EEVC Approach to Develop Test Procedure(s) for the Improvement of Crash Compatibility Between Passenger Cars

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Paper Number: 07-0331

ABSTRACT

As set out in the *Terms of Reference*, the objective of European Enhanced Vehicle-safety Committee (EEVC) Working Group (WG) 15 *Car Crash Compatibility and Frontal Impact* is to develop a test procedure(s) with associated performance criteria for car frontal impact compatibility. This work should lead to improved car to car frontal compatibility and self protection without decreasing the safety in other impact configuration such as impacts with car sides, trucks, and pedestrians.

Since 2003, EEVC WG 15 served as a steering group for the car-to-car activities in the "Improvement of Vehicle Crash Compatibility through the development of Crash Test Procedures" (VC-COMPAT) project that was finalised at the end of 2006 and partly funded by the European Commission.

This paper presents the research work carried out in the VC-COMPAT project and the results of its assessment by EEVC WG 15. Other additional work presented by the UK and French governments and industry - in particular the European industry - was taken into consideration. It also identifies current issues with candidate testing approaches. The candidate test approaches are:

- an offset barrier test with the progressive deformable barrier (PDB) face in combination with a full width rigid barrier test
- a full width wall test with a deformable aluminium honeycomb face and a high resolution load cell wall supplemented by the forces measured in the offset deformable barrier (ODB) test with the current EEVC barrier.

These candidate test approaches must assess the structural interaction and give information of frontal force levels and compartment strength for passenger vehicles.

Further, this paper presents the planned route map of EEVC WG 15 for the evaluation of the proposed test procedures and assessment criteria.

INTRODUCTION

Since the 2005 ESV-Conference [1] WG 15 continued to focus its research activities on the VC- COMPAT project [2] with unchanged Terms of Reference and Route Map. The VC-COMPAT project was completed in November 2006. It was funded by the European Commission and the contributions of national governments and industry. This paper is a compilation of the latest activities of European Enhanced Vehicle-safety Committee Working Group 15 – Car Crash Compatibility and Frontal Impact (EEVC WG15). Besides the VC-COMPAT project research work the paper 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 organisations outside the working group and reported at specific meetings.

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).

ACCIDENT AND COST BENEFIT ANALYSIS

General trends in accident data

The historical performance of passenger cars in frontal crashes has been presented to WG15 by VW. The main details were derived from the GIDAS database (Germany). 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.

There are indications that vehicle deformations, in particular compartment intrusions, 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 improvement in the fatality outcomes were observed for the different MAIS levels over the years of investigation.

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 1 was followed.

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 was defined as the number of casualties who might experience some injury risk reduction as a result of the implementation of improved compatibility. As a definite set of test procedures to assess a car's compatibility was defined, the methodologies were based on the assumptions of how a compatible car would perform.

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.

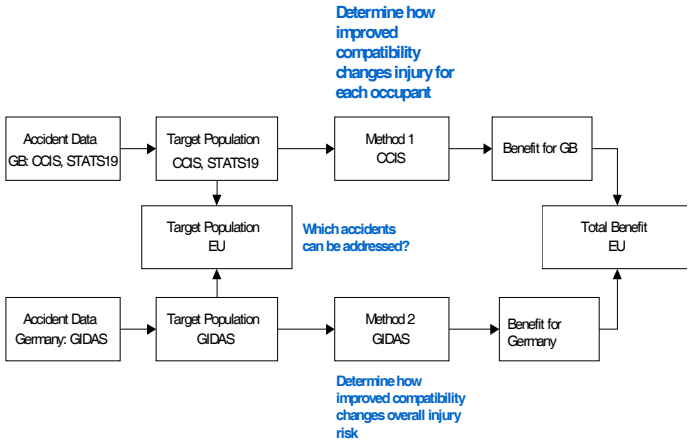


Figure 1: Benefit analysis approach.

The economic analysis was undertaken by Fiat and considered the fixed, variable, and associated 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.

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.

The costs for improved compatibility show Table 1 below.

	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

Table 1: Cost of implementing compatibility

To estimate the benefit for the EU15 the benefit estimates for GB and Germany were scaled to give the following results, see Table 2.

		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

Table 2: Predicted reduction in EU-15 casualties

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, see Table 3. 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 BASt (German Federal Highway Research Institute).

	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

Table 3: Value of EU15 Benefit

From this and the cost information presented above the cost / benefit ratio of improved frontal impact compatibility for the EU15 was estimated, see Table 4.

	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

Table 4: Cost Benefit Ratio of improved compatibility for EU15

As a result of the analysis, the cost benefit ratio appears to be better than 1:1 if all the cost benefit results are considered as a group. These results are independent of any specific crash test procedure for compatibility and only reflect the total expected benefit of improved compatibility. These estimates should be considered conservative since benefits to other crash configurations (side impact, single vehicle collisions, etc.) have not been included. In addition, the costs for vehicle modifications are likely overestimated, particularly for the worst case conditions.

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 reported to date updated and improved. In particular, the different analyses conducted with French and GB data identify how small changes to the approach will influence the result and a standardised benefit calculation for improved compatibility is not yet developed. 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 EEVC WG21 (Accident Analysis) to ensure the best database and analysis procedures are used.

TEST PROCEDURE STATUS

Overall Development Strategy

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. Good self protection is required for car to car impacts. Also good self protection is required by all vehicles for impacts with road side obstacles.

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 [3]. 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 [1] which proposes that compatibility should be introduced in two steps which are:

Short term

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

Medium term

- 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:

Set 1

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

Set 2

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

Set 3

- Combination of FWDB and PDB

Sets 1 and 2 have been formally investigated while Set 3 has not been explicitly investigated to date. Further details of the strategies for Sets 1 and 2 and the development of each approach are given in the following sections.

TEST PROCEDURE STATUS, FWDB APPROACH

The Full Deformable Barrier (FWDB) test forms part of an integrated set of two procedures proposed to assess a car's frontal impact crash performance, including its compatibility:

FWDB test:
(1) To assess structural interaction potential.
(2) To provide a high deceleration pulse to test the restraint system.

Offset Deformable Barrier (ODB) test with EEVC barrier:

(1) To assess frontal force levels.
(2) To load one side of the car to check its compartment integrity.
(3) To provide a softer deceleration pulse than the FWDB test to check the restraint system performs over a range of decelerations.

Originally the approach also included a high speed (80 km/h) ODB test to measure compartment strength using a Load Cell Wall (LCW). 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.

FWDB Test

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 LCW consists of cells of nominal size 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[1], see Figure 2. The reason that 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 is 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.

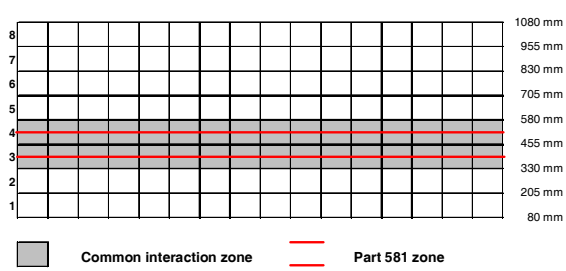


Figure 2: FWDB test LCW configuration showing row number and height above ground level.

[1] Part 581 zone: Zone from 16" to 20" above ground established by NHTSA in its bumper standard (49 CFR 581) for passenger cars.

The purpose of the deformable element has been discussed previously [3]; the main purpose being to improve detection of crossbeam structures which may not be strained in an impact with a rigid wall and to reduce engine dump loading that may otherwise confound the measured force distribution.

The FWDB Test Assessment intention is to control both self and partner protection. 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. For partner protection the car's structural interaction potential will be assessed using the measures from the LCW.

A new criterion, called the Structural Interaction (SI) criterion, has been developed to resolve issues with the previous Homogeneity Criterion [4]. Its details are described in another paper presented at this conference [5], so only a brief description is given here. Its development was based on the following requirements:

- An ability to be applied in a 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.

It is calculated from the peak cell loads recorded in the first 40 ms of the impact. Compared to using peak cell loads recorded throughout the duration of the impact (as with the previous Homogeneity 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 40 ms time interval allows detection of structures up to approximately 400 mm from the front of the vehicle, which aligns with a recent NHTSA proposal to assess the Average Height of Force (AHOF) over the initial 400mm vehicle displacement.

The SI criterion consists of two parts which assess the LCW force distribution over two different areas, Area 1 and Area 2. These parts could be applied in two phases to allow manufacturers to gradually adapt vehicle designs to become more compatible. 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 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 distribute their load more homogeneously over a larger area to reduce the likelihood of over/under-ride and the fork effect. However, further work is needed to ensure that the structural changes encouraged by this are not detrimental for side impact collisions. For example, although a strong shotgun type structure that extended to the front of the car should improve frontal impact compatibility performance it could be detrimental in side impact. If this was found to be the case, additional measures that limited the loads applied to specific areas of the LCW early in the impact may be needed to discourage this type of structure.

Some initial validation of the SI criterion has been performed. It has been shown that the SI criterion correctly distinguishes the vehicles which showed better structural interaction performance in car to car tests in the VC-COMPAT project [5, 6]. Also, it has been shown to rank the bumper crossbeam strength correctly for a series of FWDB tests performed by ACEA with a large family car with different strength bumper crossbeams [7].

The FWDB Test Repeatability has been investigated using full scale car crash tests and component sled tests. The results of this work are described in another paper presented at this conference [5]. In summary, from the limited testing performed test repeatability was found to be adequate. However, further work is recommended to check test repeatability with greater impact alignment differences and investigate the greater than expected cell load differences seen in component sled tests with a flat rigid impactor.

ODB Test

A methodology to measure a vehicle's frontal force levels in an ODB test has been developed in the VC-COMPAT project [2]. 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, see Figure 3.

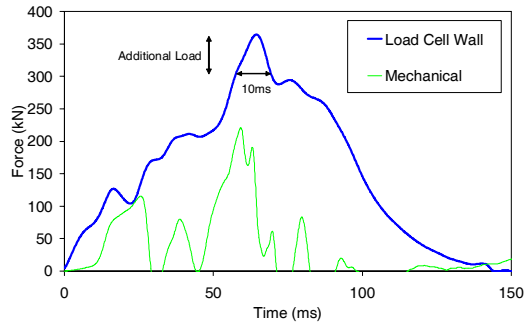


Figure 3: LCW force in ODB test showing additional load caused by 'engine dump'. Note: the mechanical force is the load applied by the powertrain components.

In initial steps to improve compatibility 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.

Further Work Required

The following work is required to complete the development of the FWDB approach:

FWDB test

Partner protection (LCW based measurements)

- Criteria and performance limits

A new criterion to assess a vehicle's structural interaction potential has been developed and shown to correctly rank different vehicles. Further work is recommended to validate the criterion 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 impacts, which could then be used to help perform a benefit analysis for the introduction of this test procedure.

- Test repeatability / reproducibility

A limited number of tests to investigate repeatability have been performed to date, which found no significant problems. Further work is recommended 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 for cells in alignment with the impactor 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 ideally 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 recommended.

- Criteria and Performance limits

Further work is recommended 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

- Criterion

Work to complete the development of a criterion to control a vehicle's frontal force levels is recommended.

TEST PROCEDURE STATUS, PDB APPROACH,

Current situation

Car to car accident data shows that fatalities and severe injury are caused by compartment intrusion. It is mainly due to unbalance energy absorption 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.

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 trends, compatibility requirements are unreachable today without changing deformable element.

Due to the current test conditions it is desirable to improve light car compartment strength without increasing the heavy car strength requirements 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.

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. Front end car designed changed a lot in the last 10 years with to respect new constraints (repeatability, pedestrian, self protection etc), so the deformable element should be revised. The element weakness causes bottoming out, constant energy absorbed and instability that leads to lack of repeatability and inaccurate FEM simulation, see Figure 4.

Figure 4: Current ODB: instability and bottoming out

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 vehicle structural load levels where compartment deformation starts. However, this increasing speed must be accompanied by a barrier change to reach compatibility requirements and to stop heavy vehicles getting stiffer and stiffer.

Checking half of the front end is needed for partner protection assessment in the future. Secondly, overlap tests are closer to real world accident data and car to car test configuration. Finally, combined with a stiffer barrier it generates higher acceleration pulses. 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.

Compatibility in car to car crashes depend on correct distribution of energy between the two vehicles. 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.

Accident studies in France show that 60% of cases of people involved (MAIS3+) in the light car would be covered by choosing 100 km/h closing velocity. It is specified that these progress will be also applicable for higher closing speeds.

In order to take advantage of the full 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.

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 structures, 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

PDB 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 first priority of the PDB approach is to harmonise the test severity (EES) for all mass range (see

Figure 5: EES evolution with introduction of PDB test procedure

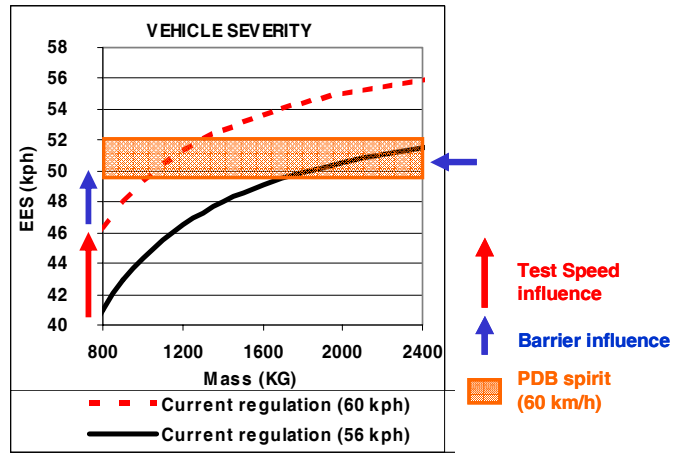


Figure 5: EES evolution with introduction of PDB test procedure

⇨ **The demand of self protection level for light cars is clearly higher than the current regulation without penalising 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 forces even if perfect force matching is unrealistic due to vehicle front end geometry (limited overhang) and same intrusion level requirement, see Figure 6.

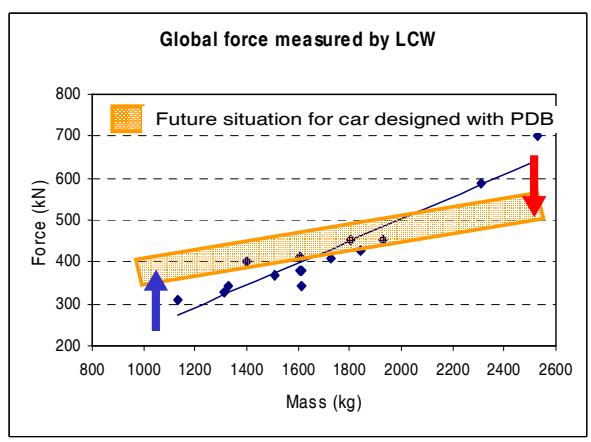


Figure 6: Possible improvement of force matching

PDB approach

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 7. 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.

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.

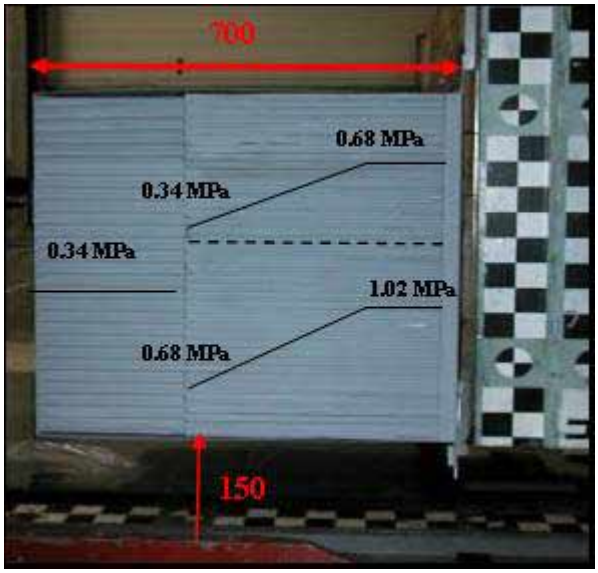


Figure 7: PDB Side view. Dimensions, position and stiffness.

PDB test Procedure

Comparing with current ECE 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

PDB Assessment

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

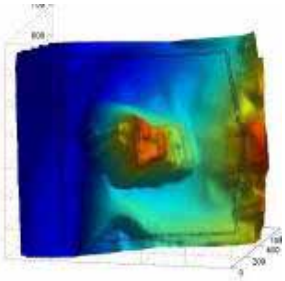
- self protection coming from vehicle analysis and dummy criteria
- partner protection coming from barrier deformation

Today, self protection assessment is very well known. According to current ECE R94 and Euro NCAP, the assessment is based on dummies criteria and possible assessment of intrusion measurements such as dashboard, firewall and A-pillar. Deceleration pulse closer to car to car accident is generated with stiffer barrier face and higher overlap.

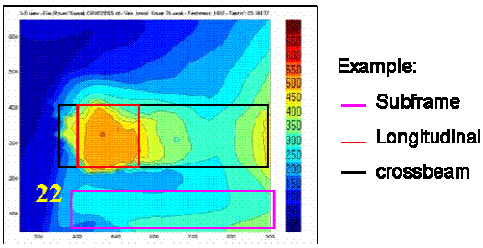
In terms of design, one way to achieve structural interaction is to offer a front surface which is homogeneous in stiffness over a surface which is large enough. In order to take advantage of all the potential for energy absorption of both cars, their structure must interact correctly. To achieve this result, the stiffness on the front block must be distributed along multiple load paths. 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, see Figure 8.

Barrier deformation



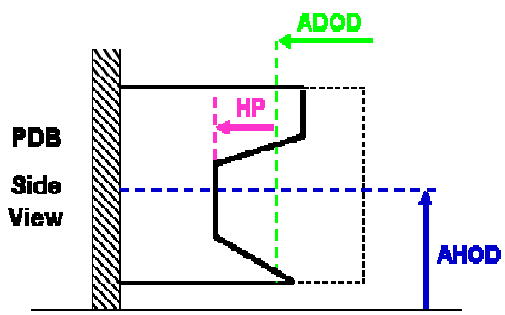
Barrier digitisation (3D)



Investigation area

Figure 8: PDB test - Barrier deformation

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 (HP): 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 the international communities. An 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.

PDB, possible Route Map for implementation

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. Dummy criteria limits are the same as the current ECE R94 and integrity of the passenger compartment could be assessed with the help of intrusion level in different parts of the front compartment. In this first phase, safety 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.

In a second step all criteria and investigations will be based on the barrier deformation. The 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.

In a long term step,to be closer to real life accident, the PDB could be fixed on a mobile trolley. A quick energy analysis 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.

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.

CONCLUSIONS AND DISCUSSION

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

3) Mixture of the two approaches.

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. 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.

The working group has identified the following general criteria for compatibility:

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

The first two 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.. There is however no validated, quantitative method to translate these into objective crash test criteria

The following discussion presents the concerns documented by the members of WG15.

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 as described above – 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. 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.

PDB Test procedure

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 PDB test is proposed to address compatibility and self protection issues and a full width rigid barrier test complements the PDB test by providing a high 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 is no current assessment criteria that objectively evaluates 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 can 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.

General opinion of the group

Working Group 15 has developed a list of assessment criteria presented in the 2005 ESV-Conference [1] 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 sheet 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.

To get an overview about the opinion of the different group members on the candidate test procedures to assess compatibility, a rating exercise was carried out in the group.

The following analysis of the ratings of the group members is divided into the four main groupings.

1) Structural interaction – The group 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 (full width rigid barrier) 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.
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.

Conclusions WG15

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 of 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
3) Three different candidate sets of procedures are proposed for assessing compatibility in passenger vehicles:

   Set 1
   - Full Width Deformable Barrier (FWDB) test
     - Structural interaction
     - High deceleration pulse
   - ODB test with EEVC barrier
     - Frontal force levels
     - Compartment integrity

   Set 2
   - Full Width Rigid Barrier (FWRB) test
     - High deceleration pulse
   - Progressive Deformable Barrier (PDB) test
     - Structural interaction
     - Frontal force matching
     - Compartment integrity

   Set 3
     - Combination of FWDB and PDB.

   Of the three candidates, only the first two have been explicitly evaluated in Working Group 15.

4) 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 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.

Recommendations for the Way Forward

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 and benefit analysis to update information on changing vehicle fleet
- Finalise the test severity (EES) for regulation test using real world crash requirements.
- 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 pulses).
- 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 if possible assessment criteria of the FWDB are sufficiently insensitive to the load spreading behind the honeycomb barrier seen in the rigid impactor tests and confirm the link between deformation and loads.
- 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 load-cells.

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.

Performance limits for 1st step:

For this 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.

Cost benefit analysis for implementation of 1st step:
The 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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ACKNOWLEDGEMENTS:

EEVC WG 15 would like to thank the EEVC Steering Committee and the European Commission for supporting and funding the VC-COMPAT project. The support of the national governments of France, United Kingdom, Germany, Sweden, and the Netherlands also ensures that work continues within the group.

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