European Enhanced Vehicle-safety Committee
Working Group 15

Car Crash Compatibility and Frontal Impact

Final Report to Steering Committee

May 2007

EXECUTIVE SUMMARY

The conclusions of the work conducted by Enhanced European Vehicle-safety Committee Working Group 15 - Car Crash Compatibility and Frontal Impact (EEVC WG15) during its current mandate are reported in the following report and are summarised below. The main items of the WG15 Terms of Reference (denoted as § comments) are provided to guide the reader.

The main task submitted to WG15 by the EEVC Steering Committee was:

§1. Develop candidate test procedures to assess car frontal impact compatibility. Work will concentrate on car to car frontal compatibility whilst also considering the effects on other accidents such as impacts with the side of cars, trucks, pedestrians and roadside obstacles

The activities of WG15 have lead to the development of two different test approaches, the Full Width Deformable Barrier (FWDB) and the Progressive Deformable Barrier (PDB) approaches. Both test approaches employ a full width and offset test condition to apply different loading conditions on the vehicle in order to measure different properties deemed as relevant for compatibility. The two test approaches can be summarized as:

Approach 1

- Full Width Deformable Barrier (FWDB) test
  - Structural interaction
  - High deceleration pulse
- ODB test with EEVC barrier
  - Frontal force levels
  - Compartment integrity

Approach 2

- Full Width Rigid Barrier (FWRB) test
  - High deceleration pulse
- Progressive Deformable Barrier (PDB) test
  - Structural interaction
  - Frontal force matching
  - Compartment integrity

These two approaches have been discussed in the group. An alternative approach, a combination of the two methods, may also be examined but has not been a formal activity in WG15.

Through the development of the different test methods, the group has agreed that the following conditions must be satisfied by any new test approach that will assess compatibility:

1) Test procedures to control compatibility must assess the structural interaction, frontal force levels, and compartment strength of the vehicle. Current passive safety levels should not be compromised if the global improvements in road safety are to be achieved.
2) One test procedure alone is not sufficient for assessing frontal impact. Both of the main test approaches combine a full width and offset type test. These two test conditions are needed to fully assess the structures and safety equipment of the vehicle.

§2. Establish criteria to rate frontal impact compatibility

The two main test approaches have put forward different parameters that are used to evaluate, and thereby rate, frontal compatibility performance of different cars. The FWDB procedure uses the distribution of forces measured on a Load Cell Wall behind a deformable element, while the PDB test uses the deformation pattern in a honeycomb barrier, to assess vehicle performance.

The FWDB approach uses both a FWDB and an ODB test to assess a car's compatibility. Two evaluation criteria for structural interaction have been developed for the FWDB procedure. These have been initially validated using the test data in VC-COMPAT. The two criteria are the Vertical Structural Interaction (VSI) and the Horizontal Structural Interaction (HSI). These two criteria are based on the principles that 1) sufficient structure (applied load) can be detected and 2) that the loads are reasonably distributed within an assessment area. These criteria need to be further evaluated with different vehicle types to confirm that the procedure properly assesses a vehicle's structural interaction performance. The criteria is currently provided with initial threshold values and with further work, the numeric output from the HSI and VSI could be further developed for rating purposes. To assess frontal force levels, a new method has been proposed to identify the load values of interest from the ODB test using using an excedence measure. The method has been proposed but threshold values still need to be identified. Initial estimates from VC-COMPAT indicate 350-400 kN may be a minimum requirement for small cars. Upper limits have not been proposed yet due to concerns expressed by the vehicle manufacturers.

The PDB approach measures the deformation of the barrier after the test and uses this information to interpret the structural interaction and force levels of the tested vehicle. Currently the ADOD and AHOD have been identified as parameters that an assessment could be based on but no performance limits have been proposed. An additional parameter that assesses the homogeneity of the vehicle structure is under development. The parameters available for the PDB have been calculated for the tests in VC-COMPAT as well as the French national research programs. However, no formal compatibility assessment criteria with proposed thresholds have been published.

§3. Identify potential benefits from improved frontal impact compatibility;

The work conducted by WG15 in the EC project VC-COMPAT has provided important information related to the benefits and potential costs of improved compatibility. Initial benefit models have been developed for GB and DE databases and these serve as an important step to future analysis of the benefit of improved vehicle compatibility. In the GB approach CCIS data were analysed: for a lower estimate, it was assumed that all intrusion related injuries were mitigated, for an upper estimate, all contact induced injuries were mitigated. The DE approach uses an assumption based on the observation that, in the VC-COMPAT test program, 5 Star Cars could absorb 30% more kinetic energy in Euro NCAP tests than in car to car tests in the absence of compartment intrusion.

Cost estimates have been made using the industrial (Fiat) expertise in the group and a cost benefit for compatibility has been estimated. The increased sale and operating costs for improving vehicle compatibility were based on modifying existing vehicle designs. While analysing the costs of modifying car design for good compatibility, it has been suggested that for the next vehicle generation, where compatibility requirements are considered from the beginning of the development of a new car model, costs could be a fraction of those estimated for modifying an existing design.

Based on the cost savings (reduced injury costs) for compatible cars and the expected costs for modified vehicles, cost benefit calculations were developed and summarised below. The calculation is conservative and was not based on a specific test method, however most cases indicate a positive cost-benefit result. The negative results generated in the exercise represented pessimistic predictions of injury reduction and unlikely manufacturing strategies if new vehicle models are being developed.

Table 1: Cost Benefit Ratio of improved compatibility for EU15.

	Ratio of financial benefits to implementation costs		
	CCIS intrusion model	CCIS contact model	German model
Best case scenario	2.05	4.51	1.34
Worst case scenario	0.74	1.63	0.48

CURRENT STATUS AND RECOMMENDATIONS FOR FUTURE WORK

Working Group 15 has developed a list of assessment criteria that is used to evaluate the current test methods. There are four main headings that address Structural Interaction, Reproduction of Collapse Modes, Test Procedure, and Other issues. Several specific questions or review items are listed under each main heading. A total of 20 different items are listed covering issues such as repeatability, availability of criteria, etc. that are used to assess the different test criteria against each other on a point-by-point basis. This list uses a numerical rating (0-3) that has been provided by the group members. WG15 does not support the use of this worksheet to sum some or all the points as method to select a test method since each point has a different weighting and these weighting factors have not been derived. The current analysis of the results are the current reflection of the Working Group assessing test procedures that are not yet fully developed.

The analysis presented below is based on two values for each factor and test: the average and variance. The entire survey of WG15 was collected and the arithmetic mean value was used to indicate the ranking of the test's effectiveness when compared to the other tests. The variance of each score indicates how much the group agreed to this point with a low number indicating a general agreement and a large number suggesting disagreement.

The following brief analysis of the table is divided into the four main groupings in the table:

1) Structural interaction – The group rates tends to rank the PDB first and then the FWDB barrier tests as being the most effective at detecting structural interaction properties in cars. The rating of each of these two tests varies from point to point but the variance indicates that the methods' performance are generally agreed to by the group
2) Reproduction of collapse modes of load paths - The group generally rates the PDB highest for most of the points in this section. The ODB (ECE R94) also rates high when it comes to compartment strength issues. The FWDB is best at measuring local forces over time. There is less agreement within the group in this section so further analysis of test data is needed create consensus within the group.
3) Test Procedure – This section is used to assess the simplicity, accuracy and repeatability of the different procedures. It is clear that the FWRB is the most reliable test method but also the least applicable according to the previous analysis. The

FWDB and ODB tests tend to be higher rated. The variance numbers indicate that consensus within the group borders between agreement/ disagreement (0.5)

4) Others – This section includes general issues such as harmonisation issues and availability of assessment criteria. Like Point 1, the FWDB and PDB are essentially similar in ranking within the group.

The current activities of EEVC WG15 have progressed to the point where candidates test approaches are available for subjectively assessing the frontal crash compatibility of vehicles (presented above). The differences in the approaches and current state of development are such that the group cannot unanimously select a final candidate that should be forwarded for potential legislated and/or consumer testing purposes. The group has prepared documents which analyse the technical points of the available test procedures. However, the final selection process requires that the candidate procedures are further developed to the point where assessment criteria and performance levels can be compared. To complete the selection of a frontal crash compatibility test procedure, the working group proposes the Terms of References presented in the following section.

DRAFTED TERMS OF REFERENCE FOR A FOLLOW UP EEVC WG ON COMPATIBILITY

The two central test procedures, the Progressive Deformable Barrier (PDB) test and the Full Width Deformable Barrier (FWDB) test, are not sufficiently developed to allow test approaches to be compared and select a preferred test procedure. The discussions within WG15 show that all test procedures have issues to be investigated and that each test procedure has specific strengths that are not often found in another. This section outlines the recommended work to reach the position to make a proposal for a 1st step to improve compatibility. The work is classified under global issues which are independent of a testing approach and work specific to a test procedure.

Global Issues:

- Further accident analysis and benefit analysis to update information on changing vehicle fleet
- Finalise the test severity (EES) for regulation test.
- Finalise assessment criteria for regulation test.
- Finalise objective assessment procedures to analyse results of car to car tests with respect to:
    - Good structural interaction
    - Good compartment strength
    - Compatible car
    - Importance of width of frontal structures.
- Identify critical injury mechanisms (in particular relevance of thorax injuries in high deceleration pulse type accidents)
- Finalise a compatibility scale for a rating system.

These global issues will require research that focuses on car-car testing as well as accident analysis using detailed databases. The work previously reported to WG15 provides an important, but incomplete basis.

Test Procedure Specific issues:

Further development of test approaches to the point where a decision on the most appropriate set of test procedures can be made.

For the FWDB the major work items are:

- Determine the link between honeycomb deformation and load cell measurements. Load spreading issues observed in rigid impactor tests should be clarified and determine if the assessment criteria are insensitive to these load variations.
- Verify that all important vehicle structures, identified in accident analysis, can be detected by the barrier (for example horizontal structures).
- Determine and control the sensitivity of the test method to the vehicle alignment with the loadcells.
- Continue to analyse the results of Offset Deformable Barrier (ODB) tests (Euro NCAP and ECE R.94) and evaluate the potential to assess compatibility issues.

For the PDB test major work items are:

- Propose and validate assessment criteria when fundamental questions have been answered
- Validate the EES calculation method
- Validate that the PDB test guarantees a minimum EES test severity for all vehicles.

For a set consisting of a combination of the two test approaches (combination of FWDB and PDB)

- Develop and propose complementary assessment criteria for a combination of the two test procedures.

Regardless of the test approach chosen as a standard for assessing compatibility, several implementation stages will be necessary to phase in the full test procedure. To identify and validate the necessary performance levels for a first step in compatibility testing, a car to car crash testing programme with associated barrier tests will be required to show that cars that meet the performance requirement perform better in car to car tests than those that do not. It is likely that modified cars will be required for this. Some of the tests already performed in the VC-COMPAT project could form a starting point for this programme.

In parallel to the initial validation of the performance criteria of a test method, an updated cost benefit analysis for implementation of the selected test method is required. Accident data should be reanalysed and better models that can identify the benefits for the specific test method need to be developed. Results from the test programme to set the performance limits will be used to make the assumptions to perform this analysis.

Depending on available research funding, the final stage of work on Compatibility could continue its work [October 2007] and finalise its work by presenting a draft regulation proposal for car to car compatibility [December 2010]. This drafted regulation proposal shall contain test protocols and assessment criteria.

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1. INTRODUCTION

This report is a compilation of the latest activities of European Enhanced Vehicle-safety Committee Working Group 15 – Car Crash Compatibility and Frontal Impact (EEVC WG15). This report is provided as requested by the EEVC Steering Committee as the current mandate period for WG15 closes. The report comprises information from three main origins: 1) activities of the individual working group members conducted in national or industrial projects; 2) joint research activities involving several working group members; and 3) activities of organizations outside the working group and reported at specific meetings. Working documents submitted to WG15 are short summaries of the projects with conclusions derived from the originating research organisation(s). It is thus important to note that there is not unanimous acceptance of the conclusions from each of these projects. As expected, there is greater agreement within WG15 when a project conclusion has been developed with several of the working group members. Conversely, greater disagreement about research findings occurs when one organisation provides its own internal research to the group. Since documentation presented to WG15 comes from many sources, not every member has detailed information for every research project submitted to the group and this makes fully objective conclusions difficult to be drawn.

Working Group 15 was created in 1996 to develop a better understanding of crash compatibility between passenger cars. This was reported in 2001. The group was then tasked with developing test procedures that would evaluate a vehicle's frontal crash compatibility. The key characteristics that were deemed to influence compatibility are:

1. Structural interaction (local geometric and stiffness properties that determine how structures will deform)
2. Global force levels (total force / deformation properties that govern how energy dissipation is shared between crash partners)
3. Compartment strength (passenger compartments must be maintain the survival space for the occupants as well as support the deformation processes in the vehicle front)

Originally a second working group (WG 16) was responsible for the revision of self protection regulations in frontal impact. This group had made the following proposal:
"While the accident analysis described above suggests that the speed should be increased to perhaps 65km/h, concerns by some EEVC experts regarding compatibility had led to the recommendation to increase the speed initially to 60km/h until there is a better understanding of compatibility. The EEVC recommends that the EC reviews this issue again when more is known about the likely influence on compatibility." [3].

The two working groups (WG 15 and 16) were merged in 2002.

The current members of WG15 consist of a nationally nominated representative and an accompanying industry consultant. The current members (January 1 2007) are:

Members

DE; E Faerber (Chairman)	BASt
FR: T Martin (Secretary)	UTAC
UK: M Edwards	TRL
SE: R Thomson	Chalmers
IT: G Della Valle	ELASIS
NL: R. Schram	TNO
ES: J Huguet	IDIADA

Industry

DE; R Zobel	VW
FR: R Zeitouni	PSA
UK: M. Harvey	Jaguar
SE: A Kling	Volvo
IT: D. Barberis	FIAT

Observers

FR: P Delannoy	Teuchos-UTAC
US: D. Smith	NHTSA

A significant activity within WG15 for has been the European Commission sponsored project VC-COMPAT (February 2003-November 2006). This project has been the main focus of the the working groups activities. All the national representatives (except Spain) were contractors in the project and the entire working group (including the industry consultants) were the steering committee for the project. Results form this project are presented in the following sections.

As described earlier, WG15 is a focus for compatibility research in Europe. Different reserch activities are presented to the working group and the main activities to note are:

- French national projects
- UK National projects (DfT)
- European automotive manufacturers (ACEA, VDA)
- Non-European activities (NHTSA, JARI, JAMA, AAM)
- Collaborative European activities

Working Group 15 compiles all of the data presented at its meeting in a list of working documents and this material is used as the basis for its operation.

2. OBJECTIVES OF WG 15

2.1. Terms of reference - May 2005

Established in February 1996, the first phase of research (1996–2001) was aimed at gaining a better understanding of frontal impact crash compatibility between cars. In March 2002, the mandate was extended to September 2005. Following the merging of EEVC WG16 (Advanced Frontal Impact Protection) with WG15 and the extension of the “VC Compat” project, the WG15 mandate was extended to June 2007.

The revised Terms of Reference are:

- Develop candidate test procedures to assess car frontal impact compatibility. Work will concentrate on car to car frontal compatibility whilst also considering the effects on other accidents such as impacts with the side of cars, trucks, pedestrians and roadside obstacles;
- Establish criteria to rate frontal impact compatibility;
- Identify potential benefits from improved frontal impact compatibility;
- Research will continue into the understanding of frontal impact protection, to help ensure that steps to improve frontal impact compatibility will also lead to improved front impact protection;
- Co-ordinate the EEVC contributions to the IHRA working group on Compatibility and Advanced Frontal Impact.

The Working Group will report its findings and will propose candidate test procedures in June 2007.

2.2. Route map

At the beginning of the VC-COMPAT project in 2003, the following route map (strategy) for WG 15 was developed. It describes the short and long term goals for vehicle crash compatibility.

General

- Proposed test procedures must address both partner and self protection in frontal impacts without decreasing current regulatory self protection levels in other impacts, in particular frontal, and no detrimental consequences for side impact configurations
- Number of additional test procedures should be kept to a minimum
- Test procedures should be internationally harmonised

Short Term (Aim to report suitable test procedures to EEVC steering June 2007)

- Improve structural interaction
- Control new requirements for passive safety (regulatory and rating) to ensure that frontal force mismatch does not become greater than current self protection force levels in particular to stop the increase of frontal force level of heavy vehicles (Note: EEVC WG15 recommends that the test speed of offset test (ECE R94) must not be raised to 60km/h without modification of the current test procedures)
- Control new requirements for passive safety (regulatory and rating) to ensure that compartment strength does not become less than current levels, especially for light vehicles

Medium Term (Aim to report suitable test procedures to EEVC steering November 2010)

- Improve compartment strength, especially for light vehicles
- First steps to improve frontal force matching
- Further improve structural interaction

The current route map was used to direct the research of VC-COMPAT. As the working group compiled new information from VC-COMPAT and supporting national activities, the route map has been re-evaluated. A current issue with the route map is that increasing the compartment strength of small cars should be considered as a short term instead of a medium term priority. In addition, some members indicate that the issues of structural interaction and frontal force levels should not be separated and must be addressed in parallel.

3. Accident and Cost Benefit Analysis

Three activities are described below but they it should be pointed out that other accident analysis results have been presented to WG15 in the recent mandate period. These three sources have been chosen to reflect the critical information for assessing the current and future activities of WG15. Only one of the activities, VC-COMPAT, was a joint effort of the working group.

3.1. General trends in accident data (VW)

The historical performance of passenger cars in frontal crashes has been presented to WG15 by VW. These results are summarised in Document 356. The first important result presented is that the US fatality rate is not improving as quickly as in Europe. This suggests that the reduction in Europe is not part of a global trend, but it is a consequence of the special situation in Europe, as a consequence of European car design and European regulation. Benefits in the European fleet are attributed to increasing levels of self protection.

Several figures are presented in the analyses and the main results are derived from the GIDAS database (Germany). There are indications that vehicle deformations for both the vehicle and its collision partner are decreasing. The reduced deformations are attributed to increased vehicle stiffness encouraged by recent legislated and consumer test requirements in Europe. Parallel to reduced vehicle deformations are reductions in occupant injury levels (lower proportions of AIS 3+) for both vehicles in the collision. The improvements in occupant safety cannot be solely attributed to post-crash rescue since no improvements in the fatality outcomes are observed for the different MAIS levels. The reader is refered to Document 356 for details.

3.2. Trends of chest injuries in French accidents (PSA)

PSA presented an analysis of accident data in EEVC WG15 Working Document 385. Frontal impacts were studied to determine the role of restraint type, compartment intrusion, and vehicle design (age). The number of crashes analyzed in this study has not been provided. The injured passengers are grouped according to their vehicles' model years as shown in Figure 1. Thorax injuries and head injuries have decreased in the newer vehicles.

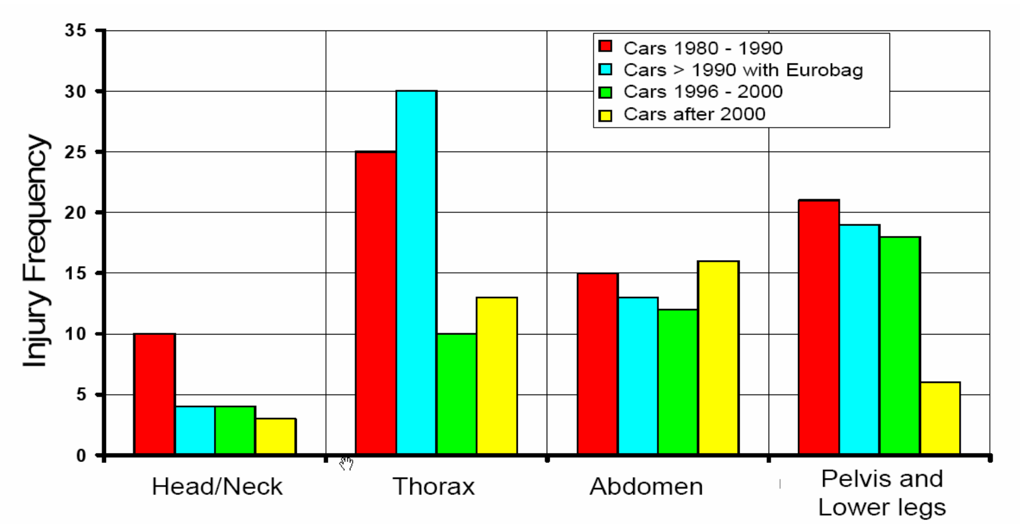


Figure 1: Frequency of AIS3+ Injuries for Vehicle Passengers

The frequency of injuries to the front passenger and drivers for the crashes shown above have been further analyzed by restraint type. A further analysis of the data indicates that newer vehicle designs, combined with load limiters, have been an enormous benefit for vehicle passengers. The data suggests that the frequency of chest injuries in the analyzed frontal crashes were halved and the severity of injury (MAIS) for each body region has been reducing with newer vehicle and restraint system designs.

3.3. VC-COMPAT cost benefit analysis

In 2004 there were, according to the Community database on Accidents on the Roads In Europe (CARE), 32,951 traffic accident deaths and 251,203 seriously injured casualties in the 15 member states of the EU-15. EFR (European Union Road Federation) state that 54% of these road fatalities were car passengers or drivers.

The aim of this part of the work was to estimate the costs and benefits for improved frontal impact car to car compatibility for Europe (EU15). For the benefit analysis, the approach illustrated in **Figure 2**. was followed.

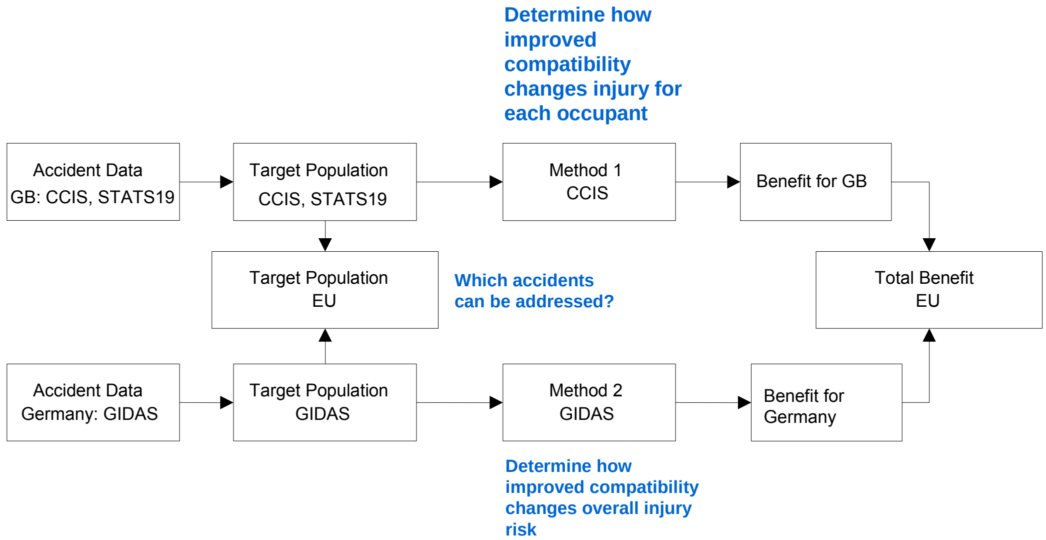


Figure 2: Benefit analysis approach.

A target population was estimated using data from Germany and Great Britain (GB) and scaled to calculate the target population for the EU15 countries. The target population is defined as the number of casualties who might experience some injury risk reduction as a result of the implementation of improved compatibility. Building on this work, TRL and BASt developed methodologies and estimated the benefit for compatibility for Great Britain and Germany, respectively. As a definite set of test procedures to assess a car's compatibility has not yet been defined, the methodologies were based on the assumptions of how a compatible car would perform. The GB analysis used detailed accident data from the Co-operative Crash Injury Study (CCIS) and national data from the STATS19 database. The German analysis used detailed accident data from the GIDAS database and German national accident statistics. The methodology used for the GB analysis was based on a retrospective review of real-world vehicle crashes that occurred in GB and an in-depth evaluation of what injuries could have been prevented if the vehicle crash performance was enhanced. The methodology only considered the crashes for injury mitigation where it was believed that it would be realistic to predict some benefit, so high speed crashes and under-run impacts were excluded. The methodology used for the German analysis was based on theoretical concepts that evaluated the current risk of car occupant injury following frontal impacts with respect to collision speed; re-assessed the risk functions for an improved compatibility vehicle fleet with better energy management characteristics and subsequently predicted the likely future casualty reductions.

The economic analysis was undertaken by Fiat and considered the fixed, variable and associate design costs. Two cases were chosen, a worst case, modification of a 4 star EuroNCAP car, and a best case, modification of a 5 star EuroNCAP car. The costs for each star rated car were then evaluated with respect to the number of car units that would be modified per year, with the greater the number of units the lower the cost per car.

The cost benefit for the EU15 countries was estimated by scaling the benefits estimated for GB and Germany and the costs estimated by Fiat. A range of predicted casualty savings for EU15 was calculated by scaling the proportional benefit estimated for GB and Germany. The financial benefit was calculated by multiplying the casualty savings by published values for the cost of fatal and seriously injured road accident casualties. The number of new registrations per year in the EU-15 vehicle fleet was used to estimate the cost per year to introduce frontal impact compatibility. A ratio was then derived based on the potential costs saved through fewer casualties due to the introduction of improved compatibility divided by the expected manufacturer costs. It should be noted that the cost benefit was calculated for the steady state, when the entire vehicle fleet is compatible. The benefit will be less during the initial years as compatible cars are introduced into the fleet.

3.3.1. Target Population

For the EU15 countries the target population for improved car to car frontal impact compatibility was estimated to be:

- About 3,466 (14%) to 7,675 (31%) fatally injured car occupants
- About 50,260 (29%) to 90,122 (52%) seriously injured car occupants

GB Benefit Analysis

The GB benefit analysis predicted that between approximately 5% (67) and 8% (124) of the GB's killed front seat car occupants would be saved and between 5% (732) and 13% (1876) of seriously injured casualties would be prevented if improved frontal impact compatibility were implemented. The lower estimate was made based on a model that assumed that improved compatibility prevented all injuries caused by *contact with a front interior intruding structures* below an impact severity of ETS 56 km/h, whilst the upper estimate was based on a model that prevented all injuries caused by *contact with a front interior structures* below this severity.

Another significant finding of the GB work was the high frequency of moderate (AIS2) and life threatening (AIS 3+) injuries sustained by car occupants due to seat belt induced loading. Figure 3 shows the original injury distribution (blue bars), improved compatibility removing intrusion injuries (red bars) and improved compatibility eliminating contact injuries (yellow bars). The majority of thoracic injury was not prevented by the injury reduction models. There is an argument that a more compatible vehicle would benefit from an improved crash pulse and therefore it would be expected to see lower seat belt loads and a reduced risk of thoracic injury. The models, by their design, did not prevent injury attributed to seat belt loading, and therefore underestimate the potential benefit that could be seen for this body region. This is important to note, as head and thoracic injury are known to be associated with fatal outcomes.

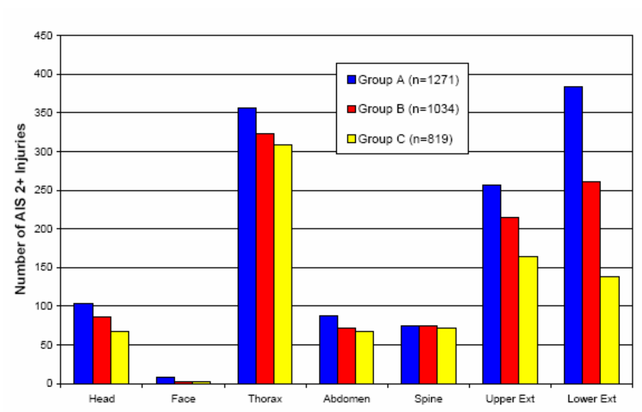


Figure 3: Distribution of AIS2+ Injuries in GB Data

German Benefit Analysis

The German benefit analysis predicted that approximately 8% of Germany's killed front seat car occupants would be saved and about 4% of seriously injured casualties would be prevented if improved frontal impact compatibility were implemented. This estimate was based on the assumption that a car with improved compatibility can absorb about 30% additional kinetic energy in frontal impacts and calculating the injury risk reduction for occupants within the target population. This assumption was based on the comparison of the performance of cars in car to car and standard offset barrier crash tests.

3.3.2. Cost Analysis

The cost of improved compatibility was estimated by Fiat using the best and worse case scenarios to give a possible range. The best case scenario was the cost estimated to modify a 5 star rated EuroNCAP car with a production of 1 million cars. The worst case was the cost to modify a 4 star rated EuroNCAP car with a production of 100,000. The total annual cost given by multiplying the cost for each car by the number of new cars registered in the EU15 every year is given in Table 2 below.

Table 2: Cost of implementing compatibility.

	Cost per car (€)	No. of cars registered p.a.	Total cost p.a. (€)
Best case scenario	102	14,211,367	1,449,559,394
Worst case scenario	282	14,211,367	4,007,605,383

EU15 Cost Benefit

To estimate the benefit for the EU15 the benefit estimates for GB and Germany were scaled to give the following results, Table 3.

Table 3: Predicted reduction in EU-15 casualties.

		Predicted Reduction in EU-15 Casualties		
	Frontal car casualties	CCIS intrusion model	CCIS contact model	German model
Fatal	16,014	721	1,332	1,281
Serious	122,084	5,982	15,383	5,128

The financial benefit for the EU15 was calculated by multiplying the benefit in terms of casualties by the value of life saved and serious injury prevented [**Table 4**]. For the GB estimate the casualty value used was that given in Road Casualties Great Britain 2005 (RCGB 2005), which estimates the average value per prevention of casualty. For the German estimate the casualty value used was that calculated by the German Federal Highway Research Institute, Höhnscheid.[1].

Table 4: Value of EU15 Benefit

	Benefit per person		Predicted Total benefit		
	Fatal	Serious	CCIS: Intrusion	CCIS: Contact	German model
RCGB 2005 (€)	2,136,262	240,043	2,976,180,313	6,538,077,822	-
German (€)	1,161,885	87,269	-	-	1,936,005,641

From this and the cost information presented above the cost / benefit ratio of improved frontal impact compatibility for the EU15 was estimated [**Table 5**].

[1] Höhnscheid, K.-J., Straube, M. (2006), " Socio-economic costs due to road traffic accidents in Germany 2004".

Table 5: Cost Benefit Ratio of improved compatibility for EU15.

	Ratio of financial benefits to implementation costs		
	CCIS intrusion model	CCIS contact model	German model
Best case scenario	2.05	4.51	1.34
Worst case scenario	0.74	1.63	0.48

The cost benefit calculations are conservative and were not based on a specific test method, however most cases indicate a positive cost-benefit result. The negative results generated in the exercise represented pessimistic predictions of injury reduction and unlikely manufacturing strategies if new vehicle models are being developed.

3.4. Recommendations for further work

Accident analyses conducted in Europe cannot reflect the performance of the most recent vehicle designs. As newer car designs are integrated into the car fleet, ongoing accident surveys must be conducted to monitor the changes in vehicle safety performance. During the VC-COMPAT project, the work from Great Britain indicated a high frequency of moderate (AIS2) and life threatening (AIS 3+) injuries sustained by car occupants due to seat belt induced loading. The majority of thoracic injury was not prevented by the injury reduction models used for the benefit analysis. There is an argument that a more compatible vehicle would benefit from an improved crash pulse and therefore it would be expected a reduced risk of thoracic injury. The benefit models, by their design, did not prevent injury attributed to seat belt loading, and therefore underestimate the potential benefit that could be seen for this body region. This is important to note, as head and thoracic injury are known to be associated with fatal outcomes.

The accident analyses from the GB, indicating a high frequency of chest injuries without significant intrusion or steering wheel motion, and the recent PSA studies [EEVC_WG15_Doc385] showed how new restraint technologies are improving occupant safety when higher acceleration pulses are expected. The GB data has not been analysed to account for restraint system type to determine if the same results were observed in the GB fleet.

Further analysis of accident data is needed to observe if other benefits of improved structural interaction can be detected in the current fleet. An improved interaction should provide more predictable crash pulses that facilitate the crash detection and safety system triggering algorithms. It is also expected that improved crash compatibility will lead to better coupling of the occupant and vehicle dynamics during the crash which facilitates the restraint system performance. It is important to use the existing accident data to begin identifying methodologies for analysing these characteristics.

Further accident data analyses are needed to allow the benefit (and cost) analyses to be updated and improved. In particular, the different analyses conducted with French and GB data identify how small changes to the analysis approach will influence the result and a standardised benefit calculation for improved compatibility is not yet developed. Results reported by the VW (EEVCWG15 Document 356) analysis should also be further evaluated to isolate particular mechanisms leading to the improved occupant casualty rates. Finally, the cost benefit analysis for a proposed crash test procedure must be recalculated to more accurately reflect the influence of the crash test procedure on vehicle designs. Future activities should be coordinated with WG21 to ensure the best database and analysis procedures are used.

4. Test Procedure Status

Two primary candidates have been investigated in WG15 and were intensively studied in the VC-COMPAT Project. This section documents the current status of the testing approaches. Champions for the testing approaches (the UK for the FWDB and France for the PDB) have submitted the text in this section.

4.1. Overall Development Strategy (From VC-COMPAT)

To assess a car's frontal impact performance, including its compatibility, an integrated set of test procedures is required. The set of test procedures should assess both the car's partner and self protection. To minimise the burden of change to industry the set of procedures should contain a minimum number of procedures which are based on current procedures as much as possible. Also, the procedures should be internationally harmonised to reduce the burden further. Above all, the procedures and associated performance limits should ensure that the current self protection levels are not decreased. Indeed, if possible for light vehicles they should be increased. Good self protection is required by all vehicles for impacts with road side obstacles. Also good self protection is required for car to car impacts. This is demonstrated by a Swedish study which shows that higher self protection levels, as measured by EuroNCAP, correlate to reduced injury in frontal car to car accidents [2].

The set of test procedures should contain both a full overlap test and an offset (partial overlap) test, as both of these tests are required to fully assess a car's frontal impact crash performance. In 2001, the IHRA frontal impact working group recommended the adoption of an offset deformable barrier and full width tests worldwide [4]. A full width test is required to provide a high deceleration pulse to control the occupant's deceleration and check that the car's restraint system provides sufficient protection at high deceleration levels. An offset test is required to load one side of the car to check compartment integrity, i.e. that the car can absorb the impact energy in one side without significant compartment intrusion. The offset test also provides a softer deceleration pulse than the full width test which checks that the restraint system provides good protection for a range of pulses and is not over-optimised to one pulse.

As mentioned previously, compatibility is a complex issue which consists of three major aspects, structural interaction, frontal force matching and compartment strength. To make vehicles more compatible substantial design changes will be needed which will require some years to implement. Because of this the set of test procedures need to be designed so that compatibility requirements can be introduced in a stepwise manner over a time period of the order of years. This requirement is reflected in the current EEVC WG15 route map [6] which proposes that compatibility should be introduced in two steps which are:

<u>Short term</u>

- Improve structural interaction
- Ensure that force mismatch (stiffness) does not increase and compartment strength does not decrease from current levels

<u>Medium term</u>

- Improve compartment strength, especially for light vehicles
- Take first steps to improve frontal force matching
- Further improve structural interaction

In summary the strategy aims for development of the set of procedures is:

- Integrated set of test procedures to assess a car's frontal impact protection

  - Address partner and self protection without decreasing current self protection levels
  - Minimum number of procedures
  - Internationally harmonised procedures
- Both full width and offset tests required
  - Full width test to provide high deceleration pulse to assess the occupant's deceleration and restraint system
  - Offset test to load one side of car for compartment integrity
- Procedures designed so that compatibility can implemented in a stepwise manner

Based on the route map and the previous activities in WG 15, methods to fully assess frontal impact and compatibility can be divided into the following approaches:

Approach 1

- Full Width Deformable Barrier (FWDB) test
  - Structural interaction
  - High deceleration pulse
- ODB test with EEVC barrier
  - Frontal force levels
  - Compartment integrity

Approach 2

- Full Width Rigid Barrier (FWRB) test
  - High deceleration pulse
- Progressive Deformable Barrier (PDB) test
  - Structural interaction
  - Frontal force matching
  - Compartment integrity

These two approaches have been discussed in the group. An alternative approach, a combination of the two methods, may also be examined but has not been a formal activity in WG15. Further details of the strategies for Approaches 1 and 2 and the development of each approach are given in the following sections.

4.2. FWDB Approach – AS SUBMITTED BY TRL

The FWDB set of tests consists of two test procedures:

- Full Width Deformable Barrier (FWDB) test to assess a car's structural interaction potential and to provide a high deceleration pulse.
- Offset Deformable Barrier (ODB) test with EEVC barrier to assess a car's frontal force levels and to load one side of the car to check the compartment integrity.

Originally the approach also included a high speed (80 km/h) ODB test to measure compartment strength. This test is not currently included in the approach because it is thought that adequate control of the compartment strength should be possible using a lower speed (e.g. regulatory or EuroNCAP) ODB test or the PDB test. However, if an absolute measure of compartment strength is required then a high speed test, either ODB or PDB, will be necessary depending on which approach is finally chosen. This is because in the lower speed test the car may not be deformed sufficiently to load the compartment fully, so the Load Cell Wall (LCW) measure in these tests will only give an indication of the load the compartment has withstood in that test which is not necessarily the maximum load that the compartment can withstand. A high speed test ensures sufficient deformation of the car to load the compartment fully so that the LCW measure gives a true indication of the compartment strength.

The FWDB set of tests builds on current tests to offer the necessary self protection and partner protection measures with a minimum number of tests.

The FWDB test is effectively a modification of the US FMVSS208 test, the modifications being the addition of a deformable element and a high resolution Load Cell Wall. The intention of the FWDB test is to control both partner and self protection. For partner protection the car's structural interaction potential will be assessed using the measures from the LCW. The premise is that cars that exhibit a more homogeneous force distribution on the LCW should have a better structural interaction. The assessment has been designed so that it can be applied in a stepwise manner and is described in detail in the section below. For self protection the occupants deceleration and restraint system performance will be assessed using dummy measures in a similar way to the current FMVSS208 test. The restraint system will be subjected to a severe deceleration pulse. One of the design criteria for the deformable element was that the car's deceleration in this test should be similar to that in a rigid wall (FMVSS208) type test to provide a similar assessment of occupant's deceleration and restraint system performance.

The ODB test is the same as the current ODB test used in Regulation 94 and EuroNCAP, but it has a LCW behind the deformable element to measure the global force. As for the FWDB test, the intention of the ODB test is to control both partner and self protection. For partner protection the car's frontal force level will be measured using the LCW. A methodology to do this has been developed in this project and is described in detail in Deliverable 27. In a first step this force could be monitored and in later steps the minimum and / or maximum force could be controlled. For self protection the compartment integrity will be assessed using dummy measures as in the current ODB test with additional compartment intrusion measures if necessary, i.e. show that car can absorb the impact energy in part of the structure without significant deformation/collapse of compartment. Also, occupant protection will be assessed using dummy measures in the usual manner with a softer occupant compartment deceleration pulse than in the FWDB test. This effectively gives an assessment of the restraint system's performance with two deceleration pulses, which ensures that it is not over-optimised for good performance with just one pulse.

4.2.1. FWDB Procedure

As mentioned in the section above the intention is that the FWDB test should be used to assess a car's structural interaction potential and provide a high deceleration pulse to assess its self protection capability.

For structural interaction, the intention is to first ensure that all vehicles have adequate structure in a common interaction zone to ensure interaction between all vehicles, e.g. low sports cars and high sports utility vehicles. Following this, the intention is to encourage vehicles to have a 'more homogeneous larger pushing surface' to improve further structural interaction. In the test work performed for this project, cars with a multi-level load design were shown to offer better structural interaction than single load path design ones.

For self protection, the intention is to assess the car's performance using dummy measures in a similar manner to the US FMVSS208 test. No work to investigate the most appropriate injury criteria and performance limits has been performed in this project. However, dummy data has been collected in FWDB tests which could be used as a basis for future work.

In this section, a detailed description of the test configuration is given, which includes an explanation of the Load Cell Wall (LCW) configuration and the purpose of the deformable element. The assessment concepts and its details, including the assessment areas, are described in the following section.

The FWDB test configuration is similar to the FMVSS208 test but it has a deformable element and a high resolution Load Cell Wall (LCW) [Figure 4]. The recommended test speed is 56 km/h which is the same as that used in US NCAP.

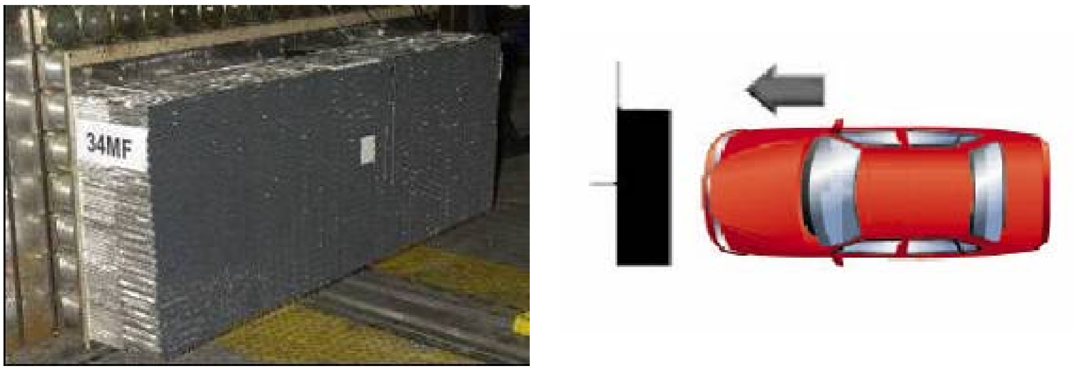


Figure 4: FWDB Test Configuration

The LCW consists of cells of nominal size of 125 mm by 125 mm. The load cells are mounted 80 mm above ground level so that the division line between rows 3 and 4 is at a height of 455 mm which is approximately mid-point of the US part 581 bumper beam test zone [Figure 5].

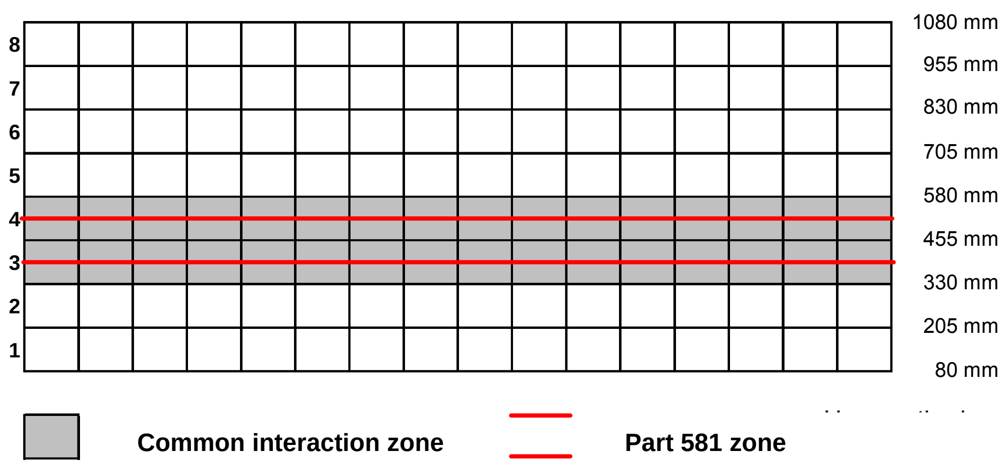


Figure 5: LCW configuration.

The reason for this particular height was chosen was to be able to detect whether vehicles had structures in alignment with the top and bottom halves of the Part 581 zone by examining the loads on rows 3 and 4 of the LCW. The intention of this was to enable the test procedure to be used to encourage all vehicles to have crashworthy structures in a common interaction zone that spans the part 581 zone. This should ensure structural interaction between high SUV type vehicles and cars as most cars have their main longitudinal structures in the Part 581 zone to meet the US bumper beam requirement as shown by the structural survey performed in Work Package 1 of this project [Figure 6]. It is important to note that the automotive industry has adopted a policy to ensure structures are located in the

Part 581 zone. Alignment of vehicle structures in Europe and North America can thus be achieved using this interaction zone.

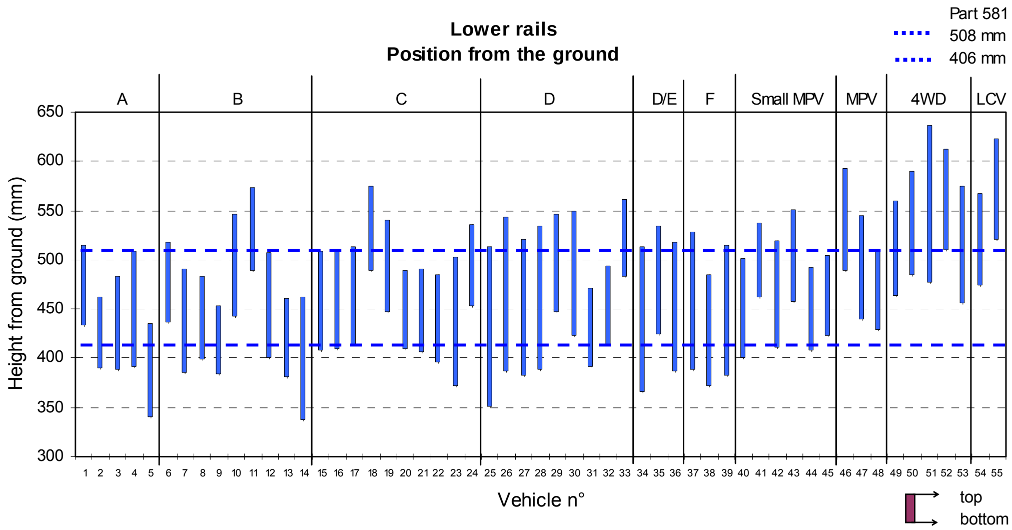


Figure 6: Lower rail ground clearance.

The deformable element consists of two layers each 150 mm deep. The front layer is made from honeycomb of crush strength of 0.34 MPa which is the same as the main body honeycomb of the current EEVC barrier. The rear layer is made from honeycomb of crush strength of 1.71 MPa. The rear layer is segmented into 125 mm by 125 mm blocks which align with each of the load cells. The reason for the segmentation is to effectively reduce the shear strength of the layer to prevent it spreading load applied in alignment with one load cell to adjacent load cells. The development of this face and its purpose are described in more detail in previous work [1]. In summary its purpose is:

- To generate relative shear in the front structure to exercise any shear connections between load paths and allow the assessment of horizontal structures, such as bumper crossbeams.
- To attenuate the engine dump loading. When the engine impacts a rigid wall, it is brought to rest very rapidly generating high inertial forces. In a car to car impact, the engine can rotate or move slightly out of the way of the other car's engine, so reducing its deceleration.
- To prevent unrealistic decelerations at the front of the car. The parts of the car that first impact the wall are decelerated instantaneously giving rise to large inertial forces. Such forces are not present in impacts with deforming structures, such as other cars.
- To prevent localised stiff structures forming preferential load paths to the wall and reduce the loading from adjacent structures which are slightly set back. This does not occur in impacts with other cars.

An additional consideration in its design was to ensure that it had a minimal effect on the occupant compartment deceleration pulse compared to a rigid wall test as the test is also intended to function as a high deceleration test.

4.2.2. Assessment

The assessment consists of two parts. The first part is the assessment of the car's structural interaction potential using the high resolution LCW measurements and the Structural Interaction (SI) criterion. The second part is the assessment of the car's self protection capability using the dummy measurements.

The Structural Interaction (SI) criterion has been developed recently to resolve issues with the previous Relative Homogeneity Criterion (RHC) [7]. Its development was based on the following requirements:

- An ability to be applied in stepwise manner to allow manufacturers to gradually adapt vehicle designs
- To encourage better horizontal force distribution (crossbeams).
- To encourage better vertical force distribution (multi-level load paths).
- To encourage a common interaction area with minimum load requirement.
- To be insensitive to bottoming out the barrier face, which was a problem with the Relative Homogeneity Criterion.

The Structural Interaction (SI) criterion is calculated from the peak cell loads recorded in the first 40 msec of the impact. Compared to using peak cell loads recorded through the duration of the impact (as with the previous RHC criterion), this has the advantage of assessing structural interaction at the beginning of the impact when it is more important and minimising the loading applied by structures further back into the vehicle such as the engine. The 40ms time interval corresponds to a B-pillar displacement of approximately 550 mm for most cars [Figure 7]. This should allow the detection of structures up to 400 mm (550 mm -150 mm) from the front of the vehicle, which is adequate for detection of most car subframe load paths. This is based on the assumption that structure that just crushes the 150 mm softer front layer of the barrier will not apply sufficient load to the LCW to be adequately detected. In addition, 400mm aligns with a recent NHTSA proposal to assess the AHOF over the initial 400mm vehicle displacement.

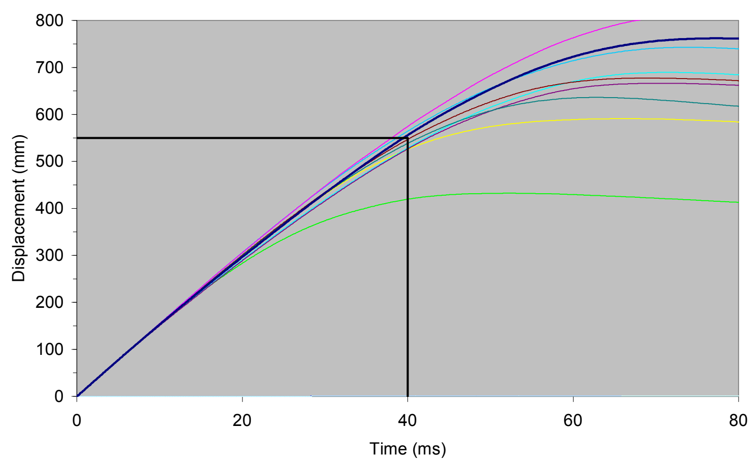


Figure 7: B-pillar Displacement vs Time Plots for FWDB Tests.

To allow manufacturers to gradually adapt vehicle designs to become more compatible, the criterion consists of two parts which could be adopted in a stepwise manner. The first part assesses over the common interaction area (Area 1) which is from 330 mm to 580 mm above ground level and consists of LCW rows 3 and 4. The intention of this part of the assessment is to ensure that all vehicles have adequate structure in alignment with this area to ensure interaction. The second part assesses over a larger area (Area 2) which is from 205 mm to 705 mm above ground level and consists of LCW rows 2, 3, 4 and 5. The intention of this part of the assessment is to encourage cars to better distribute their load better over a larger area to reduce the likelihood of over/under-ride and the fork effect. The results of tests performed as part of the VC-COMPAT project have demonstrated that cars that distribute their load vertically have better structural interaction potential.

The SI criterion consists of two components a vertical component (VSI) and a horizontal component (HSI). An outline of the steps to calculate these components for each of the assessment areas (Area 1 and Area 2) and the underlining concepts are described below. Further details of how to perform the calculations together with the supporting equations are given in the FWDB test and assessment protocol in Appendix 1.

Vertical Component (VSI)

<u>Area 1 (rows 3 & 4)</u>
The intention of VSI Area 1 is to assess if the vehicle has structure capable of generating a minimum load within the common interaction zone. The calculation steps are:

- Determine row loads by summing the peak cell loads that occur before 40 msec.
- Set minimum row load target. The current proposal is that this should be capped at 100 kN and mass dependent to ensure that lighter cars which cannot generate average loads of 100 kN are not unduly penalised.
- Determine negative deviation by summing the amount by which each row load fails to meet the minimum row load target.
- VSI Area 1 is equivalent to the negative deviation.

<u>Area 2 (rows 2 to 5)</u>
The intention of VSI Area 2 is to assess whether the vehicle has structure capable of generating a minimum row load within the larger assessment area and how evenly the load is applied vertically. The calculation steps are:

- Determine negative deviation for Area 2 in a similar way as for Area 1 above.
- Determine row load distribution using Coefficient of Variance.
- Determine VSI Area 2 by summing normalised values of negative deviation and Coefficient of Variance.
-

Horizontal Component (HSI)

<u>Area 1 and Area 2</u>
The main intention of the HSI component is to encourage strong crossbeam structures to adequately distribute the rail loading in the assessed area. Also, because vehicle structural width has been seen to be a major influencing factor in vehicle to vehicle tests performed in the VC-COMPAT project the HSI component can also be used to encourage wider structures for better structural interaction in lower overlap impacts. However, this part of the component will not be included in the assessment until it has been confirmed that wider structures have a significant benefit in real world accidents.

The calculation steps are:

1) For the crossbeam / rail strength balance part:

- Determine the peak cell loads that occur before 40 msec.
- Determine target cell load which is based on row load for each row. The maximum target cell load is [20kN], independent of vehicle mass.
- Determine negative deviations from target cell load for centre 4 load cells in each row, sum and average. Note HSI Area 1 includes only rows 3 and 4 whereas HSI Area 2 includes rows 2, 3, 4 and 5.

2) For the structural width part:

- Determine negative deviations from target load for load cells aligned with outer structure in each row, sum and average.

At present the HSI is defined as the value of the crossbeam / rail strength balance as defined above. However, in the future the structural width part may be included in the HSI component.

A proposal for implementing the SI criterion suggests two phases of application:

- Phase 1 – the vertical and horizontal components of the criterion are applied over assessment area 1 to ensure that all vehicles have adequate structure in a common interaction zone.
- Phase 2 – in addition to the requirement of Phase 1 the vertical component of the criterion is applied over assessment area 2 to encourage vehicles to spread their load better vertically.

A possible route map for the implementation of the FWDB approach is discussed in detail in section.

4.2.3. Preliminary Performance Limits

At present insufficient car to car crash test data exists to be able to set definite performance limits. However, the current VC-COMPAT data set can be examined to make initial estimates of what performance limits might be to encourage certain characteristics for better structural interaction performance. Please note that for both VSI and HSI a lower score is a better score.

For VSI Area 1, initial estimates are that a VSI Area 1 performance limit of zero with a target row load maximum of 100 kN should be used to ensure that all vehicles have structure in alignment with the common interaction zone. This is equivalent to a 100 kN minimum row load requirement for most cars.

All the vehicles tested with the LCW at the 80mm ground clearance (lower edge height) have structure in alignment with the FMVSS Part 581 zone based on results of the WP1 structural survey and therefore would be expected to result in a VSI score of zero [Figure 8]. For those vehicles tested with a 50 mm LCW ground clearance some interpretation of the results is needed to predict what would have happened had the LCW ground clearance been 80mm. For most of the test vehicles this would result in the vehicle structure moving further into alignment with row three of the LCW and so the VSI score would be expected to decrease to zero.

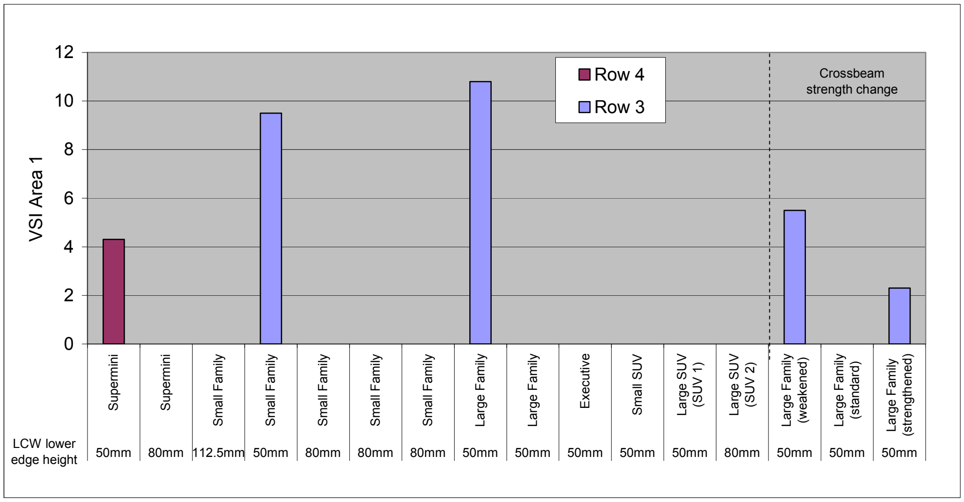


Figure 8: VSI Area 1 scores for VC-COMPAT FWDB tests.

For VSI Area 2, a performance limit of about 0.9 would distinguish between small family car 1 and small family car 2 [Figure 9]. Small family car 1 was a multi-level load path design which showed better structural interaction performance in car to car tests compared to small family car 2 which was a single load path level design [Deliverable 27]. However, this performance limit may be difficult to achieve for large SUV type vehicles because their design requires large approach angles which makes it difficult to design vehicles which can apply load to the lower part of the assessment area (row 2). Therefore, it may be necessary to have separate performance limits for large SUVs, but this should be avoided if possible.

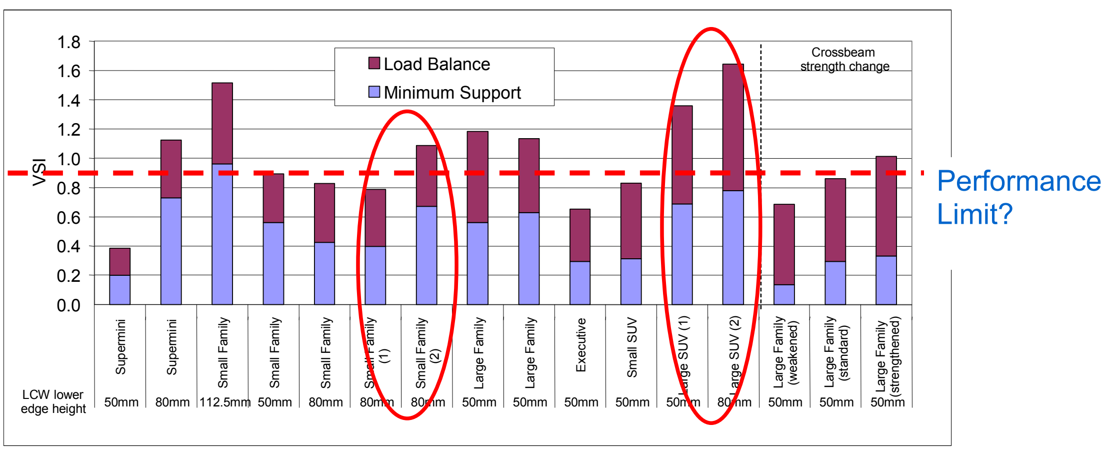


Figure 9: VSI Area 2 scores for VC-COMPAT FWDB tests.

For HSI Area 1, a performance limit of about 2.0 would distinguish the better bumper crossbeam performance of small family car 2 compared to small family car 1 [Figure 10& Deliverable 27]. It would also distinguish the better bumper crossbeam performance of the large family car with the stronger crossbeam in the series of tests performed by ACEA, the results of which were donated for use in the VC-COMPAT project [Deliverable 27].

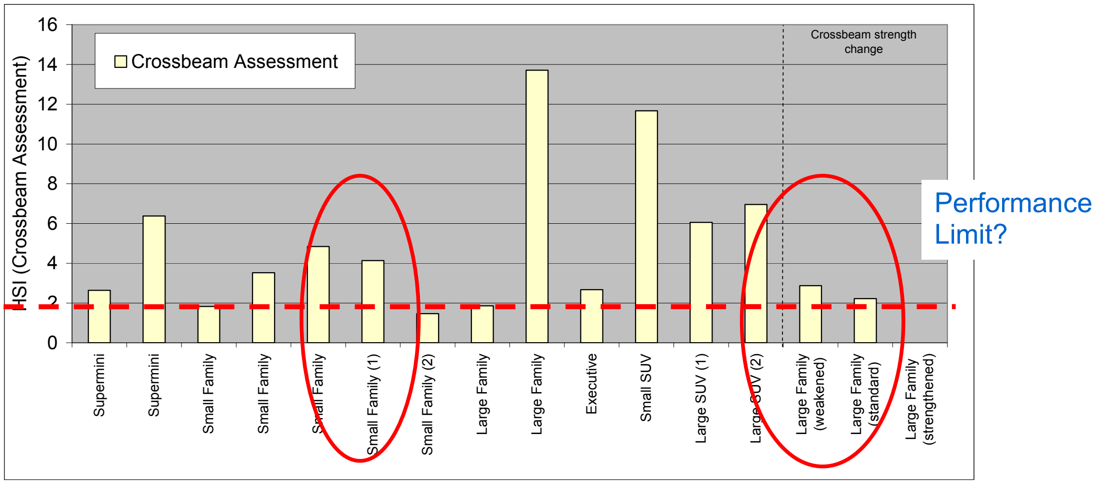


Figure 10: HSI Area 1 scores for VC-COMPAT FWDB tests.

4.2.4. <u>ODB procedure</u>

As mentioned previously, the intention of the ODB test is to control both partner and self protection. For partner protection the car's frontal force level will be measured using a Load Cell Wall (LCW). A methodology to do this has been developed in this project and is described in detail in Deliverable 27. In summary, the car's frontal force level is estimated by determining the LCW peak 10 msec excedence force. The reason that an excedence measure is used is to minimise the effect of unrealistic loads seen in this test which are not seen in car to car crashes such as those caused by the sudden deceleration of the engine when it bottoms out the barrier face [Figure 11].

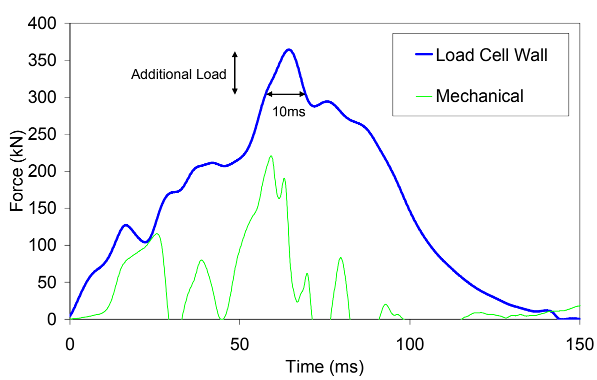


Figure 11: LCW force in ODB test showing additional load caused by 'engine dump'. Note: the mechanical force is the load applied by the powertrain components.

In a first step this force could be monitored and in later steps the minimum and / or maximum force could be controlled to encourage some degree of force matching.

For self protection the compartment integrity will be assessed using dummy measures as in the current ODB test with additional compartment intrusion measures if necessary, i.e. show that car can absorb the impact energy in part of the structure without significant deformation/collapse of compartment.

4.2.5. Route Map for FWDB Implementation

A possible route map for the implementation of the FWDB approach is described below:

Step 0 – Use LCW to monitor force levels in ODB test

At present limited evidence exists that the frontal force levels of newer vehicles are increasing, especially for heavier vehicles, which could worsen the current compatibility problem. To monitor this situation, it is proposed that a LCW is introduced into current regulation and consumer ODB tests to measure vehicle frontal force levels. This information could be used to determine if vehicle frontal force levels are changing or not and help determine future priorities for compatibility. In addition, accelerometers could also be added to the ODB tests to provide the additional information necessary to calculate the contribution of the engine load to the LCW force to help future research.

Step 1 - Introduce FWDB test to improve self protection and structural interaction

As a first step to improve a car's self protection capability and structural interaction potential, it is proposed to introduce the FWDB test. There are a number of options for introducing this test depending on which level of structural interaction improvement it is decided to enforce.

- Option 1
  - Improve self protection by controlling occupant deceleration using enforcement of dummy measures similar to the US FMVSS208 test.
  - Monitor structural interaction measures for research purposes.
- Option 2
  - Improve self protection by controlling occupant deceleration using enforcement of dummy measures similar to the US FMVSS208 test.
  - Improve structural interaction by ensuring that all vehicles have adequate structure in a common interaction area using enforcement of the criteria VSI Area 1 and HSI Area 1 with appropriate performance limits.
- Option 3
  - Improve self protection by controlling occupant deceleration using enforcement of dummy measures similar to the US FMVSS208 test.
  - Further improve structural interaction by ensuring that all vehicles have adequate structure in a common interaction area and spread their load better vertically using enforcement of the criteria VSI Area 1, VSI Area 2 and HSI Area 1 with appropriate performance limits.

Step 2 - Improve frontal force matching

Currently, without further research it is difficult to determine precisely what this step may be. However, possible options at this point are:

- Option 1
  - Further improve self-protection by increasing test speed to 60 km/h for regulation as proposed by EEVC WG16. However, this option would not be acceptable unless measures could be taken to ensure this increased test severity would not increase the frontal force mismatch between light and heavy cars.
  - Improve frontal force matching by controlling firstly minimum and possibly at a later date maximum frontal force levels using enforcement of LCW 10 msec excedence peak force level with appropriate limits.
- Option 2
  - Replace ODB test with PDB test and improve self protection and frontal force levels using measures as proposed in PDB approach.

4.2.6. Work Required to Complete Development of FWDB Approach

In this section the main work items to complete the development of the FWDB approach are outlined, firstly for the FWDB test and then for the ODB test.

FWDB Test

The main issues and work to address them are:

Partner protection (LCW based measurements)

- Criteria and performance limits
  - Criteria to assess a vehicle's structural interaction potential have been proposed and performance limits suggested. The work of the VC-COMPAT project has helped to perform an initial validation of the criteria. However, further work is required to refine the criteria, complete its validation and set performance limits. This work should include a test series to show that changing the vehicle to meet the performance requirement correlates to better performance in car to car impact, which could then be used to help perform a benefit analysis for the introduction of this test procedure.
- Test repeatability / reproducibility
  - In Europe two tests to investigate repeatability have been performed to date, which found no significant problems [Deliverable 27]. Further work is needed to check the validity of this conclusion with different vehicle types and confirm the appropriateness of the proposed vertical impact alignment tolerance of +/- 10 mm.
  - In sled component tests using a flat rigid impactor, the load distribution measured on the LCW showed a greater variation than expected. Even though it was shown that this variation should not have a substantial effect on test repeatability it is recommended that further work is performed to understand why this variation occurred and to minimise it.

Self-protection (Dummy based measures)

- Dummy
  - Work to determine the most appropriate dummy (THOR or HYBRIDIII), seating positions and size of dummy for inclusion in this test is required. Currently, some of this work is being performed in a European Commission 6th framework project called APROSYS.
- Criteria and Performance limits
  - Further work is required to determine appropriate criteria and performance limits. However, if the HYBRIDIII dummy is used as in the current FMVSS208 test, then criteria and limits could be based on those in FMVSS 208.

ODB Test

- Criteria and performance limits
  - A methodology to measure a vehicle's frontal force levels has been developed in this project. Further work is required to check the appropriateness of this methodology and set performance limits. Introducing a LCW into current ODB tests to collect data could be the first step of this further work.

4.3. PDB Approach – AS SUBMITTED BY UTAC

4.3.1. Context

- Current real life accident situation

Car to car accident data shows that fatalities and severe injury are caused by compartment intrusion. It is mainly due to unbalance energy absorbed between both cars resulting from a low level of self-protection and a high level of aggressiveness. The first step in compatibility leads to reduce this compartment intrusion by improving car structure.

- Current self protection situation

The present demand on self protection is increasing the local strength and global force deformation of all cars. The design of a large car makes it stiffer than a small one in order to compensate the mass.
Furthermore, the current frontal offset test is more severe for heavy vehicles because of the specific barrier used. Associated to self protection trend, compatibility requirements are unreachable today without changing deformable element.

- Why a new test procedure is needed?

Due to this context it is yet required to improve light cars compartment's strength without increasing heavy cars' one and to limit heavy vehicle front units' aggressiveness. In other words, it is necessary to assess the possibility to check and improve partner protection with regards to self-protection. To achieve this new requirement, an amendment of ECE R94 test procedure is needed.

- Why a new barrier face is needed?

The current European barrier face was a good compromise in the past but so far, with new compatibility requirements, these characteristics are creating new problems (greater than those expected to solve). Front end car designed changed a lot since the last 10 years to respect new constraints (repeatability, pedestrian, self protection etc…), so the deformable element is today completely obsolete. The element weakness causes bottoming out, constant energy absorbed and instability that leads to lack of repeatability and inaccurate FEM simulation (*See Figure 12 & Figure 13*).

Figure 12: Current ODB barrier instability.

Figure 13: ODB barrier bottoming out

- Why a new test speed is needed?

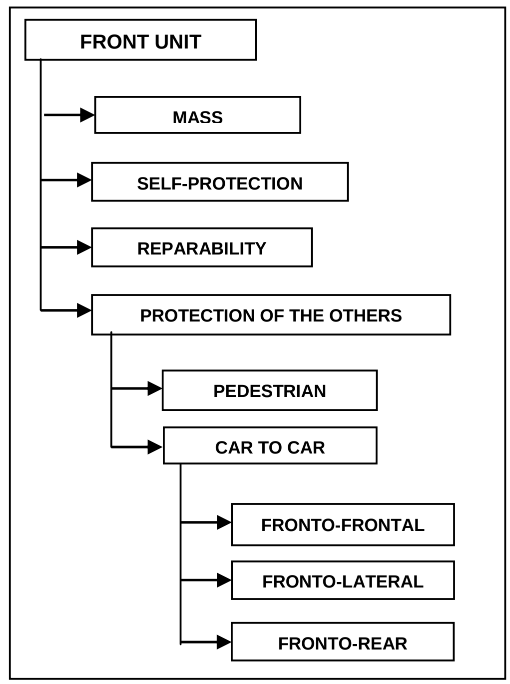
To answer the question of improving self protection level of the light car, it is necessary to increase the test speed (56 to 60 km/h) to reach compartment deformation. However, this increasing speed must be accompanied by a barrier change to reach compatibility requirements and to stop stiffer and stiffer heavy vehicle compartment.

- Why a new overlap is needed?

Checking half of the front end is needed for partner protection assessment in the future. Secondly, overlap is closer to real world accident data and car to car test configuration. Finally, combined with stiffer barrier it generates higher acceleration pulse. This test is also able to generate intrusion and acceleration pulse in the same time, considering that combinations of both are responsible for fatal and serious injuries in real world accident.

- Other constraints

The compatibility cannot be treated separately without taking into account the other constraints acting on a front unit non-aggression towards others (lateral configuration, pedestrians and reparability impacts). Furthermore requirements of the Euro 2008 standard and CO2 emissions have direct repercussion of limiting vehicle weight which is not always compatible with passive safety.



The experience is suggesting approaching compatibility design from a global viewpoint; the future regulation proposal must deal with that.

Reducing repair costs: In order to limit repair cost, insurers have defined requirements that indirectly determine the design of the front unit. However it contradicts the notion of compatibility and pedestrian safety.

Improving Protection of pedestrians: In order to improve pedestrian safety, the vehicle front end must be modified with soft bumper and lower contact zone.

Improving lateral compatibility: The requirements are identical to those for frontal impacts, as regard the front ends, with, in addition, very advanced load transfer paths to catch lower structure of the target car.

- Performances and limits

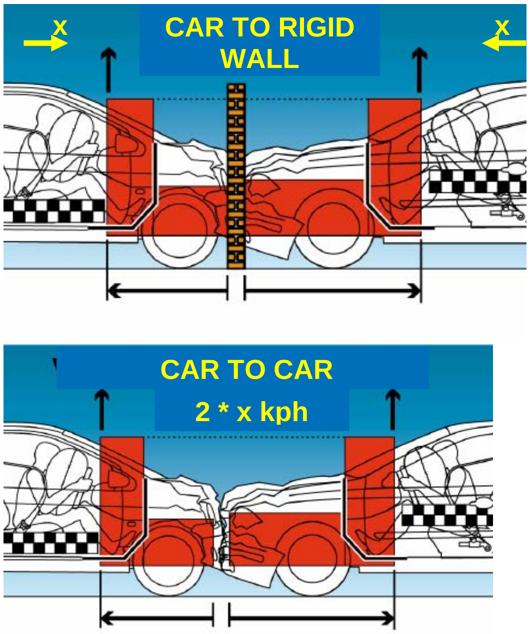


Figure 14: Energy to absorb in car to car

Compatibility in car to car depends on correct distribution of energy between the two vehicles. The ideal is to achieve a car-to-car situation featuring the same kinetics and performance as it would apply against a wall (see Figure 14).

In the case of cars that are ideally compatible impacting each other at a closing speed of 100 km/h, each car must individually sustain deformation corresponding to an impact against a wall at 50 km/h.

The objective is to offer the same survival potential in both vehicles; in other words, any intrusion should be similar to that observed in a barrier impact at half the closing speed. This is equivalent to say that the EES (Equivalent Energy Speed) is identical for both vehicles. As a consequence, the energy absorbed by each vehicle is proportional to its mass.

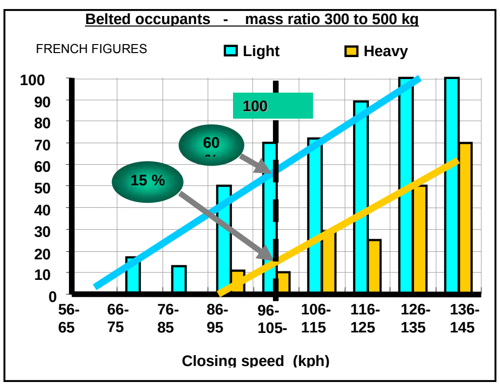


Figure 15: Cumulative % of MAIS3+

Accident studies show that 60% of cases of people involved (MAIS3+) in the light car would be covered by choosing 100 km/h closing velocity (see Figure 15).

It is specified that these progress will be also applicable for higher closing speeds.

- Structure to promote

In order to take advantage of all energy absorption potential of both cars, their structure must interact correctly. In term of design, one way to achieve good structural interaction is to offer a large front surface which a homogeneous stiffness. Ideal case would be a rigid plane between both cars sustained by multiple load paths. The real solution that satisfies all the requirements involves a multiple number of strongly inter-related load transfer paths and a progressive stiffness increase. The proposed test procedure should be able to detect this front end design, in order to put this item under control.

- Vehicle investigation area

In order to detect all structural components involved during a car to car impact, the investigation area needs to check, in height, from the subframe to longitudinal, but also, in depth, a sufficient crush distance to check lower load path back from the front end. Structural analysis performed within VC-COMPAT project shows that to take into account important front structure, the investigation area on a car needs to be included:

- in height : between 180 mm to 650 mm from the ground
- in depth: from the font bumper to 700mm

4.3.2. Strategy

The strategy of the PDB (Progressive Deformable Barrier) approach is to develop a test procedure which takes into account all following items:

- Vehicle: front end design, mass, geometry
- Accident data: structural interaction, compartment strength
- Environmental effects to increased vehicle mass: consumption, emissions, CO_2, etc…
- Current frontal test procedures
- Worldwide context: harmonization, different fleets
- Global cost: number of test proposed, number of material needed
- Other constraints: pedestrian, reparability, side impact.

⇨ **The aim of this proposal is to have a global approach to solve compatibility problem.**

The first priority of the PDB approach is to harmonise the test severity (EES) for all mass range (see Figure 16). Therefore it would be possible to speak about compatibility and to check the three main parameters defined to improve car crash compatibility:

- improve structural interaction
- control the frontal force level
- evaluate the compartment strength.

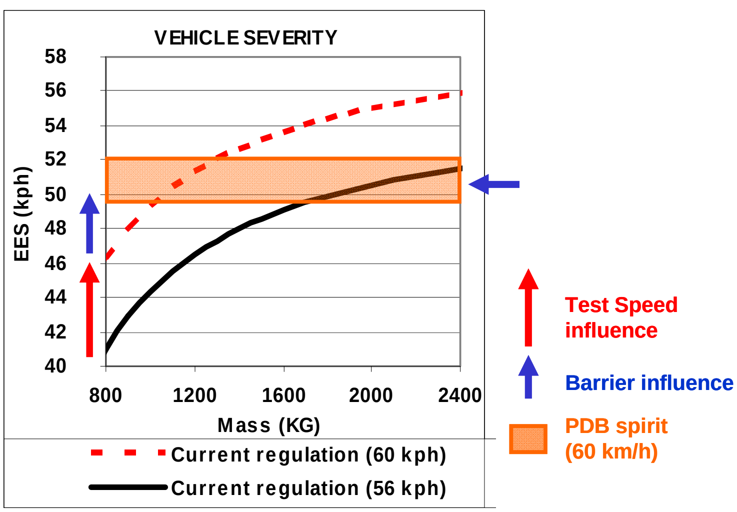


Figure 16: EES evolution with introduction of PDB test procedure

Remarks:

- Red line shows the effects of increasing speed. There is no improvement for compatibility: heavy car will be always designed stiffer than light car.

- The orange area shows the effect of introducing new deformable element. It is a chance to harmonize front end force and switch to possible force matching.

⇨ **The demand of self protection level for light cars is clearly higher than the current regulation without penalised heavy vehicles**.

The combination of deformable element and higher test speed leads to higher severity for light cars without increasing severity for heavy ones. It represents the first step towards force matching.

Due to test severity harmonization, it will allow balancing front end force even if perfect force matching is unrealistic due to vehicle front end geometry (limited overhang) and same intrusion level requirement (see *Figure 17*)

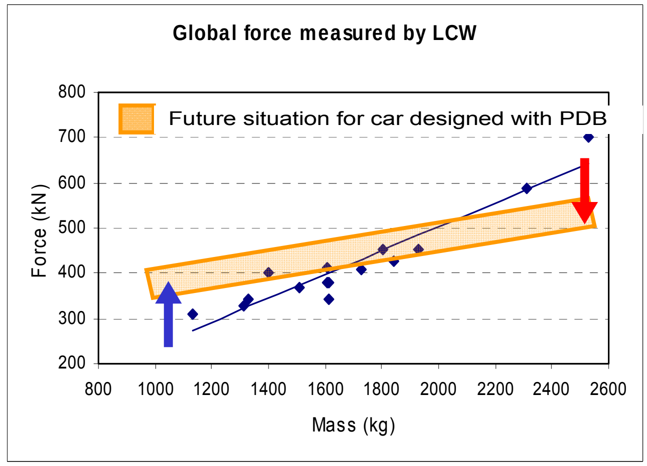


Figure 17: Possible improvement of force matching

4.3.3. <u>PDB procedure</u>

The PDB test is a 50% overlap offset test. The barrier stiffness increases with depth and upper and lower load levels to represent an actual car structure (see Figure 18). As we have seen before, the PDB barrier was designed to harmonize the test severity among vehicles of different masses; it will encourage lighter vehicles to be stronger without increasing the force levels of large vehicles. Furthermore, the dimensions and stiffness of the PDB make the bottoming-out phenomenon very unlikely. The barrier face is capable of generating sufficient differential deformation of the weak and stiff parts of the car's front structure to replicate what happens in most accidents. This will encourage future car designs to incorporate structures which distribute the force on a large surface. Consequently, the stiffness of the barrier face is adapted to check this phenomenon.

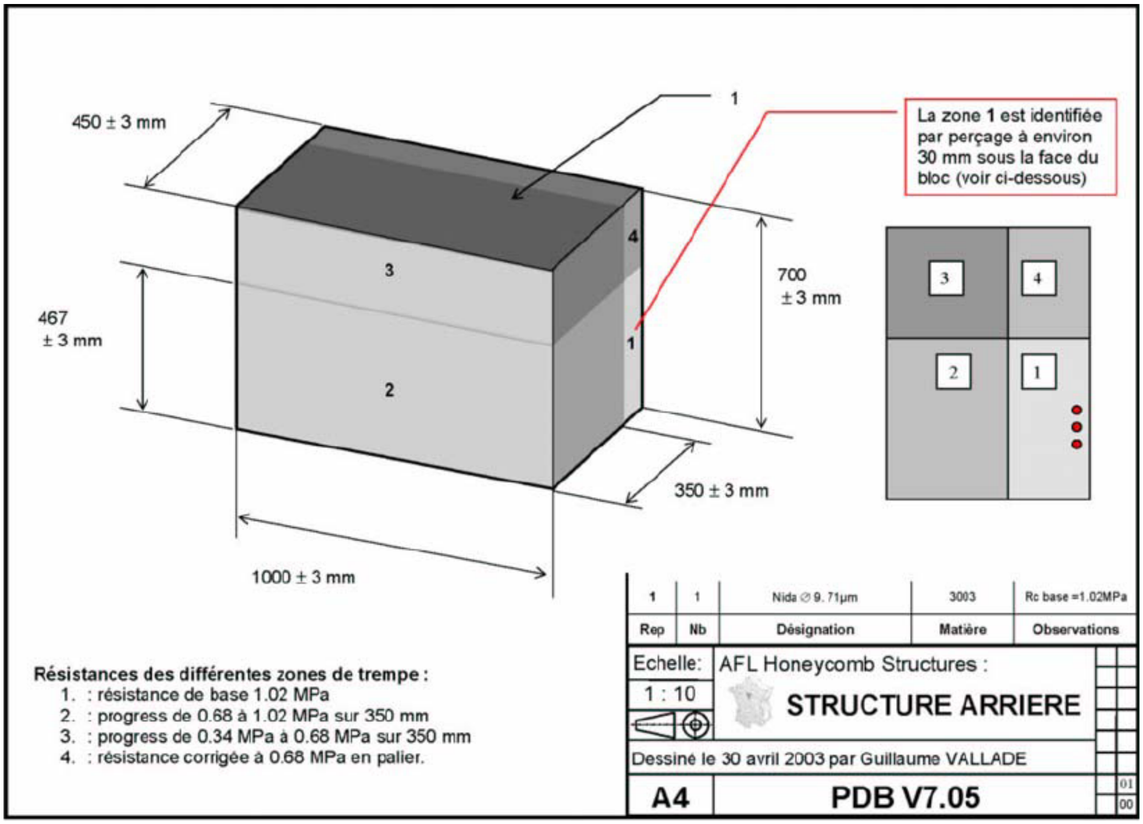


Figure 18: PDB Side view. Dimensions, position and stiffness.

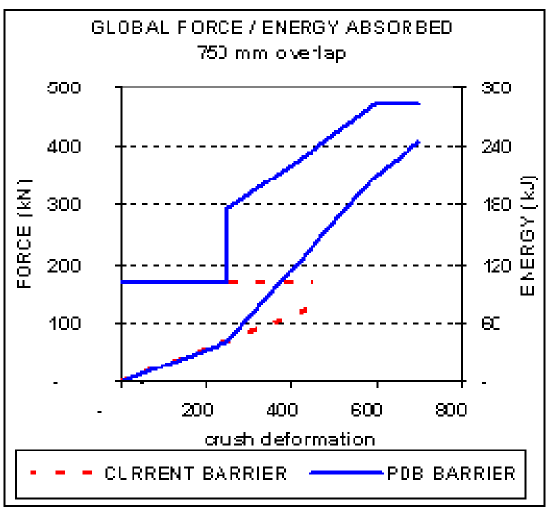
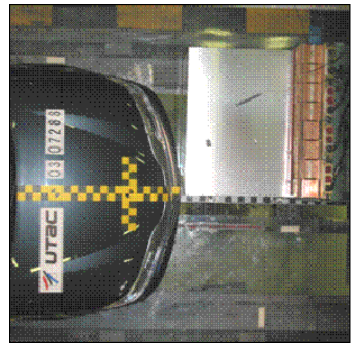


Figure 19: Force and energy capacity comparison for a same overlap

TEST Procedure



Comparing with current R94 Frontal ODB test, 3 parameters are changed:

- Obstacle : PDB Barrier
- Speed: 60 km/h
- Overlap: 50%

The aim is to answer compatibility requirements:

- Test severity harmonisation
- Structural interaction
- Frontal force level
- Evaluation of compartment strength

Change of parameters will be an answer to compatibility requirements:

		COMPATIBILITY REQUIREMENTS		
		TEST SEVERITY HARMONISATION	SELF PROTECTION	PARTNER PROTECTION
		FORCE MATCHING	COMPARTMENT / RESTRAINTS	STRUCTURAL INTERACTION
PARAMETERS	SPEED 56 → 60 km/h		√	
	BARRIER EEVC→ PDB	√	√	√
	OVERLAP 40% → 50%		√	√

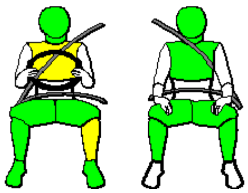
4.3.4. Assessment

Three parameters have been identified as important for compatibility. The PDB test protocol proposes tools and measurements to assess them:

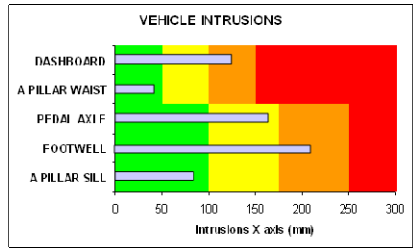
- self protection coming from vehicle analysis and dummy criteria
- partner protection coming from barrier deformation

- SELF PROTECTION

Car design for frontal crash must limit passenger compartment intrusion (first cause of fatal injuries) and generate acceptable deceleration from the occupant point of view. Higher acceleration pulse combine with higher intrusion level allows getting closer to real life accident where both parameters are responsible for fatal injuries and injured.
Today, self protection assessment is very well known. According to current ECE R94, the assessment is based on dummies criteria. EuroNCAP incorporates intrusion measurements such as dashboard, firewall and A-pillar. However the deceleration pulse in current ODB is too soft to provide sufficient structural deformation and occupant loading to effectively measure self protection. This is due to the deformation of the deformable element face. Deceleration pulse closer to car to car accident is generated with stiffer barrier face and higher overlap in the PDB test.



Dummy readings



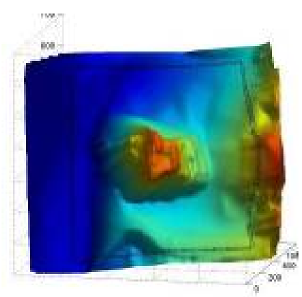
Vehicle intrusions

- **PARTNER PROTECTION**

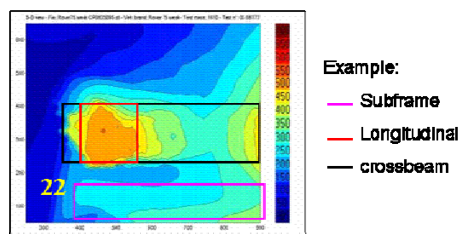
In term of design, one way to achieve structural interaction is to offer a front surface which is homogeneous in stiffness over a surface which is large enough. In order to take advantage of all the potential for energy absorption of both cars, their structure must interact correctly. To achieve this result, the stiffness on the front block must be distributed along multiple load paths. Having this is not enough, as they cannot ensure that the stiffness is homogeneously spread over the front surface. The PDB deformation already showed its capacity to verify the behaviour of new vehicles in regard to the partner protection targets.

The PDB barrier is able to detect local stiffness but also transversal and horizontal links among load paths. The barrier records front cross member, lower cradle subframe, pendants linking position and stiffness that improve vehicles compatibility.

Barrier deformation



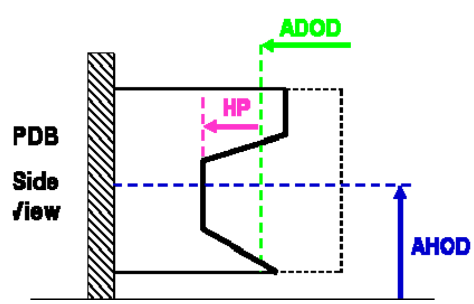
Barrier digitisation (3D)



Investigation area

The assessment proposed for the future will be based on deformation because information is inside. Laser scanning techniques are used to measure the 3D barrier deformations. Define criteria is under process, only parameters today can be proposed:

- Average Height Of Deformation (AHOD): linked to the geometry and architecture.
- Average Depth Of Deformation (ADOD): linked to the front force of the car
- Homogeneity: supposed to detect local penetration in the front barrier face that indicates bad homogeneity.



However, it is too early to introduce a partner protection assessment because, today, the notion of partner protection is not yet validated by international communities. International working group must clearly define what is a good structural interaction, what is an aggressive vehicle and suggests a aggressivity scale among vehicles. Further work is required before proposing a set of criteria.

- **SUMMARY**

With one test it will be possible to assess three main parameters that play a role in compatibility.

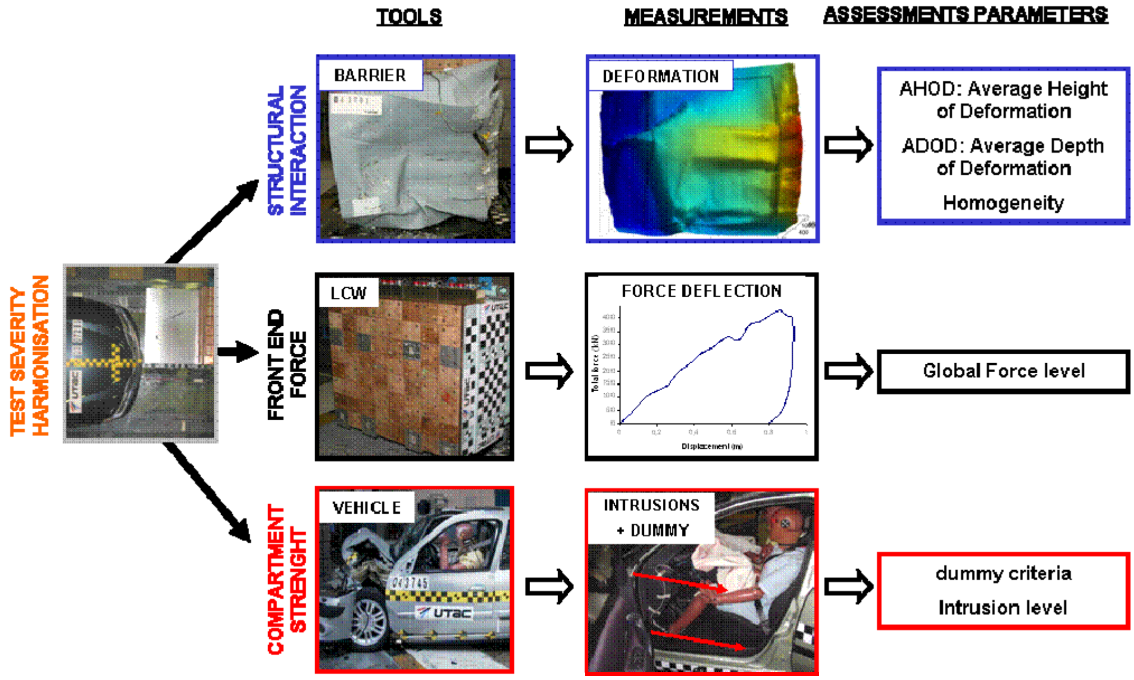


Figure 20: PDB procedure

4.3.5. Route Map for Implementation

- Step 1: Test severity harmonisation + Self protection assessment
  Aim: assess self protection + improve force matching / partner protection

  ⇨ Offset test modification: PDB introduction at 60 km/h
  + Data collection / monitoring to finalise assessment criteria for compatibility
    - Collect: barrier deformation / global force / intrusion / dummies
    - Define and choose adapted parameters / criteria / limits
    - Clarify “aggressivity” and establish an “aggressivity scale”

As a first step, the PDB approach is to replace the current ODB barrier by the PDB one in regulation. The first effect of the progressive barrier is the ability to test all vehicles at a more or less constant severity that lead to better force matching. PDB barrier introduction will be able to improve self protection of light vehicles (overloaded) without increasing heavy ones due to energy capacity absorption. Dummies criteria limits are the same than the current ECE R94 and integrity of the passenger compartment could be assess with the help of intrusion level in different part of the front compartment. In this first phase, assessment remains focused on self-protection.

This offset test could be combined with a Full Width Rigid Barrier test in order to check the restraint system.

- Step 2: Compatibility assessment
  Aim: assess self and partner protection

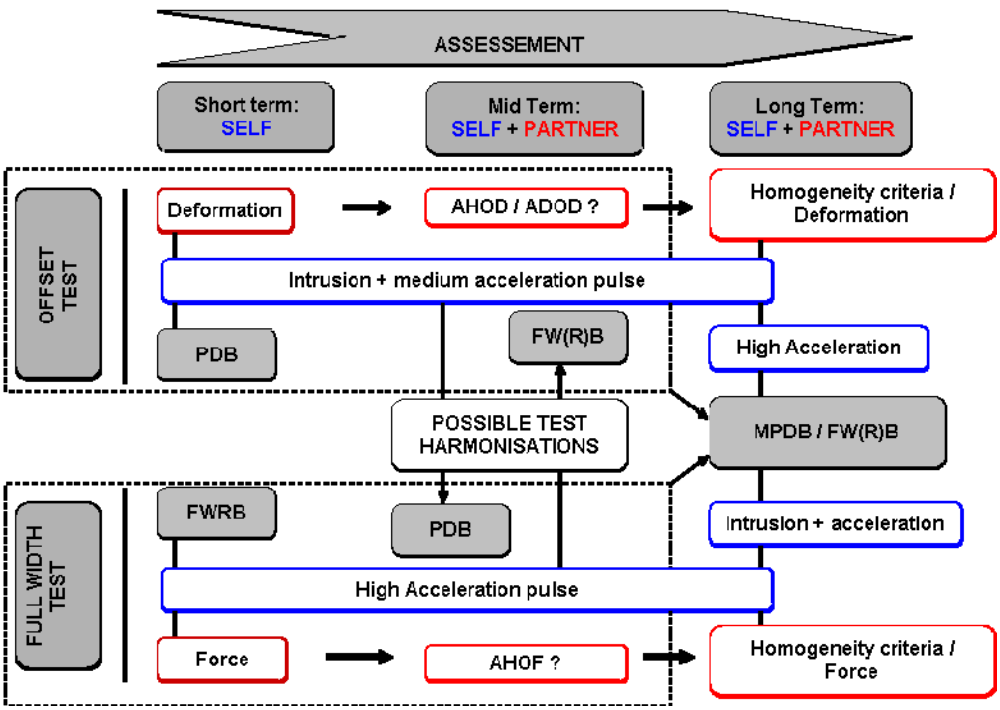
⇨ Partner protection criteria based on barrier deformation

All criteria and investigations will be based on the barrier deformation. PDB barrier is able to detect local stiffness but also transversal and horizontal links among load paths. It looks like car to car accident or test analysis, except that in this case, the barrier deformation is investigated instead of the car's. An aggressive vehicle would be identified by large and non homogeneous deformation.

- Step 3 (Long term approach): introducing Mobile PDB (MPDB)

To be closer to real life accident, the PDB could be fixed on a mobile trolley. A quick energetically approach clearly shows than this test due to conservation of momentum associated to different energy absorbed in the barrier allows to progressively switching from a light car overload to a heavy car partner protection test. The test is intended to represent a normal car to car impact.

- **POSSIBLE HARMONISATION**



4.3.6. Work Required to Complete Development of PDB Approach

- Propose criteria and associated performance limits when clear "compatibility definition" will be define by international working groups.
- Confirm that PDB approach leads to stiffer light car and allows force matching concept
- Confirm that Repeatability and reproducibility is achievable.
- Confirm that the PDB barrier will be useful for front end design with FEM simulation

4.4. Conclusions

Two main testing approaches have been investigated by WG15. These tests have been proposed as complete packages to assess compatibility and self protection for frontal impacts. They can be summarized as tests incorporating:

1) Full Width Deformable Barrier test and an Offset Deformable Barrier test
2) Progressive Deformable Barrier test and Full Width Rigid Barrier test

These two approaches have been discussed in the group. An alternative approach, a combination of the two methods, may also be examined but has not been a formal activity in WG15.

5. Working Documents and Summary of test and supporting data to develop procedures

WG 15 has amassed about 400 working documents that are listed on the EEVC website (www.eevc.org). It is not possible to summarise all the documents in this report. However some relevant information is provided in Appendix B. The text represents extracts from larger technical reports. An overview of the information in their respective sections of Appendix B is as follows:

1. C.1 Structural Analysis – UTAC: The main findings of VC-COMPAT Workpackage 1 where the geometry of vehicle structural members were documented.
2. C.2 Crash Testing: The most recent crash test results related to frontal compatibility
    a. C.2.1 Summary of VC-COMPAT Test Results –TRL: The most comprehensive test series conducted in a joint work program with WG15 national members and summarised by TRL. All the results were discussed at WG15 meetings. Some disagreements are expressed by some members but the majority of the conclusions are unanimous. The full report is available to WG15 members but it has not been made public. Vehicle models have been identified in the report and this has not been accepted for further release.
    b. C.2.2 French program – UTAC: Crash tests related to the development of the PDB barrier carried out by UTAC and French industry. A summary of the results were presented by UTAC at WG15 meetings.
    c. C.2.3 Capacity of PDB and FWDB to detect structural interaction (UTAC): An analysis of some VC-COMPAT tests and French program tests. The conclusions have been discussed but not all WG15 members are in agreement
    d. C.2.4 External Work to WG15 – Japan: The results of some Japanese research have been made by Japanese representatives invited to a limited number of WG15 meetings. Only the presentations have been made available to the group.
3. C.3 Computer Modelling
    a. C.3.1 VC-COMPAT Modelling (TNO / Chalmers): A summary of the VC-COMPAT modelling workpackage. Full documentation is available from the VC-COMPAT project and is public information.
    b. C.3.2 German Industry: A study conducted by VW investigating the potential to exploit the PDB barrier's energy absorbing capacity. Some members of WG15 have concerns about the modelling assumptions made.
    c. C.3.3 French Industry: A recent simulation study by French industry in response to criticisms about the energy absorbing capabilities of the PDB barrier.

4. C.3.4 Moving Progressive Deformable Barrier development program – TNO: A joint research program with TNO, UTAC, FTSS, GME, PSA, Renault, and AFL. The use of a PDB mounted on a moving trolley (similar to the side impact moving barrier) was investigated as a long term development in compatibility testing. A presentation has been made available to WG15 and a paper has been presented at the 2006 ICRASH conference.

6. DISCUSSION – WG15

Two testing approaches have been the focus of the WG15 research activities. These two approaches have exhibited desirable performance features but also require further development and validation. This section provides the current concerns of the working group members and suggestions for future activities. Note that in the following section a test "procedure" is a specific test condition to measure compatibility characteristics. A test "approach" is the suite of test to fully assess the vehicle's compatibility and self protection requirements in frontal impact.

Independent of the procedure, some common issues must be resolved before any test procedure can be put into general use. First, any test that assesses vehicle crash performance must be validated for as wide a range of vehicle types as possible. Particularly relevant is the classification of vehicle to be assessed. The original test procedures developed for VC-COMPAT focused on passenger vehicles up to 2.5 tonnes. Any extension of crash test requirements for vehicles up to 3.5 tonnes will require that the test equipment and materials are suitable for this range of vehicle masses.

Given that the vehicle classes subject to compatibility testing are given, the test method must be sufficient to measure and assess compatibility. The working group has identified the following general criteria for compatibility:

1) Good structural interaction
2) Good compartment strength
3) Force matching

These criteria have been investigated in the limited crash tests available to the working group and preliminary requirements have been discussed. To further the development of the procedures, a rigorous definition of the global boundary conditions for compatibility must be put forward. These boundary conditions will identify performance limits for vehicle compatibility and requires the translation of the current subjective analyses into fully objective criteria. As illustrated in the discussion of test results, there are many important physical processes that have been identified as contributing to compatible crash performance. There is however no validated, quantitative methods to translate these into objective crash test criteria

The following discussion presents the concerns documented by the members of WG15. Appendix D contains an extensive list of the comments pertaining to the for test types that could be incorporated into a compatibility testing program. This list is summarised in this section to identify the main items for further investigation.

6.1. FWDB Test Procedure

The approach promoted by the FWDB is to address both self and partner protection of the vehicle. This is accomplished by the two tests described in Section 6 – a full width and an offset test. Both tests would be required to properly assess all aspects of compatibility. The primary test method to identify the structural interaction characteristics of the vehicle is the full width test at 56 km/h using a high resolution load cell barrier with a deformable barrier face (see Section 4.2.1). The distribution of the forces measured on the barrier are used to assess the structural interaction of the vehicle. The high acceleration pulse generated in the test is also a useful test for the restraint systems. To be suitable for implementation in a legislated test program the following must be addressed:

- Understand the relationship between the honeycomb deformation and load cell measurements: Results from different testing programs indicate that the forces measured behind the honeycomb material are not necessarily distributed as suggested by the honeycomb deformation. This has been initially investigated and further work needs to determine how this variation could influence the assessment criteria.

- Must verify that all important vehicle structures can be detected by the barrier (horizontal structures): Only a limited number of vehicle types have been tested and a range of vehicle types must be tested to determine if all relevant structures are detected. This must be referenced to vehicle-vehicle testing.
- Repeatability: The test method has sensitivity due to the discrete placement of the load cells. The impact accuracy has been investigated but further work is needed to determine requirements for test accuracy (vertical and lateral) to ensure minimal variation in the assessment criteria.

6.2. PDB

The PDB Test approach contains two test procedures to assess vehicle self and partner protection. The PDB test itself is a 50% offset test at 60 km/h. The honeycomb barrier used in the test has a progressively increasing stiffness designed to represent a car's behaviour. The deformation of the barrier is used to assess the structural interaction properties of the vehicle. The deformation properties are designed to harmonise frontal force levels and the test can be considered for self protection assessment as well. Specifics of the test method can be found in Section 4.3.3. The PDB test is proposed to address compatibility and self protection issues and a full width rigid barrier test compliments the PDB test by providing a high deceleration pulse for testing interior restraint systems.

The most relevant issues that must be addressed in a PDB test procedure are

- No assessment criteria available for partner protection: The PDB collects force and barrier deformation data to assess partner protection. There are no current assessment criteria that objectively evaluate the partner protection. The available parameters do not have threshold limits.
- Calculation of absorbed barrier energy to find vehicle EES value must be validated: The PDB barrier is scanned and an absorbed energy is calculated using the deformation properties. The dynamic force deflection characteristics are not necessarily identical to the static values used to describe the barrier. Honeycomb barrier is also subject to off axis effects that will lead to lower dynamic stiffnesses and can lead to overestimates of the energy absorbed by the barrier during a crash test.
- Validate the PDB introduces a minimum EES severity for all test vehicles: The PDB barrier properties have been designed to harmonise the EES of the test vehicle, independent of mass. This harmonisation must ensure that all vehicles are sufficiently loaded to assess self and partner protection. The current range of EES is 45-52 km/h.

6.3. FWRB

A full width barrier test with a rigid face is used in North America and Japan for frontal impact requirements. The US and Japan have been using this barrier type with the 125x25 load cell wall to investigate compatibility assessment similar to the FWDB. This configuration has not been investigated by WG15 and only a FWRB is proposed in the PDB approach as a high deceleration pulse test condition.

An assessment of the FWRB test as a compatibility test condition, the following concerns have been raised by WG15:

- Does not measure structures set back from the vehicle front: Both the TRL and Japanese testing have indicated that the rigid barrier face preferentially deforms the very forward components of the vehicle and structures set back from the front (like subframes and blocker beams) may not detected in this test approach. VC-COMPAT has identified the importance of these structures and recommend that a test method can detect structures at least 400 mm behind the bumper cross beam.

- Difficult to detect connecting structures: The lack of a deformable element does not allow lateral or vertical connecting structures to be activated by shear loads acting between the main structures. Connecting structures are not readily detected by the load cell wall unless they are very near the front of the barrier (see previous point).

6.4. ODB (ECE-R94 barrier)

The current EEVC barrier used in ECE-R94 and Euro-NCAP testing has been promoted as a compartment strength test in the FWDB test approach and is also used to measure frontal force levels in the FWDB approach. There is currently no suggestion to implement the EEVC barrier in any set of tests to assess structural interaction.

Open questions related to the ECE R94 (or Euro-NCAP) test procedure are:

- Barrier instability for new generation cars: Testing conducted in France has demonstrated that the barrier may deform in different manners for the same vehicle model. This unstable behaviour can lead to different energy absorption in the barrier and raises repeatability issues.
- Difficult to assess force levels with this barrier type: The stiffness (and previously raised point on instability) make it uncertain if the barrier accurately measures the frontal force levels. As the barrier bottoms out for modern generation vehicles, high loads are measured during the engine contact with the load cell wall (engine loading or dump) that are not realistic measurements of the car-car crash loads. A method to correct for this effect has been proposed and requires further validation.
- The current test speeds for regulation cannot be increased using the existing ECE-R94 barrier without increasing the existing discrepancy in frontal stiffness and aggressiveness for the vehicle fleet. An example of this effect is shown in Figure 16. WG15 would not recommend increasing the test speed in R94 with the existing barrier face unless compatibility measures are put in place.

6.5. General opinion of the group

Working Group 15 has developed a list of assessment criteria that is used to evaluate the current test methods. There are four main headings that address Structural Interaction, Reproduction of Collapse Modes, Test Procedure, and Other issues. Several specific questions or review items are listed under each main heading. A total of 20 different items are listed covering issues such as repeatability, availability of criteria, etc. that are used to assess the different test criteria against each other on a point-by-point basis. This list uses a numerical rating (0-3) that has been provided by the group members. WG15 does not support the use of this worksheet to sum some or all the points as method to select a test method since each point has a different weighting and these weighting factors have not been derived. The complete table with the present group scores is provided in Appendix E. **Note that the scores reflected in the table are the current reflection of the Working Group assessing test procedures that are not yet fully developed.**

The table in Appendix E provides two values for each factor and test: the average and variance. The entire survey of WG15 was collected and the arithmetic mean value is provided and should indicate the ranking of the test's effectiveness when compared to the other tests. The variance of each score indicates how much the group agreed to this point with a low number indicating a general agreement and a large number suggesting disagreement. Since discrete values were submitted, general agreement is indicated when the variance is less than 0.5 and less agreement starting when variance exceeds 0.5.

The following brief analysis of the table is divided into the four main groupings in the table:

1) Structural interaction – The group rates tends to rank the PDB first and then the FWDB barrier tests as being the most effective at detecting structural interaction properties in cars. The rating of each of these two tests varies from point to point but the variance indicates that the methods' performance are generally agreed to by the group
2) Reproduction of collapse modes of load paths - The group generally rates the PDB highest for most of the points in this section. The ODB (ECE R94) also rates high when it comes to compartment strength issues. The FWDB is best at measuring local forces over time. There is less agreement within the group in this section so further analysis of test data is needed create consensus within the group.
3) Test Procedure – This section is used to assess the simplicity, accuracy and repeatability of the different procedures. It is clear that the FWRB is the most reliable test method but also the least applicable according to the previous analysis. The FWDB and ODB tests tend to be higher rated. The variance numbers indicate that consensus within the group borders between agreement/ disagreement (0.5)
4) Others – This section includes general issues such as harmonisation issues and availability of assessment criteria. Like Point 1, the FWDB and PDB are essentially similar in ranking within the group.

7. CONCLUSIONS - WG15

The conclusions of the work conducted by WG15 during its current mandate are reported in the following section. The main items of the WG15 Terms of Reference (denoted as § comments) are provided to guide the reader.

The main task submitted to WG15 by the EEVC Steering Committee was:

> ***§1. Develop candidate test procedures to assess car frontal impact compatibility. Work will concentrate on car to car frontal compatibility whilst also considering the effects on other accidents such as impacts with the side of cars, trucks, pedestrians and roadside obstacles***

The activities of WG15 have lead to the development of two different test approaches, the Full Width Deformable Barrier (FWDB) and the Progressive Deformable Barrier (PDB) approaches. Both test approaches employ a full width and offset test condition to apply different loading conditions on the vehicle in order to measure different properties deemed as relevant for compatibility. The two test approaches (and a possible combination thereof) can be summarized as:

Approach 1

- Full Width Deformable Barrier (FWDB) test
  - Structural interaction
  - High deceleration pulse
- ODB test with EEVC barrier
  - Frontal force levels
  - Compartment integrity

Approach 2

- Full Width Rigid Barrier (FWRB) test
  - High deceleration pulse
- Progressive Deformable Barrier (PDB) test
  - Structural interaction
  - Frontal force matching
  - Compartment integrity

These two approaches have been discussed in the group. An alternative approach, a combination of the two methods, may also be examined but has not been a formal activity in WG15.

Through the development of the different test methods, the group has agreed that the following conditions must be satisfied by any new test approach that will assess compatibility:

1) Test procedures to control compatibility must assess the structural interaction, frontal force levels, and compartment strength of the vehicle. Current passive safety levels should not be compromised if the global improvements in road safety are to be achieved
2) One test procedure alone is not sufficient for assessing frontal impact. All of the main approaches combine a full width and offset type test. These two test conditions are needed to fully assess the structures and safety equipment of the vehicle

§2. Establish criteria to rate frontal impact compatibility

The two main test approaches have put forward different parameters that are used to evaluate, and thereby rate, frontal compatibility performance of different cars. The FWDB procedure uses the distribution of forces measured on a Load Cell Wall behind a deformable element, while the PDB test procedure uses the deformation pattern in a honeycomb barrier to assess vehicle performance.

The FWDB approach uses both a FWDB and an ODB test to assess a car's compatibility. Two evaluation criteria, the Vertical Structural Interaction (VSI) and the Horizontal Structural Interaction (HSI) have been developed for the FWDB procedure and are described in Section 4.2.2. These two criteria are based on the principles that 1) sufficient structure (applied load) can be detected and 2) that the loads are reasonably distributed within an assessment area. These criteria need to be further evaluated with different vehicle types to confirm that the procedure properly assesses a vehicle's structural interaction performance. The criteria are currently provided with initial threshold values and with further work, the numeric output from the HSI and VSI could be further developed for rating purposes. To assess frontal force levels, a new method has been proposed to identify the load values of interest from the ODB test using an excedence measure (see Section 4.2.4).. The method has been proposed but threshold values still need to be identified. Initial estimates from VC-COMPAT indicate 350-400 kN may be a minimum requirement for small cars. Upper limits have not been proposed yet due to concerns expressed by the vehicle manufacturers.

The PDB approach measures the deformation of the barrier after the test and uses this information to interpret the structural interaction and force levels of the tested vehicle. Currently the ADOD and AHOD (see Section 4.3.4) have been identified as parameters that and assessment could be based on but no performance limits have been proposed. An additional parameter that assesses the homogeneity of the vehicle structure is under development. The combination of parameters available for the PDB have been calculated for the tests in VC-COMPAT as well as the French national research programs. However, no formal compatibility assessment criteria with proposed thresholds have been published.

§3. Identify potential benefits from improved frontal impact compatibility;

The work conducted by WG15 in the EC project VC-COMPAT has provided important information related to the benefits and potential costs of improved compatibility. Initial benefit models have been developed for GB and DE databases and these serve as an important step to future analysis of the benefit of improved vehicle compatibility. In the GB approach CCIS data were analysed: for a lower estimate, it was assumed that all intrusion related injuries were mitigated, for an upper estimate, all contact induced injuries were mitigated. The DE approach uses an assumption based on the observation that, in the VC-COMPAT test program, 5 Star Cars could absorb 30% more kinetic energy in Euro NCAP tests than in car to car tests in the absence of compartment intrusion.

Cost estimates have been made using the industrial (Fiat) expertise in the group and a cost benefit for compatibility has been estimated. The increased sale and operating costs for improving vehicle compatibility were based on modifying existing vehicle designs. While analysing the costs of modifying car design for good compatibility, it has been suggested that for the next vehicle generation, where compatibility requirements are considered from the beginning of the development of a new car model, costs could be a fraction of those estimated for modifying an existing design.

Based on the cost savings (reduced injury costs) for compatible cars and the expected costs for modified vehicles, cost benefit calculations were developed and summarised below. The calculation is conservative and was not based on a specific test method, however most cases indicate a positive cost-benefit result. The negative results generated in the exercise represented pessimistic predictions of injury reduction and unlikely manufacturing strategies if new vehicle models are being developed.

Table 1: Cost Benefit Ratio of improved compatibility for EU15.

	Ratio of financial benefits to implementation costs		
	CCIS intrusion model	CCIS contact model	German model
Best case scenario	2.05	4.51	1.34
Worst case scenario	0.74	1.63	0.48

Details of the cost benefit can be found in Section 3.3.

§4. Research will continue into the understanding of frontal impact protection, to help ensure that steps to improve frontal impact compatibility will also lead to improved front impact protection;

Testing and simulation work that has been undertaken by, or reported to, WG15 has been a fundamental source of information related to vehicle frontal designs. Due to the various versions of the test and assessment procedures investigated in the last mandate period, considerable information has been gained about how vehicles interact with each other and the crash test barriers. The role of different elements of vehicle frontal structures (longitudinal beam location, cross beam strength, etc.) have become better understood and this information has been disseminated from WG15 and its activities in VC-COMPAT to the main stakeholders in automotive safety. In particular, one specific activity in VC-COMPAT was to develop a list of desirable features for compatible vehicles.

§5. Co-ordinate the EEVC contributions to the IHRA working group on Compatibility and Advanced Frontal Impact.

EEVC WG 15 has been represented at earlier IHRA meetings through the chair and secretary. In addition, IHRA compatibility and WG15 have held join meetings and attended workshops to promote information exchange. After 2005 IHRA has not had any activities and WG15 has not had any formal link to IHRA. WG15 anticipates future exchanges with the next IHRA (or similar) networking organisation.

8. RECOMMENDATIONS FOR THE WAY FORWARD

The two central test procedures, the PDB and FWDB, are not sufficiently developed to allow test approaches to be compared and select a preferred test procedure. The discussions of WG15, summarized in Appendices D and E show that all test procedures have issues to be investigated and that each test procedure has specific strengths that are not often found in another. This section outlines the recommended work to reach the position to make a proposal for a 1st step to improve compatibility. The work can be classified as global issues which are independent of a testing approach and work specific to a test procedure.

Global Issues:

- Further accident analysis and benefit analysis to update information on changing vehicle fleet
- Finalise the test severity (EES) for regulation test.
- Finalise assessment criteria for regulation test.
- Finalise objective assessment procedures to analyse results of car to car tests with respect to:
    - Good structural interaction
    - Good compartment strength
    - Compatible car
    - Importance of width of frontal structures.
- Identify critical injury mechanisms (in particular relevance of thorax injuries in high deceleration pulse type accidents)
- Finalise a compatibility scale for a rating system.

These global issues will require research that focuses on car-car testing as well as accident analysis using detailed databases. The work previously reported to WG15 provides an important, but incomplete basis.

Test Procedure Specific issues:

Further development of test approaches to the point where a decision on the most appropriate set of test procedures can be made.

For the FWDB the major work items are:

- Determine the link between honeycomb deformation and load cell measurements. Load spreading issues observed in rigid impactor tests should be clarified and determine if the assessment criteria are insensitive to these load variations.
- Verify that all important vehicle structures, identified in accident analysis, can be detected by the barrier (for example horizontal structures).
- Determine and control the sensitivity of the test method to the vehicle alignment with the loadcells.

For the PDB test major work items are:

- Propose and validate assessment criteria when fundamental questions have been answered (identified in Section)
- Validate the EES calculation method
- Validate that the PDB test guarantees a minimum EES test severity for all vehicles

For a set consisting of a combination of the two test approaches (combination of FWDB and PDB)

- Develop and propose complementary assessment criteria for a combination of the two test procedures

Regardless of the test approach chosen as a standard for assessing compatibility, several implementation stages will be necessary to phase in the full test procedure. To identify and validate the necessary performance levels for a first step in compatibility testing, a car to car crash testing programme with associated barrier tests will be required to show that cars that meet the performance requirement perform better in car to car tests than those that don't. It is likely that modified cars will be required for this. Some of the tests already performed in the VC-COMPAT project could form a starting point for this programme.

In parallel to the initial validation of the performance criteria of a test method, an updated cost benefit analysis for implementation of the selected test method is required. Accident data should be reanalyzed and better models that can identify the benefits for the specific test method need to be developed. Results from the test programme to set the performance limits will be used to make the assumptions to perform this analysis.

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Appendix A. FWDB Test and Assessment Protocol

FULL WIDTH DEFORMABLE BARRIER TEST AND ASSESSMENT PROTOCOL

1. AIM OF TEST

The aim of the full width deformable barrier test is to assess and control structural interaction. This is achieved by controlling the force distribution measured on a load cell wall to encourage the development of structures that behave in a more homogeneous manner.

2. AIM OF THIS DOCUMENT

It is the aim of this document to provide the basis for performing the full width test and the subsequent analysis procedure. It must be noted however, that many aspects of both the test procedure and the analysis procedure have yet to be clearly defined. In such cases recommended specifications and/or values have been suggested for use for the time being. These will be identified by the use of square brackets.

The layout of this document follows that of the current Regulation 94 for frontal impact protection, with the section headings following test procedure annex headings within Regulation 94. It is intended that this document can be used as a standalone document for the purposes of conducting and analysing the results of the full width test. However, certain details relating to specific aspects of the test procedure and the analysis procedure may be found by referring to the relevant section of Regulation 94.

3. TEST PROCEDURE

The test procedure follows the layout of annex 3 of the current Regulation 94 (Sub-headings are related to those used in annex 3 of the R94 test protocol):

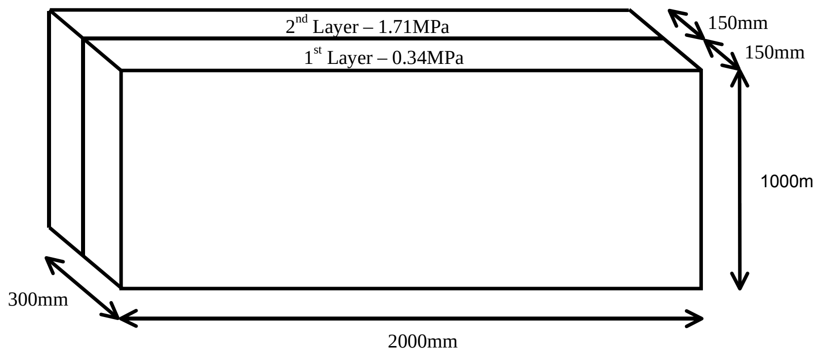
3.1. Installation and preparation of the vehicle

Barrier

The front face of the barrier consists of load cell wall fronted by a deformable structure as specified below.

Deformable element

The deformable element is formed from two layers of aluminium honeycomb, with an overall depth of 300mm and a minimum height and width of 1000mm and 2000mm respectively. [For larger vehicles the height and the width of the deformable element should be increased in 125mm increments vertically and 250mm increments horizontally to ensure that no part of the vehicle could directly impact the LCW.]



The first layer of the deformable element has a crush strength of 0.34MPa and is 150mm deep, the second layer has a crush strength of 1.71MPa and is 150mm deep. In addition, the second layer is segmented every 125mm in the horizontal and vertical directions starting at 125mm from the outer edges. The position of each of the slots is to be measured from the outer edge of the barrier to prevent compound errors. The two layers are to be joined with a muslin interlayer and there is to be no cladding on any faces other than the mounting face. The mounting face is to be clad with a 0.5mm aluminium sheet which protrudes a set distance [40mm] from the upper and lower faces of the barrier to provide mounting flanges for attachment to the load cell wall.

The certification of the crush strength of both the aluminium honeycomb cores used in the deformable element are to be in accordance with the certification procedure described in annex 9 paragraph 2 of Regulation 94.

Further details about the barrier face can be found be referring to Annex A of this document.

Load cell wall (LCW)

The load cell wall is to be formed by a matrix of individual load cells with a spacing of 125mm in the horizontal and vertical directions. The width of the load cell wall is to be equal to or greater than the width of the deformable barrier and to be exactly divisible by 250mm. The height is to be equal to or greater than the height of the deformable element. [Width 2000mm, height 1000mm].

Further requirements / details for the load cell wall can be found by referring to Annex B of this document.

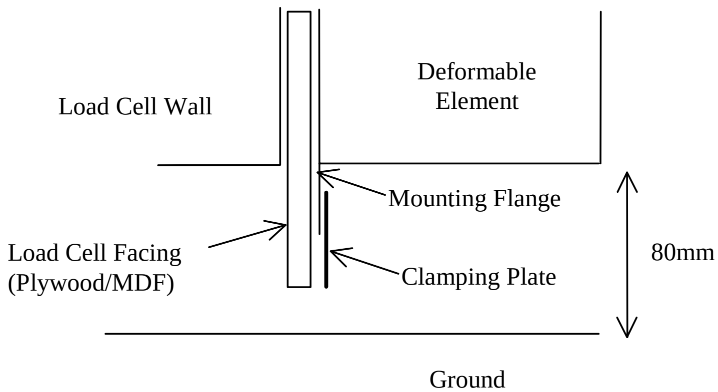
3.1.1. Orientation of the barrier

Alignment of the load cell wall

The lower edge of the load cell wall is to be parallel to the ground and at a height of 80mm relative to the ground. The load cell wall is to be rigidly attached to the barrier with its front face in the same plane as the front face of the barrier.

Alignment of deformable element

The lower edge of the deformable element, excluding the mounting flanges, is to be aligned with the lower edge of the load cell wall. The vertical centreline of the deformable element is to be aligned with the vertical centre line of the load cell wall. In order to attach the deformable element to the load cell wall, the MDF facings on the lower row of load cells are to extend below the lower edge of the load cells. The barrier is fixed to the load cell wall by means of a clamping plate along the upper edge and along the lower edge. The bolts used to attach the clamping plate must not pass through the mounting flange.



[If the impact area of the test vehicle were likely to exceed the upper edge of the deformable element when at the minimum height of 1000mm, an alternative option to increasing the height of the deformable element would be to increase the height of the LCW relative to the ground. This is provided that the lower edge of the impact area is a minimum of 125mm further from the ground level in the vertical direction than the lower edge of the deformable element when in the new position. The proposed increase in height would be in 125mm steps beginning at 80mm relative to the ground.]

Alignment of vehicle to barrier

The fore/aft centre line of the vehicle is to be aligned with the vertical centre line of the deformable element facing the barrier. The vertical alignment of the vehicle is to be recorded prior to the test. The measurement is the vertical distance between the wheel to ground contact for each wheel and the wheel arch immediately above the contact patch. Prior to measurement the vehicle will be at test mass and rolled back and forward at least one vehicle length to settle the vehicle.

3.1.2. State of Vehicle

The requirement is that the test vehicle be representative of the series production and the mass of the vehicle to be equivalent to the unladen kerb mass plus the mass equivalent to 90 per cent of the mass of fuel required to fill the fuel tank full. The test mass will be the vehicle mass plus the additional mass of two instrumented Hybrid III dummies, or equal to a specified test mass [EuroNCAP test mass].

3.2. Dummies

3.2.1. Front seats

As per Regulation 94. This requires a dummy corresponding to the specifications for a 50th percentile Hybrid III to be installed in each of the front outboard seats. The positioning of these dummies will be in accordance with the conditions specified in annex 5 of Regulation 94. The dummy positioned in the driver's seat and the dummy positioned in the passenger seat are required to be equipped for recording the data necessary to determine the performance criteria with measuring systems corresponding to the specifications in annex 8 of Regulation 94.

3.2.2. Rear seats

There is no requirement for dummies to be positioned in the rear seats.

3.3. Propulsion of Vehicle

As per Regulation 94. This requires that the vehicle shall not be propelled by its own engine, that at the moment of impact the vehicle will not be subject to any external steering or propelling device and that tphe impact accuracy will not be more than 20mm laterally out of line in either direction. [The impact accuracy will not be more than 10mm vertically out of line in either direction.]

3.4. Test Speed

The vehicle speed at the moment of impact shall be 56 +/-1 km/h.

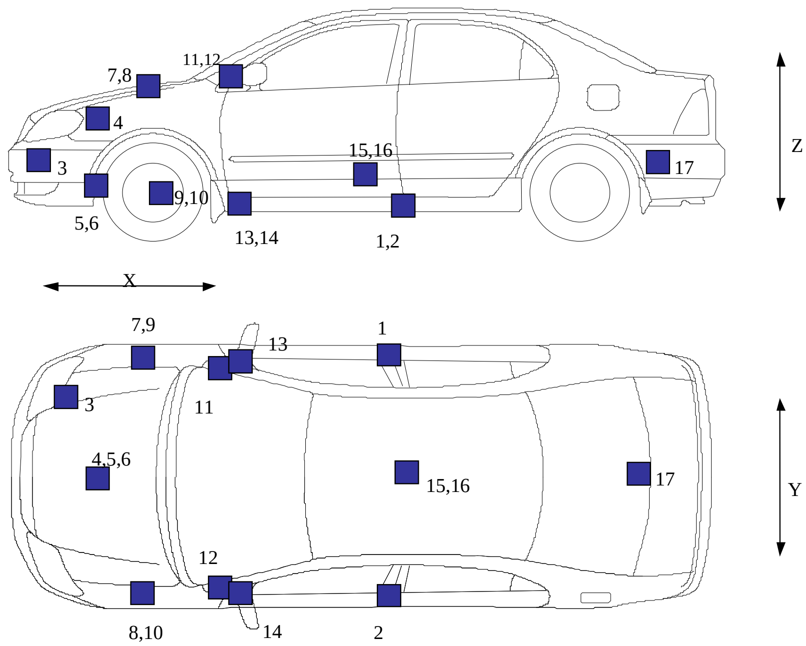
3.5. Dummy Measurements

As per regulation 94. This requires measurement in the head, neck, femur and tibia of the dummy.

3.6. Vehicle Measurements

3.6.1. Vehicle instrumentation

The minimal vehicle instrumentation required for this test is one accelerometer, measuring in the direction of travel of the vehicle, at the base of each B-Pillar. [However, for research purposes and to provide an accurate indication of the structural component and mechanical component of the force measured by the load cell wall, the following additional instrumentation can be used]



- Accelerometers

No.	Position Name	Direction
1	RHS B-Pillar (standard instrumentation)	X
2	LHS B-Pillar (standard instrumentation)	X
3	RHS or LHS Lower-rail at leading edge	X
4	Engine top central	X
5	Engine sump central	X
6	Gearbox central	X
7	RHS Turret	X
8	LHS Turret	X
9	RHS Strut	X
10	LHS Strut	X
11	RHS A-Pillar at junction with windscreen crossbeam	X
12	LHS A-Pillar at junction with windscreen crossbeam	X
13	RHS A-Pillar near junction with sill	X
14	LHS A-Pillar near junction with sill	X
15	Tunnel at centre of gravity in X and Y	X
16	Tunnel at rate sensor	X,Y,Z
17	Rear Crossbeam central	X,Y,Z

- Rate sensor at tunnel
- Airbag current clamp
- Seat belt gauges – driver only

3.6.2. Speed time history

This speed time history is obtained from longitudinal accelerometer at the base of B-Pillar on the driver's side of the test vehicle.

3.6.3. Deformation measurements

The deformation measurements are the same as for EuroNCAP frontal test protocol V4. The pre-test and post-test positions of all accelerometers should be recorded. [In addition, for the purposes of research the following occupant compartment intrusion measurements can be taken]

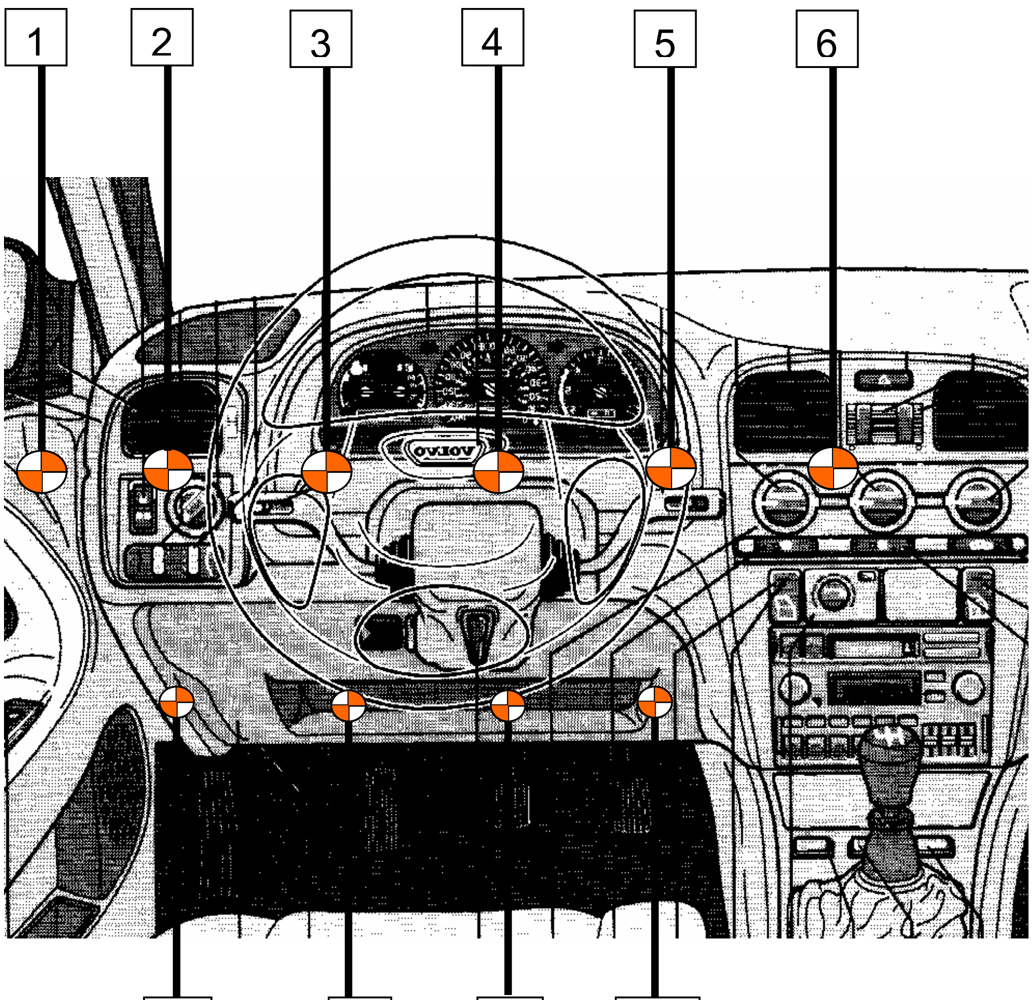
Instrument Panel Top (IPT)

1. Locate front lower corner of the side window in Z.
2. Locate outer edge of IP within height Z to Z+25mm and place target sticker.
3. Locate subsequent target stickers every 100mm (at the height defined by 2) inboard until the centreline of the vehicle. (typically 6 stickers)

Note: Z is positive in the downwards direction

Instrument Panel Base (IPB)

1. Locate the highest point along the centreline of the seat squab and determine height in Z and distance from vehicle centreline
2. Locate target sticker in on nearest point on the IP in the same Z height and distance from the vehicle centreline.
3. Locate target stickers every 100mm inboard and outboard along the IP until the centre console and the outer edge of the IP is reached



Problems wit[illegible] arget loca[illegible]

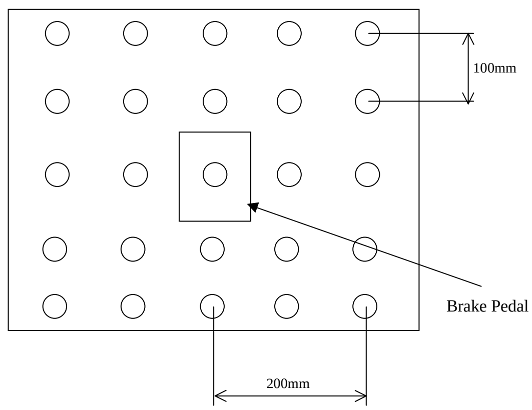
If significant d[illegible] on is nee[illegible] hen be[illegible] geme[illegible] eeded and the criteria that need consideration are:

1. Try to locate target stickers on major components of the instrument panel – do not locate on the steering column surround as this will move independently of the majority of the IP.

2. At all times try to maintain the target stickers in the Z and X axis defined and only vary the Y axis by 100mm - if going below the instrument binnacle requires less deviation then proceeding around the top then place the target stickers in the former position.

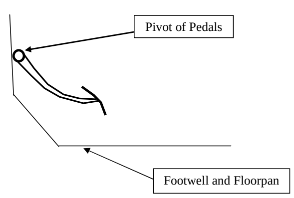
Footwell Intrusion

1. Remove all carpet from the footwell requiring measurement.
2. Locate a target sticker behind the brake pedal in the same X and Z location as that brake pedal.
3. Place a pre-cut carpet with holes spaced at 100mm in the footwell and locate one of the pre-cut holes over the target sticker defined in 2. (Carpet can follow the contours of the footwell). If pre-cut carpet not available, use the 3D Arm to position target stickers.
4. Locate additional target stickers in the location of the pre-cut holes. Only place stickers up to a maximum of 200mm either side of the brake pedal. Place stickers up to a maximum of 200mm (if possible) above and 300mm below the point defined in 2.
5. If locations tie up with local features on the footwell (such as drain holes) then move target sticker the minimum distance to clear such feature.



Pedal Axis

1. Locate the outboard end of the clutch/brake pedal pivot axis.
2. Locate a target sticker at point defined by 1.



4. PERFORMANCE CRITERIA (SELF PROTECTION)

The performance of the occupants is based upon the assessment of the dummy performance criteria against the specifications in paragraph 5.2.1 of Regulation 94. The determination of the performance criteria is in line with Annex 4 of Regulation 94.

The performance of the vehicle is based upon the specifications for the vehicle performance in paragraph 5.2.2 of Regulation 94, which specifies the residual steering wheel movement,

5. PERFORMANCE CRITERIA (PARTNER PROTECTION)

The assessment of the vehicle frontal force distribution is based upon the load cell wall force measurements. [Specifications for the performance of the vehicle based upon the criteria defined from the load cell wall measurements have yet to be determined.]

5.1. Structural Interaction Criterion

The structural interaction criterion consists of a vertical structural interaction (VSI) component and a horizontal structural interaction (HSI) component. Each component has two parts. The first part assesses over a common interaction area (Area 1) which is from 330 mm to 580 mm above ground level and consists of LCW rows 3 and 4. The second part assesses over a larger area (Area 2) which is from 205 mm to 705 mm above ground level and consists of LCW rows 2, 3, 4 and 5. [To allow manufacturers to gradually adapt vehicle designs to become more compatible, the component parts could be adopted in a stepwise manner].

5.1.1. Data Processing

Load cell wall data

The load cell wall data consists of a set of $N_{row} \times N_{col}$ data channels, in each of which the data is a record of the load cell force against time and N_{row} is the number of rows, N_{col} the number of columns in the load cell array. The vehicle performance criteria based upon the load cell wall force.

Filtered data set

Each load cell wall data channel is filtered at CFC60. Note that it is desirable for each channel to contain a few milliseconds of data before time zero, so that the initial filter transients will have disappeared before time zero. This initial data before time zero can then be discarded before the rest of the analysis.

Peak cell load

This is the peak load cell force recorded up to 40ms after time zero (from the filtered data set) and is denoted as x_{ij} where i denotes the row and j denotes the column.

5.1.2. Vertical Structural Interaction (VSI) Component

The VSI component of the criterion is based on the concepts of minimum support and load balance within a defined assessment area. The methodologies to calculate the minimum support, load balance and the target load are described in sections 0 to 0. The methodologies to calculate the VSI component for Area 1 and Area 2 are described in sections 0 and 0.

Minimum support measure

To assess minimum support a target row load is set and the sum of the negative deviations from the target row load for those rows within the assessment area is calculated. Vehicles that apply a row load above the target row load would have a negative deviation of zero for that row. Vehicles that apply a row load below the target row load would be assessed based on the sum of the negative deviations. To allow for lighter cars to meet a minimum support requirement the target load would need to be mass dependent and capped.

Minimum support = sum of the negative deviations from a target row load

$$NDev = \sum_{Row(i)} \left(F_i \leq F_{target} \Rightarrow F_{target} - F_i \right)$$

Where:

NDev = Negative deviation

$P \Rightarrow Q$ = If P is true then Q else 0

Row(i) = Denotes row number within assessment area vertical limits

F_i = Peak row load for row *i* (sum of peak load cell forces up to 40ms)

F_{target} = Target row load

Load balance measure

To assess load balance a co-efficient of variance (CV) measure using the row loads for those rows within the assessment area is used. CV is considered a good measure for comparing the scatter of distributions with different mean values. Vehicles that have better load balance in the vertical direction would result in lower CV values.

Load balance = Co-efficient of variance for the row loads

$$CV = \frac{\sigma_{row}}{\overline{F}_{row}}$$

Where:

CV = Co-efficient of variance

σ_{row} = Standard deviation of the peak row loads (within assessment area)

$\overline{F}_{row}$ = Average of the peak row loads (within assessment area)

Target row load

This is defined as F_{target} and is the sum of the peak load cell forces divided by 5. The target row load is capped at [100kN]

F_{target} = sum of peak load cell forces / 5 if <100, otherwise 100

$$F_{target} = 100 + \left[\frac{\sum_{i=1}^{8}\sum_{j=1}^{16} x_{ij}}{5} \leq 100 \Rightarrow \frac{\sum_{i=1}^{8}\sum_{j=1}^{16} x_{ij}}{5} - 100 \right]$$

Where:

x_{ij} = Peak force for load cell in row *i* column *j* (up to 40ms)

Area 1 assessment

The assessment area is defined as rows 3 and 4. There is no requirement for a load balance measure. For the first step assessment area the equation for the VSI component is as follows:

VSI_{step1} = sum of negative deviations from a target row load for rows 3 and 4

$$VSI_{step1} = \sum_{Row(i)=3}^{4} \left(F_i \leq F_{target} \Rightarrow F_{target} - F_i \right)$$

Where:

$P \Rightarrow Q$ = If P is true then Q else 0

i = Denotes row number (within assessment area vertical limits)

F_i = Peak row load for row *i* (sum of peak load cell forces up to 40ms)

F_{target} = Target row load

Area 2 assessment

The assessment area is defined as rows 2 to 5. Both the minimum support and load balance measures are applied. The VSI measure is the sum of the normalised minimum support and normalised load balance measures. In addition, weighting functions can be used to prioritise between the minimum support and load balance measures. For the second step assessment area the equation for the VSI component becomes:

VSI

VSI_{step2} = weighted normalised balance measure + weighted normalised minimum support measure

$$VSI_{step2} = \alpha * CV_n + \beta * NDev_n$$

$$CV_n = \frac{\sigma_{row(2to5)}}{\overline{F}_{row(2to5)} * CV_{range}} \qquad NDev_n = \frac{\sum_{Row(i)=2}^{5} \left(F_i \le F_{target} \Rightarrow F_{target} - F_i\right)}{NDev_{range}}$$

Where:

$P \Rightarrow Q$ = If P is true then Q else 0

$\alpha; \beta$ = Weighting factors [these remain to be determined]

CV_n = Normalised co-efficient of variance

$NDev_n$ = Normalised sum of the negative deviations from a target row load

CV_{range} = Expected range of CV measure

$NDev_{range}$ = Expected range of NDev measure

$\sigma_{row(2to5)}$ = Standard deviation of the peak row loads (rows 2 to 5)

F_i = Peak row load for row *i* (sum of peak load cell forces up to 40ms)

$\overline{F}_{row(2to5)}$ = Average of the peak row loads (rows 2 to 5)

F_{target} = Target row load

5.1.3. Horizontal Structural Interaction (HSI) Component

The HSI component of the criterion is based on the concept of encouraging strong crossbeams to adequately distribute lower rail loading. An option exists for the HSI component to be used to encourage wider structures for better structural interaction in lower overlap impacts. [This optional part is not currently included as part of the assessment and will not be included until it has been confirmed that wider structures have a significant benefit in real world accidents.]

Crossbeam / rail balance measure

To encourage development of strong crossbeams the measure compares the load applied cross the centre of the LCW to the load applied ahead of the lower rails. For each row within an assessment area the measure calculates the sum of the negative deviations from a target cell load for the centre four load cells. A more balanced load distribution results in lower negative deviations.

Crossbeam/rail balance measure = sum of negative deviations from the target cell load for the centre four load cells

$$NDev_{centre} = \sum_{Row(i)} \sum_{Column(j)} TC_i \geq x_{ij} \Rightarrow TC_i - x_{ij}$$

Where:

$NDev_{centre}$ = Negative deviation for vehicle centre

$P \Rightarrow Q$ = If P is true then Q else 0

x_{ij} = Peak force for load cell in row *i* column *j* (up to 40ms)

TC_i = Target load for cell in row *i*

W = Vehicle width

Row(i) = 3 to 4 (step 1); 2 to 5 (step 2)

Column(j) = 7 to 10 (centre four columns)

The measure is normalised based on the number of columns within the assessment area.

$$NDev_{centre(n)} = \frac{NDev_{centre}}{4}$$

Where:

$NDev_{centre}$ = crossbeam/rail balance measure

$NDev_{centre(n)}$ = normalised crossbeam/rail balance measure

Optional outer support measure

To encourage wider structures for lower overlap impacts the assessment area for the crossbeam/rail balance measure was revised to look at the balance between the load applied out wide and the load applied ahead of the lower rails. The assessment width was 80% of the vehicle width and excluded the centre six load cells.

Outer support measure = sum of negative deviations from the target cell load for the load cells aligned with the outer structure

$$NDev_{outer} = \sum_{Row(i)} \left[\sum_{Column(j)} \left(TC_i \geq x_{ij} \Rightarrow TC_i - x_{ij} \right) + \sum_{Column(k)} \left(TC_i * n \geq x_{ik} \Rightarrow TC_i * n - x_{ik} \right) \right]$$

$$n = \frac{W * 0.8}{250} - INTEGER\left(\frac{W * 0.8}{250} \right)$$

Where:

$NDev_{outer}$ = Negative deviation for vehicle outer structure

$P \Rightarrow Q$ = If P is true then Q else 0

x_{ij} = Peak force for cell in row *i* column *j* (up to 40ms)

x_{ik} = Peak force for cell in row *i* column *k* (up to 40ms)

TC_i = Target load for cell in row *i*

W = Vehicle width

n = Adjustment factor for load cells with partial overlap

Row (i) = 3 to 4 (step 1); 2 to 5 (step 2)

Column (j) = $\left(9 - INTEGER\left(\frac{W * 0.8}{250} \right) \quad to \quad 5 \right)$ and $\left(12 \quad to \quad INTEGER\left(\frac{W * 0.8}{250} \right) + 8 \right)$

Column (k) = $\left(8 - INTEGER\left(\frac{W * 0.8}{250} \right) \right)$ and $\left(INTEGER\left(\frac{W * 0.8}{250} \right) + 9 \right)$

The measure is normalised based on the number of columns within the assessment area – wider vehicles are assessed over a greater number of columns and consequently have the potential for higher negative deviations.

$$NDev_{outer(n)} = \frac{NDev_{outer}}{(W * 0.8/125) - 6}$$

Where:

$NDev_{outere}$ = outer support measure

$NDev_{outer(n)}$ = normalised outer support measure

W = vehicle width

Target cell load

The target cell load is based on the row load and is set to encourage a structure that spread the row load evenly over the vehicle frontal width. In addition, there is a requirement to cap the target cell load. Without this, unachievable target cell loads could be set for vehicles with very high row loads. Based on the vehicle test results it is proposed that the row is initially capped at [20kN].

$$TC_i = 20 + \left[\sum_{j=1}^{16} x_{ij} * \frac{125}{W} \leq 20 \Rightarrow \sum_{j=1}^{16} x_{ij} * \frac{125}{W} - 20 \right]$$

Where:

$P \Rightarrow Q$ = If P is true then Q else 0

x_{ij} = Peak force for load cell in row *i* column *j* (up to 40ms)

TC_i = Target load for cell in row *i*

W = Vehicle width

Area 1 assessment

The vertical extent of the assessment area is defined as rows 3 and 4. For the first step assessment area the equation for the HSI component is as follows:

HSI = weighted normalised crossbeam/rail balance measure

$$HSI_{step1} = NDev_{centre(n)}$$

Where:

$NDev_{centre(n)}$ = normalised crossbeam/rail balance measure – *Row (i)* = 3 to 4

Area 1 assessment (including optional outer support)

Including the optional outer support measure the equation is as follows [This optional part is not currently included as part of the assessment and will not be included until it has been confirmed that wider structures have a significant benefit in real world accidents]:

HSI = weighted normalised crossbeam/rail balance measure + weighted normalised outer support measure

$$HSI_{step1} = \alpha * NDev_{centre(n)} + \beta * NDev_{outer(n)}$$

Where:

$\alpha; \beta$ = weighting factors

$NDev_{centre(n)}$ = normalised crossbeam/rail balance measure – *Row (i)* = 3 to 4

$NDev_{outer(n)}$ = normalised outer support measure – *Row (i)* = 3 to 4

Area 2 assessment

The vertical extent of the assessment area is defined as rows 2 to 5. For the second step assessment area the equation for the HSI component is as follows:

HSI = weighted normalised crossbeam/rail balance measure

$$HSI_{step2} = NDev_{centre(n)}$$

Where:

$NDev_{centre(n)}$ = normalised crossbeam/rail balance measure – *Row (i)* = 2 to 5

Area 2 assessment (including optional outer support)

Including the optional outer support measure the equation is as follows [This optional part is not currently included as part of the assessment and will not be included until it has been confirmed that wider structures have a significant benefit in real world accidents]:

HSI = weighted normalised crossbeam/rail balance measure + weighted normalised outer support measure

$$HSI_{step2} = \alpha * NDev_{centre(n)} + \beta * NDev_{outer(n)}$$

Where:

$\alpha; \beta$ = weighting factors

$NDev_{centre(n)}$ = normalised crossbeam/rail balance measure – *Row (i)* = 2 to 5

$NDev_{outer(n)}$ = normalised outer support measure – *Row (i)* = 2 to 5

6. REFERENCES

1. European New Car Assessment Protocol (EuroNCAP), Frontal Impact Testing Protocol, Version 4, January 2003.
2. United Nations Regulation 94, Uniform Provisions Concerning the Approval of Vehicles with Regard to the Protection of the Occupants in the Event of a Frontal Collision.

Annex A

Deformable Barrier Face Specification [subject to review]

1. Component and material specifications

The external dimensions of the barrier are illustrated in Figure 21. The deformable element is formed from two layers of aluminium honeycomb, with an overall depth of 300mm, a height of 1000mm and a width of 2000mm. [For larger vehicles the height and the width of the deformable element should be increased in 125mm increments vertically and 250mm increments horizontally to ensure that no part of the vehicle directly impacts the LCW.]

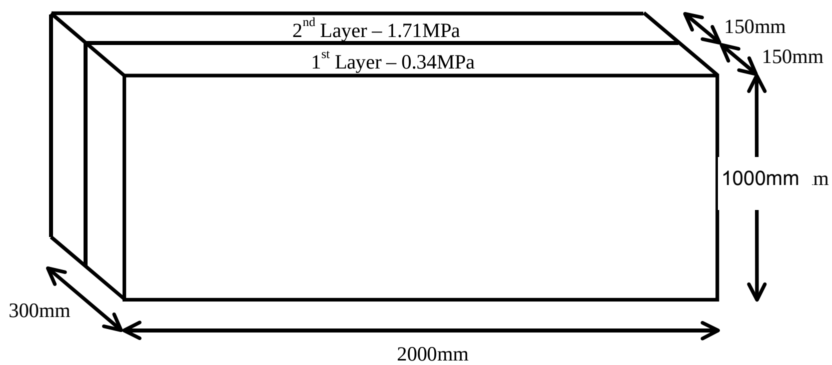


Figure 21: Full Width Deformable Barrier external dimensions (not to scale).

The first (front) layer of the deformable element has a crush strength of 0.34MPa and is 150mm deep, the second (rear) layer has a crush strength of 1.71MPa and is 150mm deep. In addition, the second layer is segmented every 125mm in the horizontal and vertical directions starting at 125mm from the outer edges. The position of each of the slots is to be measured from the outer edge of the barrier to prevent compound errors. The two layers are joined with a muslin interlayer and there is to be no cladding on any faces other than the mounting face. The mounting face is the rear face of the 1.71MPa layer. The mounting face is to be clad with a 0.5mm aluminium sheet which protrudes a set distance of 40mm from the upper and lower faces of the barrier to provide mounting flanges for attachment to the load cell wall.

The dimensions of the individual components of the barrier are listed separately below.

a. Front honeycomb layer

Dimensions	All dimensions should allow a tolerance of [± 2.5 mm]
Height:	1000 mm (in direction of honeycomb ribbon axis)
Width:	2000 mm
Depth:	150 mm (in direction of honeycomb cell axes)

Material:	Aluminium 3003 (ISO 209, part 1)
Foil thickness:	0.076 mm
Cell size:	19.14 mm
Density:	28.6 kg/m^3
Crush strength:	0.342 MPa +0% -10%

b. Rear honeycomb layer

Dimensions	
Height:	1000mm [± 2.5mm] (in direction of honeycomb ribbon axis)
Width:	2000mm [± 2.5mm]
Depth:	150mm [± 1mm] (in direction of honeycomb cell axes)

Material:	Aluminium 3003 (ISO 209, part 1)
Foil thickness:	0.076 mm
Cell size:	6.4 mm
Density:	82.6 kg/ m^3
Crush strength:	1.711 MPa +0% -10%

c. Backing sheet

Dimensions	
Height:	1080 mm ± 2.5 mm
Width:	2000 mm ± 2.5 mm
Thickness:	0.5 mm ± 0.1 mm

Material:	Aluminium 5251

d. Adhesive

The adhesive to be used throughout should be a two-part polyurethane (such as Ciba-Geigy XB5090/1 resin with XB5304 hardener, or equivalent).

2. Aluminium honeycomb certification

The certification procedure that should be followed for the materials in the Full Width Deformable Barrier is described in Annex 9 Paragraph 2 of Regulation 94, these materials having a crush strength of 0.342 MPa and 1.711 MPa respectively.

3. Adhesive bonding procedure

The adhesive bonding procedure that should be followed for materials in the Full Width Deformable Barrier is described in Annex 9 Paragraph 3 of Regulation 94.

4. Construction

a. The rear honeycomb layer is segmented every 125mm in the horizontal and vertical directions starting at 125mm from the outer edges. The position of each of the segmentation slots is to be measured from the outer edge of the barrier to prevent compound errors. [The slot size is to be less than 5mm wide.]

b. The rear honeycomb layer shall be bonded to the backing sheet with adhesive such that the cell axes are perpendicular to the sheet.

c. The front honeycomb layer shall be adhesively bonded to the rear honeycomb layer by means of a muslin interlayer sheet, such that the cell axes are perpendicular to the sheet.

Annex B

LCW Specification [subject to review]

1. Dimensions and layout

a. Load cell dimensions

Each load cell tile on the load cell wall (LCW) has a nominal frontal area of 125mm x 125mm. However, when mounted on the LCW the load cells must have sufficient clearance between the adjacent cells to prevent interaction of the load cell tiles under maximum shear loads. The suggested external dimensions of each individual load cell face in the LCW are shown in Figure 22.

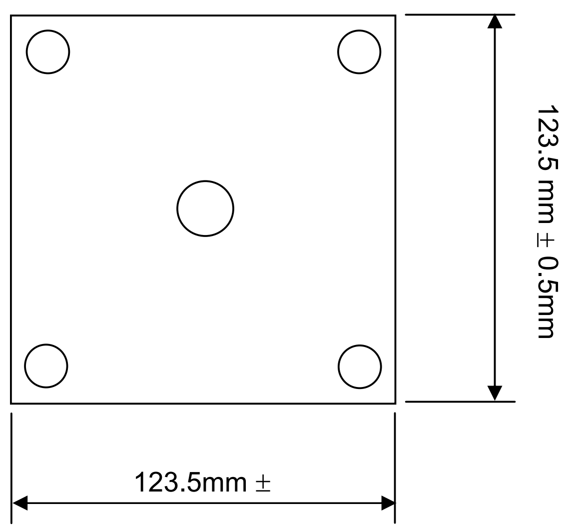


Figure 22: Suggested load cell front face dimensions.

Each load cell shall be faced with an 18mm thick MDF panel the same size as the load cell face. Any of these MDF facings which become damaged (e.g. dented, split, etc.) should be replaced with undamaged MDF facings.

Each load cell must have threaded holes on the loading face to allow the mounting of deformable barrier faces and the MDF facings. A suggested pattern of holes is shown in Figure 22 above.

b. Full LCW

The full load cell wall, for the purposes of the FWDB test, is to comprise of 128 load cells arranged in a matrix of cells 16 wide by 8 high. The full LCW should have frontal dimensions of 2000mm wide by 1000mm high. The height of the bottom of the LCW above ground should be adjustable. [For the FWDB test, the height of the bottom of the LCW above ground is 80mm.]

The load cells shall be spaced such that the centre of each load cell is 125mm apart in the vertical and horizontal direction. This spacing shall be measured from the centre of the uppermost corner cell on the load cell wall in order to avoid compound errors (Figure 23). This can be achieved by mounting the load cells on a backplate to provide the precise location of each load cell.

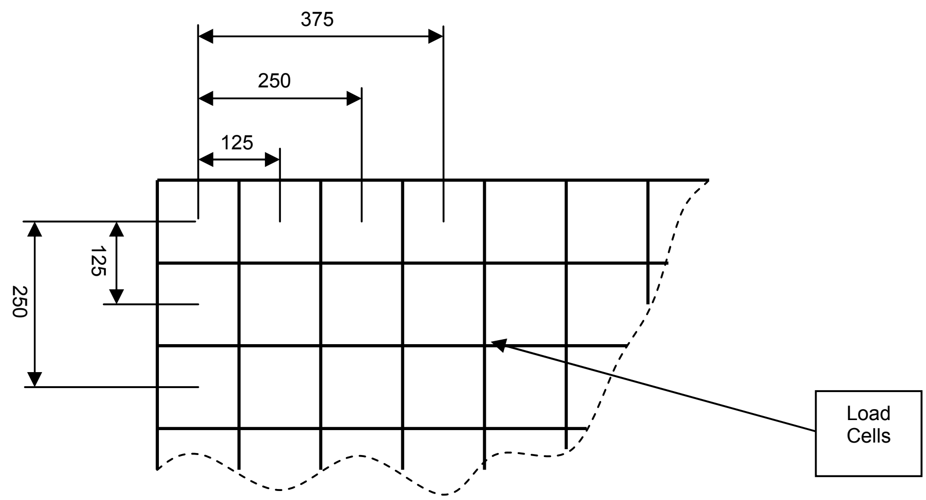


Figure 23: Spacing of the load cell centres on the load cell wall, showing measurement from the centre of the cell at the top corner of the LCW to avoid compound errors. *(All dimensions in mm)*

c. LCW flatness

The impact face of the load cell wall, including MDF facings, should be flat - no cell should be either recessed or protrude relative to any of its surrounding cells. The surface flatness is check by offering up a flat edge to the load cell wall – this flat edge should bridge two or more load cells. There should be no visible gap [greater than 0.5mm] between the flat edge and the surface of a load cell. If any cells are found to protrude or be recessed, remedial action should be taken to correct this.

2. Load Cell Technical Specifications

A list of the technical requirements of the load cells is provided in Table 2 below.

Table 2: Load cell technical specification.

Nominal area of each load cell impact face	125 x 125mm
Rated load	300kN
Safe overload	600kN
Shear load	100kN
Offset loading error	< 3% (300kN)
Linearity error	< 1.1% (300kN)
Compression / Shear load crosstalk	< 0.5% (300kN)
Cell Mass	< 6kg
Mass difference tolerance between load cells	± 0.2kg
Dynamic response	> 10kHz
Resonant frequency	> 5kHz
Operational temperature range	0^{o}C to $+70^{o}$C

Appendix B. PDB Test and Assessment Protocol

PDB TEST PROTOCOL

Version 2.3
February 2006

TABLE OF CONTENTS

1. Aims of the test procedure

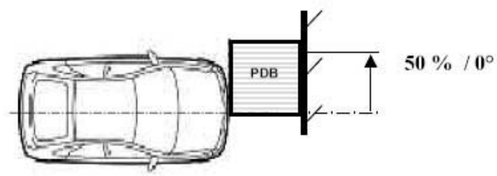
The target is to control partner protection in addition of self-protection on the same test, in the same time:

- The self-protection assessment would be based on dummies and vehicle performance.
- The partner protection would be based on barrier deformation. In other words put under control the energy absorption behaviour of the front unit threw pressure analysis.

2. Test procedure

2.1. Test configuration

The proposal is to update the current ECE R94 frontal ODB test. Three parameters are changed:



- Obstacle : PDB Barrier ⇨ To avoid bottoming out, more stable
- Speed: 60 km/h ⇨ To check compartment strength
- Overlap: 50% ⇨ To be close to car to car test

Note: This test procedure follows the annex 3 of the current regulation 94. All parameters which are not described or explained in this document need to be in accordance with the current regulation.

2.1.1. Test speed

The vehicle speed at the moment of impact shall be 60 km/h -0/+1 km/h.

2.1.2. Overlap / Angle

The vehicle shall overlap the barrier face by 50% ± 20 mm.

The front face of the deformable structure is perpendicular within ± 1° to the direction of travel of the test vehicle.

2.1.3. Obstacle

The barrier used is the Progressive Deformable barrier: **PDB version 8.0**.

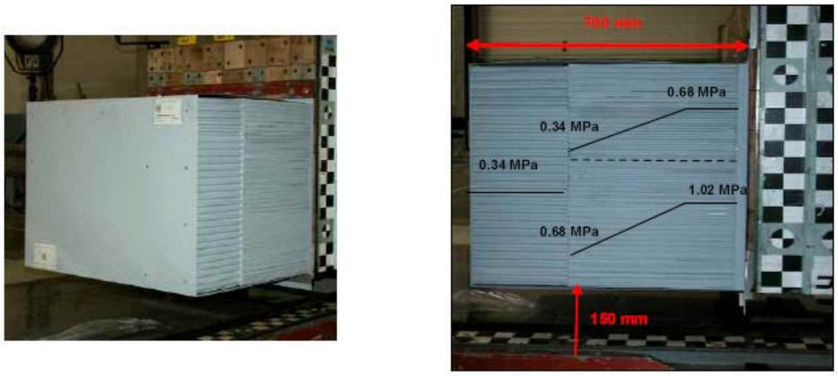
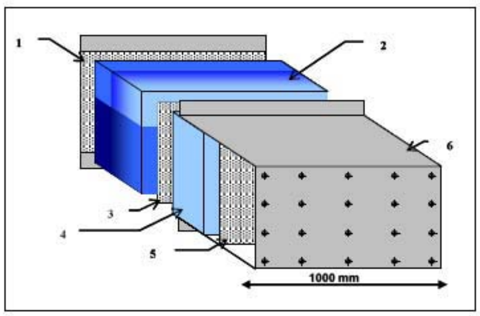


Figure 1: PDB barrier version 8.0 mounted on a HRLCW



1 – Back plate
2 – Rear deformable element
3 – Intermediate plate
4 – Front deformable element
5 – Front plate
6 – Covering plate

See Annex 1: Technical specifications of PDB v8.0

The deformable barrier shall be fixed on a high resolution load cell wall in order to measure the global force behind the barrier. The lower edge of the barrier is positioned at 150 mm from the ground.

See Annex 2: for barrier positioning and mounting specifications

2.2. Vehicle preparation

2.2.1. General specification

The test vehicle shall be representative of the series production, shall include all the equipment normally fitted and shall be in normal running order. Some components may be replaced by equivalent masses where this substitution clearly has no noticeable effect on the results measured. In order to cover all the series range the worse case is selected that is to say the heaviest car with the biggest engine.

2.2.2. Mass

For the test, the mass of the vehicle submitted shall be the unladen kerb mass. The fuel tank shall be filled with water to mass equal to 90% of the mass of a full as specified by the manufacturer with a tolerance of ± 1%.

The test mass will be the vehicle mass plus the additional mass of two instrumented hybrid III dummies.

2.2.3. Vehicle instrumentation

The minimal vehicle instrumentation required is one accelerometer at the base of each B-Pillar. However for research purposes the additional instrumentation is used:

	L	T	V
B-Pillar RHS	√	√	√
B-Pillar LHS	√	√	√
200 mm behind B-Pillar LHS	√		
A-Pillar LHS	√		
Engine Top central	√		
Engine bottom central	√		
Gear box bottom	√		
Arm suspension LHS	√		
Turret LHS	√		
Front subframe middle	√		
Cross of the side member and the firewall	√		
TOTAL	15 channels		

Note: Instrumentation for a left hand Drive car. For a right hand drive car, instrumentation required on the left (LHS) becomes on the right (RHS).

2.2.4. Deformation measurements

The minimum deformation measurements required are the following.
- Dashboard LHS
- Footwell
- A-Pillar at waist level

- A-Pillar at sill level
- Pedal axle LHS

However for research purposed more intrusions measurements can be done.

See Annex 3: Additional intrusion measurements.

2.3. Dummies

Two instrumented Hybrid III dummies shall be installed in the front seats. The positioning of these dummies is in accordance with R94 specifications.

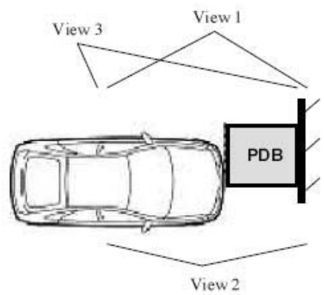
The following measurements are necessary for the verification of the performance criteria.

	Driver			Passenger		
	X	Y	Z	X	Y	Z
Head acceleration	√	√	√	√	√	√
Neck upper force	√	√	√	√	√	√
Chest acceleration	√	√	√	√	√	√
Chest deflexion		√			√	
Pelvis acceleration	√	√	√	√	√	√
Femur left force		√			√	
Femur right force		√			√	
Femur left acceleration		√			√	
Femur right acceleration		√			√	
Knee slider right		√			√	
Knee slider left		√			√	
Tibia upper force right	√		√	√		√
Tibia upper moment right	√	√		√	√	
Tibia lower force right	√		√	√		√
Tibia lower moment right	√	√		√	√	
Tibia upper force left	√		√	√		√
Tibia upper moment left	√	√		√	√	
Tibia lower force left	√		√	√		√
Tibia lower moment left	√	√		√	√	
Seat belt at upper diagonal belt		√			√	
Seat belt at lap belt outside		√			√	
TOTAL	**37 channels**			**37 channels**		

2.4. Video

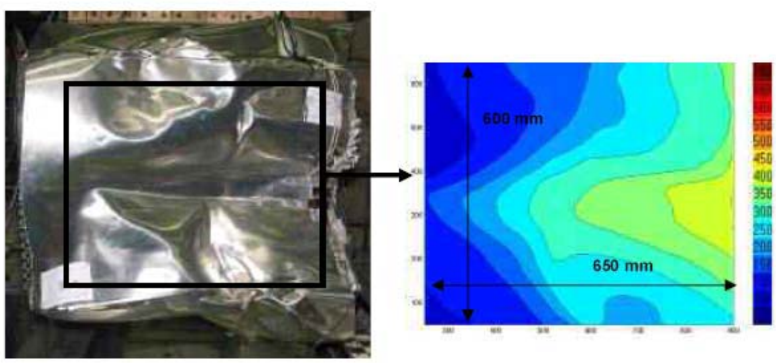
5 high speed film cameras are required on the test. There are positioned as follow:

- Camera 1: Left view
- Camera 2: Right view
- Camera 3 ¾ rear left view
- Camera 4: under view
- Camera 5: upper view



2.5. Barrier measurement

The partner protection assessment is based on the barrier deformation. After crash the front face of the barrier is digitised in order to know the shape of the deformation. The file obtained from the digitisation is processed in the PDBsoft V1.0. This software is free and available on EEVC WG15 Website. Some parameters are calculated automatically by this software as the PPAD (Partner Protection Assessment from Deformation), AHOD (average height of deformation and ADOD (average depth of deformation) and the energy absorbed by the barrier in order to calculate the EES.

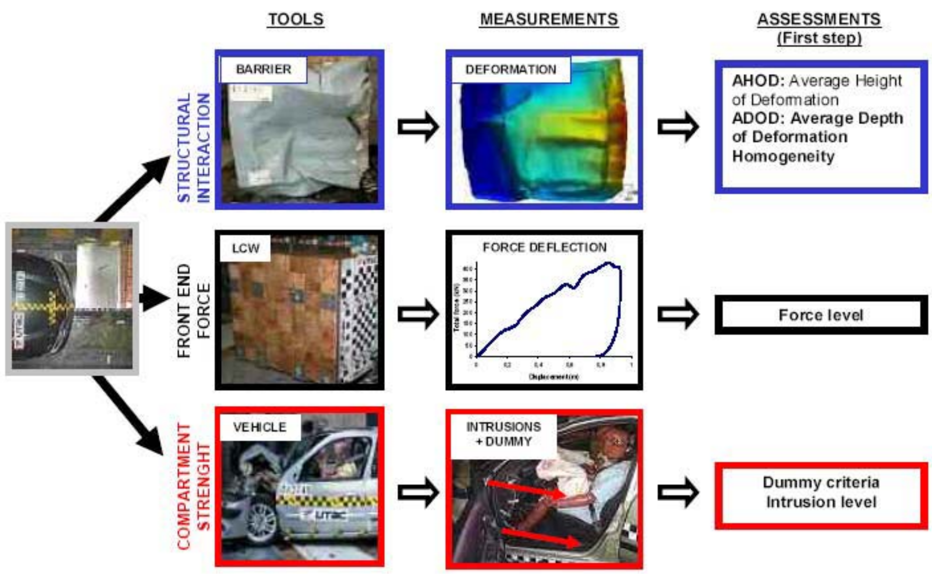


See Annex 4: Barrier digitisation specifications

3. Assessment

Three parameters have been identified as more or less important for compatibility. The PDB test protocol proposes tools and measurements to assess them:

- Barrier deformation for assessing structural interaction
- Global force for assessing Front end force (if it is needed in the future)
- Passenger compartment intrusion and dummy readings for assessing compartment strength



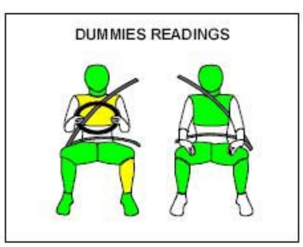
The limits and criteria proposed in this document are still under evaluation. More researches are needed and discussions in international working groups are necessary to fix limits.

3.1. Self protection

The self protection assessment would be based on dummies criteria with limits as in the current R94 regulation and following WG16 proposals on intrusion measurements.

3.1.1. Dummy

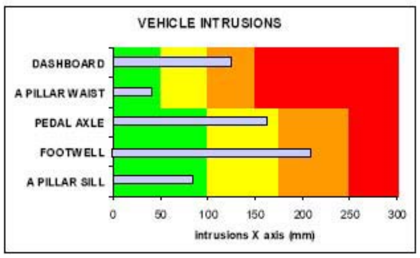
Dummy performances need to be in accordance with ECE R94 limits.



⇨ R94 LIMITS

3.1.2. Intrusions

Intrusion limits could be defined as it is on the upper region or in the lower region of the compartment.



⇨ INTRUSION LIMITS?

- Good
- Acceptable
- Marginal
- Poor

3.1.3. Front end force

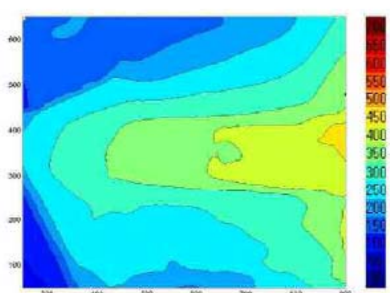
If it is needed and if it is proven that the force measurement is accurate, an assessment could be introduced for the front end force.

A minimum frontal force level could be fixed as a first step in order to improve compartment strength for small cars and to ensure a minimum self protection level.

3.2. Partner protection

The partner protection assessment is based on PDB deformation. The shape of the barrier gives information about front unit homogeneity as a combination of the force distribution and the pushing surface.

After having digitising the barrier shape (*see Annex 4: Barrier digitisation specifiactions*), an assessment is made based on the deformation (*see Annex 5: Analysis of the numeric barrier*). The complete method is described in the document "PDBsoftV1.0 - user guide" available on the EEVC WG15 website www.eevc.org/wgpages/wg15/wg15index.htm on the page "WG publications".



⇨ LIMITS? { PPAD, ADOD, AHOD, Energy, EES

4. Finite element PDB model

Finite element models of the PDB are available:

- Pam crash: developed by ESI
- Radioss: Developed by Mecalog

5. Task to develop the test procedure

Annex 1: Technical specifications of PDB v8.0

- General presentation

The PDB deformable barrier is a stacking of two deformable cores and aluminium sheets. The rear deformable core is chemically etched in order to provide two growing resistance areas and two constant resistance areas. The front deformable core provides same crush characteristics as EEVC Offset Deformable Barrier.

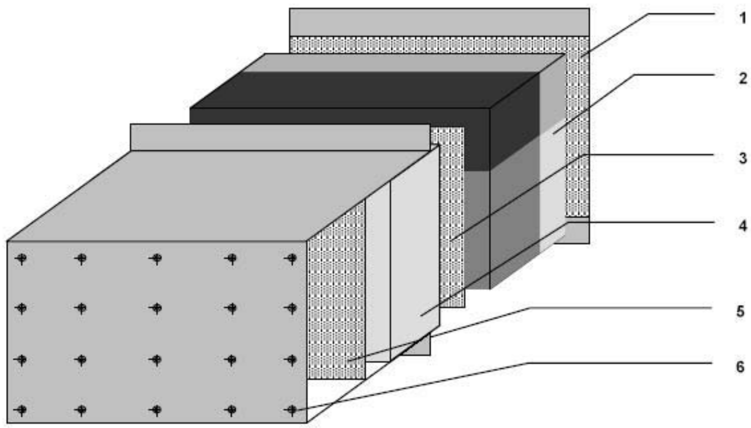


Fig 1 – fragmented view

1 – Back plate
2 – Rear deformable core
3 – Intermediate plate
4 – Front deformable core
5 – Contact plate
6 – Covering plate

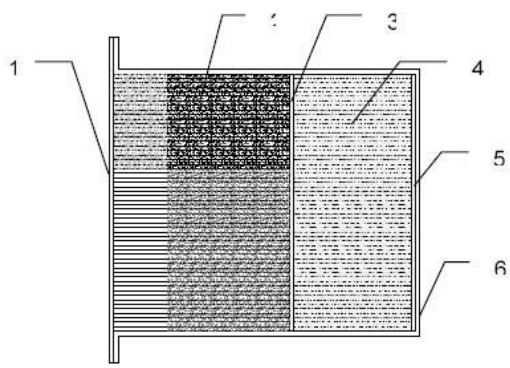


Fig 2 – Side view

- Material and component specifications

<u>Back plate:</u>
Material
Aluminium plate 1050A H14 alloy
Dimensions
Thickness: 30/10 mm
850 mm x 1000 mm ± 2.5 mm

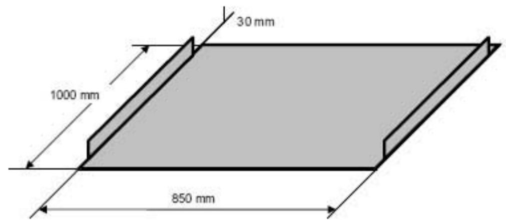


Fig 3 – back plate

<u>Rear deformable core:</u>
Material
Aluminium hexagonal honeycomb core
Cell size: Ø 9.5 mm ± 10%
Dimensions
Thickness: 450 mm ± 1 mm
L x l : 1000 mm x 700 mm ± 5 mm

The rear deformable core is chemically etched in order to provide two growing resistance areas and two constant resistance areas. The resistance characteristics are shown below:

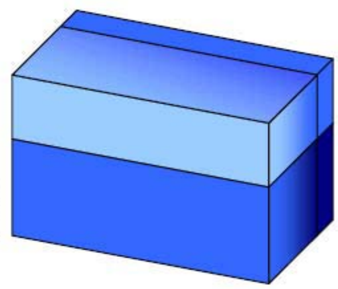


Fig 4 – Rear deformable core

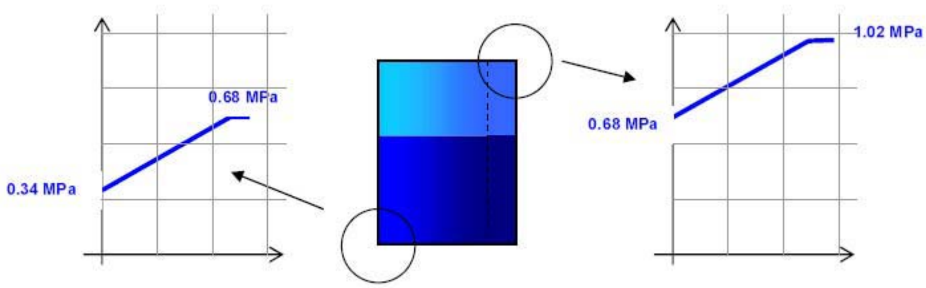


Fig 5 – Rear core crushing behaviour

<u>Intermediate plate:</u>
Material
Aluminium plate 5754 111 alloy
Dimensions
Thickness: 5/10 mm
1000 mm x 700 mm ± 2.5 mm

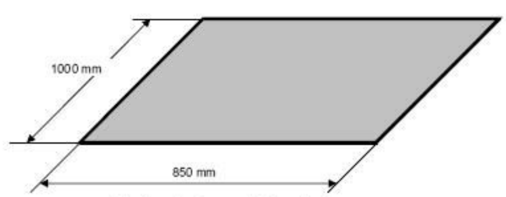


Fig 6 – Intermediate plate

Front deformable core
Material
Aluminium hexagonal honeycomb core
Cell size: Ø 19 mm ± 10%
Dimensions
Thickness: 250 mm ± 1 mm
L x l : 1000 mm x 700 mm ± 5 mm

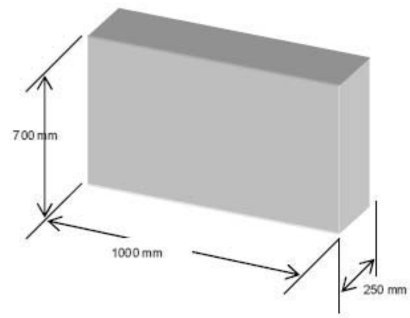


Fig 7 – Front deformable core

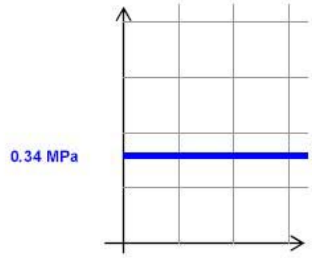


Fig 8 – Front core crushing behaviour

Contact plate
Material
Aluminium plate 1050A H24 alloy
Dimensions
Thickness: 15/10 mm
1000 mm x 700 mm ± 2.5 mm

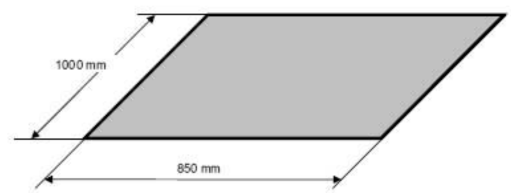


Fig 9 – Contact plate

Covering plate
Material
Aluminium plate 5754 H22 alloy
Dimensions
Thickness: 8/10 mm

The covering plate has two mounting flanges of 75 mm allowing wall fixation.

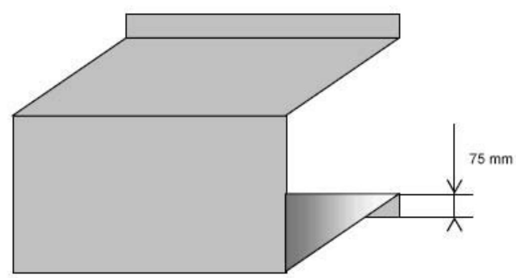
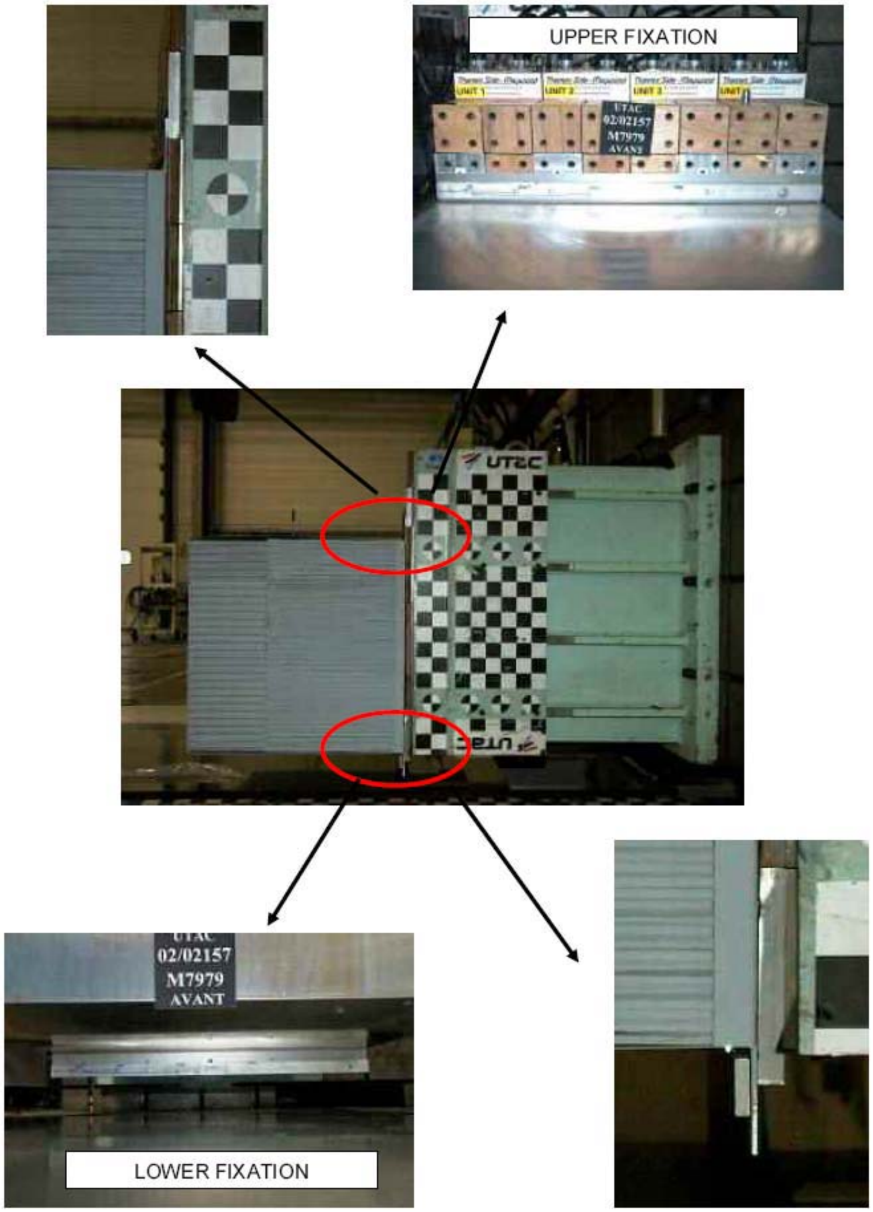


Fig 10 – Covering plate

Adhesives
The adhesive to be used should be a two part epoxy (such as AXSON H9940) or equivalent.

Annex 2: Barrier positioning and mounting



Annex 3: Additional intrusion measurements

	Measured points	*Before crash (mm)*			*After crash (mm)*			***Delta (mm)***		
	Under	X	Y	Z	X	Y	Z	X	Y	Z
1	Gear box (same X as the engine)									
2	Engine									
3	Subrame rear middle									
4	Subframe rear left (Fixation)									
5	Subframe rear right (Fixation)									
6	Subframe left									
7	Subframe right									
8	Longitudinal Left									
9	Longitudinal Right									
10	Steering ball L									
11	Steering ball R									
12	Steering rack middle									
13	Subframe middle									
14	Fixation subbframe front Left									
15	Fixation subbframe front Right									
16	Crush can Left (rear)									
17	Crush can Right (rear)									
18	Global deformation Left									
19	Global deformation middle									
20	Global deformation Right									
	Front unit left side									
21	Crossbeam middle									
22	Connexion higher load path / lower rail									
23	Suspension turret Left									
24	Suspension turret Left (bis)									
25	Windscreen pillar Left (outside)									
26	Wheel axis Left									
	Inside left									
27	A-pillar Left upper									
28	A-pillar Left lower									
29	Windscreen left									
30	Dashboard Left									
31	Steering column									
32	Dashboard middle									
33	Wheelhouse deformation Left									
34	Firewall (driver axis)									
35	Firewall (projection middle pedal)									
36	Breaking pedal									
37	Pedal axis left									
38	Pedal axis right									
	inside right									
39	Windscreen outside right									
40	Windscreen right (inside)									
41	Dashboard Right									
42	Wheelhouse Right									
43	Firewall (passenger axis)									
	Front unit right									
44	Wheel right									
45	Suspension turret right									
46	Suspension turret right (bis)									
47	Windscreen right (outside)									

Door aperture (Front door)

Before crash			*After crash*			***DELTA***		
	Up	down		Up	down		Up	down
LHS			LHS			LHS		
RHS			RHS			RHS		

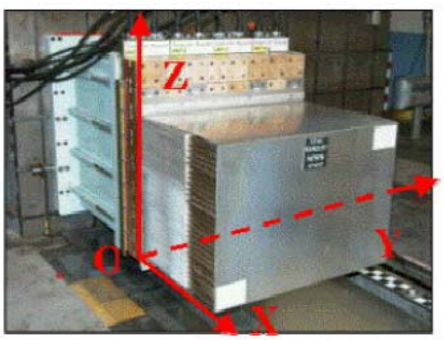
Annex 4: Barrier digitisation specifiactions

This operation consists in a 3D measurement of the barrier front surface to know its deformations. The result file contains 3D coordinates of points and is processed in the PDB software in order to calculate the Partner Protection Assessment of Deformation (PPAD) and to make a graphic representation of the deformation.

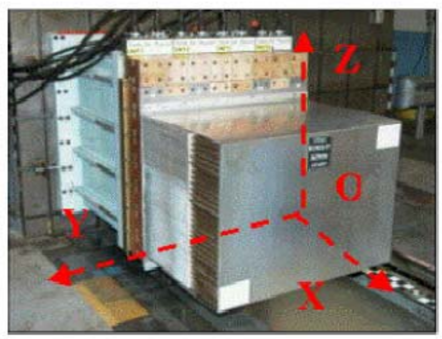
The file obtained from digitisation must follow these specifications:

- Reference point: The reference point (origin) is located on the opposite side of the deformation (see following figures for details)

For a left hand drive car:



For a right hand drive car:



- Only the front surface is digitised.
- Digitisation parameters:
  - Number of nodes ≈ 40000
  - Number of elements ≈ 80000
  - Unit: mm
  - Mean distance between 2 nodes ≈ 12 mm.
- The coordinates of nodes are included in the following intervals in each axis:

For a left hand drive car:

x : 0→700 mm
Y : 0 →1000 mm
Z : 0 →700 mm

For a right hand drive car

x : 0 → 700 mm
Y : -1000 → 0 mm
Z : 0 → 700 mm

- File format: STL, UNV, PAT and NAS

Example of each file format accepted: see "PDBsoftV1.0_UserGuide.doc" available on the EEVC WG15 website www.eevc.org/wgpages/wg15/wg15index.htm on the page "WG publications"

Annex 5: Analysis of the numerical barrier

The analysis of the barrier is performed with the PDBsoftV1.0 the software is available on the EEVC WG15 website www.eevc.org/wgpages/wg15/wg15index.htm on the page "WG publications".
See "PDBsoftV1.0 - user guide" for details on the software

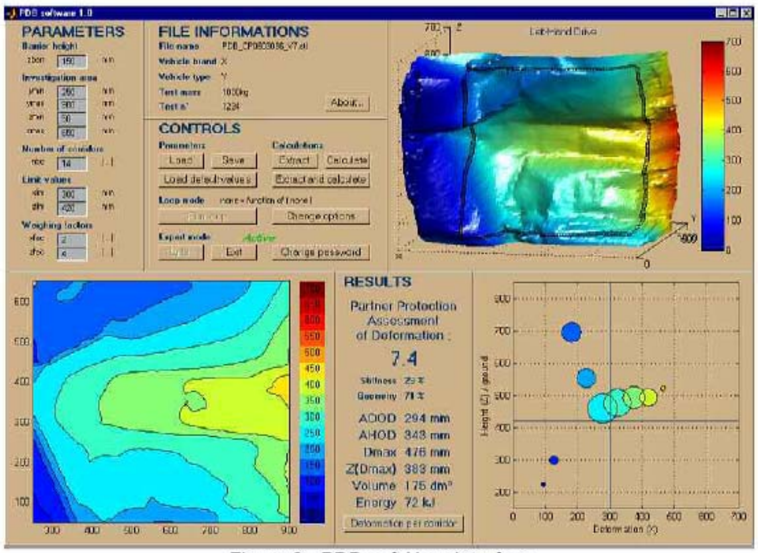


Figure 2 : PDB soft User interface

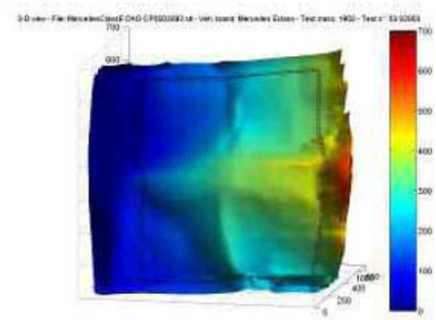
The file is extracted and processed to calculate the following parameters:

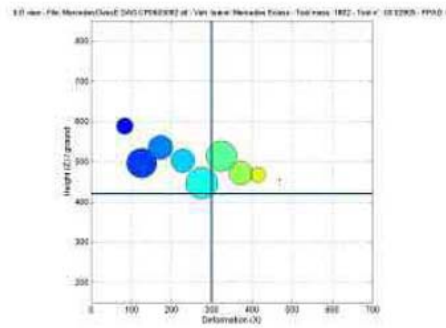
} PPAD: Partner Protection Assessment of Deformation

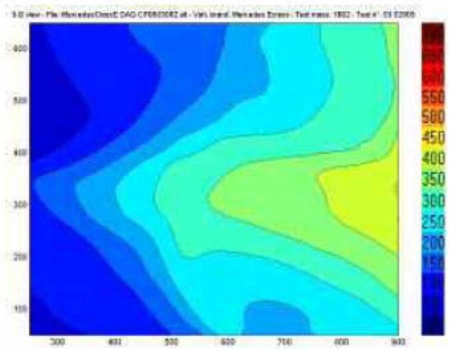
→ influence of the stiffness parameter in the formula
→ influence of the geometry parameter in the formula of PPAD

→ Average Depth Of Deformation
→ Average Height Of Deformation from the bottom of the barrier
→ Maximum deformation
→ Height at the deformation maximum
→ Calculation of the total volume deformed
→ Calculation of the energy absorbed by the barrier based on the volume of deformation and stiffness of the barrier.

3 graphs and 1 excel file are exported with all the data and parameters:







The formula to calculate the PPAD is:

For each surface (Si) :
Average height: Zi
Average deformation: Xi

$$R=\sum_{i=1}^{13}\left(\frac{Zi}{Z\lim}\right)^4*\left(\frac{Xi}{X\lim}\right)^2*Si$$

$$PPAD = \frac{0,52}{10}R^{0,55}$$

Appendix C. Summary of test and supporting data to develop procedures

C.1 Structural Analysis – UTAC

This section describes the main findings of VC-COMPAT Workpackage 1 where the geometry of vehicle structural members were documented.

There are two structural properties that determine a vehicle's "aggressivity" to its opponent: physical strength (or stiffness) of the vehicle components and the position of these components. The first property is associated with the frontal force level compatibility and the second describes a geometric compatibility. The objective of the structural survey was to measure and create a database of the position and dimensions of vehicle structures involved in frontal and side impact. This database will be used to study current geometric compatibility.

The specific tasks undertaken were to:

- Define the main vehicle structures involved in frontal and side car-to-car impacts.
- Define a representative group of vehicles for measurement.
- Measure the vehicles and generate the database.
- Analysis of the database to determine suitable interaction areas for car-to-car impacts.

A measurement procedure was developed by the group using the results of previous activities. The structural database contains the following information:

- General information of the vehicle (model, engine and subframe type, mass, length, etc.).
- The front unit measurement (position of bumper, engine, subframe, lower rail, crush can, footwell, etc.).
- Side unit measurement (A, B and C pillar, position of floor sills, fender, etc.).

55 cars have been measured with the goal to have cars from different segments and car manufacturers in order to get a good average of the European fleet. This selection represents 61% of the European sales in 2003.

Information contained in the structural database has been helpful to understand the results obtained in car-to-car and car-to-barrier testing. The database provides the positions of the main frontal structures which must engage in car-to-car impacts to ensure good structural interaction. A typical analysis is shown in *Figure 24* where the vertical position of the vehicle structures can be described in terms of the maximum, minimum, average, and weighted average values. Similar analyses for the lateral position and sectional dimensions can be conducted.

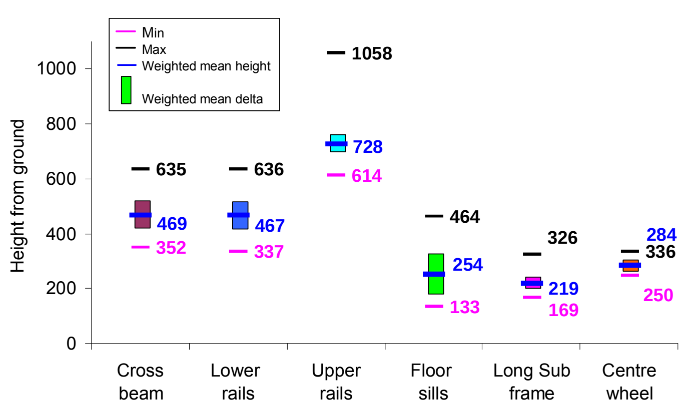


Figure 24: Vertical positions of significant structural components

This survey provides useful data for developing an assessment area for compatibility test procedures. For example, an assessment area would have encompass a vertical range between about 180 mm and 800 mm to include the subframe, main rail, upper rail and wheel sill load paths.

C.2 Crash Testing

C.2.1 Summary of VC-COMPAT Test Results –TRL

This section describes the most comprehensive test series conducted in a joint work program with WG15 national members (summarised by TRL.) All the results were discussed at WG15 meetings. Some disagreements are expressed by some members but the majority of the conclusions are unanimous. The most debated results were those involving the SUVs (Test Series 4 in the following discussion). The full report is available to WG15 members but it has not been made public. Vehicle models have been identified in the report and this has not been accepted for further release.

The objective of the VC-COMPAT test work was to perform crash tests and associated analysis to continue the development and perform initial validation of the Full Width Deformable Barrier (FWDB) and Progressive Deformable Barrier (PDB) approaches.

Currently, the FWDB and PDB approaches consist of the following tests to assess both a car's partner and self protection performance:
FWDB Approach:

- A FWDB test to assess a car's structural interaction potential (partner protection) and to provide a high deceleration pulse to assess the restraint system (self protection).
- An Offset Deformable Barrier (ODB) test to assess a car's frontal force levels (partner protection) and to check the compartment integrity (self protection).

PDB Approach:

- A Full Width Rigid Barrier (FWRB) test to provide a high deceleration pulse to assess the restraint system (self protection).
- A PDB test to assess a car's structural interaction potential and frontal force levels (partner protection) and to check the compartment integrity (self protection).

Work has focused mainly on the FWDB and PDB test procedures with some work performed on the ODB test procedure for frontal force matching. The main reason for this decision was that the first step of the current EEVC WG15 route map [6] requires a test procedure that can assess a vehicle's structural interaction potential. Both the FWDB and PDB test procedures have the capability to do this.

<u>C.2.1.1 Approach</u>

The crash test and data collection work consisted of three separate activities. The first two activities were car-to-car and car-to-barrier testing. These were the main focus of this work package. The third activity was to collect and analyse load cell wall force data from 64km/h ODB tests.

The main aim of the car-to-car and car-to-barrier test activities was to provide data to validate the FWDB and PDB test procedures. Firstly, vehicle characteristics that improved compatibility performance were identified from the car to car tests. These characteristics are referred to as beneficial characteristics. Secondly, an assessment was made of whether or not these beneficial characteristics were adequately identified in the FWDB and PDB tests. A further aim of the car-to-car test activity was to answer the following fundamental questions:

- Can good structural interaction be achieved with a current generation single-level load path car?
- Is a subframe load path a disbenefit in impacts with higher vehicles (SUVs)?
- What size should the assessment area be for the FWDB and PDB tests?

In addition, car to barrier tests were performed to check that the procedures could be used to assess cars irrespective of mass, engine orientation, etc.

C.2.1.2 Test Programme

The car-to-car tests performed as part of the VC-COMPAT project can be subdivided into a number of test series (Table 3).

Table 3 ***-: Car-to-car test programme***

	Vehicles	Organisation	Aim of test series
1.	Small Family (1 load path) Small Family (1 load path)	BASt	Series 1: Investigate difference in structural interaction performance of vehicle that spreads its load well vertically (two load path level design) with one that doesn't (single load path level design).
2.	Small Family (1 load path) Small Family (2 load path)	TNO	
3.	Small Family (2 load path) Small Family (2 load path)	UTAC	Series 2: Investigate difference in structural interaction performance of vehicle that spreads its load well vertically (two load path level design) with one that doesn't (single load path level design) *for state of the art current design cars*.
4.	Small Family (1 load path) Small Family (1 load path)	FIAT	
5.	Small Family (1 load path) Small Family (2 load path)	TRL	
6.	Supermini Supermini	FIAT	Series 3: Investigate difference in performance of light vehicle when impacted by cars with different structural interaction potential (single and two level load path vehicles used in test series 2).
7.	Supermini Small Family (2 load path)	UTAC	
8.	Supermini Small Family (1 load path)	BASt	
9.	SUV (no SEAS) Small Family (2 load path)	BASt	Series 4: Investigate difference in performance of car in impact with SUV if it has an additional load path not necessarily in alignment with the SUV vehicle structure (single and two level load path cars used in test series 2). Investigate if the performance of the car is improved if the SUV has a secondary energy absorbing structure (SEAS).
10.	SUV (SEAS) Small Family (2 load path)	TRL	
11.	SUV (no SEAS) Small Family (1 load path)	VW*	
12.	SUV (SEAS) Small Family (1 load path)	BASt ADAC*	

*Tests performed outside of the VC-COMPAT project to which the group have access to the results

The different test series investigated changes in vehicle design and vehicle mass upon compatibility performance. The test configuration chosen for the car to car impacts in this project was a 50 percent overlap of the narrowest vehicle with a closing speed of 112 km/h.

Examples of a car with a single load path level and two load path level design are shown (Figure 25).

Figure 25: **Examples of cars with single and two load path levels.**

The car-to-barrier tests performed are shown in (Table 4). FWDB, PDB and ODB test data was available for all vehicles tested in the car-to-car test programme.

Table 4: **Car-to-barrier test programme**

	Full Width	PDB (tests with v7 barrier only)	64 ODB (LCW Data)	80 ODB	EuroNCAP Assessment
Supermini 1	√ LCW 50mm[1]	√ v7 (WG15)[3]	X	√ (EUCAR)	3*
Supermini 2 (Car to car series 3)	√ LCW 80mm[2]	√ v7[2]	√ (364kN)	X	3*
Supermini 3	X	√ v7[4]	X	X	4*
Supermini 4	X	√ v7 (LHD)[4] √ v7 (RHD)[4]	X	X	5*
Small family 1 (Car to car series 1 – single level loadpath)	√ LCW 112.5mm[1] √ LCW 50mm (TRL)[1]	√ v7[2]	√ (341kN)	X	4*
Small family 2 (Car to car series 1 - 2 level loadpath)	√ LCW 165mm (WG15)[3]	X	√ (391kN)	√ (EUCAR)	4*
Small family 3 (car to car series 2 – 2 level loadpath)	√ LCW 80mm[2] √ LCW 80mm (TRL)[2]	√ v7[2]	√ (401kN)	X	5*
Small family 4 (car to car series 2 – 1 level loadpath)	√ LCW 80mm[2]	√ v7[2]	√ (457kN)	X	5*
Large Family 1	√ LCW 50mm (WG15)[3]	√ v7 (LHD)[4] √ v7 (RHD)[4]	√ (440kN)	X	5*
Large family 2	X	√ v7 (LHD)[4] √ v7 (RHD)[4]	X	X	5*
Large family 3	√ LCW 50mm (ACEA)[5]	X	X	X	4*
Executive 1	X	√ v7 (WG15)[3]	√ (461kN)	X	4*
Executive 2	√ LCW 50mm[1]	√ v7[1]	√ (463kN)	X	5*
Small SUV	√ LCW 50mm[1]	√ v7[1]	√ (475kN)	X	4*
Large SUV 1 (car to car series 4)	√ LCW 50mm[1]	√ v7[1]	√ (691kN)	X	5*
Large SUV 2 (car to car series 4)	√ LCW 80mm[2]	√ v7[2]	√ (789kN)	X	5*
Large family 3 Modified (weakened and strengthened crossbeams)	√ LCW 50mm (ACEA)[3]	√ v7 (ACEA)[3]	X	X	N/A

C.2.1.3 Results Car-to-Car Test Summary – Identification of beneficial characteristics

Test Series 1 (SFC 1 / SFC 2) & 2 (SFC 3 / SFC 2)

The aim of these two test series was:

- To investigate the difference in structural interaction potential of a two-level load path vehicle design compared to a single-level load path vehicle design.

Please note that only the results of test series 2 are summarised here as these tests were performed with current state of the art design cars, test series 1 wasn't, so the results of test series 2 were thought to be more relevant.

To judge the difference structural interaction performance of the cars in the car-to-car tests, a comparison to a benchmark test has to be made to normalise the effect of other compatibility parameters such as frontal force levels and compartment strength. The benchmark test used was a 64 km/h ODB test, because the EES in of each car in this test and a car-to-car test with a 50% overlap and a closing speed of 112km/h are approximately equal. In addition, a car's deformation behaviour should be best in the 64 km/h ODB test because cars are, in general, designed for optimum performance in this test. The closer the performance of the car in the car-to-car test to the benchmark test, the better the structural interaction performance.

The aim of this test series was to investigate the structural interaction potential of a current generation two-level load path vehicle design (SFC 2) compared to a current generation single-level load path vehicle design (SFC 3). The tests performed as part of this test series were:

- SFC 2 to SFC 2 (two-level load path design to two-level load path design)
- SFC 3 to SFC 3 (single-level load path design to single-level load path design)
- SFC 2 to SFC 3 (two-level load path design to single-level load path design)

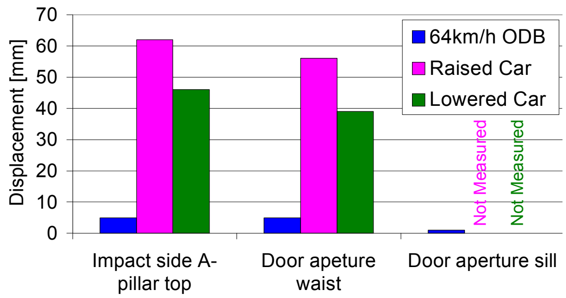
The SFC 2 to SFC 2 and SFC 3 to SFC 3 tests were performed with a 50 percent overlap, a closing speed of 118 km/h and a ride height difference of 60 mm between the cars to emphasize the effect of any over/underride that might have occurred. The slightly higher closing speed was due to a problem with the test facility performing the SFC 3 to SFC 3 test. It was decided to perform the SFC 2 to SFC 2 test at the higher speed to allow direct comparison with the SFC 3 to SFC 3 test. The SFC 2 to SFC 3 test was performed with a 50 percent overlap, a closing speed of 112 km/h and no variation in ride height.

For the SFC 3 to SFC 3 test, significant under/override was observed. The main rail of the lowered SFC 3 bent down substantially and the rail of the raised SFC 3 bent up, showing instability of the main rails (Figure 26). For the SFC 2 to SFC 2 less over/underride was observed. There was less vertical movement of the main rails even though the vertical connections between main rails and engine subframe failed (Figure 27). From detailed examination of the vehicles it is believed that under/override occurred at the beginning of the impact but it was limited by the interaction of the front impact side wheel and the subframe of the opposing car.

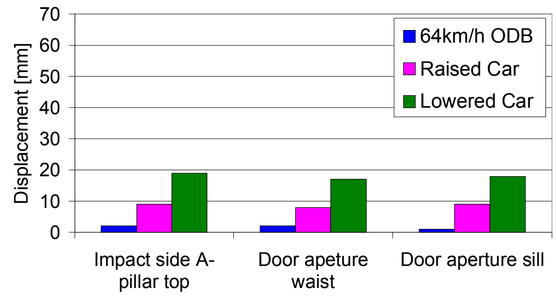
Figure 26: Car-to-car test with the single load path level SFC 3, showing the over/underriding.

Figure 27: Car-to-car test with two load path level SFC 2, showing the contact of the impact side front wheel with the subframe crossbeam of the opposing car.

To judge the structural interaction performance of the cars in these tests, a comparison to a benchmark test was made. The benchmark test used was a 64 km/h ODB test because the EES of each car in this test and a car-to-car test with a 50 percent overlap and a closing speed of 112 km/h are approximately equal. A car's deformation mode behaviour should be best in the 64 km/h ODB test because cars are, in general, designed for optimum performance in this test. When the performances of the cars in the car-to-car tests were compared to those in the benchmark test, it was seen that the performances of the two-level load path SFC 2 was closer to the benchmark. This is illustrated by a comparison of compartment deformation measures, in particular the A pillar movement and door aperture closure (Figure 28). This result indicates that the structural interaction performance of the two level load path design car was better than a single level load path design. Improving the structural interaction performance likely increased the effective compartment strength of the SFC 2, because with improved interaction the compartment is likely to be loaded in a more predictable and even manner. This supports the argument to have a metric that encourages the design of cars with good vertical load spreading capabilities.



Single load path level SFC 3



Two load path level SFC 2

Figure 28: Comparison of the door aperture intrusions between the car-to-car tests and 64 km/h ODB tests

For the SFC 3 to SFC 2 test, the performance of the SFC 2 was compared to the raised SFC 2 in the SFC 2 to SFC 2 and the performance of the SFC 3 with the lowered SFC 3 in the SFC 3 to SFC 3 test. This was based on the relative heights of the bumper crossbeams, the SFC 2 crossbeam centre height higher than the SFC 3 crossbeam centre height (Figure 29).

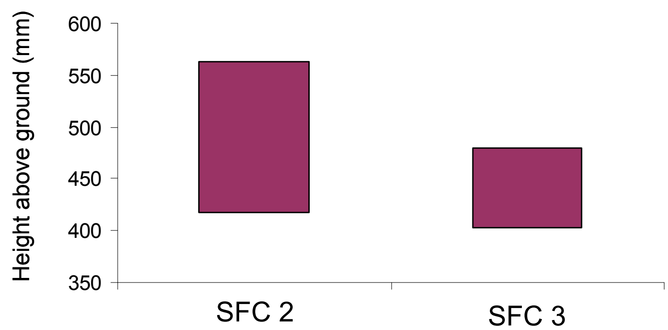


Figure 29: SFC 3 and SFC 2 bumper crossbeam heights (VC-COMPAT structural survey)

The performance of the SFC 2 (two-level load path design) in the SFC 2 to SFC 3 test was similar to the performance in the previously reported SFC 2 to SFC 2 test (Figure 30) and the SFC 2 64km/h ODB test.

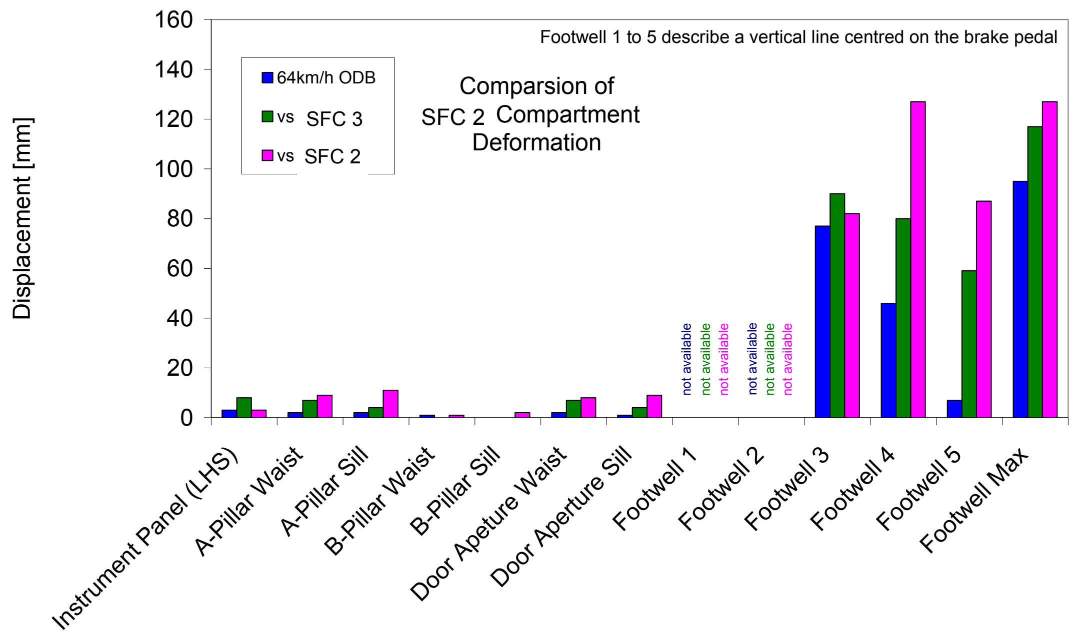


Figure 30: SFC 2 intrusion comparison

The performance of the SFC 3 (single-level load path design) was improved compared to the previously reported SFC 3 to SFC 3 test (Figure 31). The failure mode of the SFC 3 front structure was closer to the baseline 64km/h ODB test in the test with the SFC 2 compared to the test with the SFC 3 (Figure 32). There was better stability of the lower rail in the vertical direction, good wheel engagement with the SFC 2 subframe.

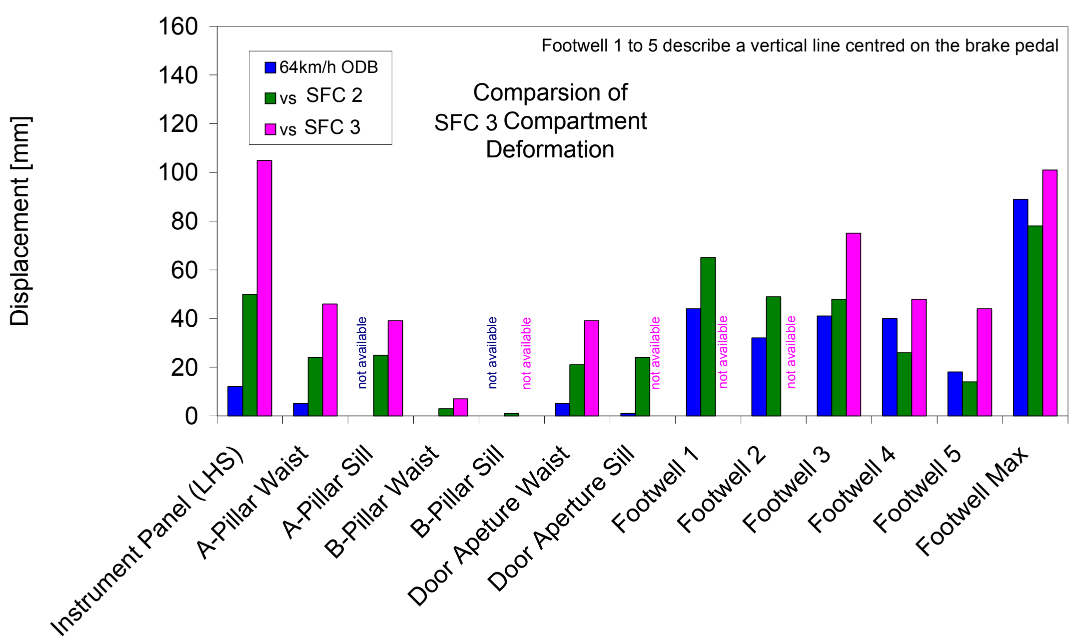


Figure 31: SFC 3 intrusion comparison

vs SFC 2 | vs ODB (64km/h) | vs SFC 3

Figure 32: SFC 3 deformation comparison

The conclusion was that there was better structural interaction for the SFC 3 vs SFC 2 test compared to the previously reported SFC 3 vs SFC 3 test. However, as mentioned previously, the closing speed in the SFC 3-to-SFC 3 test was slightly higher than the closing speed in the SFC 3-to-SFC 2 test, 118km/h compared to 112km/h. It is difficult to distinguish proportions of contribution to improved performance from improved structural interaction and reduced test severity (the lower test severity would also contribute to better performance).

Summary of Conclusions

Test series 2 demonstrated that designs with a better vertical load distribution give improved structural interaction:

- SFC 3 to SFC 3 test demonstrated structural interaction problem
    - o Poor vertical load distribution of SFC 3
    - o Unstable activation of SFC 3 lower rail load path leading to under/override
- SFC 2 to SFC 2 and SFC 2 to SFC 3 demonstrated improved structural interaction
    - o Greater vertical load distribution of SFC 2
    - o Better load path stability of SFC 2 and improved structural interaction

Identification of Beneficial Characteristics:

The test series conclusion(s), supporting evidence and beneficial characteristics that the proposed test procedures should identify are given in summary form in **Table 5**.

Table 5: Summary table - Test series 2 (SFC 2 ; SFC 3)

Conclusion(s)	Supporting Evidence (observations)	Characteristics that assessment should identify
Structural interaction performance of two-level load path SFC 2 better than single load path SFC 1	SFC 3 to SFC 3 test demonstrated poor structural interaction - Performance worse than 64 km/h ODB test (intrusion and dummy injury measurements) - Unstable lower rail load path activation leading to over/underride (observation of rail movement and vehicle deformation) SFC 2 to SFC 2 and SFC2 to SFC 3 tests demonstrated improved structural interaction - SFC 2 and SFC 3 performance closer to 64 km/h ODB test (intrusion and dummy injury measurements) - SFC 2 performance vs SFC 3 comparable to SFC 2 vs SFC 2 (intrusion and dummy injury measurements) - SFC 2 subframe engaged front wheel of opposing vehicle (observation of detailed deformation) better load path stability of SFC 2 and of SFC 3 (observation of rail movement)	Additional load pat of SFC2 (vertical load spreading capability of SFC 2 better than SFC 3)

Test Series 3 - Supermini 2; SFC 2; SFC 3

The aims of this test series were to investigate the effect of mass ratio and to see if the performance of lighter vehicle is improved against car with two load path levels. The tests performed as part of this test series were:

- Supermini 2 to Supermini 2 - mass ratio 1:1
- Supermini 2 to SFC 3 (single-level load path small family car) – mass ratio 1:1.3
- Supermini 2 to SFC 2 (two-level load path small family car) – mass ratio 1:1.3

The tests were performed with a 50% overlap of the narrower vehicle and a closing speed of 112km/h. The ride height difference for the Supermini 2 to Supermini 2 test was 60mm to emphasize any under/override that might have occurred.

In the Supermini 2-to-Supermini 2 test there was initial over/underride due to unstable activation of the Supermini 2 lower rail load path. The result of this poor interaction was greater deformation of the lower car when compared to the 64km/h ODB test (Figure 33). The deformation of the raised car was less than the lowered car indicating a structural interaction and compartment strength problem. This also shows that the compartment strength of the Supermini 2 is sensitive to the distribution of loads into the occupant compartment.

Figure 33: Deformation of the Supermini 2 occupant compartment

The lowered Supermini 2 in the Supermini 2-to-Supermini 2 was compared to the performance of the Supermini 2 in the Supermini 2-to-SFC 2 and Supermini 2-to-SFC 3 tests. In each of the tests, there was initial over/underride due to unstable activation of the Supermini 2 lower rail load path. This was limited by an interaction between the upper to lower rail vertical connection of the Supermini 2 and the lower rail / crossbeam structure of the target vehicle. This led to the conclusion that the structural interaction assessment should encourage good vertical connections between the upper and lower rails. However, the stiffer main rail / crossbeam structure of the partner vehicle overloaded the weaker upper load path of the Supermini 2 resulting in collapse of the occupant compartment (Figure 34). This collapse of the occupant compartment demonstrates the importance of high compartment strength for light cars.

Although the compartment performance of the Supermini 2 was similar for both the SFC 2 and SFC 3 tests, there is some evidence that structural interaction with the two-level load path SFC 2 was better than with the single-level load path SFC 3 – the subframe crossbeam of the SFC 2 engaged the wheel/sill load path of the Supermini 2 – the collapse of the Supermini 2's occupant compartment in all tests prevented an objective assessment of the difference in the structural interaction between the cars.

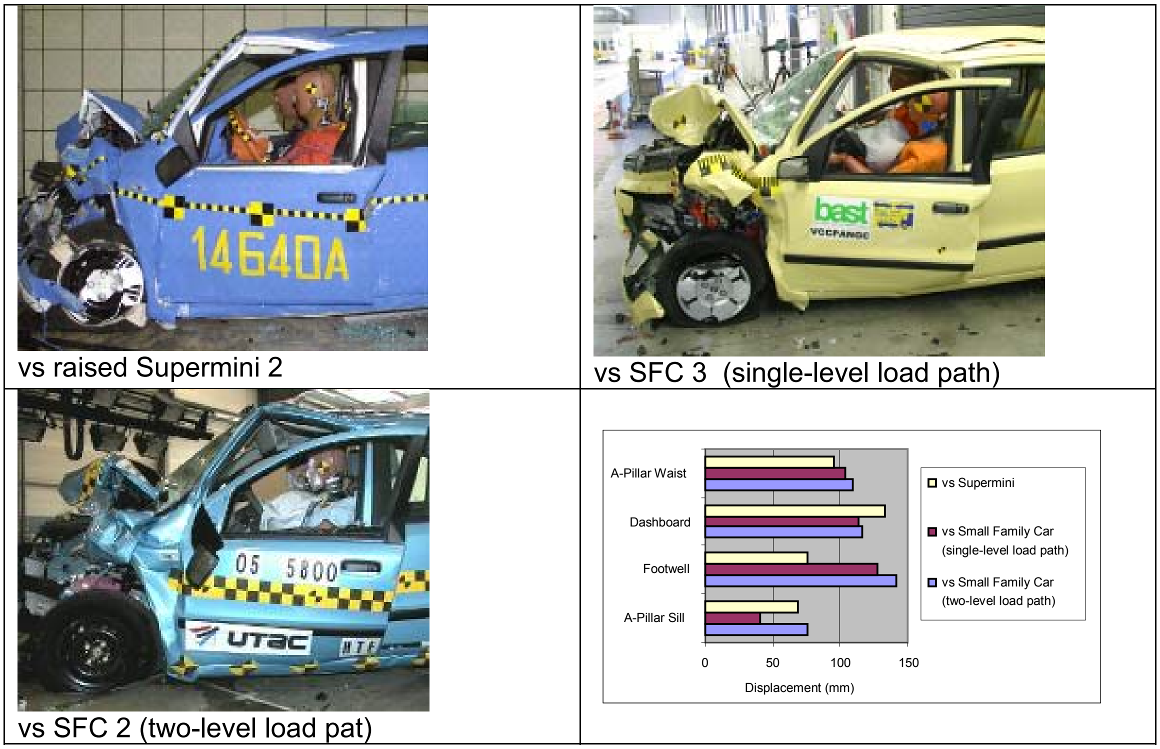


Figure 34: Deformation of the Supermini 2 occupant compartment

The Supermini 2 demonstrates poor structural interaction (unstable rails) which either causes or exacerbates the compartment collapse. This was demonstrated in the Supermini 2 to Supermini 2 test were one compartment remained stable and one collapsed. Improving the Supermini 2's structural interaction potential is likely to increase its effective compartment strength, because with improved interaction the compartment is likely to be loaded in a more predictable and even manner. In an impact with a car with better structural interaction potential, the Supermini 2 still performed poorly because of its low compartment strength. To ensure good compatibility, both structural interaction and compartment strength need to be evaluated.

Summary of Conclusions

- Supermini 2 compartment upper load path was overloaded in all tests demonstrating importance of high compartment strength for light cars
- Supermini 2 upper/lower rail connection helped improve interaction with partner vehicle
- Supermini 2 to Supermini 2 test demonstrated structural interaction problem
  - o Unstable activation of lower rail load path for lowered car leading to under/override which either causes or exacerbates the compartment collapse.
- SFC 2 to Supermini 2 test engaged Supermini 2 wheel/sill load path better than in SFC 3 to Supermini 2 test as a result of the interaction with SFC 2 subframe load path

Identification of Beneficial Characteristics

The test series conclusion(s), supporting evidence and beneficial characteristics that the proposed test procedures should identify are given in summary form in **Table 6.**

Table 6: Summary table – Test series 3 (Supermini 2; SFC 2 ; SFC 3)

Conclusion(s)	Supporting Evidence (observations)	Characteristics that assessment should identify
Supermini 2 upper load path was overloaded in all tests	Supermini 2 to Supermini 2, Supermini 2 to SFC 3 and Supermini 2 to SFC 2 tests demonstrated a compartment strength problem - Supermini 2 compartment intruded in all tests (intrusion measurements - upper level >100mm) - Opponent car stiffer lower rail overload Supermini 2 upper load path (observation of detailed deformation) Note: raised Supermini 2 in Supermini 2 to Supermini 2 test did not demonstrate a compartment strength problem	Compartment strength of small car
Supermini 2 upper to lower rail vertical connection helped improve structural interaction	Supermini 2 to Supermini 2, Supermini 2 to SFC 3 and Supermini 2 to SFC 2 tests demonstrated a structural interaction benefit - Upper to lower rail connection engaged partner vehicle crossbeam / lower rail (observation of detailed deformation)	Vertical connections between upper and lower rails
Structural interaction performance of two-level load path SFC 2 better than single-level load path SFC 3 and single-level load path level Supermini 2	Supermini 2 to SFC 2 test demonstrated a structural interaction benefit - SFC 2 subframe interaction with Supermini 2 front wheel (observation of detailed deformation) Supermini 2 to Supermini 2, Supermini 2 to SFC 2 and Supermini 2 to SFC 3 tests demonstrated a structural interaction problem - Unstable Supermini 2 lower rail load path activation led to under/override (observation of rail movement and vehicle deformation)	Additional load path of SFC 2 (vertical load spreading capability of SFC 2 better than SFC 3 and Supermini 2)
Supermini 2 crossbeam failed to distribute lower rail loads	Supermini 2 to Supermini 2 test demonstrated a structural interaction disbenefit - Crossbeam failed to adequately distribute lower rail loads (crossbeam displaced rearwards relative to lower rail)	Imbalance between weak crossbeam and stiff lower rail

Test Series 4

The tests performed as part of this test series were:

- SFC 2 to SUV 1 – mass ratio 1:1.6
- SFC 2 to SUV 2 – mass ratio 1:1.8
- SFC 3 to SUV 1 – mass ratio 1:1.6
- SFC 3 to SUV 2 – mass ratio 1:1.8 (test results contributed to VC-Compat)
-

The SUVs (SUV 1 and SUV 2) were chosen based on keeping frontal force levels constant (both had approximately the same frontal force levels measured in the 64km/h ODB test) to enable the investigation of structural interaction.

The tests were performed with a 50% overlap of the narrower vehicle and a closing speed of 112km/h. there was no adjustment of the ride height. Please note that the SFC 3 to SUV 2 test was performed outside of the VC-COMPAT group and the VC-COMPAT group had no control over the collection of the results.

SFC 2 / SFC 3 to SUV 1

The SUV 1 employed a secondary energy absorbing structure (SEAS) below the main rails to promote interaction with the small family car front structure. The tests were performed with a 50% overlap of the narrower vehicle and a closing speed of 112km/h.
For the test with the SFC 2, there was initial over/underride of the opposing lower rail structures. This was countered by interaction between the subframe crossbeam (SEAS) of the SUV 1 and the lower rail to the subframe hanger of the SFC 2, and by the engagement of the SUV 1 wheel/sill load path with the subframe crossbeam of the SFC 2 (Figure 35).

SUV 1 wheel loading

SUV 1 SEAS engagement

Figure 35: SFC 2 deformation showing the engagement with the SUV 1

The result was that the loads applied by the SUV 1 were well distributed into the occupant compartment of the SFC 2, which made the most of its compartment strength. This limited the intrusion into the occupant compartment (Figure 36).

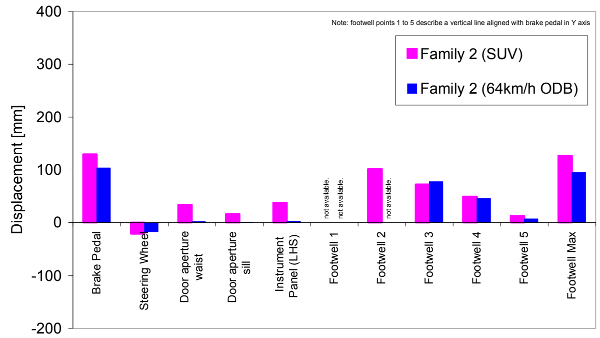


Figure 36: Deformation of the SFC 2 occupant compartment for the test with the SUV 1 and compared to the 64km/h ODB test.

For the test with the SFC 3, there was initial over/underride with the SFC 3 lower rail moving beneath the SUV 1 lower rail. The SFC 3 crossbeam engaged the vertical connection between the SUV 1 lower rail and subframe. The load applied by the SFC 3 crossbeam to this connection resulted in downwards rotation of the undeformed SUV 1 lower rail leading edge. The higher stiffness of the SUV 1 in this impact resulted in SFC 3 absorbing more than its share of the impact energy. This was demonstrated by the large intrusion of the SFC 3 occupant compartment (Figure 37).

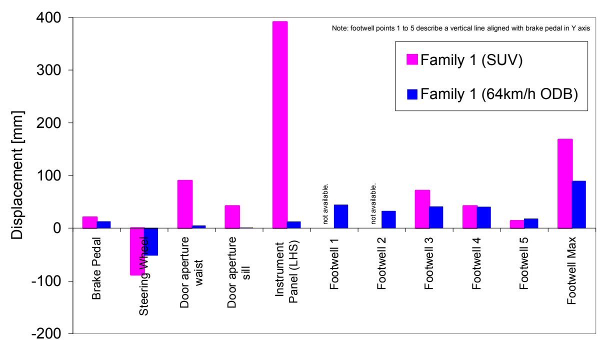


Figure 37: Deformation of the SFC 3 occupant compartment for the test with the SUV 1 and compared to the 64km/h ODB test.

The structural interaction performance of the SFC 2 in the impact against the SUV 1 demonstrated that there was no disbenefit for the two level load path small family car in the impact with a vehicle with a higher structure, in fact a benefit was observed.

SFC 2 / SFC 3 to SUV 2

The SUV 2 had primary energy absorbing structures (PEAS) that were reasonably aligned with the front structure of the SFC 2 and SFC 3. The tests were performed with a 50% overlap of the narrower vehicle and a closing speed of 112km/h.

For the test with the SUV 2 there was dynamic lateral misalignment of the lower rails in both vehicles. The width of front structure of SUV 2 in this test was less than for the SUV 1 in the previous tests. The lower rail of SUV 2 directly loaded the footwell of the SFC 2 resulting in penetration of the footwell, whilst the crossbeam of the SUV 2 loaded the A-Pillar. The strong crossbeam of SUV 2 in this test limited the maximum extent of the footwell penetration by directing the lower rail loading into a stiffer part of the opposing vehicle structure. Figure 38 shows the limited deformation of the lower rail and crossbeam structures of SUV 2. The result of this test was higher occupant compartment intrusion compared to the test with SUV 1 (Figure 39).

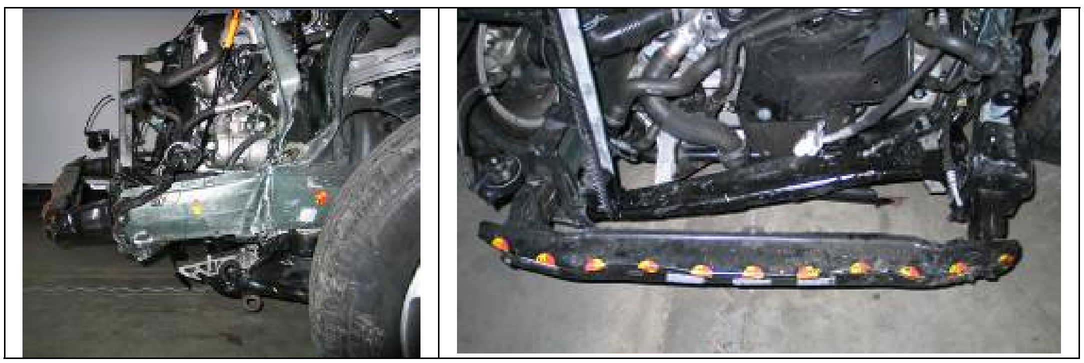


Figure 38: Deformation of the impact side lower rail and bumper crossbeam for SUV 2

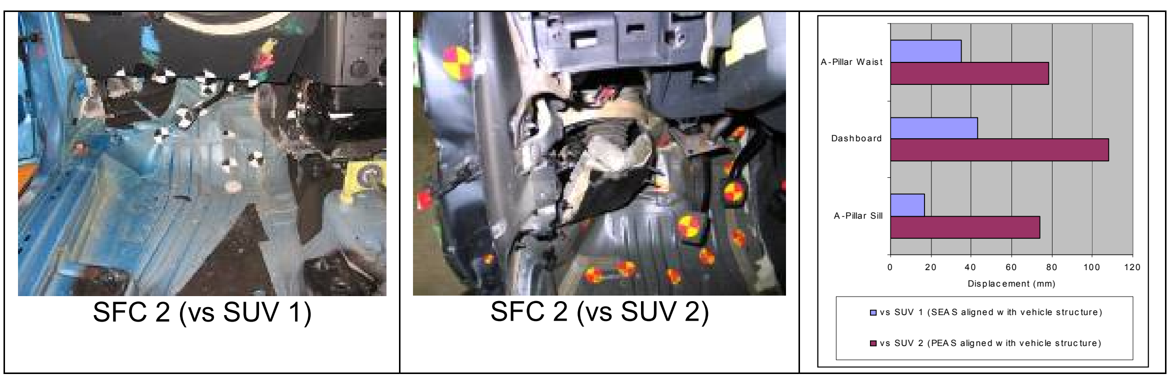


Figure 39: Deformation of the SFC 2 occupant compartment in the tests with the two SUVs (SFC 2 – SUV 1; SFC 2 – SUV 2)

There was poor structural interaction between SFC 3 and SUV 2, with the SUV 2 initially overriding the SFC 3. This was shown by the downward movement of SFC 3 lower rail. The SUV 2 lower rail remained stable in the vertical direction (Figure 39).

Figure 40: Deformation of the SFC 3 and SUV 2 showing the downward movement of the SFC 3 lower rail and the limited vertical movement of the SUV 2 lower rail

There was subsequent dynamic lateral misalignment of the opposing lower rails with the lateral (inward) movement of SUV 2 lower rail. This misalignment would have reduced the effective stiffness of the SUV 2 in this impact test. The result was similar footwell and instrument panel intrusion for the SFC 3 when compared to the baseline 64km/h ODB test (Figure 41). Following the dynamic lateral misalignment of the lower rails, the SUV 2 lower rail initially loaded and then moved outboard of SFC 3 A-Pillar. The loading of the SFC 3 A-Pillar can be observed in greater deformation of the door aperture in comparison to the baseline 64km/h ODB test (Figure 41). However, it is considered that this performance - dynamic lateral misalignment resulting in low compartment intrusion for the lighter car in a high mass ratio impact - would not be predictable in the real world.

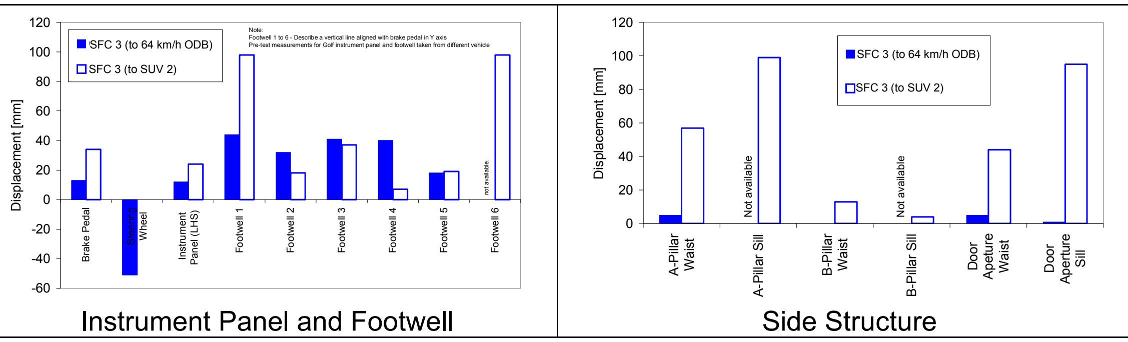


Figure 41: SFC 3 occupant compartment intrusions for test with SUV 2 and 64km/h ODB test.

The assessment should encourage strong crossbeams for directing the applied loads into the stiffer parts of the opposing vehicle structure. The lateral misalignment results in different vehicle performance. However, further study is required to define the relevance of this observation in real world accidents (accident analysis).

Summary of Conclusions

- SFC 2 performance better than SFC 3 in impact with SUV 1
  - Lower compartment intrusion measures for SFC 2 cf SFC 3
    - SFC 2 shows better structural interaction
    - SFC 2 has higher compartment strength
- SFC 2 and SFC 3 tests with SUV 2 demonstrated poor interaction
  - Dynamic lateral misalignment of lower rail load paths

        - Unpredictable in real world accidents
    - Due to dynamic misalignment
        - Reduction in energy absorption of SUV 2
        - Compartment measures reduced cf tests with SUV 1
        - Results in back-loaded deceleration pulse

Identification of Beneficial Characteristics

The test series conclusion(s), supporting evidence and characteristics that the proposed test procedures should identify are given in summary form in **Table 7** for those characteristics determined as beneficial and **Table 8** for those characteristics that had a large effect on the performance of the vehicles.

Table 7: Beneficial characteristics – Test Series 4 (SFC 2; SFC 3; SUV 1; SUV 2)

Conclusion(s)	**Supporting Evidence (observations)**	**Characteristics that assessment should identify**
Structural interaction benefit for two-load path level SFC 2 (no disbenefit)	SFC 2 to SUV 1 test demonstrated a structural interaction benefit - SFC 2 subframe engaged SUV 1 front wheel (observation of subframe and wheel deformation) - SFC 2 subframe hanger engaged SUV 1 subframe crossbeam (observation of hanger and subframe deformation)	Additional load path of SFC 2 (vertical load spreading capability of SFC 2 better than SFC 3)
SUV 1 bumper crossbeam failed to distribute lower rail loads	SUV 1 to SFC 2 and SUV 1 to SFC 3 test demonstrated a structural interaction problem - SUV 1 bumper crossbeam failed to distribute lower rail loads (failure of bumper crossbeam)	SUV 2 crossbeam distributes lower rail loading over centre of vehicle better than SUV 1
SUV 2 bumper crossbeam able to distribute lower rail loads	SUV 2 bumper crossbeam in test with SFC 2 demonstrated a structural interaction benefit - SUV 2 bumper crossbeam engaged SFC 2 A-Pillar (observation of detailed deformation) - SUV 2 bumper crossbeam distributed lower rail loads into SFC 2 A-Pillar (limited deformation of crossbeam structure)	
SFC 3 bumper crossbeam able to distribute lower rail loads	SFC 3 bumper crossbeam in test with SUV 1 demonstrated a structural interaction benefit - SFC 3 bumper crossbeam engaged SUV 1 subframe hanger (observation of detailed deformation) - SFC 3 bumper crossbeam distributed lower rail loading (limited deformation of crossbeam structure)	SFC 3 crossbeam distributes lower rail loading over centre of vehicle
SFC 3 occupant compartment overloaded in test with SUV 1	SFC 3 to SUV 1 test demonstrated a stiffness problem - SFC 3 compartment dynamically less stiff than SFC 2 in tests with SUV 1 - SFC 3 compartment intruded substantially more compared to SFC 2 in tests with SUV 1	SUV 1 frontal force level greater than SFC 3 compartment strength
Vertical structural interaction performance of two-level load path SUV 1 better than SUV 2	SUV 2 to SFC 3 test demonstrated a structural interaction problem - Over/underride of SUV 2/SFC 3 lower rail structures prior to horizontal misalignment (observation of rail movement)	Additional load path of SUV 1 (vertical load spreading capability of SUV 1 better than SUV 2)
	SUV 1 subframe in tests with SFC 2 and SFC 3 demonstrated a structural interaction benefit - Subframe interaction with SFC 2 subframe hanger (observation of detailed deformation) - Subframe hanger interaction with SFC 3 crossbeam (observation of detailed deformation) - Subframe engaged front wheel of opposing vehicle (observation of detailed deformation)	

Table 8: Other characteristics – Test Series 4 (SFC 2; SFC 3; SUV 1; SUV 2)

Conclusion(s)	Supporting Evidence (observations)	Characteristics that assessment should identify
Dynamic horizontal misalignment problem observed for SFC 2 and SFC 3 impacts with SUV 2 (not predictable interaction)	Narrow front structure of SUV 2 (cf SUV 1) resulted in dynamic horizontal misalignment of lower rails in test with SFC 2 and SFC 3 - Increase in SFC 2 compartment intrusion compared to SFC 2/SUV 1 (intrusion upper 93mm cf 30mm, lower 79mm cf 64mm) - SUV 2 lower rail penetrated SFC 2 footwell (observation of detailed deformation) - SUV 2 crossbeam loaded SFC 2 A-Pillar (observation of detailed deformation) - Lower SFC 3 compartment intrusion compared to SFC 3/SUV 1 (intrusion upper 41mm cf 229mm, lower 99mm cf 185mm) - SUV 2 lower rail initially loaded SFC 3 compartment (observation of detailed deformation) - SUV 2 lower rail disengaged SFC 3 compartment (observation of detailed deformation)	SUV 1 applied greater load out wide than SUV 2

C.2.1.4 Car to Barrier testing - Development and Validation of Test Procedures

Work was performed to develop the FWDB approach. In this approach, to monitor (and control) end of crash force levels, it is proposed to use load cell wall (LCW) force measurements from ODB tests. However, engine impact on LCW (engine dump) in the ODB test with an EEVC barrier can give an incorrect measure of vehicle force level. A methodology was developed to minimise this problem which used an excedence approach, i.e. the force level exceeded over a set time period. Based on the available test data, a time period of 10ms was suggested. A comparison of the LCW force histories and the peak LCW force measurements for repeat tests carried out at the same test facility found that the LCW force measurement in the 64 km/h ODB test was reproducible.

The validation of both the FWDB and PDB tests was conducted in three parts. The initial validation was based on the ability of the tool / measurement to detect the beneficial characteristics, this being the load cell wall force distribution in the case of the FWDB test and the barrier deformation profile in the case of the PDB test. The second part was the ability of the criterion in the case of the FWDB test to detect the beneficial characteristics and the parameters in the case of the PDB test to detect the beneficial characteristics and rate the vehicle aggressivity. The third part was an assessment of the repeatability of the test procedures.

From the work done to validate the FWDB test the following conclusions were made:

- The assessment tool – the force distribution measurement – was shown to recognise the vehicle characteristics beneficial to compatibility identified from the car-to-car tests, specifically additional load paths and lower rail / crossbeam imbalance. However, the assessment tool only indirectly detects connections with a length close to or less than the load cell spacing, i.e. it detects the effect they have on the overall load distribution but does not directly detect load from them. This includes most vertical connections.
- The assessment criterion – the VSI and HSI – was shown to recognise the vehicle characteristics beneficial to compatibility identified from the car-to-car tests, specifically additional load paths and lower rail / crossbeam imbalance. However, the assessment criterion only indirectly detects connections with a length close to or less than the load cell spacing.
- The assessment tool and assessment criterion have also been shown to recognise differences in vehicle front structure width. However, further study is required to define the relevance of this observation in real world accidents
- Comparison of the results from two tests in which the vertical impact alignment difference of the car with the LCW was about 1mm showed the load cell wall force distribution measurement and the assessment criterion (VSI and HSI area 1) to be repeatable (This

was based on the fact that the majority of peak cell loads were within 5kN, whilst the row and columns loads were within 10kN. Further tests are needed to identify the maximum vertical impact alignment tolerance permissible for test repeatability).

From the work done to validate the PDB test the following conclusions were made:

- Tests performed on this program help to validate the tool and measurements proposed by PDB test procedure. The obstacle, test speed and overlap chosen are able to reproduce front end loading and collapse mode observed in car to car tests.
- First and main goal of the PDB is also validated, energy absorption capability of the barrier face changed vehicle test severity. PDB introduction will allow harmonising vehicle front end force, an essential step before hoping solving incompatibility problems.
- As regard self protection, the combination of new obstacle, higher speed and overlap make this test severe for the light car without penalise heavy one.
- Regarding partner protection, tests performed show that sufficient information to assess it is contained in the barrier deformation. The PDB deformation is able to detect different front end design in terms of geometry and stiffness. Due to its accurate recording, this barrier will give good evaluation of structural interaction performance level. However, before proposing criteria based on this deformation, we will have to quantify with objective data what it is really needed, what is a good structure engagement, what is an aggressive car in other words: what is a compatible car etc...

C.2.1.5 Summary

The main characteristics that influence a car’s compatibility potential, in particular its structural interaction, have been identified. The FWDB and PDB approaches have been developed further and initial validation has shown that they are both capable of distinguishing the beneficial characteristics that influence a car’s compatibility. However, at the moment it is not possible to recommend a definite set of procedures because the FWDB and PDB approaches are so different that currently an adequate comparison cannot be made between them. To be able to make this comparison and the consequent choice, it is likely that both procedures will have to be developed further to a state where the performance criteria and initial proposals for performance limits are determined. At the moment, criteria have been proposed for the FWDB test but are still under development for the PDB test.

C.2.2 French program – UTAC

Crash tests related to the development of the PDB barrier carried out by UTAC and French industry. A summary of the results were presented by UTAC at WG15 meetings.

C.2.2.1 Introduction:

To validate the PDB approach and compare it with other offset procedures, many tests have been performed in a regulation approach with different cars from European market (light and heavy, old and new generation, left and right hand drive) in different test configurations: current R94 at 56 km/h, R94 at 60 km/h as suggested by EEVC WG16 and PDB protocol at 60 km/h. 24 tests have been performed to complete the study.

C.2.2.2 Test matrix

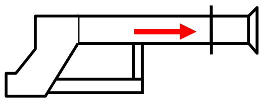
Three test configurations have been investigated:

Regulation ECE R94:
- Test Speed: 56 km/h
- Overlap: 40 %
- Barrier: current ODB

EEVC WG16 proposal:
- Test Speed: 60 km/h
- Overlap: 40 %
- Barrier: current ODB

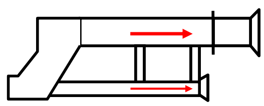
Updated ECE R94:
- Test speed: 60 km/h
- Overlap: 50 %
- Barrier: PDB

Four vehicle types have been investigated:



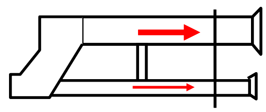
Super Mini Car 1
SMC1 -1151 Kg

New generation with stiff front single load path and high compartment strength.



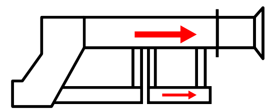
Super Mini Car 2
SMC2 -1130 Kg

Old generation with weak front double load paths and weak compartment strength



Family Car 1
FC1-1747Kg

Last generation with stiff front double load paths with advanced lower load paths and high compartment strength



Family Car 2
FC2-1677 Kg

New generation with stiff single load path with added lower load path and high compartment strength

Note: Cars were tested in regulation approach that means in the worst case: heaviest mass, all options and largest engine.

A total of 24 have been performed and analyzed in order to validate the PDB approach.

Car model	SMC1		SMC2		FC1		FC2	
Driving side	LHD	RHD	LHD	RHD	LHD	RHD	LHD	RHD
ECE R94	√	√	√	√	√	√	√	√
WG16 proposal	√	√	√	√	√	√	√	√
PDB	√	√	√	√	√	√	√	√
TOTAL	24 tests analyzed							

C.2.2.3 <u>Results</u>

- Comparison of different offset barrier tests:

Bottoming out of the barrier face in case of stiffer front-ends of the larger vehicles is avoided. PDB is the ability to check the front unit design.

Figure 42: front deformation of 2000 kg family vehicle against current ODB barrier

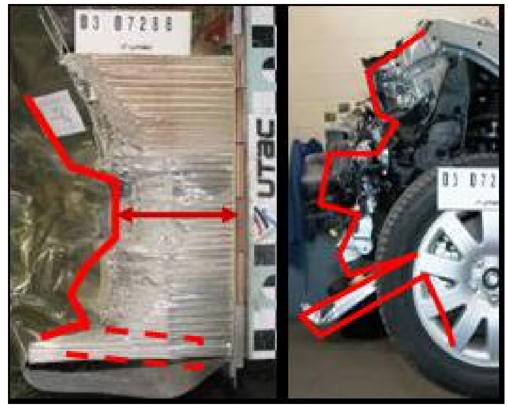


Figure 43: front deformation of the same family vehicle against PDB barrier

- Validation of the possibility to generate constant severity for all cars

The test series demonstrated higher absorption potential of the PDB. This leads in a non constant energy absorbed by the vehicle depending on the force deformation.

When considering the PDB barrier test, severity in terms of energy absorbed for light cars increased and became close to EEVC WG 16 proposal (see *Figure 45*). On the opposite, severity for heavy vehicles stays remained close to current R94 without being below. Current self protection severity is not compromised and light vehicle compartment can be investigated

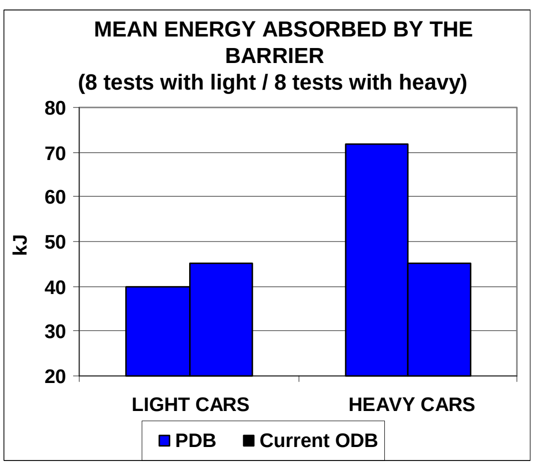


Figure 44: Energy absorbed by the barrier

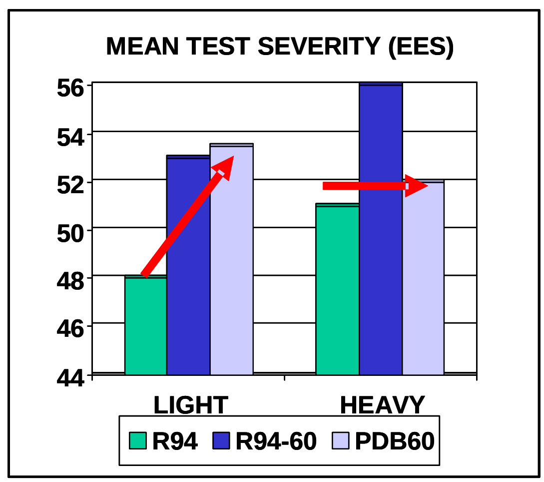


Figure 45: Mean test severity in terms of EES

- Self protection evaluation

Intrusions / acceleration: PDB provides lower acceleration pulse than full width; however the test is able to generate in the same time acceleration and intrusion both parameters responsible for fatal and serious injuries (see *Figure 24*)**.** This combination makes this test closer to real life accident.

Dummy criteria: PDB test can be severe for some categories of vehicles, especially old generations of light cars. However, recent generation of vehicles with high compartment strength, fitted with high performance restraint system is not sensitive to this increasing severity

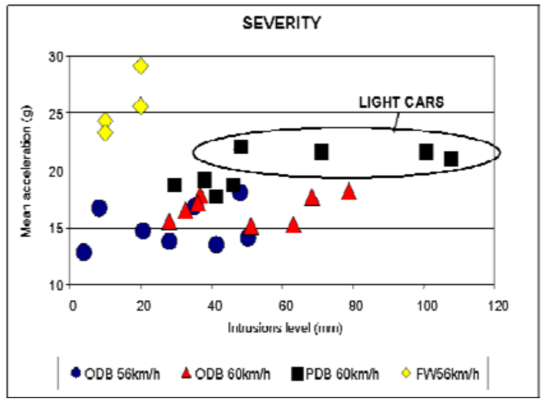
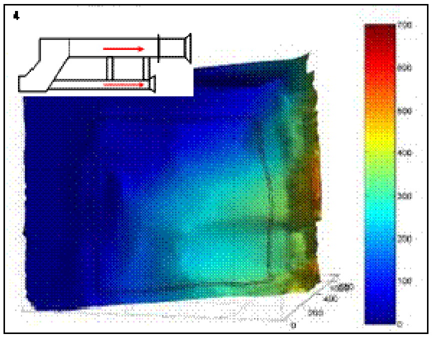


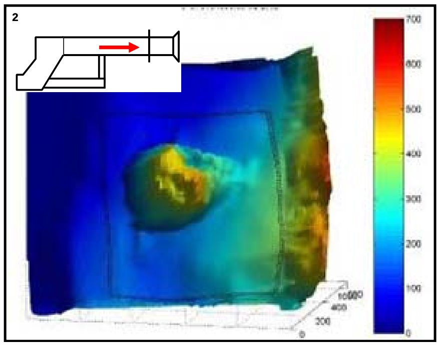
Figure 46: Acceleration vs intrusion

- Partner protection

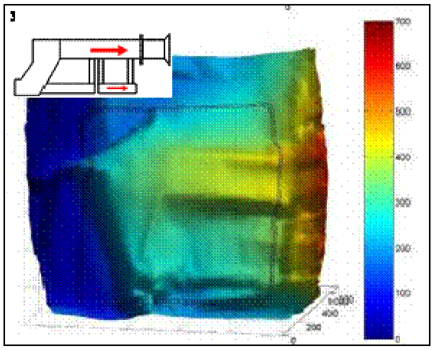
The PDB barrier is able to detect local stiffness but also transversal and horizontal links among load paths. The barrier records front cross member, lower cradle subframe, pendants linking position and stiffness that improve vehicles compatibility. Future assessment criteria proposed for PDB will be based on deformation because information is recorded in the barrier.



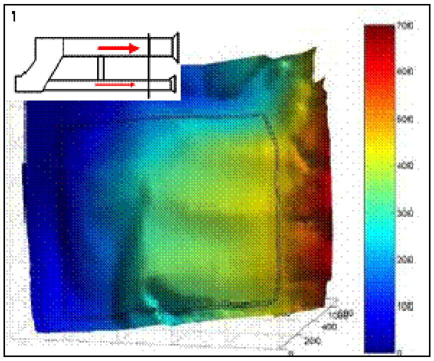
Super Mini Car 2:
Multiple weak load paths car do not penetrate the barrier. Forces are well distributed. Front deformation is homogeneous. This soft stiffness (old generation) design tends to disappear with self protection and reparability requirements.



Super Mini Car 1*:*
Stiff longitudinal with weak cross beam penetrates the barrier. Forces are badly distributed. Cross member is not able to spread the force coming from the longitudinal. The surface area in front of the load path is not matched to with its stiffness. Deformation is inhomogeneous.



Family Car 2:
Forces generated by stiff longitudinal are well distributed by the cross beam. However, this one over crushed the barrier compare with lower load path. Front deformation is homogeneous in front of the cross beam, but quite inhomogeneous in height.



Family Car 1:
High forces generated by longitudinal and subframe are well distributed on a large surface. No over crushed between upper and lower load paths. Deformation is homogeneous.

C.2.2.4 Conclusion

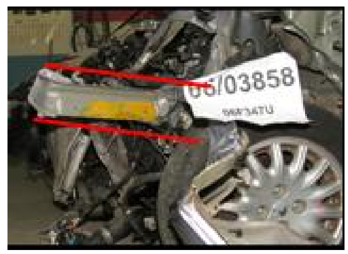
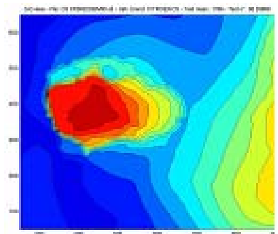
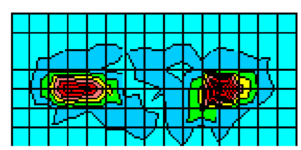
After having compared the different offset test proposed, considered current and future generation of cars in Left Hand Drive and Right Hand Drive, it appears that tests with the current EEVC barrier is not adapted to new compatibility requirements. It promotes an inhomogeneous fleet due to non adapted deformable element. Furthermore, raising test speeds without changing deformable element could become very dangerous for compatibility issues and does not represent an answer for heavy / light vehicle compartment strength harmonization. Furthermore, current barrier deformation does not allow investigating partner protection.

Harmonization of offset test severity is considered as the main priority. Unfortunately, as we have seen before, unstable obstacle, bad reproducibility and bottoming out make tests with current barrier far from this objective. The replacement of the current deformable barrier by the PDB one is becoming the first priority. At the same time, light car compartment strength is ensured by a test speed fixed at 60 km/h corresponding to WG16 suggestions. This proposal would be able to check both self and partner protection and easy to introduce as a regulation.

C.2.3 Capacity of PDB and FWDB to detect structural interaction (UTAC)

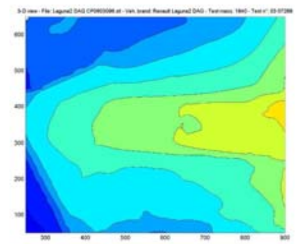
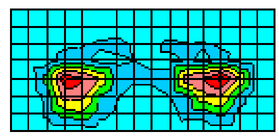
This section describes an analysis of some VC-COMPAT tests and French program tests. The conclusions have been discussed but not all WG15 members are in agreement.

The aim of this study was to check the correlation between accident analysis and structural detection in PDB and FWDB test.

FC1: Stiff longitudinal & weak crossbeam			
PDB			
Accident analysis			
FWDB			

FC1: Stiff longitudinal & weak crossbeam:

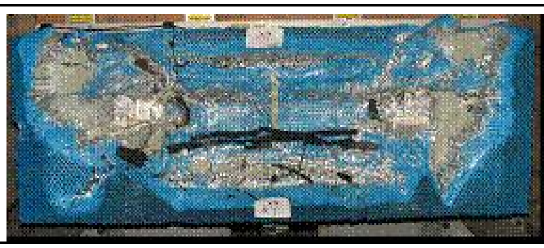
- Real life accident shows stiff and undeformed longitudinal
- PDB test clearly shows very stiff and undeformed longitudinal
- FWDB test shows stiff longitudinals and crossbeam
- PDB results similar to real life accidents

FC2 : Stiff longitudinal & stiff crossbeam			
PDB			
Accident analysis			
FWDB			

FC2 : Stiff longitudinal & stiff crossbeam:

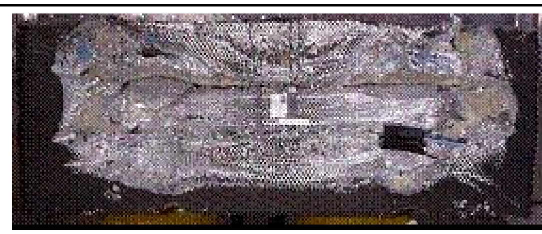
- Real life accident shows very stiff and useful crossbeam
- PDB test clearly shows very stiff crossbeam
- FWDB test does not detect stiff and useful crossbeam
- PDB clearly detect useful structure in real life accidents

FC1 FWDB - Weak crossbeam



2	2	3	6	6	9	5	6	5	8	3	6	5	2	3	0
3	3	8	8	7	4	2	7	5	3	6	8	9	8	2	2
2	4	16	36	33	18	3	4	5	6	17	49	24	10	4	2
1	1	3	9	5	5	8	5	5	7	16	9	7	4	0	0
0	0	4	2	0	5	5	6	4	8	3	7	3	1	0	1
0	0	0	2	2	0	3	4	2	5	0	4	0	2	0	0

FC2 FWDB - Stiff crossbeam



0	1	2	4	4	6	7	4	4	6	5	6	4	4	4	1
0	1	2	7	7	3	3	5	4	3	6	4	6	2	1	1
1	1	12	28	26	20	9	6	6	7	24	25	32	20	2	1
0	1	6	22	22	10	6	3	3	5	8	18	20	8	0	0
1	1	6	12	14	7	4	2	3	3	7	7	12	3	0	0
2	2	1	1	1	2	1	1	1	2	1	1	1	1	2	0

Comparison FC1 / FC2:

- Force distribution in FWDB shows little difference between Family car 2 and Family car 1
- Compatibility test procedure must discriminate between such different cars
- Test procedure needs to detect useful structure in real life accident

C.2.3.1 Conclusion

The basis of this study is to identify useful or aggressive structures in real life accidents and to check if FWDB and PDB test procedures are able to detect them.

The first example studied is a car fitted with a stiff longitudinal and a weak crossbeam. Real life accident shows in several cases that this longitudinal is very stiff and undeformed. This structure was detected on PDB test. Test performed in PDB test clearly shows this very stiff and undeformed longitudinal. FWDB test shows stiff longitudinals and the print of the weak crossbeam.

The second case is a car fitted with a stiff longitudinal and a stiff crossbeam. Real life accident shows this stiff and useful crossbeam. PDB test clearly shows the stiff crossbeam whereas the FWDB test does not detect stiff and useful crossbeam.

The comparison between these 2 cars shows that looking at the force distribution in FWDB, there is no difference whereas the behavior in real life accident is completely different.

Compatibility test procedure must discriminate between such different cars. It is very important to make a link between real life accident and test results in order to detect aggressive structure and useful structures.

C.2.4 External Work to WG15 – Japan

The results of some Japanese research have been made by Japanese representatives invited to a limited number of WG15 meetings. Only the presentations have been made available to the group. The documents are used as reference information at this time.

C.2.4.1 Toyota

Toyota presented test data of car to SUV and SUV tests against FWDB and PDB. In the test series to study structural interaction, in one test set the SUV was unmodified (baseline test) in the other test set the SUV was modified with a stiffer bumper cross beam and a weakened front end frame (prototype test). In the car to car test both SUV's were tested against a small passenger car. In the test series to study stiffness matching effects a large passenger car, a body on frame type SUV and a monocoque body type SUV were tested against a small passenger car, the FWDB and the PDB.

- Test series to study structural interaction:

Although the riding heights were not adjusted in the small passenger car to SUV tests, in the test with the modified SUV the frames of both cars met firmly together and deformed effectively. The intrusion at the dashboard level of the small passenger was in addition less critical. The modified SUV also got better scores in FWDB and PDB assessment criteria which were under consideration end 2005. Toyota concluded that both FWDB and PDB seem to be a useful tool to improve structural interaction. But Toyota think that the FWDB test is a better instrument for structural interaction improvement than PDB because high resolution load cell wall data are useful for analysis.

- Test series to study stiffness matching:

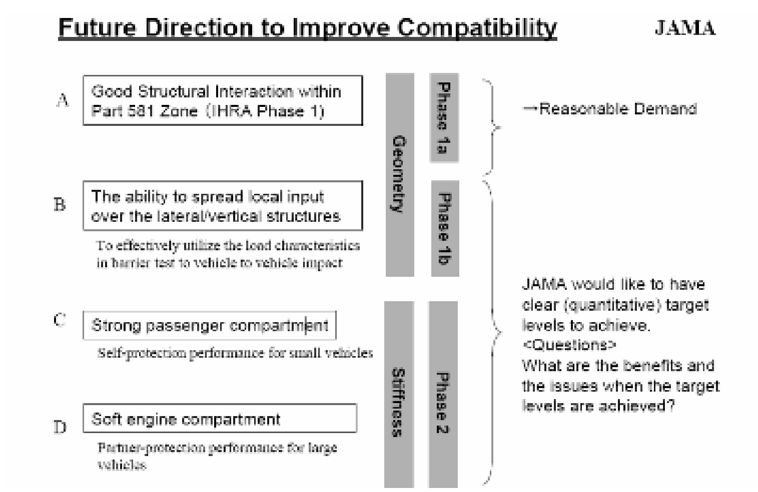
From the car to car test results Toyota concluded that force mismatch plays an important role in compatibility. The body on frame SUV absorbed the least energy of all cars in the car to car tests. But in the FWDB barrier test this vehicle type showed the best score when using the assessment criterion of negative horizontal force deviations from a target load (HNT). Concerning the PDB tests Toyota concluded that PDB deformations and deformation based assessment criteria, e.g. average depth of deformation, do not correspond to the results of the car to car tests. The amount of energy absorbed by the PDB before a total force of 400kN (measured behind the PDB) however seems to have the potential to assess the vehicle stiffness and seems to correspond to the car to car test results.

Summarising, Toyota concludes that the key to good compatibility is not only good structural interaction but also stiffness matching. The PDB test procedure is one candidate method to evaluate stiffness matching of different car types. The metric using LCW force may be better for stiffness evaluation than the metric using honeycomb deformation. It is important for good structural interaction that strength is matched between bumper cross beam and front end lower rail. HNT evaluated FWDB tests is a good metric for strength matching between bumper cross beam and front end lower rail. For better FWDB test evaluation method Toyota supplied proposals for the improvement of HNT and homogeneity metrics.

C.2.4.2 JAMA work

JAMA carried out 2 car to SUV tests to analyse the effect of geometry matching. In one test both vehicles impacted against each other in their normal riding height, in the second test the riding height of the SUV was lowered by 57mm to align the structural member height of both cars. The override/underride effect was lower in the test with adjusted longitudinal height. Also the upper body dummy levels were lower for both cars in this test. For the lower legs however the dummy values in the small passenger car were higher due to higher intrusions at the lower car structures in this car. This effect will be taken under further consideration.

The future direction of JAMA research to improve car to car compatibility is summarized in the graph below.



C.2.4.3 JARI

JARI carried out 2 FWDB tests with the same car model (car type SUV, weight about 2to) to evaluate the repeatability of this test method. The injury criteria variance in the front dummies was in the normal range. Significant vehicle deformation differences were observed at the centre of bumper beam and the supplementary energy absorption system (SEAS). From detailed force measurement evaluation JARI concluded that the average height of force (AHOF) and the assessment of the negative deviations of a vertical target level (VNT) can be

considered to have good repeatability in FWDB tests. From the difference of the deformation of the honeycomb the repeatability of horizontal force deviations from a target load (HNT) and homogeneity could not be assessed. The photos below show the deformed full width deformation elements of the 2 FWDB tests.
Eberhard will summarize the results from the presentation (WG 15 report 360&363)

C.3 Computer Modelling

C.3.1 VC-COMPAT Modelling (TNO / Chalmers)

C.3.1.1 Frontal Ftorce Levels

A methodology for developing generic vehicle models has been developed in previous WG 15 studies and was updated in VC-COMPAT. The generic vehicle model can be adapted to specific vehicles by changing properties of the spring characteristics. Two crash tests are required to obtain vehicle properties. The generic model is based on the assumption that the structural interaction is ideal in car-to-car impacts.

In a stiffness harmonization among vehicles of different masses, it is possible to only increase the stiffness of smaller vehicles and maintain adequate compartment strength for mass ratios up to 1.6. When smaller vehicles have global force levels of 350-400 kN, they are able to activate the frontal crush zones of larger vehicles sufficiently. Vehicle occupants can, within the capabilities of the computer models, survive the high accelerations that occur in these impacts. However, to harmonize stiffness levels without also decreasing the stiffness of larger vehicles would create small vehicles which are very stiff. It would therefore be desirable to also decrease the stiffness of larger vehicles. One method for decreasing the stiffness without reducing the energy absorbing capacity is to extend the vehicle front. An extension of 50 mm in larger vehicles reduces acceleration levels and decreases the required stiffness levels in the opposing smaller vehicle.

C.3.1.2 Fleet Study Analysis of Improved Front-end Design

A numerical vehicle fleet consisting of 7 different manufacturers models was developed for the MADYMO software. These models were used to study various impact configurations in car-car impacts as well as observe the crash performance in proposed test procedures. The existing smaller vehicle models were shown to not provide good crash behaviour without modifications.

Different vehicle improvement strategies were investigated. These strategies were inline with the objectives of the candidate test procedures. Improved crash behaviour was observed in both vehicle to barrier and vehicle to vehicle crash configurations. The improvements were noticeable in the fleet wide injury distribution. Compatibility measures were shown to reduce some injury criteria.

Influence of Frontal Compatibility in Side Impact
As expected, the design of the front of a vehicle influences the injury risk of the passengers in the struck vehicle in a side impact. An investigation of vehicle stiffness using the side impact barrier was used to determine correlations between measurements on the vehicle front and the passenger injury risks. The average Height of Door Force (AHoDF) was shown to correlate with the dummy measurements. Thus the vertical force distribution of vehicle fronts should be monitored for any potential problems in side impacts.

C.3.1.3 FE Model development

As part of the VC-COMPAT project the FE models of the FWDB and PDB barriers were further refined and made available for the automotive industry and research community.

C.3.2 German Industry (As submitted by VW)

This study conducted by VW investigated the potential to exploit the PDB barrier's energy absorbing capacity. Some members of WG15 have concerns about the modelling assumptions made.

In a vehicle to rigid barrier collision, all of the kinetic energy of the vehicle must be dissipated through deformation of the vehicle, preferably in the front-end “crumple zone”. However, in a collision with a deformable barrier, the deformation is shared. As the deformation potential of the barrier increases, the need for the vehicle structure to deform is decreased. If enough deformation potential is present in the barrier, and the vehicle structure is able to support the forces arising during the collision, a vehicle could collide with the barrier with little or no deformation to its own structure.

German industry is concerned that the PDB provides too much deformation potential, and that a vehicle could be designed with a reduced front-end “crumple zone,” but still meet the self-protection requirements of the test. Such a vehicle design would have catastrophic results in real world collisions with trees or other rigid objects, because the vehicle front end would have insufficient deformation potential. This would consequently lead to deformation of the compartment and compartment failure.

Compartment deformation occurs when the forces transmitted to the compartment are too high. Naturally, the forces reacted in a collision with a rigid object are significantly higher than the forces that are reacted by a deformable element. German industry is concerned that a vehicle designed for a PDB test will not require the same level of compartment stiffness as a vehicle designed for the existing ODB, since ultimately the ODB becomes a rigid barrier when it bottoms out.

To investigate this potential shortfall, simulations were performed with a small passenger car with a very stiff longitudinal and crossbeam. The goal of stiffening the front structure was not to reflect a proposed design change (stiffer structures are naturally more expensive in terms of both cost and weight) but rather to test the effect of reducing the available potential deformation energy. Instead of deforming, the stiff longitudinal acts as a direct load path between the vehicle compartment and the barrier.

For the purposes of comparison, the simulations were also performed for an unaltered model of the car. The weight of the vehicles was identical. The figures below show the two models at the time of maximum deformation in a 60km/h collision with the PDB.

As seen clearly in Figure 47, the PDB has undergone significantly more deformation, and hence absorbed more energy, in the test with the modified passenger car. However, it has not bottomed out. Also, the compartment of the modified car does not have greater intrusions than the compartment of the standard car. The compartment accelerations, shown in Figure 56, are also very similar for the two vehicles, indicating that dummy values measured in this test would be very similar. This simulation shows that a vehicle with less potential deformation energy is able to perform as well as a standard vehicle in a PDB test.

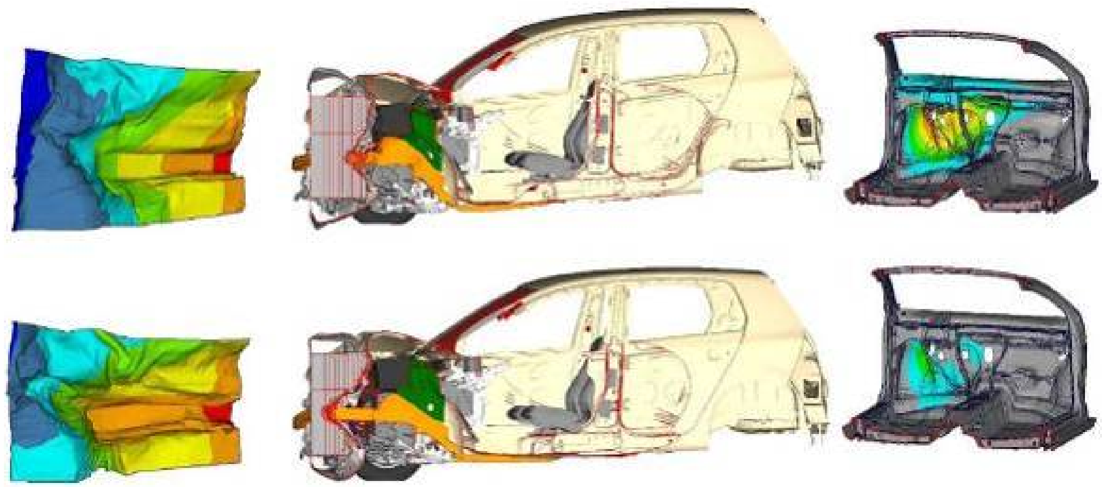


Figure 47 Standard (top) and modified (bottom) passenger car to PDB collisions. Barrier deformation (left), cross-section through left longitudinal (middle) and firewall intrusions (right).

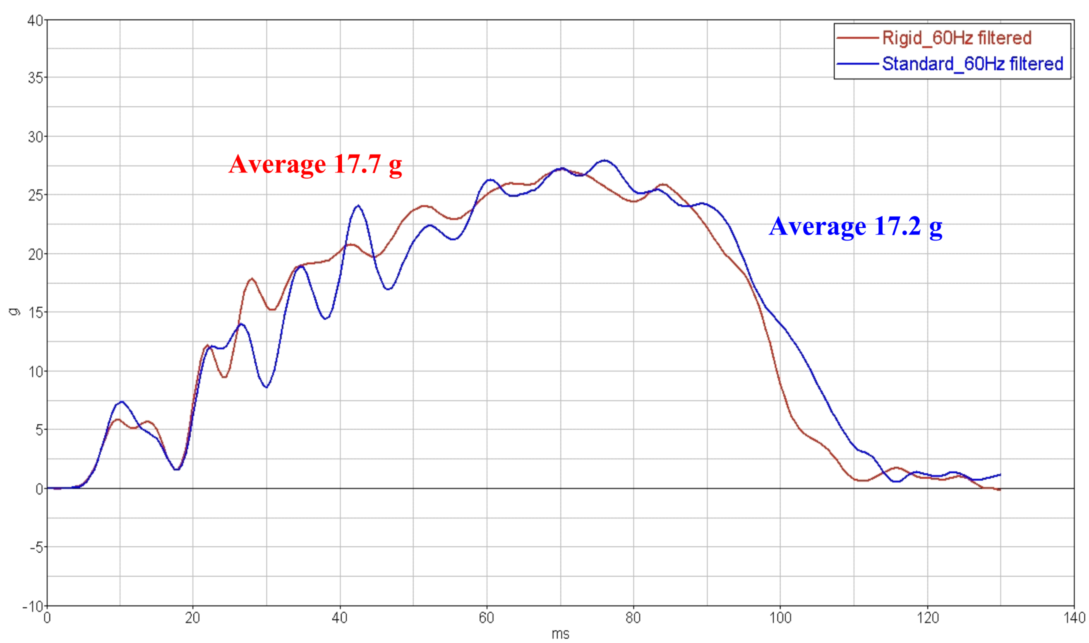


Figure 48: Standard (blue) and modified (red) compartment accelerations for passenger car to PDB collisions.

To confirm that the stiffening of the front end structures indeed reduced the available potential deformation energy of the car, the same models were simulated in collisions against the ODB at the 56 km/h R94 test speed and the 64 km/h EuroNCAP test speed. The figures below show the results at the time of maximum deformation.

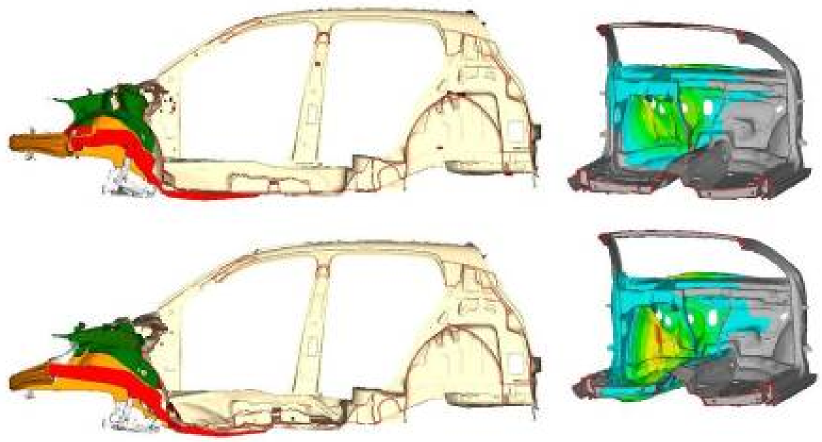


Figure 49: Standard (top) and modified (bottom) passenger car to ODB collisions at R94 test speed (56 km/h). Cross-section through left longitudinal (left) and firewall intrusions (right).

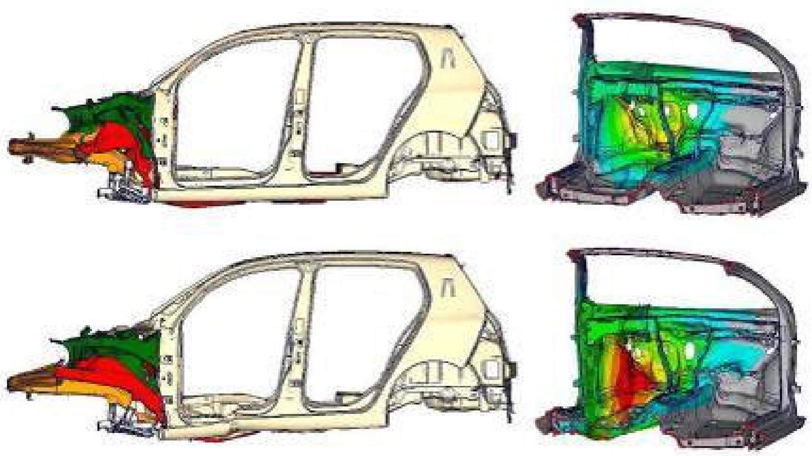


Figure 50: Standard (top) and modified (bottom) passenger car to ODB collisions at EuroNCAP test speed (64 km/h). Cross-section through left longitudinal (left) and firewall intrusions (right).

Clearly, the modified vehicle does not have sufficient potential deformation energy to protect its occupants in the event of a collision with the ODB. At the EuroNCAP test speed, the modified vehicle experienced substantial compartment deformation. Also at the R94 test speed, there is clearly greater deformation of the passenger compartment when compared to the standard vehicle.

From these simulations, it was concluded that the PDB would not highlight deficiencies in available potential deformation energy, and would hence allow the production of unsafe vehicles. Such deficiencies are detected by the existing R94 barrier, so a change from the existing barrier to the PDB may involve significant risks.

C.3.3 French Industry (PSA)

A recent simulation study by French industry in response to criticisms about the energy absorbing capabilities of the PDB barrier.

FRONT END AND COMPARTMENT REINFORCEMENT INFLUENCE ON PDB

- Introduction

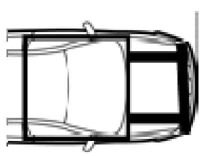
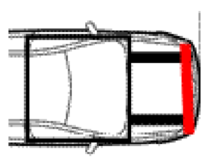
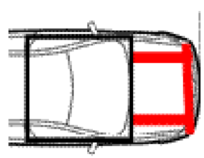
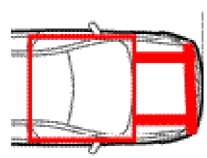
Some questions were raised concerning the possibility to use the energy absorption capacity of the PDB leading to a lower test severity for the car and to a possible reduction of the self protection level.

The aim of this study is to check if these concerns are realistic and if it is possible for a car manufacturer doing so.

Two different test procedures are generally used nowadays to design a car structure:
- Offset deformable barrier test which creates shear in the front end and a lot of intrusion.
- Full width rigid barrier test which generates high deceleration pulse for the occupants but low intrusion.

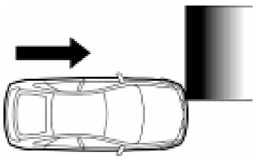
In order to have a global approach of the problem, the work performed was to check the influence of compartment and front end reinforcement on both test procedures: PDB and FWRB test.

- Virtual testing matrix

		Case 1	Case 2	Case 3	Case 4
					
		Reference	Case 1 + Rigid front interface	Case 2 + Reinforced front end	Case 3 + stiff compartment
Citroen FC	Mass	Ref=2161 kg	Ref + 3,5 kg	Ref + 12,6 kg	Ref + 36,9 kg
	PDB	√	√	√	√
	FWRB	√	√	√	√
Renault SMC	Mass	Ref=1461 kg	Ref + 7,6 kg	Ref + 11,4 kg	Ref + 20,8 kg
	PDB	√	√	√	√
	FWRB	√	√	√	√

- Results PDB at 64 km/h

PDB AT 64 KM/H



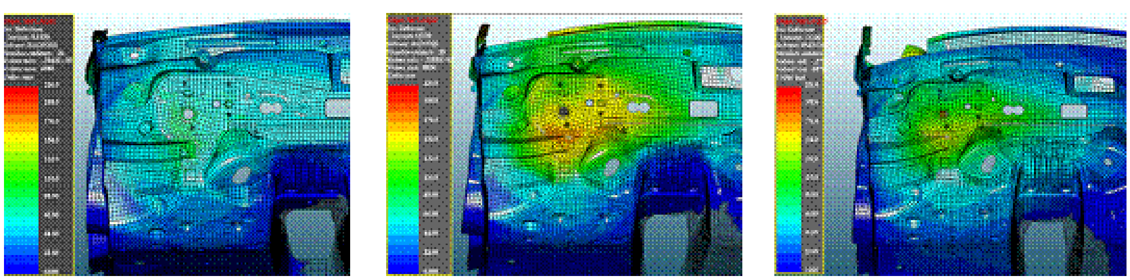
Test configuration :

- speed : 64km/h
- Overlap: 50%
- Barrier: PDB
- Mass: best selling

RESULTS: Citroen FC			
PDB at 64 km/h	Case 2	Case 3	Case 4
Mass (kg)	2165	2174	2198
E barrier (kJ)	129	129	139
EES (km/h)	46,7	47,2	46,7
Average accel (g)	15,3	15,8	16,3
Compartment intrusion (mm)	61	**113**	82

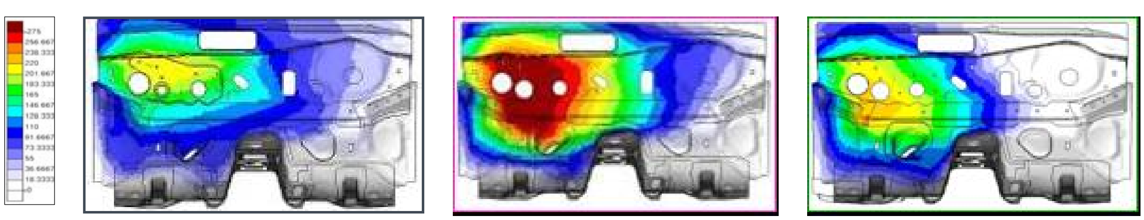
RESULTS: Renault SMC				
PDB at 64 km/h	Case 1	Case 2	Case 3	Case 4
Mass (kg)	1461	1469	1473	1482
E barrier (kJ)	75	78	79	89
EES (km/h)	52.5	52.1	51.9	50.3
Average accel (g)				
Compartment intrusion (mm)	115	94	187	143

- Front unit reinforcement doesn't influence EES
- Front unit reinforcement leads to higher intrusions in the compartment (case 3)
- Higher compartment strength can not compensate over intrusions (case 4)
- Higher force deformation and acceleration are detected by PDB.



Case 2 Case 3 Case 4

Figure 51: Citroen FC - PDB64km/h - Compartment passenger intrusions

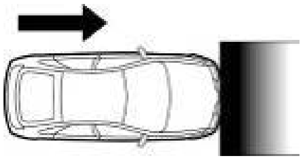


Case 2 Case 3 Case 4

Figure 52: Renault SMC - PDB64km/h - Compartment passenger intrusions

- Results FWRB at 56 km/h

FWRB AT 56 KM/H



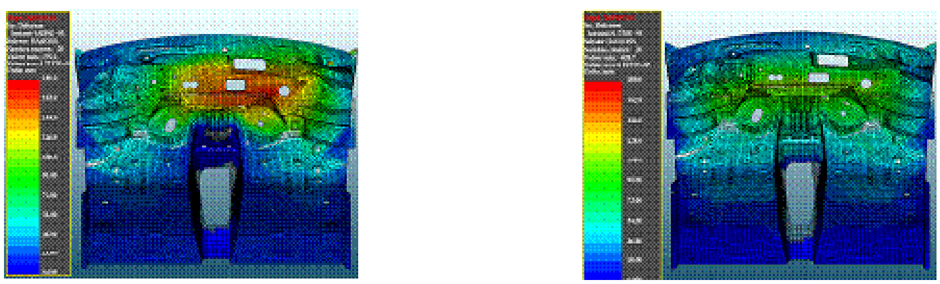
Test configuration :

- speed : 56km/h
- Overlap: 100%
- Barrier: rigid
- Mass: best selling

RESULTS: Citroen FC		
FWRB at 56 km/h	Case 2	Case 4
Mass (kg)	2165	2198
Average accel (g)	19,3	24,7
Compartment intrusion (mm)	66	57

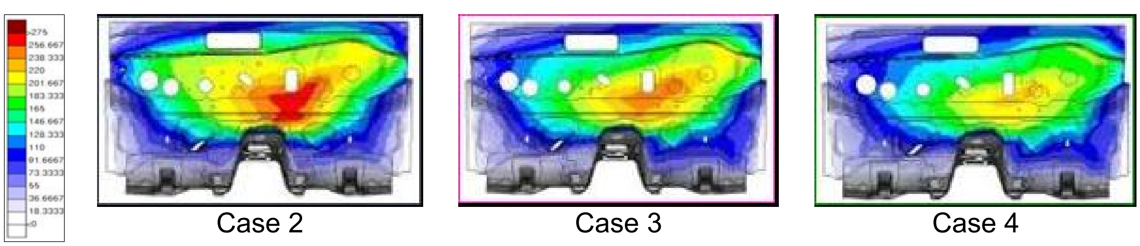
RESULTS: Renault SMC				
FWRB at 56 km/h	Case 1	Case 2	Case 3	Case 4
Mass (kg)	1461	1469	1473	1482
Average accel (g)	23.7	24.4	25.0	26.0
Compartment intrusion (mm)	86	85	79	75

- Front unit reinforcement leads to higher acceleration: severe for occupant
- Front unit reinforcement leads to bad collapsing
- No evident intrusion reduction in spite of reinforcements



Case 2 Case 4

Figure 53: Citroen FC – FWRB56km/h - Compartment passenger intrusions



Case 2 Case 3 Case 4

Figure 54: Renault SMC - FWRB56km/h - Compartment passenger intrusions

C.3.3.1 Conclusion

- The study performed on two different cars in two test configuration show that:
- The front end reinforcement is detected by PDB, looking at compartment intrusions and acceleration pulse.
- The front end reinforcement is detected by FWRB test, looking at acceleration pulse.

- The compartment reinforcement can not compensate front end reinforcement.
- The reinforcement performed on the car doesn't influence the EES on PDB test.
- Trying to use energy absorption capacity of the PDB is not a good strategy because it leads to worse safety performances and higher mass which is counter productive with others constraints like CO2, consumption, emission…

C.3.4 Moving Progressive Deformable Barrier development program – TNO

For the short term assessment of compatibility two test procedures are under development within the VC-COMPAT-project and EEVC WG15; the FWDB and PDB procedures. In addition a potential future regulatory test procedures to assess vehicle-to-vehicle compatibility for mid to long term is being developed. 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.

C.3.4.1 Objective

The objectives of the project is to develop a future step in compatibility testing for the mid to long term. The main goal in the project is to check the feasibility and merits of a Moving Deformable Barrier (MDB) in a frontal offset test procedure.

C.3.4.2 Approach

The initial step in the project was to develop a trolley equipped with a High Resolution Loadcell Wall (HR-LCW) and with a mass and inertia properties that are representative for an average European car. 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 masses as shown in Table 9. 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.

Table 9: Tested vehicles

Vehicle brand and model	Vehicle test mass	MPDB mass	Mass ratio vehicle/trolley	Test house
SFC 1	1403	1486	0.94	TNO
SFC 1	1406	1486	0.95	TNO
SFC 2	1250	1486	0.84	TNO
SFC 3	1313	1486	0.88	UTAC
FC 1	1853	1486	1.25	UTAC

C.3.4.3 Results

A trolley was developed with adjustable mass between 1300 and 1800 kg with corresponding inertia properties. The inertia properties for vehicles of different weight were derived from the NHTSA database. The barrier is equipped with a HR-LCW as shown in Figure 55. The HR-LCW is light weight to ensure the correct inertia properties of the trolley and has eight columns and six rows of 125x125mm loadcells.

In this project the PDB barrier was chosen as deformable element because this is seen as currently the best barrier to assess frontal compatibility in an offset test. The assessment of both partner and self protection will be based on the assessment protocol of the Progressive Deformable Barrier (PDB) test procedure, which is currently still under development. Additionally, advanced assessment criteria will be developed based on Load Cell Wall readings and trolley accelerations.

Further details of the trolley development can be found in the I-Crash paper 2006-71 presented at the I-Crash conference in Athens July 2006.

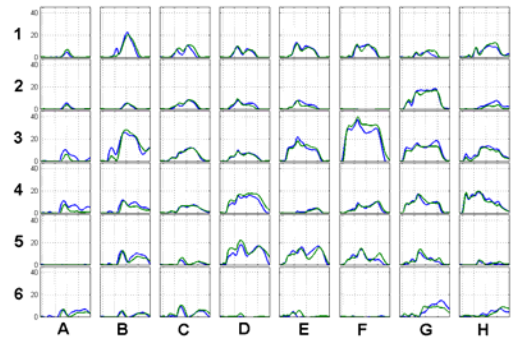
Figure 55- Final design of the MPDB with HR-LCW and PDB barrier.

The developed barrier was run with and without deformable element into a rigid wall to check if the design was capable of handling the forces that occur in a frontal crash. Secondly, the HR-LCW was validated by component tests with various deformable elements, by comparing acceleration and force signals and checking the ability to discriminate and detect structures. All test results were positive and gave confidence to continue the project and perform the series of MPDB-to-car tests.

<u>MPDB-to-car tests</u>

The test specifications for the MPDB-to-car tests are chosen in such a way that an equal amount of initial kinetic energy is put into the test when compared to a static PDB test for a car of mass ratio 1. This results in a closing speed of 90 km/h (both car and MPDB at 45 km/h). The offset and ground clearance are equal to the static PDB test at respectively 50% and 150mm.

The first two tests were performed with a SFC 2 to investigate the practicality and repeatability of the draft test procedure. The test results, vehicle and trolley accelerations, vehicle deformations etc, showed a very good correspondence between both tests. The barrier deformation and LCW recordings also showed a very good similarity as can be seen in Figure 56.



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

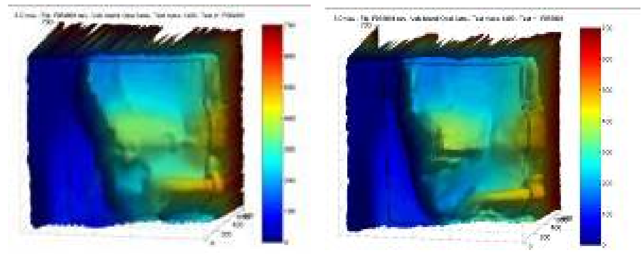


Figure 56 – LCW recordings and barrier deformations of both SFC 1-to-MPDB tests

Based on the acceleration signals of the vehicles, shown in Figure 57, it can be concluded that the test severity was higher for the smaller vehicles compared to the larger vehicle. Table 10 shows that all vehicles deform the barrier in a different manner. For instance the SFC 2 penetrates the barrier at a small contact area in the beginning of the crash resulting in a lower acceleration level. On the other hand it can be seen that the FC 1 has a very homogeneous front end shown as a constantly increasing acceleration signal. When the velocity profile of the trolley is examined in Figure 58 it is clear that a difference in mass results in a different post crash velocity. The higher the mass the larger the delta V of the trolley, which shows that a moving barrier test is a more realistic representation of a car-to-car crash than a fixed barrier.

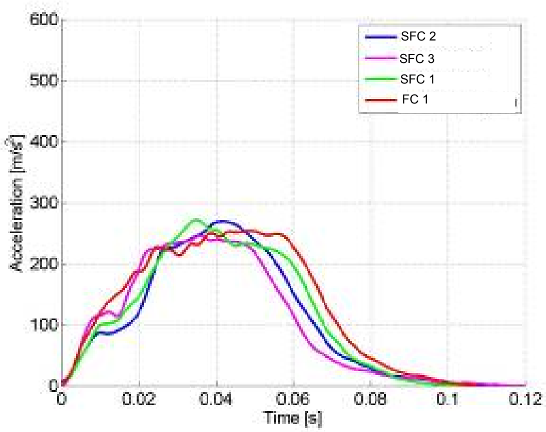


Figure 57 – Trolley acceleration for all tested vehicles

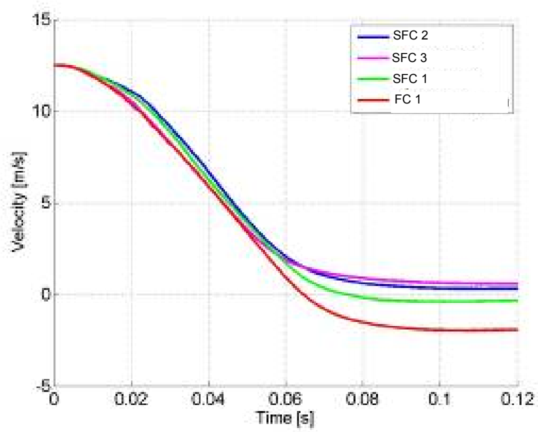


Figure 58 – Trolley velocity for all tested vehicles

<u>Moving PDB versus fixed PDB</u>

Another goal of this research was to check the influence of making the barrier mobile on crash severity. Therefore the test results of the fixed and mobile PDB tests were compared. When comparing the barrier deformations, shown in Table 10, it can be concluded that in the MPDB the deformations and, due to the increasing stiffness of the barrier, peak accelerations are larger for the smaller vehicles and are less for the heavier FC 1. The severity for the SFC 2 with mass ratio ~1 is equal in both methods as was intended to be.

Table 10 – Barrier deformations of both the MPDB and PDB tests for the different vehicles

		PDB	MPDB
SFC 2	*ADOD (X) [mm]*	204	232
	AHOD (Z) [mm]	458	466
SFC 3	*ADOD (X) [mm]*	147	195
	AHOD (Z) [mm]	417	438
SFC 1	*ADOD (X) [mm]*	228	232
	AHOD (Z) [mm]	480	493
FC 1	*ADOD (X) [mm]*	294	273
	AHOD (Z) [mm]	492	510

C.3.4.4 Conclusion and recommendations

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. 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 SFC 2 with mass ratio ~1 it was shown that the severity was in-line with the fixed PDB procedure. The heavier FC 1 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.

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.

Appendix D. WG 15 Comments on Test Procedures

Test Method	Category / Sub-Category	Comment
Accident analysis		Additional work required to determine why a high frequency of moderate (AIS2) and life threatening (AIS 3+) injuries due to seat belt induced loading was seen in the GB benefit analysis and why the majority of thoracic injury was not prevented by the injury reduction models - is the deceleration pulse already a major problem? Could be a request to WG21
Benefit		Estimate benefit for specific recommendation. Could also be confirmed by WG21. Methodologies should be reviewed by WG21.
General	Tool	Verify that EES value is adequate for all vehicle masses (accident analysis)
All	Assessment	Determine and verify assessment criteria thresholds
All	Measurement	Determine measurement accuracy and required tolerences for assessment criteria
All	Measurement	Clear description of instrumentation requirements with tolerances for measurements
EEVC/ ECE-R94	TOOL	Barrier instability for new generation car, stiffness of barrier too low for modern vehicles as they bottom out the barrier which was not the original intent
EEVC/ ECE-R94	TOOL	Test severity increases with car mass with constant test speed and makes force matching unreachable
EEVC/ ECE-R94	Tool	Bottoming out of barrier causes undesired inertial loads for measurement of a cars frontal force
EEVC/ ECE-R94	ASSESSMENT / Force level	Difficult to assess force levels with this barrier type and configuration with constant speed tests
EEVC/ ECE-R94	Assessment	No Structural interaction potential possible because of load speading in the barrier and subsequent barrier bottoming out
EEVC/ ECE-R94	Tool / assessment	Appropriateness of assessment and setting of performance limit - more LCW ODB data required for this ideally with accelerometers on car body and powertrain to investigate further engine dump loading issue.
FWDB	Tool	Test repeatability - further work required with rigid impactors to investigate unexpected level of variation in load distribution
FWDB	Tool/Measurement / Force Levels	The barrier spreads forces to surrounding loadcells, so that force may be measured where there is no deformation or load. The extent of this problem must be investigated.
FWDB	TOOL / Measurement	Honeycomb instability can influence force measurement
FWDB	Tool	Cannot fully identify instabilities in the frontal structure due to ideal loading of front structure - must be complemented with an offset test (PDB or ODB)
FWDB	Tool	Far from real life accidents and car to car structural behaviour, closer than a rigid barrier test
FWDB	Tool	The FW method forces the crossbeam to deform in an unnatural mode.
FWDB	TOOL / Structural interaction	Must verify that all important vehicle structures can be detected by the barrier
FWDB	Tool and assessment	Test repeatability / reproducibility - car testing required to assess repeatability of tool and assessment ofr other vehicle types
FWDB	Assessment	Relevance of wider structures - accident analyis to support development structural width component of HSI
FWDB	Assessment	HSI/VSI requires further validation with forseeable front constructions (no unexpected behaviour due to non-standard configurations)

FWDB	Measurement	Sensitivity must be determined for the vehicle alignment with the load cell positions
FWDB	Assessment	Assessment critieria must have limitations to limit loads in higher sections of the barrier undesirable for side impacts
FWDB	Assessment	Validation - series of car to car and barrier tests required to validate (PDB and / or FWDB tests) - series will most likely require modification of cars in order to keep variables constant.
FWDB	Assessment / Structural Interaction	Will the test procedure properly detect and assess the cross beam strength, in particular curved cross beams (linked to HSI)
FWDB	PROCEDURE (TOOL?)	Influence on acceleration pulse and EES due to Deformable Element compared to FWRB
FWRB	Tool	Not realistic deformation modes
FWRB	Tool	Cannot measure internal structures (ie bumper beams) set back from front of vehicle
PDB	Tool	Suitability to test all M1 and N1 vehicles < 3.5 tonnes total permissible weight - work is required to check suitability of test for high mass vehicles and vehicles which might attach themselves to barrier
PDB	Tool	Test severity (EES) - work is required to ensure that severity of test for all vehicles meets a minimum requirement. Ideally, accurate assessment of energy absorbed in barrier is required to achieve this.
PDB	Assessment	If a minumum force requirement is needed, the suitability to assess force levels of light vehicles and investigate possible competing requirements of achieving minimum force level requirement and minimum EES requirement - current SMART car test results can help to start answer this but ODB test needed to complete test series.
PDB	Tool / parameter	Test repeatability / reproducibility investigated for heavier vehicles
PDB	Assessment	No assessment criteria - only measured parameters
PDB	Assessment	Validation - series of car to car and barrier tests required to validate (PDB and FWDB) tests - series will most likely require modification of cars in order to keep variables constant.
PDB	Measurement	Verify laser measurement system is meaningful for car types - some vehicles could tear out barrier sections but have compatible behaviour

Appendix E. Analysis of Test Procedures

This table is a list of the criteria used within WG15 to discuss the performance of the different test procedures. This version of the table reflects the discussions conducted in September 2006. Numbers in brackets indicates number of responses. No test procedure was completely developed and validated and thus these are only interim results. WG15 uses this table for internal discussions and is provided for information only. WG15 does not recommend that the values in the table are summed in any way to choose a test procedure.

	BARRIER TYPE	FWRB		FWDB		R 94		PDB	
	Summary for Working Group	WG 15		WG 15		WG 15		WG 15	
		Average	Variance	Average	Variance	Average	Variance	Average	Variance
1	**STRUCTURAL INTERACTION**								
1.1	Reproduction of frontal car to car accident structural loading	0.1	0.1 (7)	0.4	0.6 (7)	1.1	0.5 (7)	2.3	0.2 (7)
1.2	Show vertical force/deformation distribution of the car front	0.7	0.6 (7)	1.7	0.2 (7)	0.9	0.1 (7)	2.1	0.5 (7)
1.3	Show horizontal force/deformation distribution of the car front	0.7	0.6 (7)	1.7	0.6 (7)	0.9	0.5 (7)	2.0	0.7 (7)
1.4	Show time history of local forces/deformations	1.7	0.9 (7)	2.1	0.8 (7)	0.4	0.6 (7)	0.1	0.1 (7)
1.5	Potential to show strength of lateral connections between load paths	0.1	0.1 (7)	1.4	0.3 (7)	1.7	0.6 (7)	2.3	0.2 (7)
1.6	Potential to show strength of vertical connections of horizontal load paths.	0.1	0.1 (7)	1.1	0.5 (7)	1.0	0.3 (7)	2.1	0.5 (7)
2	**REPRODUCTION OF COLLAPSE MODES OF LOAD PATHS**								
2.1	Reproduction of frontal car to car accident collapse modes	0.3	0.2 (7)	0.9	0.5 (7)	1.3	0.2 (7)	2.3	0.2 (7)
2.2	Show time history of total forces	2.3	0.2 (7)	2.4	0.6 (7)	2.1	0.5 (7)	2.0	1.0 (7)
2.3	Potential to show energy absorption of car front structures	1.3	1.9 (6)	1.7	0.7 (6)	1.7	0.7 (6)	2.0	0.8 (6)
2.4	Compartment Strength to Maintain Compartment Integrity - (stability)	0.3	0.2 (7)	0.4	0.3 (7)	2.0	0.7 (7)	2.0	0.3 (7)
2.5	Potential to measure compartment strength - (compartment force)	0.1	0.1 (7)	0.1	0.1 (7)	1.6	1.0 (7)	1.4	0.6 (7)
2.6	Potential to show possibly unstable collapse modes	0.2	0.2 (7)	0.2	0.2 (6)	0.7	0.3 (6)	1.3	0.7 (6)
2.7	Potential to evaluate compartment integrity - (intrusion)	0.4	0.3 (7)	0.4	0.3 (7)	2.0	0.3 (7)	1.9	0.1 (7)
3	**TEST PROCEDURE**								
3.1	Simplicity of test procedure	2.6	0.3 (7)	2.0	0.7 (7)	2.1	0.1 (7)	1.1	0.5 (7)
3.2	Repeatability of test procedure / Reproducibility	2.6	0.3 (7)	1.9	0.1 (7)	1.9	0.1 (7)	2.0	0.3 (7)
3.3	Accuracy of measurements (deformations/forces)	2.5	0.3 (6)	2.0	0.5 (5)	2.2	0.6 (6)	2.0	0.5 (5)
4	**OTHERS**								
4.1	Potential to harmonise with existing legal test procedures for frontal impact.	2.7	0.2 (7)	1.9	0.5 (7)	2.9	0.1 (7)	1.6	0.3 (7)
4.2	Applicability to all vehicle types	2.7	0.2 (7)	2.6	0.6 (7)	1.9	0.5 (7)	2.1	0.8 (7)
4.3	Availability of objective assessment criteria	1.3	0.6 (7)	1.6	0.3 (7)	1.1	0.5 (7)	1.6	0.3 (7)
4.4	Resistant to misuse *(Question not clear for all members – low response)*	1.0	0.0 (2)	1.0	0.0 (2)	1.5	1.7 (4)	0.7	0.3 (3)

NO: 0; LOW: 1; MEDIUM: 2; HIGH: