up to the a-column. The wheel base left was shortened around 9 cm and on the right around 15 cm. The passenger space remained intact, the injury risk for the occupants depends mainly on the acceleration load.



Figure 9. Vehicles after the impact against the rigid barrier with 83 kph (left) and impact against the 'Styroporbeton' cushion with 81 kph.

CASE 9: STYROPORBETON (190/190)

A Ford Escort crashed with 94,5 kph with 100% overlap against the barrier with a homogeneous density. The deceleration during a time of 195 ms was 136 m/s² with a maximum value of 28 g (see Appendix). The frontal part of the vehicle was deformed approx. 30 cm.

The front axle shifted 10 cm to the rear. The passenger space was intact, the injury risk is given by the acceleration load.

CASE 10: STYROPORBETON (190/330)

Crash against an element with two different qualities of 'Styroporbeton' with an impact speed of 97 kph and 50% overlap.

The impacted barrier was deformed on the subjected side completely, the other side remained almost undeformed. After the barrier was used up, the rear of the vehicle rose highly, the vehicle made a 90° counter clockwise rotation and came approx. 1 m to the right and 1,5 m to the rear to the deadlock. On the impacted side of the vehicle it came to substantial deformations. The left side of the vehicle was destroyed up to the A-pillar. The driver's door was blocked after the crash, the roof was warped. The passenger compartment was reduced, the steering wheel and the pedals were shifted inward. The front of the vehicle was bent to the left and the frontal axle was shifted about 54 cm to the rear on the driver's side. On the other side the distance between front and rear wheel became larger.

The main danger for the occupants might result from the intrusions and not only from the acceleration loads.

CONCLUSION

Both elements which were crashed with 100% overlap brought good results but the second part of the 1. element was too stiff. The deformation of the vehicles is similar to the deformation of a crash against a rigid concrete barrier with 40 to 50 kph. There are no intrusions into the passenger safety cell and therefore only the acceleration load is important for the occupant safety and this load can be handled by a modern safety system.

The offset-crash with 50% overlap brought intrusions but the acceleration load is on a lower level because the deformation distance is larger. Such kind of impacts are a great problem for all automobile producers and only an adequate structure and vehicle design can reduce this problems.

The 'Styroporbeton' element was designed harder than the TMA-element for a better utilization of the limited traffic space. So the vehicle front also deforms and the deformation distance for dissipating the energy can be reduced (see Figure 10.).

For the computer simulations the measured vehicle accelerations were brought to a vehicle model in which a

dummy model was placed on the front-seat passenger side (see Figure 12.). Because of the different element dimensions a direct comparison is problematic but the values shows the tendencies of the passenger load. But the intrusions into the passenger compartment are not calculated and therefore for example the tyre pile shows relative low passenger loads but during the tests intrusions into the safety cell occurred and therefore the risk for the occupants will be higher than the 'Styroporbeton' impact (see Figure 11.).

ACKNOWLEDGEMENT

The authors wish to acknowledge the funding and support from the Styrian government of this study.

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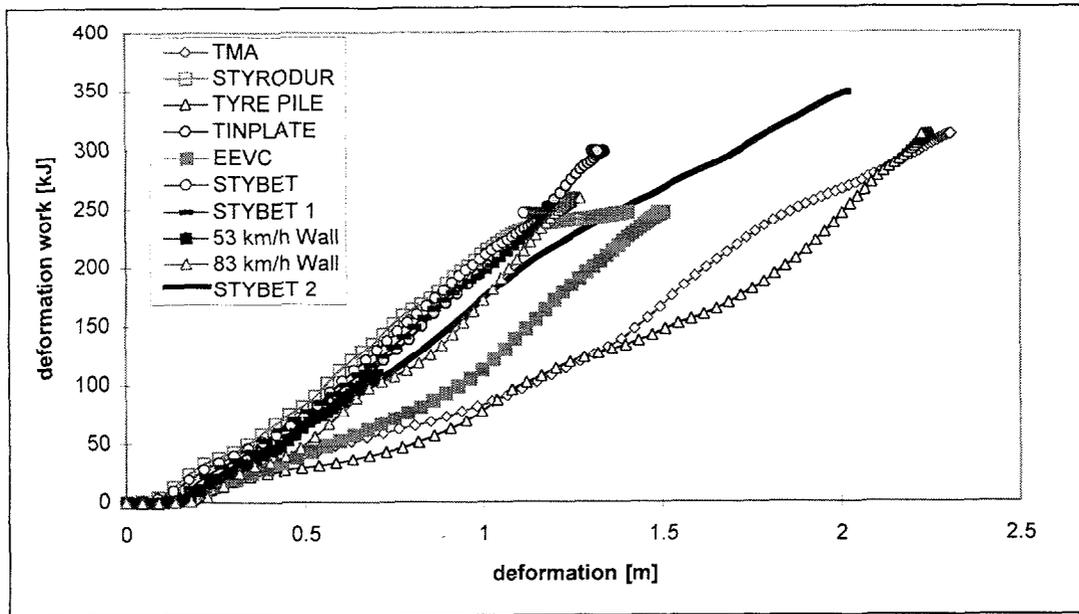


Figure 10. Deformation work and dynamic deformation for different elements

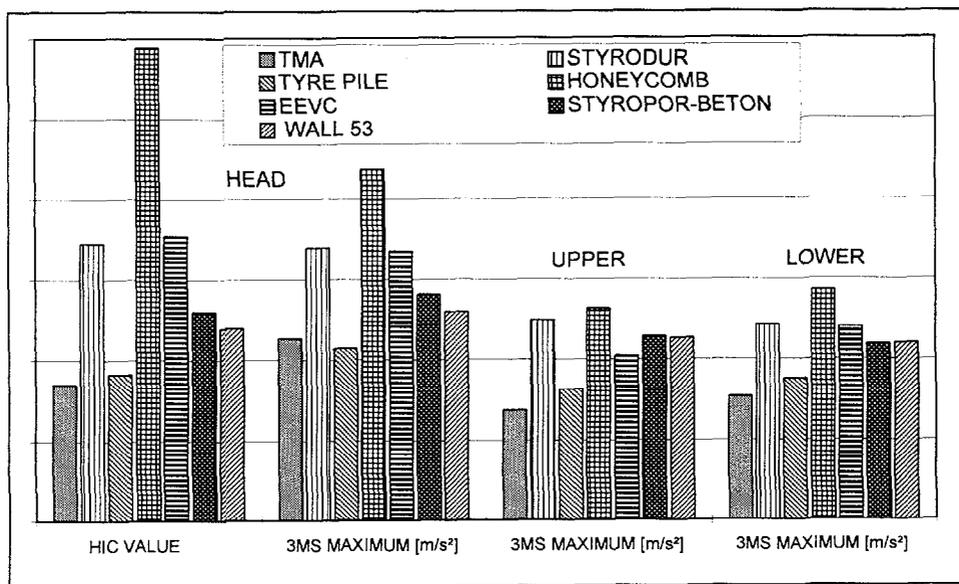


Figure 11. Comparison of injury parameters calculation for passenger side

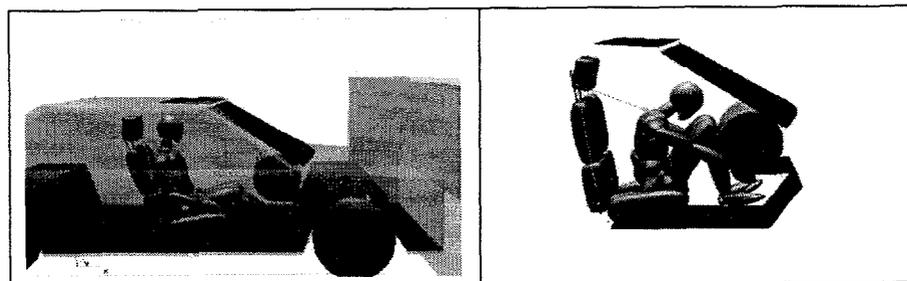
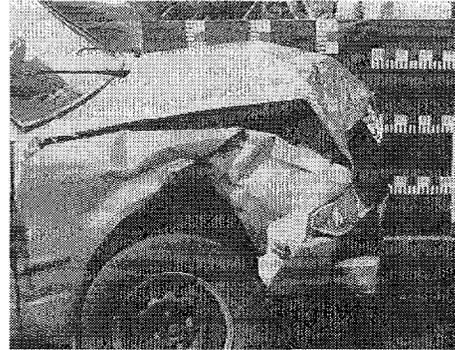
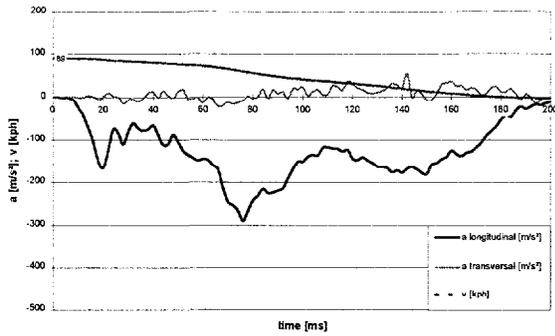


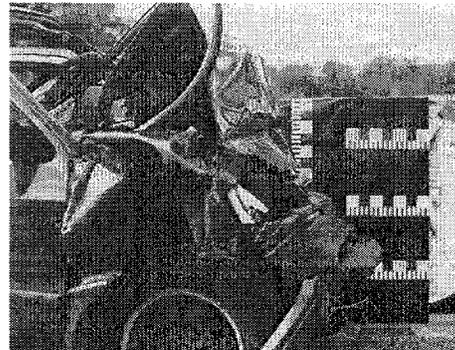
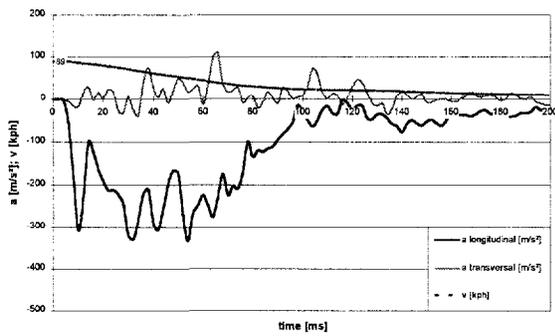
Figure 12. Model for simulation

APPENDIX

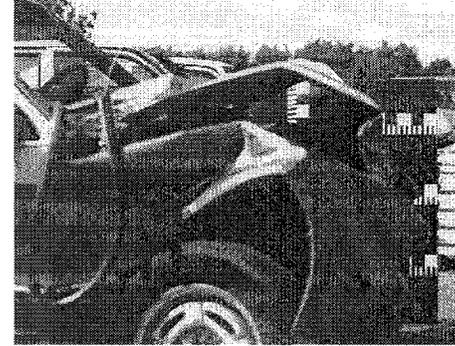
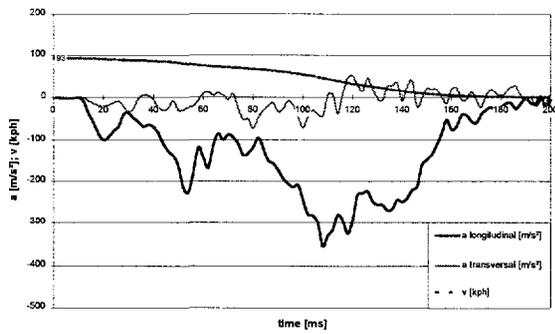
Case 1: TMA, 89 kph, 100%



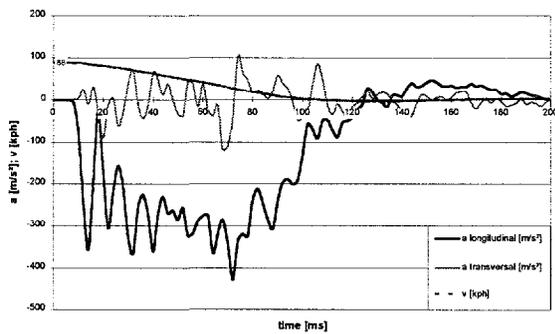
Case 2: Styrodur, 89 kph, 100%



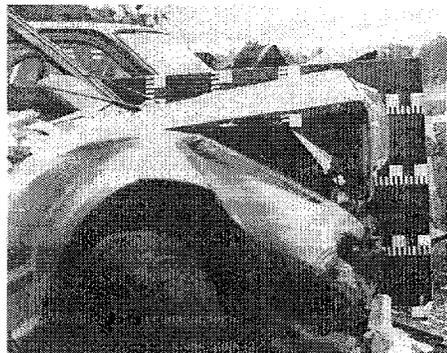
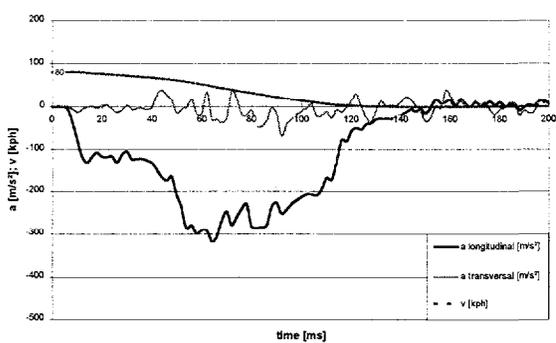
Case 3: Tire pile, 93 kph, 100%



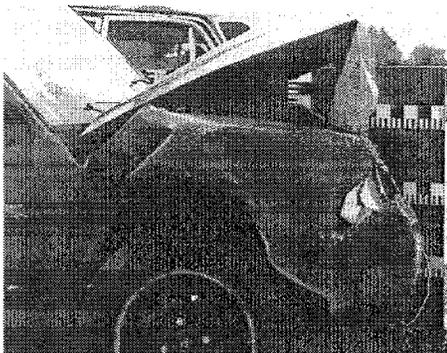
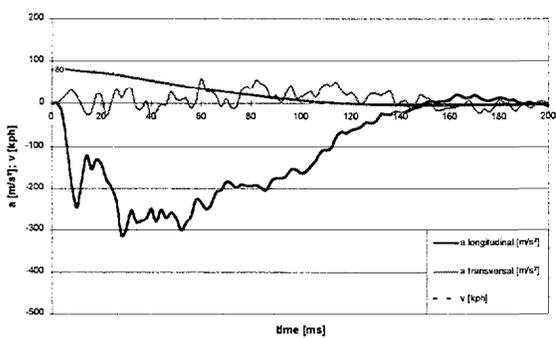
Case 4: Tinplate element, 88 kph, 100%



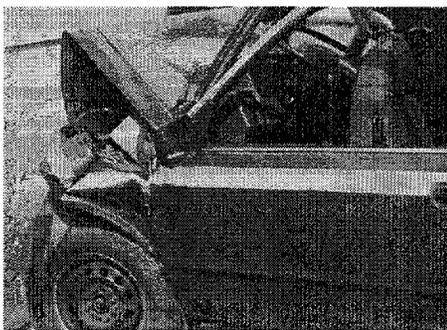
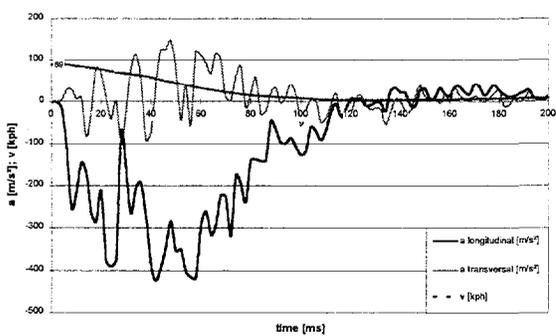
Case 5: EEVC, 80 kph, 100%



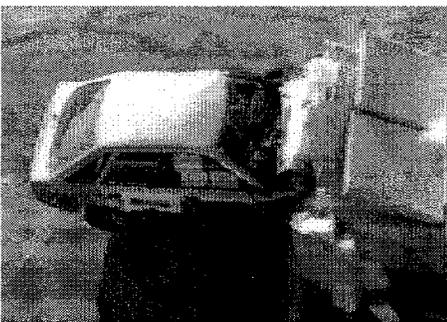
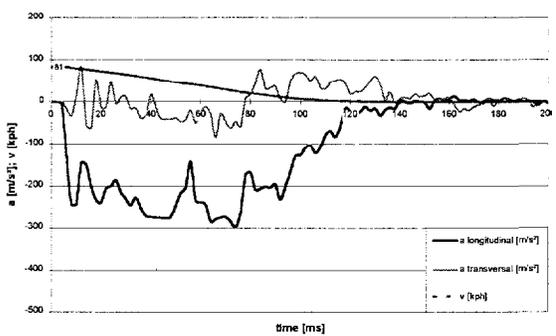
Case 6: 'Styroporbeton', 80 kph, 100%



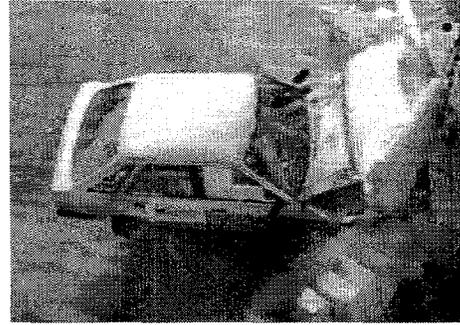
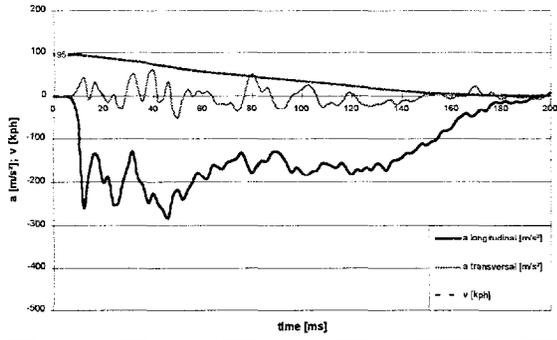
Case 7: rigid wall, 89 kph, 100%



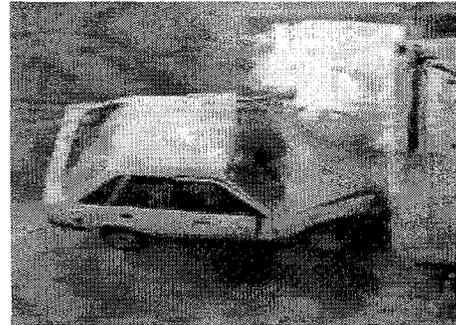
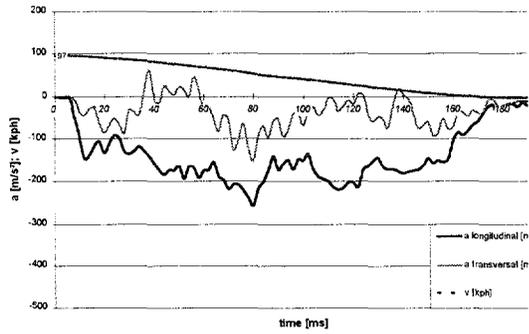
Case 8: Styroporbeton, 81 kph, 100%



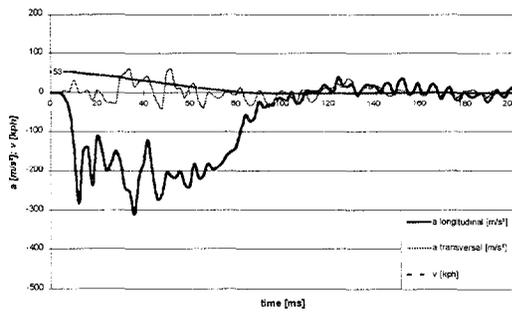
Case 9: Styroporbeton, 95 kph, 100%



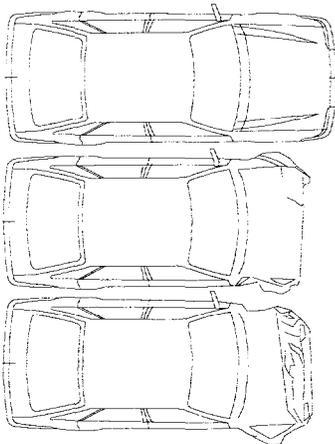
Case 10: Styroporbeton, 97 kph, 50%



Case 11: rigid wall, 52 kph, 100%



Compared deformations



Ford Escort: original state

Ford Escort: 52 kph rigid wall impact

Ford Escort: 95 kph 'Styroporbeton' impact