THE DEVELOPMENT OF A MOBILE DEFORMABLE BARRIER TEST PROCEDURE

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ABSTRACT

Frontal compatibility assessment, including self and partner protection, is a major topic in crash safety testing today. Currently none of the regulatory and consumer test procedures is able to assess the vehicle on vehicle frontal compatibility on the three main aspects; structural interaction, frontal stiffness and compartment strength. It is hypothesized that a test procedure using a Mobile Deformable Barrier (MDB) could be able to assess compatibility on the aspects mentioned above. This paper presents the development of a MDB test trolley for frontal offset testing and its full scale test results.
First, a load sensing trolley was developed. The specifications of the trolley, mass, CoG and inertia properties are based on EU and US vehicle geometry databases. The trolley mass was made adjustable between 1300 kg and 1800 kg, with tunable inertia properties. The trolley was designed to be equipped with the progressive deformable barrier (PDB) as deformable element. The PDB was chosen based on the available test-data and for its stability and its ability to allow a barrier face deformation measurement to evaluate partner protection.
Based on the current PDB test protocol, a test protocol has been developed for the MDB, called MPDB test procedure. A number of vehicles, ranging from small to large, were tested according the MPDB protocol. The closing speed was selected such that comparable initial kinetic energy is involved as in a static PDB test for a mid sized car with mass of 1500 kg. The test results with the full scale MPDB tests were analyzed and compared to test results of static PDB tests with the same vehicle. It was concluded that for small vehicles the severity of the MPDB tests is relatively higher than for larger vehicles.
The MPDB test procedure was shown to be feasible and repeatable. Further investigations into test parameters like trolley mass and test velocity are recommended.

INTRODUCTION

Frontal compatibility assessment is a major topic in crash safety research world-wide. With the changing fleet composition, the differences between cars are increasing in terms of mass, front end stiffness and geometry. Research in the field of compatibility is ongoing world-wide and a general objective of the compatibility research is to ensure that future vehicle developments are more balanced in terms of occupant protection of both striking and struck vehicle, in case of a vehicle-to-vehicle collision.
Methods to assess frontal compatibility should take into account three aspects:

- Structural interaction to ensure an optimal force transfer between the colliding vehicles
- Compartment strength to prevent compartment collapse
- Frontal stiffness to match deformation force levels between the colliding vehicles

Moreover, the occupant's self-protection should not be compromised by increasing the level of partner protection.
Currently none of the regulatory and consumer test procedures is able to assess vehicle to vehicle compatibility on these main aspects. The current procedures are for self-protection assessment and restraint system optimization only, which is not necessarily beneficial for partner protection. Furthermore there is a lack of world-wide harmonization in the current protocols.

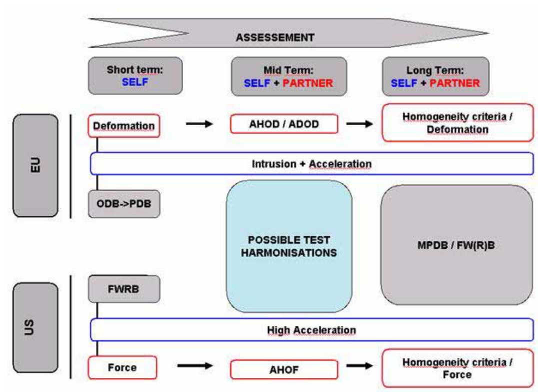


Figure 1. Future outlook for compatibility assessment. AHOD: average height of deformation. ADOD: average depth of deformation. AHOF: average height of fore

A short, mid, and long term view on compatibility assessment, taking also into account the desire for world-wide harmonization acknowledging fleet differences across the world, are presented in Figure 1. For the short term assessment of compatibility two test procedures are under development within EEVC WG15; the FWDB and PDB approaches.
For the long term, a mobile deformable barrier test procedure for compatibility testing is generally seen as the best achievable compromise by both Europe and US, and therefore opens the possibility for harmonization. To support the foreseen long term direction of compatibility assessment, TNO Automotive decided to develop the required load sensing MDB for frontal offset testing. A clear demand has emerged for advanced assessment of car compatibility, based on a more innovative approach. By combining smart measurement technology, in-depth knowledge on compatibility and crash test experience, this projects aims to develop an advanced compatibility test method for assessing frontal compatibility. Partners in this project are TNO, initiator and project-management, UTAC, GME, PSA, Renault, AFL and FTSS.

OBJECTIVES

The goal of this project is to develop a future step in compatibility testing for the long term. This step should take self as well as partner protection into account. The partner protection assessment will be based on the barrier deformation as well as on loadcell wall recordings.
The first objective to achieve this goal is to design and develop a trolley equipped with a high resolution loadcell wall. Second the feasibility and merits of a Moving Deformable Barrier (MDB) in a frontal offset test procedure are assessed.

APPROACH

The initial step in the project was to develop a trolley equipped with a High Resolution Loadcell Wall (HR-LCW) and with mass and inertia properties that are representative for an average European car. The long term approach of a mobile test procedure is based on the hypothesis that the striking vehicle is an average car. Therefore, the trolley with deformable barrier should be representative for a vehicle class in Europe or US. The main specifications of the trolley, such as mass, CoG location and inertia properties are based on European and US vehicle geometry databases [1, 2] and current regulations also using a trolley. Secondly, the developed trolley is calibrated and the LCW is evaluated by performing MDB-to-wall tests.

As final step in this project a series of MPDB-to-car tests are performed with vehicles of different mass as shown in Table 1.

Table 1.
Details of the vehicles used in the MPDB-to-car tests

Vehicle brand and model	Vehicle test mass	MPDB mass	Mass ratio vehicle/trolley
Opel Astra	1403	1486	0.94
Opel Astra	1406	1486	0.95
Citroen C2	1250	1486	0.84
Renault Clio	1313	1486	0.88
Renault Laguna	1853	1486	1.25

The first two tests are performed with identical vehicles to check the test repeatability. The MPDB-to-car results are compared with the results of static PDB tests to study the effect of mobilizing the barrier.

TROLLEY DEVELOPMENT

The trolley dimensions are based on specifications of European vehicles which are presented in Table 2. The inertia properties of the trolley are based on the values given in the NHTSA database for a large range of vehicles [1]. The default mass of the trolley was selected to be 1500±25 kg and the trolley mass was made adjustable between 1300 and 1800 kg for research purposes. All other main dimensions of the trolley were selected to fit in the range found for an average European passenger car.
In addition the MDB trolley mass is in line with the trolley-mass of proposed test procedures for side impact, AE MDB in Europe and the IIHS in the US.

Table 2.
MPDB design specifications (default conditions)

Description	Average EU vehicle [2]	MDB
Total mass [kg]	1200-1700	1500
CG location from front, w.r.t. length [m]	0.43 – 0.47	0.45
Vehicle front to front axle distance H [m]	0.720 – 0.980	0.900
Vehicle front to CG distance I [m]	1.700 – 2.100	1.900
Vehicle front to rear axle distance J [m]	3.200 – 3.700	3.500
Overall length K [m]	3.800 – 4.700	4.250
CG height L [m]	0.560 – 0.640	0.600
Axle height M [m]	0.270 – 0.290	0.280
Wheel base [m]	2.450 – 2.750	2.600
Mass front axle [kg]	710 – 990	900
Mass rear axle [kg]	465 -735	600

Deformable barrier
The trolley was designed to be equipped with a deformable element. In this study the progressive deformable barrier (PDB) was used as a deformable element for its stability and its ability to allow a barrier face deformation measurement in order to evaluate the potential aggressiveness of cars.

Force measurement
For advanced assessment criteria the feasibility and potential of additional force measurements in MDB tests is evaluated in this project. The trolley is equipped with a light weight high resolution strain gauge loadcell wall (HR-LCW) behind the deformable element. In total 48 strain gauge loadcells of 125x125 mm are mounted in 6 rows and 8 columns to the front of the trolley. The HR-LCW, developed by FTSS, is equipped with a built-in data-acquisition system so that the trolley is a stand alone system. In addition it is possible to mount the HR-LCW to the right or left hand side of the trolley to be able to test LHD and RHD vehicles. The final trolley design with HR-LCW and PDB barrier is shown in Figure 2.

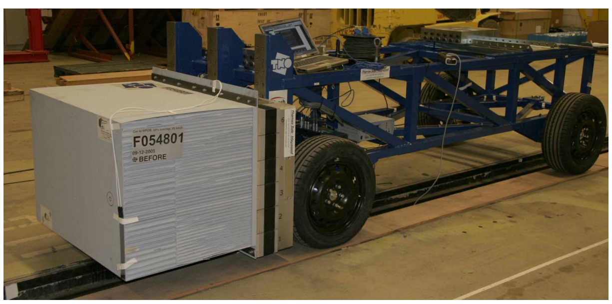


Figure 2. Final design of the MPDB with HR-LCW and PDB barrier

CALIBRATION TESTS

After the development of the trolley a calibration test was performed with the PDB as deformable element mounted to the trolley face. The trolley was driven into a rigid wall at a velocity of 45 km/h at perpendicular impact angle shown in Figure 3.

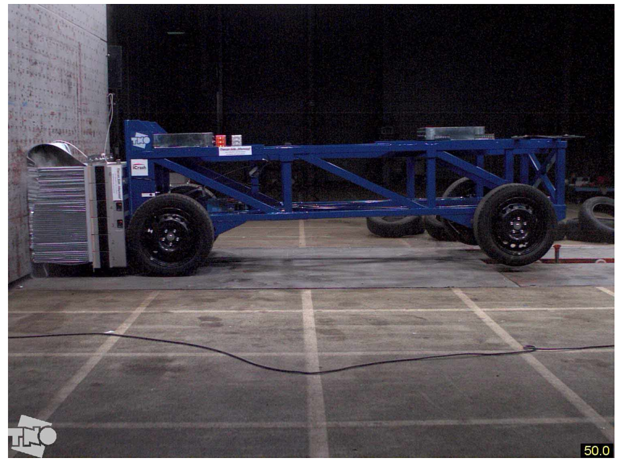


Figure 3. MPDB calibration test result

As a first evaluation of the HR-LCW the total recorded force, the summation of the 48 loadcells, and the trolley mass times acceleration are compared and presented in Figure 4. The trolley acceleration was measured in the trolley CoG.
In general, the curves of the acceleration and force measurements show a good correlation. The summation of the load cell wall force results in a lower total force with a maximum difference smaller than ~8%. The slight difference is most probably caused by yaw and pitch of the trolley during impact, but most important the trolley sustained the test without any problems.

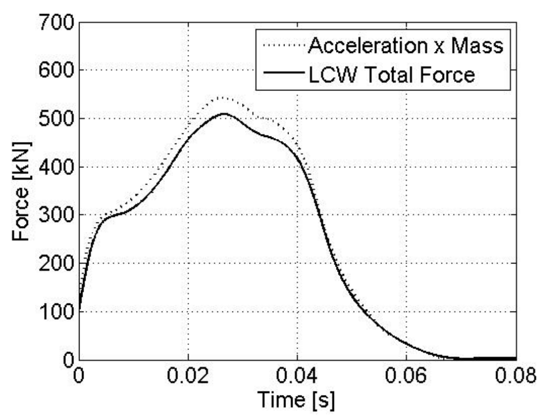


Figure 4. Force vs time of the calibration test

Secondly the LCW of the trolley was further evaluated by running the trolley into a rigid wall twice at 35 km/h. At one of the two tests a rigid block of 250x250x100 mm was mounted on the rigid wall and aligned with the 4 middle loadcells, see Figure 5.

Figure 5. Rigid wall with a square block mounted on it

In these tests the trolley mass was set to 1500 kg and the trolley was equipped with a barrier face of 1000x700x400 mm honeycomb with a constant stiffness between 0.34 and 0.40 MPa. Again the total recorded force by the loadcell wall is compared with the trolley mass times trolley acceleration for both tests, shown in Figure 6 and Figure 7.
The acceleration times mass and the total recorded force again show a good correlation. Although the deformable face was made from material with a constant stiffness, the total force is increasing after reaching the theoretical plateau force between 5 and 10 ms. Air trapped in the barrier causes an increase in stiffness when the barrier deforms. It is noted that air locking or air inclusion is strongly related to the selected test conditions (full overlap, rigid wall).

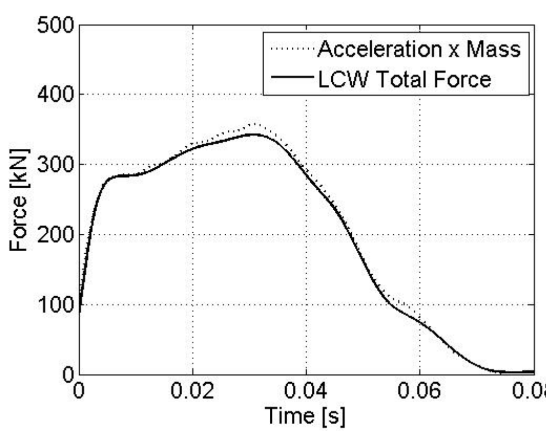


Figure 6. Trolley into the flat rigid wall

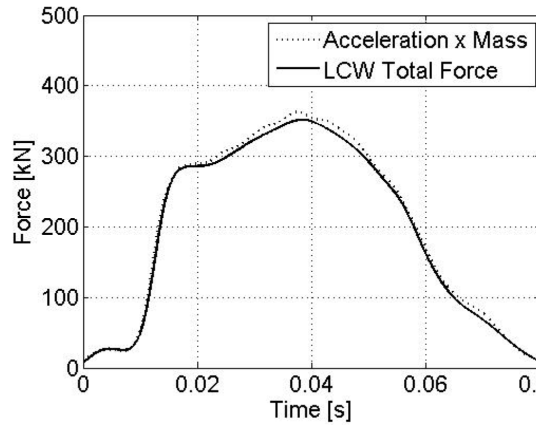


Figure 7. Trolley into flat wall with the rigid block

The force versus time measurements for each individual loadcell for the two tests is given in Figure 8. The rigid block mounted on the wall was aligned with loadcells D3, D4, E3 and E4. These loadcells clearly show a different recording when compared to the surrounding loadcells were for the test with the block the force build up was post-poned. Because of a slight misalignment and some spread of loads due to the back plate at the back of the honeycomb material, the loadcells in the column next to the block also observe some loading at the start of the measurement (e.g. see column F, row 3 and 4). The lowest row of loadcells was not fully covered with deformable material and hence equivalent lower loads are recorded by row 1.

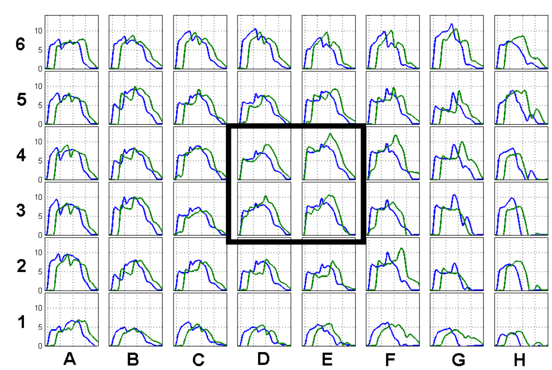
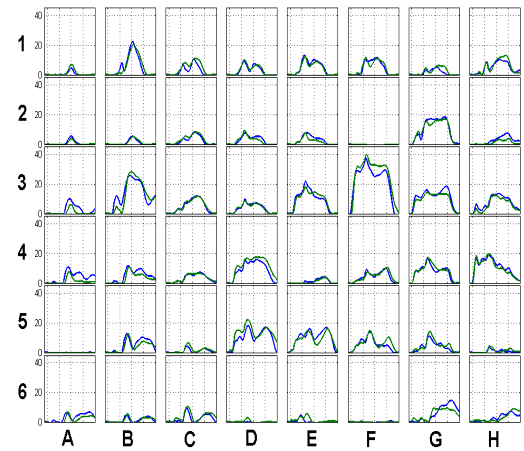
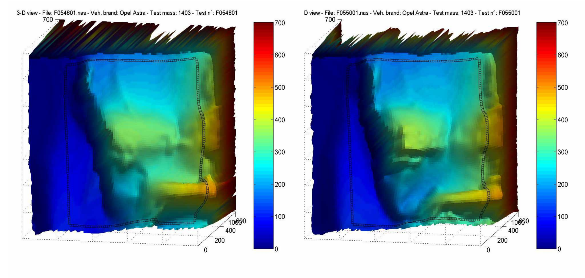


Figure 8. Forces (kN) in time for all loadcells, frame indicates the rigid block at the rigid wall

MPDB-TO-CAR TESTS

Following the good results of the calibration tests the project continued by performing MPDB-to-car tests. The test specifications for the MPDB-to-car tests are chosen in such a way that an equal amount of initial





	Test 1	Test 2
ADOD (X)	242.2 mm	231.8 mm
AHOD (Z)	492 mm	493 mm

Figure 9. Load cell wall recordings and barrier deformations of both Astra-to-MPDB tests

kinetic energy is put into the test compared to a static PDB test for a car of mass ratio 1, using a 1500 kg trolley. This results in a closing speed of 90 km/h (both car and MPDB traveling at 45 km/h). The offset and ground clearance are chosen equally to the static PDB test at respectively 50% and 150mm. Other test specifications like seat position, dummy positioning are according to the PDB protocol as well.

Repeatability

Two MPDB-to-car tests were performed with an Opel Astra to investigate the practicality and repeatability of the draft test procedure.

The HR-LCW recordings show a good correlation between the two MPDB-to-Astra tests on individual load cell level as can be seen in Figure 9.

Furthermore the barrier deformation, also shown in Figure 9, shows a very good resemblance between the two tests.

Based on these results it is concluded that the test method is shown to be feasible and repeatable.

MPDB-to-vehicle test

In addition to the repeatability tests vehicles with different mass ratios compared to the trolley mass of 1500 kg were tested, see Table 1. The effect of mass and car design of the vehicles in terms of acceleration levels is examined.

The vehicle accelerations in **Figure 10**, show that the test severity was higher for the smaller vehicles compared to the larger vehicle based on the acceleration levels.

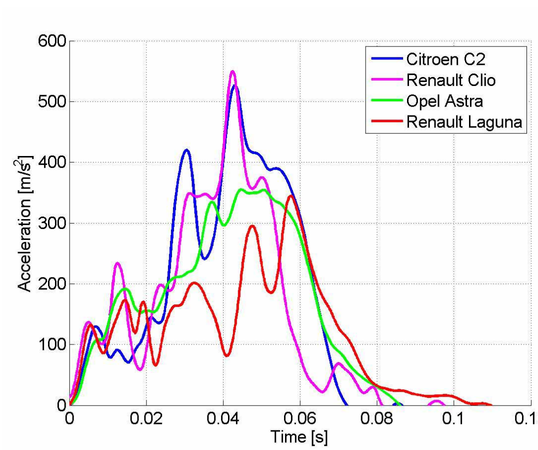


Figure 10. Vehicle accelerations for all tested vehicles

The trolley acceleration profiles in Figure 11 show that all vehicles deform the barrier in a different manner. For instance the Citroen C2 penetrates the barrier at a small contact area in the beginning of the crash resulting in a lower acceleration level at the beginning of the pulse. On the other hand the Renault Laguna and Clio have a homogeneous front end shown as a constantly increasing acceleration signal right from the start of the crash.

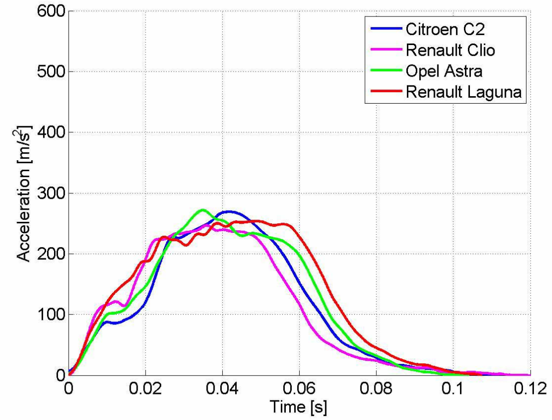


Figure 11. Trolley acceleration for all tested vehicles

When two vehicles collide with a mass ratio other than one there will be a post-crash velocity. This effect is also seen in the post crash velocity of the trolley. For a mass ratio of 1 the post crash velocity will be equal with the rebound vehicle velocity in case of a static PDB tests. Figure 12 shows the velocity profile of the trolley for all tested vehicles. The heaviest vehicle, being the Renault Laguna, forces the trolley in a negative post-crash trolley velocity due to the higher mass of the Laguna compared to the trolley mass. In other words, the higher the mass the larger the delta V of the trolley. In addition the delta V increases for vehicles lighter than 1500 kg.

This implies that a moving barrier test is a far more realistic representation of a car-to-car crash than a fixed barrier test.

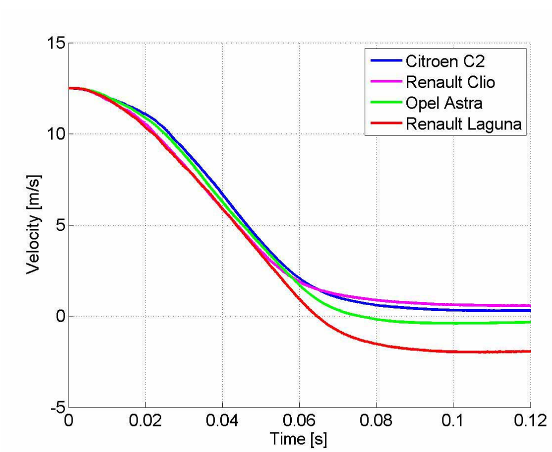


Figure 12. Trolley velocity for all tested vehicles

Moving PDB versus fixed PDB

To get a full understanding of the effect of mobilizing the barrier the energy levels of the MPDB are compared with fixed PDB tests. As mentioned before, the test velocities of the MPDB tests were chosen in such a way that the level of kinetic energy was equal for both MPDB and PDB tests for the Opel Astra with mass ratio 1. The kinetic energy that is put into each test is illustrated in Figure 13. For the C2 and Clio with a mass ratio smaller than 1 more energy is involved in the MPDB test compared to the PDB test. For the Laguna with a mass ratio over 1 less energy is involved.

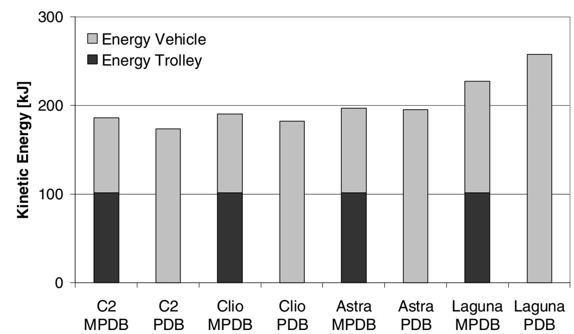


Figure 13. Kinetic energy comparison for all tested vehicles

For both PDB and MPDB the kinetic energy vs. mass is shown in Figure 14. The difference in the slope of the energy-mass curve for the MPDB and the PDB is a result of a partly fixed amount of the initial kinetic energy is by the constant trolley mass and velocity. In other words the severity of the crash in terms of EES is more inline over the mass range than for a fixed barrier test. However, more research is needed to find the most appropriate trolley mass and test velocity so that the test procedure will improve partner protection without decreasing the self-protection, in particular for heavy vehicles.

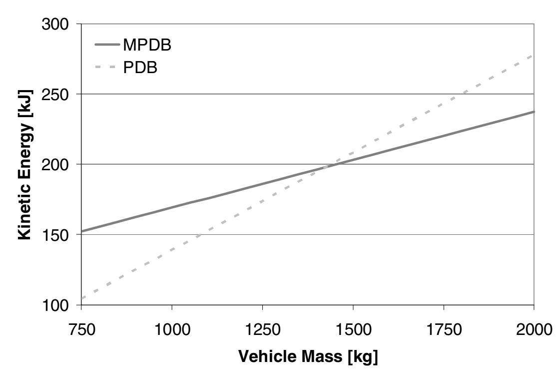


Figure 14. Kinetic energy vs mass for both PDB and MPDB

Finally for all vehicles the barrier average deformations for both MPDB and PDB tests are compared. Again the same effect regarding

mobilization of the barrier is demonstrated inline with the differences in initial kinetic energy and in delta V.
For the Citroen C2 and Renault Clio the deformations are higher in the MPDB tests due to the higher severity and energy level.

Table 3 – Barrier deformations of both the MPDB and PDB tests for the different vehicles

		PDB	MPDB
Citroen C2	*ADOD (X) [mm]*	204	232
	AHOD (Z) [mm]	458	466
Renault Clio	*ADOD (X) [mm]*	147	195
	AHOD (Z) [mm]	417	438
Opel Astra	*ADOD (X) [mm]*	228	232
	AHOD (Z) [mm]	480	493
Renault Laguna	*ADOD (X) [mm]*	294	273
	AHOD (Z) [mm]	492	510

CONCLUSIONS

Within the project a HR-LCW trolley was successfully developed to be used for frontal offset testing. The trolley mass and inertia properties can be altered to find the optimal set-up for improving partner and self-protection without decreasing the current level of self protection.
The test results show that the severity for small cars is increased due to a higher initial kinetic energy level. This resulted in higher acceleration levels and larger barrier deformations. For the Opel Astra with mass ratio ~1 it was shown that the severity was in-line with the fixed PDB procedure. The heavier Renault Laguna showed a decrease in acceleration level and barrier deformation which means that the severity of the crash is less for vehicles with mass ratio > 1.
The MPDB test protocol has shown to be feasible and a far better representation of a car-to-car collision than static barrier tests. More-over the MPDB protocol has the potential of assessing all compatibility issues without decreasing the current level of self-protection.

RECOMMENDATIONS

As a final step in this initial project a MPDB and PDB test using a vehicle with a mass ratio >> 1 is scheduled.
Further work is ongoing to develop an advanced assessment protocol using HR-LCW measurement, barrier deformations and trolley accelerations.
The final test specifications of a MPDB protocol, such as trolley mass and closing speed, must be defined on accidentology studies and the prediction of trends in vehicle design and masses.

REFERENCES

[1] http://www-nrd.nhtsa.dot.gov/database/nrd-11/veh_db.html

[2] T. Martin, "Car geometrical/ structural database and analysis of car to car geometric compatibility" UTAC VC-Compat WP1-D9v1.1, June 2004.