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SEVENTH FRAMEWORK PROGRAMME

FIMCAR
XII – Influence on Other Impact Types

FIMCAR
frontal impact and compatibility assessment research

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CONTENT

EXECUTIVE SUMMARY

The objective of this deliverable is to describe the expected influence of the candidate test procedures developed in FIMCAR for frontal impact on other impact types. The other impact types of primary interest are front-to-side impacts, collisions with road restraint systems (e.g. guardrails), and heavy goods vehicle impacts. These collision types were chosen as they involve structures that can be adapted to improve safety. Collisions with vulnerable road users (VRU) were not explicitly investigated in FIMCAR. It is expected that the vehicle structures of interest in FIMCAR can be designed into a VRU friendly shell.

Information used for this deliverable comes from simulations and car-to-car crash tests conducted in FIMCAR or review of previous research. Three test configurations (full width, offset, and moving deformable barriers) were the input to the FIMCAR selection process. There are three different types of offset tests and two different full width tests. During the project test procedures could be divided into three groups that provide different influences or outcomes on vehicle designs:

1. The ODB barrier provides a method to assess part of the vehicles energy absorption capabilities and compartment test in one test
2. The FWRB and FWDB have similar capabilities to control structural alignment, further assess energy absorption capabilities, and promote the improvements in the occupant restraint system for high deceleration impacts.
3. The PDB and MPDB can be used to promote better load spreading in the vehicle structures, in addition to assessing energy absorption and occupant compartment strength in an offset configuration.

The consortium selected the ODB and FWDB as the two best candidates for short term application in international rulemaking. The review of how all candidates would affect vehicle performance in other impacts (beside front-to-front vehicle or frontal impacts with fixed obstacles) however is reported in this deliverable to support the benefit analysis reported in FIMCAR. The grouping presented above is used to discuss all five test candidates using similarities between certain tests and thereby simplify the discussion.

The common theme is the potential to structurally align vehicle components with the opposing structures. In some cases, like truck RUPs (Rear Underrun Protection), requirements of the collision partner are not ideal for passenger vehicle designs. Introduction of performance requirements that harmonise geometric alignment will support future harmonisation of crashworthiness designs, independent of passenger cars. International harmonisation of concepts like the common interaction zone will improve future vehicle and infrastructure safety performance.

The final assessment approach that was developed within the FIMCAR project duration does not have a horizontal load spreading assessment. The FWDB was not suitable for this procedure and a validated (M)PDB deformation metric for load spreading in the vertical and horizontal directions is still in the final stages of development. Preferably, a load spreading metric could be introduced into a future offset test like the (M)PDB. The load spreading metric would address many impact conditions identified in impacts with vehicle sides, HGVs, and roadside equipment.

Stiffness issues with current vehicle designs are not expected to be affected negatively by the FIMCAR approach. The combination of a FWDB and ODB will create a balanced frontal

stiffness that cannot be expected to be softer than vehicle side structures, nor stiffer than HGV frames. Current compartment strength needs to be maintained and the frontal stiffness can be tuned to appropriate levels through the combined full width and offset test requirements.

The current test candidates and final assessment procedure selected by FIMCAR do not have any obvious negative implications for side impacts, HGV impacts, nor impacts with road equipment. The worst case scenario is that the introduction of a FW metric with minimum load requirements in Rows 3&4 can lead to sub-optimisation and worsened horizontal load spreading. This risk is small and the selection of a FWDB will likely mitigate this side effect. The deformable barrier dampens the peak loads and introduces a need to have larger contact surfaces to generate sufficient loads in the assessment area.

The current assessment approach in FIMCAR may introduce limited improvements for the investigated collisions, but it is expected that the harmonisation of interaction areas of HGV and road side equipment will allow to a convergence to compatible structural designs in the road and traffic network.

1 INTRODUCTION

1.1 FIMCAR Project

For the real life assessment of vehicle safety in frontal collisions the compatibility (described by the self and partner-protection level) between the opponents is crucial. Although compatibility has been analysed worldwide for years, no final assessment approach was defined. Taking into account the EEVC WG15 and the FP5 VC-COMPAT project activities, two test approaches are the most promising candidates for the assessment of compatibility. Both are composed of an off-set and a full overlap test procedure. However, no final decision was taken. In addition, another procedure (tests with a moving deformable barrier) is under discussion in today's research programmes.

Within the FIMCAR project, different off-set, full overlap and MDB test procedures will be analysed to be able to propose a compatibility assessment approach, which will be accepted by a majority of the involved industry and research organisations The development work will be accompanied by harmonisation activities to include research results from outside the consortium and to disseminate the project results taking into account recent GRSP activities on ECE R94, Euro NCAP etc.

The FIMCAR project is organised in six different RTD work packages. Work package 1 (Accident and Cost Benefit Analysis) and Work Package 5 (Numerical Simulation) are supporting activities for WP2 (Offset Test Procedure), WP3 (Full Overlap Test Procedure) and WP4 (MDB Test Procedure). Work Package 6 (Synthesis of the Assessment Methods) gathers the results of WP1 – WP5 and combines them with car-to-car testing results in order to define an approach for frontal impact and compatibility assessment.

1.2 Objective of this Deliverable

The objective of this deliverable is to describe the expected influence of the candidate test procedures developed in FIMCAR for frontal impact on other impact types. The other impact types of primary interest are front-to-side impacts, collisions with road restraint systems (e.g. guardrails), collisions with objects and heavy goods vehicle impacts. Collisions with vulnerable road users were not explicitly investigated in FIMCAR. It is expected that the vehicle structures of interest in FIMCAR are designed into a VRU friendly shell.

Information used for this deliverable comes from simulations and car-to-car crash tests conducted in FIMCAR or review of previous research.

1.3 Structure of this Deliverable

This deliverable starts with a brief review of the test candidates discussed within in FIMCAR and the rational for selecting the FIMCAR assessment approach. This chapter is followed by a discussion of the expected design changes of vehicles for the different assessment procedures. Based on these findings the implications for the struck car in side impact collisions, the implications for HGV (Heavy Goods Vehicles) impacts, especially rear and front underrun protection devices, and the implications for impacts against safety equipment of infrastructure are analysed. Finally all findings are discussed as a whole.

2 REVIEW OF PRIMARY TEST CANDIDATES

2.1 Introduction

Three test configurations (full width, offset, and moving deformable barriers) were the input to the FIMCAR selection process. There were 2 different offset tests, 2 different full width tests, and 1 MPDB. During the project test procedures could be divided into 3 groups that provide different influences or outcomes on vehicle designs:

1. The ODB barrier provides a method to assess part of the vehicles energy absorption capabilities and compartment test in one test
2. The FWRB and FWDB have similar capabilities to control structural alignment, further assess energy absorption capabilities, and promote the improvements in the occupant restraint system for high deceleration impacts.
3. The PDB and MPDB can be used to promote better load spreading in the vehicle structures, in addition to assessing energy absorption and occupant compartment strength in an offset configuration.

The final decision process and resulting test procedures of the FIMCAR project are presented in FIMCAR Deliverable D6.3 [Thomson 2013]. The consortium selected the ODB and FWDB as the two best candidates for short term application in international rulemaking. The review of how all candidates would affect vehicle performance in other impacts (beside front-to-front vehicle or frontal impacts with fixed obstacles) however is reported in this deliverable to support the benefit analysis reported in FIMCAR Deliverable D1.2 [Edwards 2013]. The grouping presented above is used to discuss all five test candidates using similarities between certain tests and thereby simplify the discussion. An overview of the three test groups is presented in the following sections.

2.2 Off-set Deformable Barrier Procedure (ODB)

The ODB frontal crash test was developed from 1989-1995 [Thomson 2013], and it simulates the collision of the tested vehicle against another vehicle of similar mass. The main characteristic is the use of a deformable barrier, which was developed by the European Enhanced Vehicle Safety Committee (EEVC). The test consists of a frontal crash where the car impacts the barrier which overlaps of 40% of the driver's side of the vehicle (Figure 2.1). This is the current procedure described in UN-ECE Regulation 94 and European Directive 96/79/EC where the test speed is 56 km/h. From 1996, Euro NCAP [Euro NCAP 2013] adopted this procedure for a European consumer information program with the speed increased up to 64 km/h.

FIMCAR has chosen the ODB test as the main candidate for evaluating the self-protection of the vehicle and ensuring the compartment strength is maintained at current levels. A drawback of the method is that it does not allow for direct measurements of the vehicle structure for compatibility assessment.

Details of the ODB test method with proposed modifications are available in FIMCAR Deliverable D2.2 [Lazaro 2013/1]

Figure 2.2: ODB Test Configuration

2.3 Full Width Rigid/Deformable Barrier Procedure (FWR/DB)

The FWDB is a modification of the standard Full Width Rigid Barrier that has been used for frontal impact protection for several decades. The FWDB and FWRB use the same approach for assessing structural alignment of vehicles using a Load Cell Wall consisting of an array (cell size 125x125) of load cells and both tests promote self-protection for vehicles' occupants in high overlap tests. Although very similar, the FWDB offered some technical advantages over the FWRB and was the final selection. The decision process for FIMCAR is described in FIMCAR Deliverable D6.3 [Thomson 2013]. The FWDB barrier has a 300 mm honeycomb barrier. The honeycomb has two layers, a soft initial layer and a stiff rear layer. The honeycomb helps to damp out the engine contact forces on the wall. The impact speed for the test is proposed to be 50 km/h.

The vehicle structures are assessed with forces summed across the Load Cell Wall rows with the goal to promote structural alignment of primary energy absorbing structures (PEAS) in an vertical area between 406-508 mm (above ground), referred to as a common interaction zone and known as the Part 581 zone in US federal regulations [GPO 2011]. The proposed metric for the FWDB, presented below, requires a minimum force in Rows 3&4 of the Load Cell Wall in the first 40 ms of impact. A similar approach was proposed for the FWRB but with a shorter assessment period and no possibility for assessing loads under Row 3 without a second test.

- Up to time of 40 msec:
  - F4 + F3 ≥ [MIN(200, 0.4F_{T40}) kN
  - F4 ≥ [MIN(100, 0.2F_{T40}) kN
  - F3 ≥ [MIN((100-LR), (0.2F_{T40}-LR))] where:
    - F_{T40} = Maximum of total LCW force up to time of 40 msec
    - Limit Reduction (LR) = [F2-70] kN and 0 kN ≤ LR ≤ 50* kN

*Note values for Limit Reduction to be confirmed taking into account differences in test speed

Because of the similarities in the test evaluation, analyses of a full width test group (FWRB and FWDB) are presented in the following chapters. More details of the FW tests (Figure 2.3) and their development are available in FIMCAR Deliverable 3.2 [Adolph 2013].

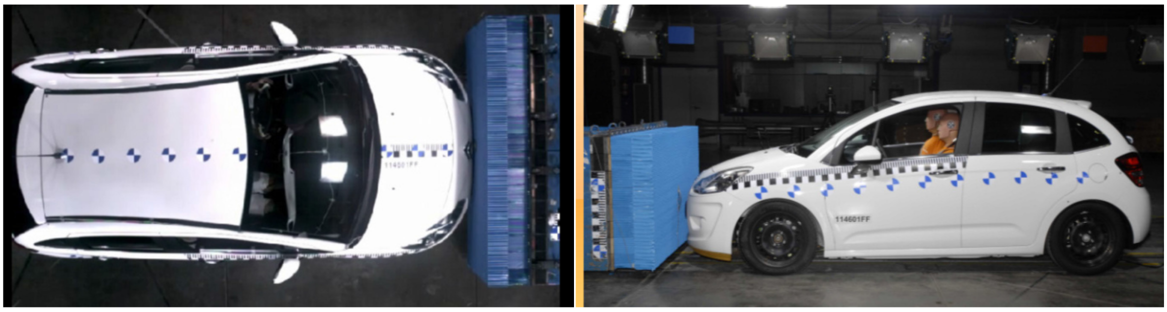

Figure 2.3: FWDB Test Configuration

2.4 Progressive Deformable Barrier / Moving Progressive Deformable Barrier (M)PDB

An alternative to the ODB fixed barrier testing is the (M)PDB approach that was part of the FIMCAR research activities in Work Packages 2 and 4. Both tests incorporate the deformable barrier face developed in France and are evaluated in FIMCAR Deliverables D2.1, D2.2 and D4.2 [Lazaro 2013/1, Lazaro 2013/1, Versmissen 2013]. The test parameters are presented in *Table 1*. As shown in Figure 2.4*:* the honeycomb barrier can be mounted on a fixed or moving barrier of fixed weight.

Table 1: Test Characteristics for (M)PDB.

PDB	MPDB
Deformable barrier: PDB v8 Vehicle speed: 50 km/h Overlap: 50% Angle: 0 degrees	Trolley mass: 1500kg Deformable barrier: PDB v8 Trolley speed: 50 km/h Vehicle speed: 50 km/h Overlap: 50% Angle: 0 degrees

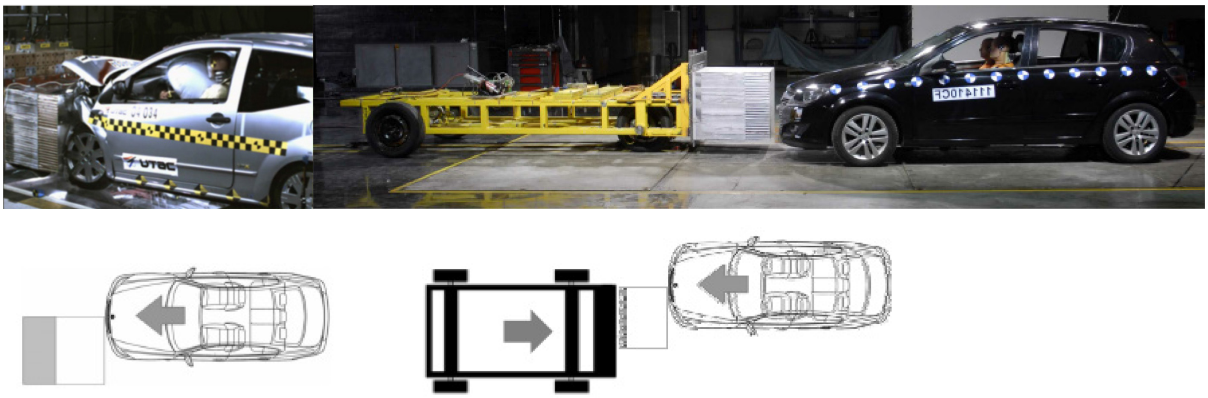

Figure 2.4: Test Configuration PDB (left) MPDB (right).

The PDB barrier honeycomb crush strength is progressively stiffer and is intended to represent an average car. The deformation pattern of the barrier after the test is scanned and used to evaluate the vehicle's compatibility performance for both the PDB and (M)PDB tests. The assessment process for both tests is thus identical. The main difference between the PDB and MPDB test is the delta-v dependency introduced by the moving trolley. Vehicles lighter than the trolley are subjected to a higher test severity than the equivalent PDB test speed and vice-versa.

Assessment of the (M)PDB barrier deformations are under development and are recommended for further development after FIMCAR. The 3D scan information after a test is used to discriminate between vehicles with homogeneous deformations Figure 2.5 (left) or local stiffnesses, Figure 2.5 (right).

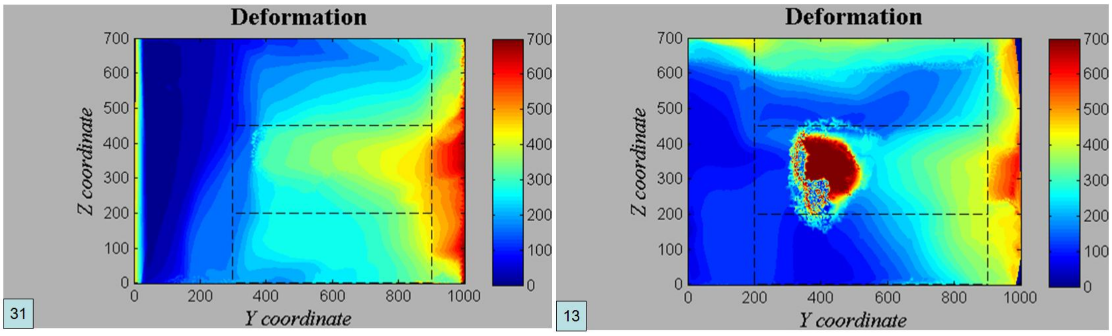

Figure 2.5: PDB Scan Examples.

3 EXPECTED DESIGN CHANGES FOR VEHICLES

The combination of the full width and off-set test procedure has two main advantages:

1) it creates two different structural loading conditions that are representative of the majority of real world frontal crashes
2) it produces an assessment environment with different restraint system loads and sensing requirements to avoid single point optimisation

The introduction of any new frontal impact test procedures must produce modifications to the vehicle fleet to improve crashworthiness performance and thereby improve occupant safety. A positive benefit to society is needed and FIMCAR Deliverable D1.2 [Edwards 2013] describes the expected outcomes for three options:

- No change (only the existing ODB)
- Addition of a FW test to the existing ODB
- Adding the FW test and replacing the ODB with a (M)PDB

These options mirror the grouping of test candidates used in this deliverable.

FIMCAR has developed a list of vehicle characteristics which are desirable for good crashworthiness performance in frontal impacts (seen in Figure 3.1) and also identifies which test methods are most suitable to assess and control them. The remainder of this chapter will discuss the vehicle design changes expected from implementation of the different test methods. This information will then be used in the subsequent chapters to describe the likely consequences of the new frontal impact requirements investigated by FIMCAR on other impact types.

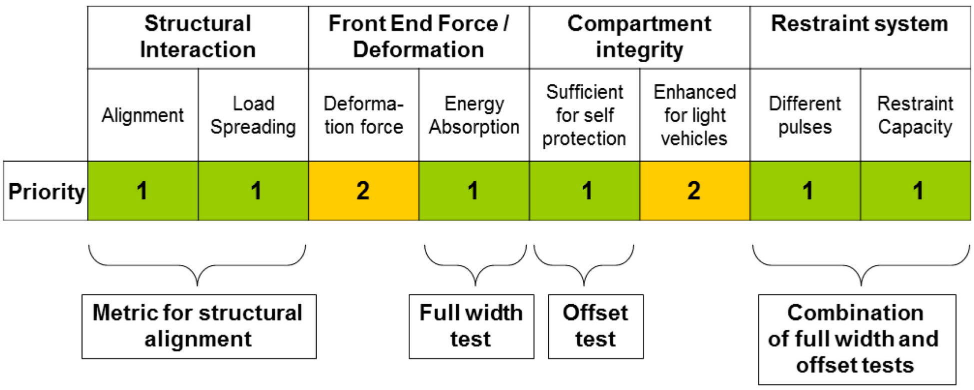

Figure 3.1: FIMCAR Compatibility Characteristics and Priorities.

3.1 Off-set Deformable Barrier Procedure (ODB)

The ODB test procedure selected by FIMCAR will probably result in no significant design changes in vehicles over those that have already been observed because it has already been in place for many years. The main contribution of the ODB is the promotion of a strong and stable occupant compartment in an offset impact condition. The concentrated loading on one side of the vehicle promotes a strong foot well and A-pillar/sill combination to resist intrusion. The test also requires the vehicle structure to absorb its own kinetic energy (minus that absorbed in the barrier) in the offset configuration. The addition of a requirement for A-pillar deformations to be less than 50 mm will guarantee sufficiently strong occupant compartments by enforcing the stability of the forward occupant cell. There is no explicit requirement for compartment stability in the current UN-ECE Regulation 94 that ensures a minimum level for Europe. Euro NCAP tests tend to promote stronger compartment designs than R94 but this is not a mandatory test.

The ODB test procedure encourages vehicles to have a stiff compartment which is useful in in car-to-car accidents and car-to-objects accidents. However, impacts against narrow objects at the corner or in the middle of the vehicle will not be addressed with the ODB test procedure. The ODB test procedure is the state-of-the-art for self-protection in single vehicle accidents and statistics show it is the same level for light and heavy vehicles [Chauvel 2009, Pastor 2009/1, Pastor 2009/2]. In contrast, heavy vehicles can be more aggressive in car-to-car collisions when they collide with lighter vehicles. A mass difference in car-to-car collisions creates a higher delta-v in the lighter collision partner. Older vehicle generations have also exhibited issues related to the overcrushing of lighter vehicles and resulting problems with compartment integrity due to a vehicle fleet where frontal forces are proportional to the vehicle mass [Faerber 2007]. The latter problem was not identified in the latest accident analysis in FIMCAR Deliverable D1.1 [Thompson 2013/1]

3.2 Full Width Rigid/Deformable Barrier Procedure (FW)

The FW test procedures fulfil two objectives in the FIMCAR project. They create a requirement for structural alignment that has shown to be beneficial in car-to-car collisions. The structures located 406-508 mm above the ground will be required to exceed a threshold force in the first stages of the collision and thus reduce the risk for over/underride. Some basic requirements for vertical load spreading are included because the structures need to provide a certain level of force distribution in Rows 3 and 4 with possible extension to Row 2.

The FW test procedures both create a stiff pulse that will require occupant restraint systems to be improved compared to vehicles designed only for the ODB. This high pulse test also promotes a change in the frontal force level designs so that the ride down accelerations will be suitable for the injury criteria selected. Without the FW, smaller vehicles can exploit the current ODB and have stiffer front structures than desirable, causing short ride down distances and high acceleration loads on the occupant.

3.3 (Moving) Progressive Deformable Barrier Procedure (M)PDB

Although not part of the final selection of test procedures in FIMCAR, the (M)PDB capabilities are presented for information and potential development.

The (M)PDB provides an opportunity to modify the test severity of a vehicle depending on its mass. The PDB test results to date have indicated that the test is more severe for lighter vehicles than heavy vehicles in most cases. In a MPDB test, vehicles lighter than the trolley would experience a more severe crash than if the barrier was fixed. Conversely, vehicles heavier than the trolley would experience a less severe crash severity than if the barrier was fixed. Both of these characteristics are desirable for lighter vehicles, but the consortium ranked this issue as Priority 2 (see Figure 3.1) and severity reference levels for the different vehicle masses have not been resolved. The selection of different test speeds and trolley reference masses was investigated in FIMCAR and the information presented in Table 1 reflects the current status for the procedures.

In addition to the potential to offer the test severity for a vehicle depending on its mass, the (M)PDB offers barrier deformation metrics from the test to promote better load spreading in vehicle designs. The test data from FIMCAR shows that the PDB deformations can be used to identify horizontal load spreading issues in a vehicle and future development could be used to establish thresholds for vehicle performance. Vertical load spreading could also use a similar approach. The advantages of vertical and horizontal load spreading have also been identified in previous research [Faerber 2007, Thompson 2013/1]. Vertical load spreading promotes more robust structures to resist over/underrun behaviour and horizontal load spreading promotes designs that resist fork effect and small overlap issues.

4 IMPLICATIONS FOR SIDE IMPACT

4.1 Review of Current Status of Side Impact

Side impact issues have been recently reviewed by EEVC WG 13 [EEVC 2010]. They conducted a review of injury issues observed in accident analysis, characteristics of different test methods, and cost benefit analyses of different solutions.

Current side impact protection in Europe is controlled by a moving deformable barrier (MDB) test in regulation (UNECE R95 and 96/27/EC) and both MDB and pole impact tests in consumer rating programmes (Euro NCAP). The MDB test device is supposed to represent the force/deflection characteristics of a vehicle front. However, when the properties of the barrier were reviewed by the EEVC group, they were not found to be representative of current vehicles and hence a new advanced energy absorbing barrier was developed recently to address this issue. Critics of the MDB question the relatively even distribution of forces on the side of the struck vehicle which may not be true in a real car-side impact. The pole impact test addresses single vehicle collisions when vehicles depart the roadway and slide sideways into vertical structures. Both tests promote adequate padding and airbag protection systems for occupants and ensuring sufficient structures in the door, sill, and roof to resist intruding objects.

Two recent studies that have investigated side impact compatibility in recent years were found in the literature. These are a study performed by Honda [Takizawa 2009] and one by the EC funded FP6 project APROSYS [Thompson 2007]. Both studies used the following approach:

- To investigate the effect of modifying the characteristics of a Mobile Deformable Barrier (MDB) such as geometry, stiffness, mass, velocity, on the protection offered by a side impacted car.
- To investigate the effect of modifying the characteristics of the frontal structures of an impacting car on the protection offered by a side impacted car.

The APROSYS study was based on FE modelling only whereas the Honda study was based on FE modelling and full-scale testing. The findings from both studies were similar. They are summarised below:

- MDB impacts
    - The main conclusions from the barrier-to-car tests / simulations were that reduction of loading of the target vehicle in alignment with the occupant's upper body in combination with increased structural interaction with the target vehicle's sill were the most important factors relating to an improvement in side impact compatibility. This indicated that matching of the bullet vehicle's vertical stiffness distribution to the target vehicle's stiffness is important, as lower loads are required at the less stiff upper levels of the target vehicle and more load is required at the stiffer sill level.
- Car-to-car impacts
    - The main conclusion from the car-to-car impacts was that structural interaction between bullet and target vehicle structures is important in reducing the risk of injury, whilst stiffness matching between these structures is important to prevent overloading of the target vehicle's structures, in particular the B-pillar by the bumper crossbeam and the sill by the subframe load path.

From these conclusions some guidelines can be derived for changes to a car's front-end structures related to its compatibility in side impact:

- High frontal structures should be discouraged to reduce loading of the impacted car's side in alignment with the dummy.
- Homogeneous structures which interact with more of the impacted car's side structures should be encouraged provided they are not so stiff that the impacting overload the side structures (sill and B-pillar).

4.2 Changes Expected from FWDB

The FWDB currently is designed to promote a front structure that is not too stiff in a car-to-barrier impact. The deformations of a car front during a car-to-car side impact are typically much less than a frontal car-to-barrier impact indicating. The relative stiffness of front structures to side structures was observed in the study by Takizawa et. al. [Takizawa 2007]. Their study showed that reducing the longitudinal stiffness from the standard vehicle reduced the side impact intrusion. However their study did not confirm that the new longitudinal design was still suitable for frontal impact safety. The main influence the FWDB will have on side impacts is the influence of force distributions within the vehicle front end. The common interaction zone addressed by the current metric in Rows 3&4 is quite high relative to the sill in a passenger car. However, the current proposed side barrier AEMDB produces forces particularly between 350 mm and 550 mm (see Figure 4.1) which is aligned with the FW metric in Rows 3&4.

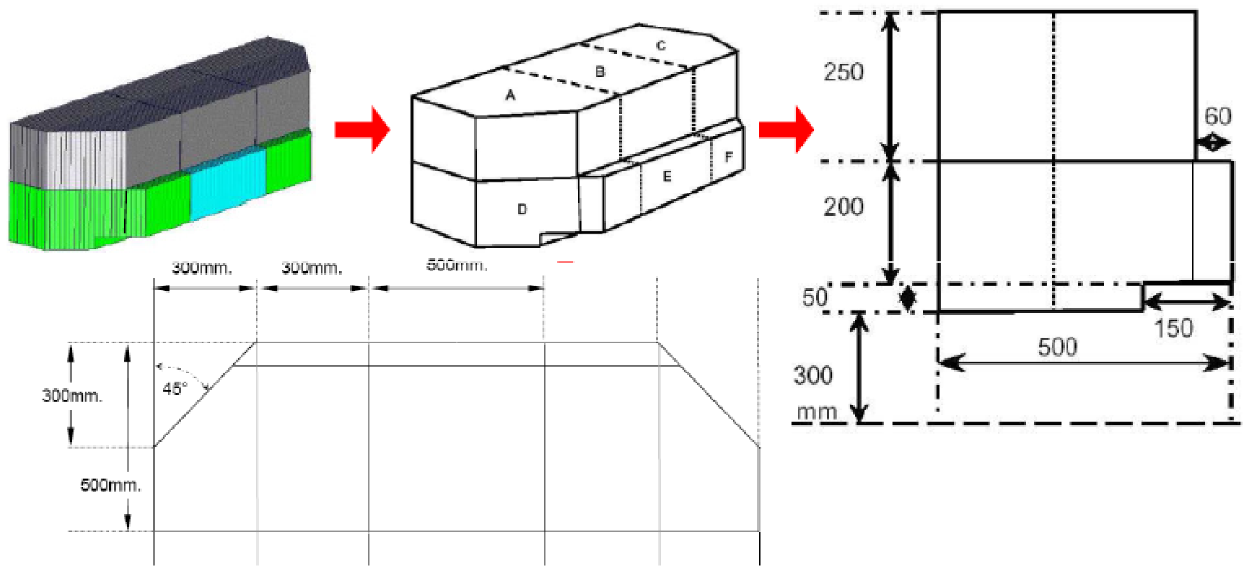

Figure 4.1: Geometry of the AEMDB [EEVC 2010]

Simulation studies [O'Brien 2010] identified the main benefits of different load spreading strategies and summarised in *Table 2* .The main benefits coming from a vehicle designed with the FWDB would be to include some vertical load spreading so that loads are distributed from Row 2 to Row 4. Side impact crash tests were conducted in FIMCAR that highlighted the benefits of having lower load path forward of the front tires [Sandqvist 2013] near the front of the vehicle. Tests and simulations were conducted with a vehicle modified by removing the lower structures identified in Figure 4.2. The sill of the struck vehicle was not contacted directly in any of the tests or simulations, but improved vertical load spreading distributed the deformation over the vehicle side and reduced maximum door intrusion.

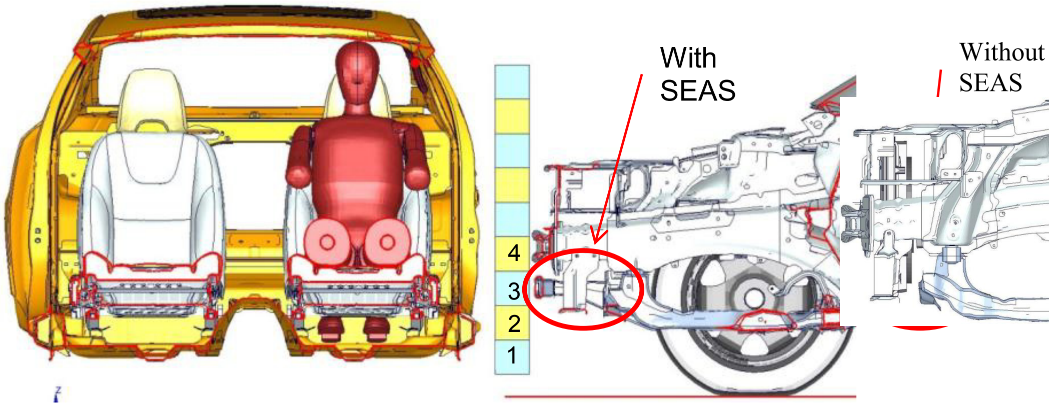

Figure 4.2: Pre-crash alignment compared to load cell wall.

Table 2: Summary of vehicle loading strategies in side impacts [O'Brien 2010].

Horizontally homogeneous front-end	→ Effective when loads are transferred to the struck vehicle's A- and C-pillars. → May be detrimental when loads are focussed on a weak B-pillar.
Vertically homogeneous front-end	→ Effective when loads are transferred to the struck vehicle's sill and floor.
Stiffened door crossbeams	→ Reduce deformation but are not complimentary with front-end homogeneity.
Stiffened B-pillar	→ Complimentary with a horizontally homogeneous front-end structure.
Stiffened sill	→ Complimentary with a vertically homogeneous front-end structure.
Most effective changes to basis models	→ Similar changes are effective for front-to-front and front-to-side collisions. → Stiffening of B-pillar and sill results in complimentary improvements.

The current FWDB metric includes a credit for loads in Row 2 under certain conditions but the FWRB requires an additional test (currently not available) to reliably assess the structures shown in Figure 4.2. The type of test that has been proposed to complement the FWRB is the Over Ride Barrier (ORB) being evaluated in the US [Patel 2009]. FIMCAR numerical simulation analysis shows that meeting the current ORB criteria does not necessarily require well performing cars [Adolph 2013, Stein 2013].

The results from FIMCAR agree with the study by Takizawa et al. [Takizawa 2007]. The combination of FE simulations with different structural concepts, as well as physical tests showed that the best occupant response was encountered when good vertical and horizontal load spreading was achieved. When only one load path (longitudinals) was implemented in the striking vehicle, it was better to keep the structures as low as possible.

Horizontal load spreading is identified in FIMCAR as a desirable vehicle characteristic (Figure 3.1) and load spreading was shown to improve partner protection, particularly when more than one vertical side structure is contacted. The use of a single load path at bumper level can produce aggressive behaviour in front-to-side impacts if weak horizontal load spreading is not complemented with vertical load spreading and load application into the floor of the struck car. The crash tests showed how the cross beam can wrap around the B-pillar and introduce local intrusions in the vehicle side due to the stiffness of longitudinals. Other studies [O'Brien 2010] have confirmed this aggressive behaviour if the horizontal loads are not suitably distributed across the vehicle and a typical example is shown in Figure 4.3.

The results of FIMCAR and external research support the development of a structural alignment metric that controls the height of the structures as well as encouraging vertical load spreading. The Limit Reduction will credit loads in Row 2 that promotes load spreading towards the sill of the struck car during a lateral impact.

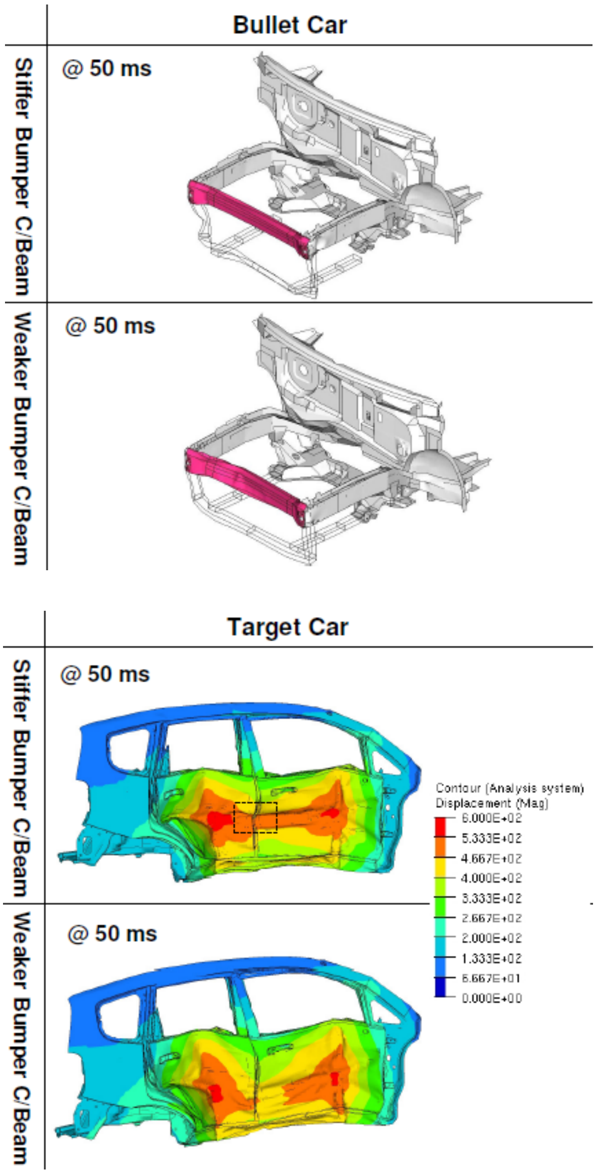

Figure 4.3: Influence of horizontal load spreading on side impact intrusion [Takizawa 2007].

The FW test metrics have no horizontal load spreading components. Vehicle frontal structures will thus not likely exhibit improvements in their horizontal load spreading and improve their compatibility in side impacts. The use of a FWDB will reduce the risk of mis-use of the FW test by exploiting local loadpaths since the force applied to one load cell is, in practice, limited by the crush strength of the honeycomb. The damping characteristics of the FWDB is advantageous over the FWRB in this case.

4.3 Changes Expected from ODB

As mentioned earlier, the existing ODB will not modify future vehicle designs to promote load spreading vertically or horizontally. No additional improvement for side impact protection is expected from the ODB. However, no disadvantages are expected.

4.4 Changes due to (M)PDB

The (M)PDB can be used to promote the vertical and horizontal load spreading desired in front-to-side impacts as discussed above. As shown in Figure 2.5, the deformation pattern in the (M)PDB could be used to predict vehicle behaviour in a side impact. There has been no activity to correlate the (M)PDB results for the SUV used in the side impact simulations and tests as presented in Section 4.2. Section 3.3 mentions that the (M)PDB has no validated compatibility metrics assigned to the barrier deformation. A metric based on the slope of the barrier deformations appears to be promising and can be used in future applications to promote better horizontal load spreading and avoid the local intrusions shown in Figure 4.3. Similar metrics for vertical load spreading would also encourage this component of compatibility. Therefore the presumed influence on the (M)PDB test on vehicle front structures would be to improve vertical and horizontal load spreading. The benefits for side impact will be found from performance criteria that encourage the vertical load spreading that engages the sill and horizontal load spreading that eliminate local deformations when stiff longitudinal structures penetrate the softer side areas of the vehicle. Initial estimates of the benefit of a combined PDB/FW test are presented in FIMCAR Deliverable D1.2 [Edwards 2013] and show the benefit of an additional metric for horizontal load spreading that the FWDB test cannot provide.

4.5 Summary

The introduction of new frontal impact compatibility criteria in FIMCAR will have some limited benefit in side impacts if manufacturers use the vertical load spreading options for the FWDB. There is a risk that the encouragement of structural alignment in Rows 3&4 can lead to preferred loading high on the vehicle side. There are no horizontal load spreading requirements proposed in the FIMCAR recommendations so there will not be any explicit encouragement of stiffer horizontal crossbeams nor punishment for developing weak crossbeams. The use of a FWDB will limit the sub-optimisation potential available in a FWRB where high contact loads on limited cells can be used to meet the target row loads.

There is a weak possibility that vertical load spreading could improve with the introduction of a FWDB test. It is still beneficial in side impacts if structures have loads in Rows 3&4 compared to vehicles which have their structure located even higher (Row 5&6). The future inclusion of a (M)PDB would permit greater control of load spreading that benefits side impact.

The recommendation of FIMCAR to combine the current ODB with a full width test will balance any tendencies of vehicles to develop overly stiff frontal structures with the offset test because the full width test should encourage longer and gentler ride down behaviour. The combination of full width and offset tests will thus balance each other and not introduce worse conditions that currently observed for side impact.

5 IMPLICATIONS FOR IMPACTS WITH HEAVY GOODS VEHICLES

5.1 Review of Current Status of HGV-Car Impacts

The main issues for passenger vehicle crashes into Heavy Goods Vehicles (HGV) are addressed in UN-ECE Regulations 58 and 93 for Rear and Front Underrun protection systems (RUPs and FUPs), respectively. Both specify geometric and structural requirements for devices fitted to HGVs and their trailers to reduce the risk of passenger cars underriding the larger frame elements of the HGV chassis.

For FUPs, the guard structure can have a maximum ground clearance of 400 mm on an unladen vehicle and the corresponding value is 550 for rear guard structures. Both have requirements for a minimum vertical section height to ensure there is a reaction surface for impacting vehicles to react against.

Structural adequacy of the underrun guards is controlled by point loads that are applied to specific locations. These loads are well under the peak deformation loads of cars and are activated by even small vehicles. Krusper and Thomson investigated FUP force levels in [Krusper 2008/1, Krusper 2010]. One observation from accident analysis [Krusper 2008/2] was that the point loads for the FUP did not always resist overriding and that the lateral load spreading of the FUP was often poor on the outboard sections.

5.2 Changes Expected from FWDB

The FWDB metric will encourage car structures above 400 mm which is the maximum for FUP but not for a RUP. Thus frontal impacts can be expected to improve due to better alignment of car and truck structures. Vehicles currently designed with lower front structures will be encouraged to raise the main structures to be aligned with the FUP interaction area.

Horizontal load spreading for a passenger car would be beneficial if the FUP or RUP exhibits poor load spreading. Many real world cases involve small overlap and horizontal load spreading would be a benefit for these cases too. The FW tests do not offer incentives for improving horizontal load spreading.

SUVs and LTVs, that have been designed with higher main structures than passenger cars, could run the risk of overriding the FUP on trucks. These higher vehicles will be required to incorporate structures below their main longitudinals or, alternatively, redesign the front longitudinals to be more in line with the interaction area between 400 and 500 mm.

RUPs are currently higher than desirable for most M1 vehicles. The maximum ground clearance of 550 mm is over the main interaction area defined for the FWDB although the actual area of measurement on the FWDB is up to 580 mm due to the load cell resolution. The upper border of Row 4 will become a new constraint for vehicle designers and this may encourage structures that were above 580 mm to be lowered to apply loads in Row 4 and thus insure the vehicle crash loads are credited in the assessment. This can allow for some better alignment of structures in the case of rear impacts into HGVs. Modification to the RUP requirements are preferred, as the current RUP designs are too high to engage the structures of most cars. Car-to-truck rear impact conditions are made even worse when pre-impact braking and the resulting vehicle pitch introduces even more vertical offset between the RUP and car bumpers.

5.3 Changes Expected from ODB

The current ODB does not have any mechanism to encourage better alignment of car structures with HGVs. The maintenance of a strong occupant compartment is needed and accident data from Germany [Thompson 2013] highlights the need for good self protection and compartment stability in impacts with HGVs.

5.4 Changes due to (M)PDB

The (M)PDB metrics are currently proposed to encourage horizontal load spreading within the same vertical area as the FWDB. Current development of a deformation metric can incorporate an appropriate assessment area to encourage the vertical load spreading needed for both FUP and RUP interactions. The addition of horizontal load spreading from a (M)PDB metric would enhance the vertical load spreading and structural alignment contributed by the FWDB. An added possibility with the MPDB is increased self protection of smaller vehicles than would be possible with a fixed barrier test. The MPDB trolley mass will create a higher impact severity for all vehicles below 1500 kg and can be used to promote better safety for smaller vehicles when they collide with HGVs. The current standard for M1 vehicles only addresses the severity level for a single vehicle collision but not for a heavier collision partner vehicle. The current impact severity for (M)PDB vehicles with a mass over 1500 is not fully resolved and there is a possibility that these occupants of these vehicles can have higher injury risks.

5.5 Summary

The new FIMCAR frontal impact procedure will provide opportunities for better structural interaction between passenger cars and HGVs. There are no function based requirements in Europe that will encourage better structural alignment between passenger cars and trucks. As shown in this section, there are challenges to encourage vehicles to be aligned with RUPs and this may be better addressed through modification of the RUP requirements.

The current FUP and RUP structures are not mandated with sufficient energy and force capacity for impact severities that are encountered on the roads. There is evidence that the structural capacity of FUPs were not sufficient to prevent overriding in some collisions [Krusper 2008/1, Krusper 2010].

6 IMPLICATIONS FOR IMPACTS WITH ROAD INFRASTRUCTURE

6.1 Review of Current Status of Car-to-Road Infrastructure Impacts

The testing of roadside equipment is prescribed in Europe by standards developed by CEN TC226. These standards describe CE marking requirements for construction products which will control the sale of construction products in Europe. Guardrail and crash cushions are regulated by EN 1317 while vertical structures (poles, sign posts) are covered under EN 12767. Both of these test standards incorporate crash tests of different size vehicles with different speeds and angles, when appropriate.

Parallel to Europe, guidelines have been developed in the US which describe crashworthiness requirements for roadside equipment. The latest document describing test conditions is the Manual for Assessing Safety Hardware (MASH) [AASHTO 2009]. The US does not have formal regulations but requires MASH approved devices on roads that are part of the National Highway System. As a result, all new roadside safety devices are essentially designed to MASH requirements.

In both Europe and the US, roadside hardware is designed for impacts with a set of reference vehicles. In Europe, passenger vehicles of 800 and 1500 kg are used to represent passenger cars while in the US an 1100 car and 2240 kg pickup truck are used. Test speeds range from 70 to 110 km/h depending on the application and impact angles will vary from head on (0 deg) impacts to a maximum oblique impact angle of 20 or 25 degrees in Europe or US, respectively.

Two main issues for roadside equipment and the safety of vehicle passengers is the stiffness and structural interaction between cars and horizontal structures like guardrails. Figure 6.1 shows the geometry of vehicle structures compared to the main horizontal elements in guardrails. It is important for harmonisation that the requirements for roadside equipment do not diverge for the US and European market. FIMCAR has adopted the US definition of a common interaction zone and this will allow for better geometrical designs for vehicles and roadside equipment internationally.

The influence of vehicle stiffness is not so well understood in Guardrail Impacts. Wu et al [Wu 2004] showed that the lateral stiffness of vehicles should not be too low as this could lead to higher injury risks. Unfortunately only the US frontal impact requirement FMVSS 208 has any true oblique impact element although this situation is seldom tested in US quality control testing.

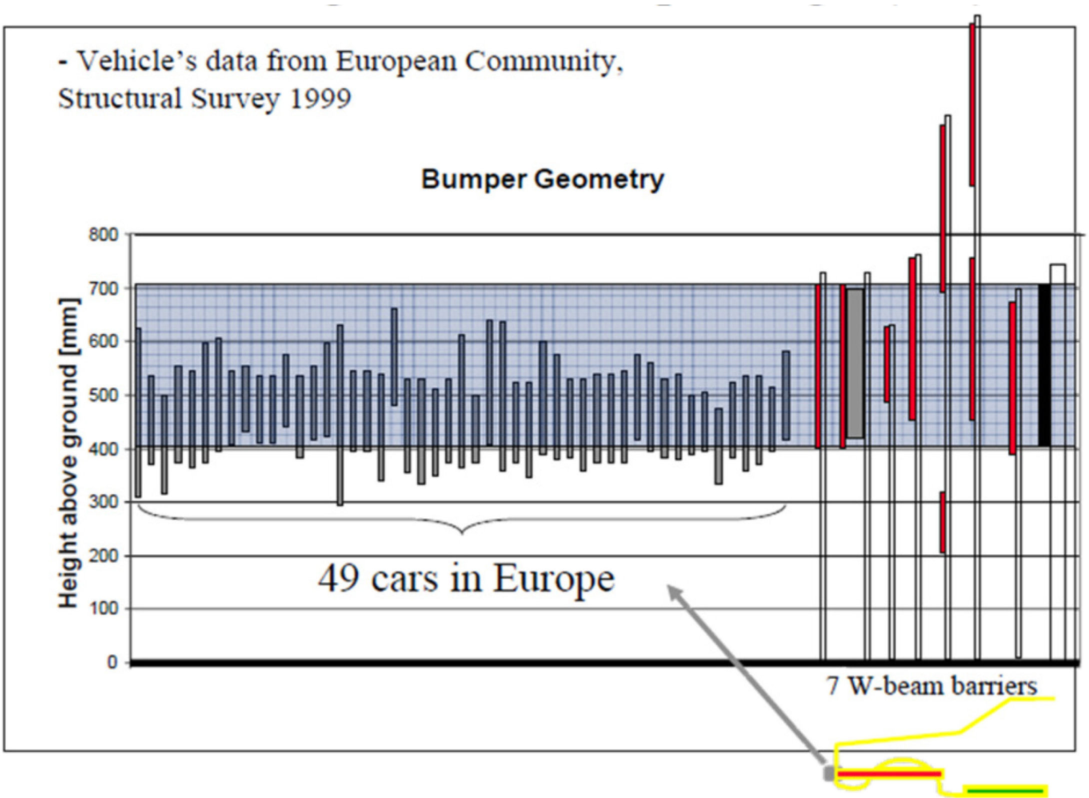

Figure 6.1: Vehicle Structures and Typical Guardrail Geometries [Wu 2003].

6.2 Changes expected from FWDB

The FWDB offers manufacturers of both vehicles and roadside hardware to identify common interaction zones where structures should interact. This would be addressed by the structural alignment metric in Rows 3&4. The FWDB will not address the issues corner impacts to the structure due to the load conditions in the FWDB.

Road equipment with narrower vertical elements increases the demands on horizontal structures in the vehicle. Strong bumper crossbeams would be desirable to reduce intrusion of the occupant compartment. The RISER project noted that impacts with narrow roadside objects were associated with more fatal accidents and that many of these fatalities could be attributed to intrusion into the occupant compartment [Naing 2008]. The FWDB has not been found suitable for developing horizontal load spreading metrics to address this issue.

6.3 Changes expected from ODB

The current ODB is not expected to change vehicle designs to be more suitable for roadside collisions than what they are currently. The offset loading condition requires some bending resistance in the vehicle front but there are no new metrics that are going to encourage more robust structures with the current offset protocol.

Alignment of frontal structures is somewhat encouraged by the bumper element on the ODB. However the FWDB will actively control this feature in vehicles.

6.4 Changes due to MPDB

The MPDB has already been identified as a potential tool for encouraging load spreading in vehicle frontal designs. If a suitable metric is defined, horizontal load spreading could then be better incorporated into vehicle structures. The horizontal load spreading metric could also be envisioned to provide wider front structures that improve the corner impacts of the vehicle with structures like guardrails.

6.5 Summary

The main benefits of the FIMCAR frontal impact assessment approach are to encourage structural alignment of vehicle and road infrastructure. The main benefits would be realised in the FWDB test where vertical vehicle geometry is actively assessed and controlled. The new requirements will be an important input for road designers to ensure that future systems are built to known structural architectures in vehicles.

7 DISCUSSION

The influence of the candidate test procedures and assessment procedures on other impact types has been presented. The common theme is the potential to structurally align vehicle components with the opposing structures. In some cases like truck RUPs, requirements of the collision partner are not ideal for passenger vehicle designs. Introduction of performance requirements that harmonise geometric alignment will support future harmonisation of crashworthiness designs, independent of type of passenger cars.

The final assessment approach that was developed within the FIMCAR project duration does not have a horizontal load spreading assessment. The FWDB was not suitable for this procedure and validated (M)PDB deformation metric for load spreading in the vertical and horizontal directions is still in the final stages of development. Preferably, a load spreading metric could be introduced into a future offset test like the (M)PDB. The load spreading metric would address many impact conditions identified in impacts with vehicle sides, HGVs, and roadside equipment. The benefits of stepwise implementation of the FWDB and (M)PDB assessment criteria on frontal impacts is presented in FIMCAR Deliverable D1.2 [Edwards 2013] and shows that structural alignment, provided by the FWDB, only addresses part of the safety issue.

Stiffness issues with current vehicle designs are not expected to be affected negatively by the FIMCAR approach. The combination of a FWDB and ODB will create a balanced frontal stiffness that cannot be expected to be softer than vehicle side structures, nor stiffer than HGV frames. Current compartment strength needs to be maintained and the frontal stiffness can be tuned to appropriate levels through the ODB test and A-pillar performance as well as the dummy criteria.

In total no negative side effect resulting from the FIMCAR assessment approach is expected. However, not all potential for improvements of other impact types is exploited following the lack of load spreading assessment.

8 CONCLUSIONS

The current test candidates and final assessment procedure selected by FIMCAR do not have any obvious negative implications for side impacts, HGV impacts, nor impacts with road equipment. The worst case scenario is that the introduction of a FW metric with minimum load requirements in Rows 3&4 can lead to single point -optimisation and worsened horizontal load spreading that may manifest itself in other impact configurations. This risk is small and the selection of a FWDB will likely mitigate this side effect. The deformable barrier dampens the peak loads and introduces a need to have larger contact surfaces to generate sufficient loads in the assessment area.

The current assessment approach in FIMCAR may introduce limited improvements for these investigated collisions, but it is expected that the harmonisation of interaction areas will allow a convergence to compatible structural designs in the road and traffic network.

GLOSSARY

EEVC:	European Enhanced Vehicle Safety Committee
EEVC WG13	EEVC Working Group on Side Impact
EEVC WG15	EEVC Working Group on Frontal Impact Compatibility
Euro NCAP:	European New Car Assessment Programme
FUP:	Front Underrun Protection device of HGV
FW:	Full Width Frontal Impact test
FWDB	Full Width Deformable Barrier test
FWRB	Full Width Rigid Barrier test
HGV:	Heavy Goods Vehicle
IIHS:	US Insurance Institute
LCW:	Load Cell Wall
MDB:	Movable Deformable Barrier test
MPDB:	Movable Deformable Barrier test using the PDB barrier face
NHTSA:	US National Highway Traffic Safety Administration
ODB:	Off-set Deformable test (used for current ECE R94)
Part 581 zone:	Bumper zone according to FMVSS Part 581 Bumper Standard
PEAS:	Primary Energy Absorbing Structures
PDB:	Progressive Deformable Barrier test (50% offset frontal impact test)
Row 3:	3^{rd} Row of an LCW from bottom (i.e., ranging from 330 to 455 mm)
Row 4:	4^{th} Row of an LCW from bottom (i.e., ranging from 455 to 580 mm)
RUP:	Rear Underrun Protection device of HGV
SEAS:	Secondary Energy Absorbing Structures
VC-Compat:	EC funded project (FP5) Vehicle Crash Compatibility
VRU:	Vulnerable road user (typically pedestrians, cyclists, motorcyclists)

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