CURRENT STATUS OF THE FULL WIDTH DEFORMABLE BARRIER TEST

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ABSTRACT

To improve compatibility in car frontal collisions it is generally agreed that better structural interaction, matching frontal forces (stiffnesses) and a strong occupant compartment, in particular for small cars, are required. The Full Width Deformable Barrier (FWDB) test is part of a portfolio of tests being considered to assess a vehicle's frontal impact performance, including its compatibility. For compatibility, it aims to assess a vehicle's structural interaction potential using measurements from a high resolution Load Cell Wall behind the deformable element. For self protection, it aims to provide a high compartment deceleration pulse, similar to the current US NCAP test, to assess a vehicle's restraint system.

This paper describes the benefit predicted for the implementation of improved compatibility in GB and the current status of the FWDB test. For the FWDB test, it clarifies remaining issues including test repeatability and describes the new 'Structural Interaction' (SI) criterion. The SI criterion is designed to ensure that vehicles have an adequate structure in a common interaction area to interact with their collision partners and to encourage stable multi-load path structures. It consists of vertical and horizontal components that are divided into parts that could be adopted in a stepwise manner, to allow the gradual development of more compatible vehicles, appropriate for application in a regulatory framework.

INTRODUCTION

Following the introduction of the European frontal and side impact Directives and EuroNCAP, car safety has made a major step forward. Even so, there are still about 1,500 car occupants killed and 15,000 seriously injured in GB annually [1]. Approximately 60 percent of these occur in frontal impacts. The next step to improve frontal impact protection further is to improve compatibility in vehicle-to vehicle impacts.
Much research has been performed to understand compatibility, which has identified three main influencing factors: structural interaction, frontal force matching and compartment strength.

Structural interaction is relevant for all frontal impacts and describes how well vehicles interact with their impact partner, either another vehicle or a road-side obstacle [2]. If the structural interaction is poor, the energy absorbing front structures of the vehicle may not function as efficiently as designed, leading to an increased risk of compartment intrusion at lower than designed impact severities and a less optimum (more back-loaded) compartment deceleration pulse. Also, 'triggering' of the restraint system may be less effective due to a less predictable crash pulse. Examples of poor structural interaction are override and the fork effect [2].

A vehicle's frontal force levels are related to its mass. In general, heavier vehicles have higher force levels as a result of the current test procedures and manufacturer's desire to keep crush space to a minimum [3]. As a consequence, in a collision between a light vehicle and a heavy vehicle, the light vehicle absorbs more than its share of the impact energy as it is unable to deform the heavier vehicle at the higher force level required. Matched frontal force levels would ensure that both vehicles absorb their share of the kinetic energy, which would reduce the risk of injury for the occupant in the lighter vehicle.

Compartment strength is an important factor for self-protection, especially for light vehicles. In the event where vehicle front structures do not absorb the impact energy as designed the compartment strength needs to be sufficiently high to ensure minimal compartment intrusion. Beyond this, there is scope for better optimisation of the car's deceleration pulse to minimise restraint induced deceleration injuries.

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 as good self protection is required for impacts with road-side obstacles. Indeed, if possible, for light vehicles they should be increased. The set of test procedures should contain both a full overlap test and an offset (partial overlap) test as recommended by the IHRA frontal impact working group [4]. A full width test is required to provide a high deceleration pulse to control the occupant's deceleration and check that the vehicle's restraint system provides sufficient protection at high deceleration levels. An offset test is required to load one side of the vehicle to check compartment integrity, i.e. that the vehicle 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.

The European Enhanced Vehicle-safety Committee (EEVC) Working Group 15 is working to develop an integrated set of test procedures to assess a vehicle's frontal impact performance [5]. One of the main candidate procedures is the Full Width Deformable Barrier (FWDB) test, the development of which is being led by the UK. The other is the Progressive Deformable Barrier (PDB) test, led by France [6].

This paper describes an estimation of the benefit for the implementation of improved compatibility in Great Britain (GB) and the current status of the Full Width Deformable Barrier (FWDB) test

GB BENEFIT

The GB national accident data (STATS19), averaged for the years 1999 to 2003, shows that about 60% of the car occupant casualties occur in frontal impacts [Table 1].

Table 1.
Average casualties from RAGB 1999 to 2003 inclusive, front car occupants

First point of impact	Car Occupant Police Injury Severity	
	Fatal	Serious
Did not impact	29	328
Front	898	10055
Back	54	1200
Offside	257	1899
Nearside	252	1459
Total	1490	14941

Of these casualties about 70% occur in collisions with another vehicle, a collision type which compatibility directly addresses [Table 2].

Table 2.
Average casualties from RAGB 1999 to 2003 inclusive, front car occupants, front collisions

Number of Vehicles	Police Casualty Injury Severity	
	Fatal	Serious
Single vehicle	281	2823
1 other vehicle	415	5494
At least 2 other vehicles	202	1738
Total	898	10055

To determine the benefit of implementing improved compatibility both the national and in-depth accident databases were used. The in-depth data used were from the UK Co-operative Crash Injury Study (CCIS) collected from 1998 to 2006. CCIS is a sub-sample of the STATS19 database and can be weighted to describe national trends.

The methodology used to estimate the benefit was as follows:

- Divide occupants in STATS19 national accident database involved in frontal impacts into the following groups categorised by object struck.
    1. Another car
    2. A 'heavy' vehicle (e.g. Light Goods vehicle, Heavy goods vehicle)
    3. An object (roadside)
- Form equivalent data sets for CCIS in-depth data and estimate the benefit for each individual occupant.
- Scale STATS19 national accident data using benefit proportions calculated from CCIS data sets.

A total of 4,061 front seat occupants who experienced frontal impacts to their cars and whose injury information was known were selected for inclusion in the CCIS equivalent data sets. All the selected occupants were seated in cars registered in 1996 or later. 40% of the cars were registered after 2000.

Two distinct processes were used to determine the individual benefit for each occupant. Firstly, the nature and severity of damage that their car experienced was evaluated to determine if it is realistic for a future improved compatible vehicle to manage such a crash and offer improved occupant protection. This was achieved by determining if the occupant was included in the target population defined by the crash selection criteria shown in Table 3. If occupants were not in the target population, it was assumed that they would experience no benefit.

Table 3.
Target population selection criteria

Selection criteria	**Cases included**
Belt Restraint System Use	Only restrained occupants
Occupant Seating Position	Only front seat occupants
Overlap	> 20%
Principle Direction of Force	10, 11,12, 1 and 2 o'clock
Accident severity (Estimated Test Speed)	All accidents up to 56 km/hr
Mass ratio	All mass ratios
Under-run	Exclude under-run cases for Larger Vehicles (Group 2)

Secondly, for occupants in the target population each injury experienced by each occupant was evaluated to decide whether the injury and associated mechanism would be mitigated by compatibility improvements to the frontal car structure. To do this two injury models were applied to estimate which injuries, if any, would be mitigated or removed from the database.

The models were constructed on the assumption that for frontal collisions up to a severity of 56 km/h ETS (approximately the severity of the EuroNCAP frontal impact test), improved compatibility should result in a car being able to absorb the impact energy in its frontal structure with minimal occupant compartment intrusion and an improved deceleration pulse with better restraint triggering. To represent minimal occupant compartment intrusion Model (1) {Intrusion based} removed all injuries caused by contact with an intruding internal front structure. To represent the improved deceleration pulse and restraint triggering as well, Model (2) {Contact based} removed all injuries caused by contact with any internal front structure, regardless if it had intruded or not. Model (1) produces a sub-set of the benefit seen in Model (2).

Using these injury reduction models the MAIS[1] for each occupant was re-calculated and compared with the original MAIS to estimate a benefit in terms of MAIS reduction as illustrated in Table 4 for the Group 1 equivalent data set (struck another car) for Model 1 {Intrusion based}.

[1] MAIS: Maximum Abbreviated Injury Score.

Table 4.
MAIS distribution for car-car (Group 1), before and after application of compatibility intrusion Model 1

MAIS	**Original CCIS Occupant Sample Group 1**	**Model (1) Occupants, assuming prevention of intrusion-caused injuries**	
	No.	**No.**	**Change**
6	6	6	0
5	26	19	-7
4	31	31	0
3	126	97	-29
2	304	288	-16
1	1227	1251	+24
0	311	339	+28
Total	2031	2031	-

The distribution of AIS 3+ injury by body region is shown for the original data and after the application of the injury reduction models [Figure 1].

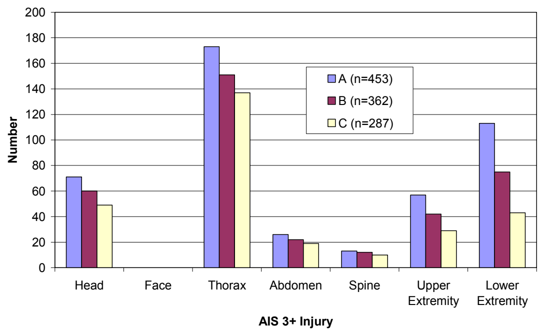

Figure 1. Distribution of AIS 3+ Injuries for original data and after application of injury reduction models.

This Figure illustrates the high frequency of thoracic injuries. Also illustrated is the fact that the compatibility benefit models do not significantly reduce this because the principal cause of injury to the thorax was found to be seat belt loads and not contact with the vehicle interior. This issue requires further investigation because thoracic injuries are known to be associated with fatal outcomes.

To convert the proportional benefit estimated using the CCIS database in terms of MAIS into the police injury classifications of fatal and seriously injured a transfer function was developed. This was done by correlating the original MAIS 2+ distribution for all occupants within the target population against the casualties' injury outcome with respect to the police injury classifications to give a percentage risk of sustaining fatal or serious injury for a given MAIS [Table 5].

Table 5.
Derivation of transfer function between injury classifications

MAIS	Percent of Casualties (%)		Original number of casualties		
	Fatal	Serious	Total	Fatal	Serious
6	100	0	15	15	0
5	89.4	10.6	47	42	5
4	58.7	41.3	63	37	26
3	5.2	94.8	213	11	202
2	0.7	99.3	460	3	448
Total	-	-	798	108	681

Following this, the CCIS calculated proportional benefit, in terms of fatal and seriously injured, was scaled using the national accident data to give the benefit for GB. It was predicted that between approximately 5% (67) and 8% (124) front seat car occupants killed in GB 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 authors believe that this is a reasonable and conservative estimate of the benefit for the following reasons. Firstly, no account is made for the possible benefit that improved compatibility may give to side impact casualties. Secondly, the models do not account for any benefit for a reduction in the number of injuries to different body regions, if there are other injuries of the same severity that are not mitigated. For example, if a driver has sustained a fracture to his right femur (AIS score 3) due to contact with the intruding facia and multiple rib fractures (AIS score 3) due to seat belt loading, only the femur fracture will be prevented in the model. Therefore, when the most severe injury is assessed, his overall injury severity remains the same. However, in contrast it is accepted that not all contact based injuries would in reality be mitigated. It is known that significant numbers of lower limb injuries result from contact with a car interior that has not intruded.

Another significant finding of the work was the high frequency of moderate (AIS2) and life threatening (AIS 3+) injuries sustained by car occupants due to seat belt induced loading. Also, 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 injury models, by their design, did not account for injury attributed to seat belt loading, and therefore possibly underestimate the potential benefit that could be seen for this body region. This is an area which requires further work, as head and thoracic injuries are known to be associated with fatal outcomes.

In summary, the model finds significant benefits, and on balance can be argued to both over and under estimate injury reduction, dependant on the specific body region injured. A verification of the model was undertaken by reviewing individual crashes and evaluating the model's predicted benefits with respect to the actual crash characteristics.

FULL WIDTH DEFORMABLE BARRIER TEST

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 [6]. However, if an absolute measure of compartment strength is required then a high speed test will be necessary. This is because in the lower speed test the car may not be deformed sufficiently to load the compartment fully, so the 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 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[2] [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.

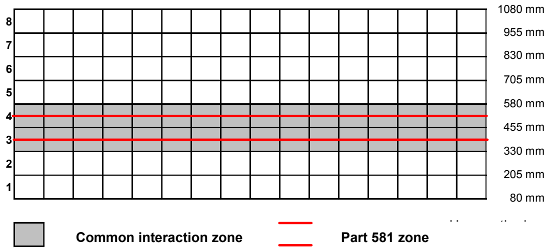

Figure 2. FWDB test LCW configuration showing row number and height above ground level.

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 intention of the FWDB test 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. The premise is that cars that exhibit a more homogeneous force distribution on the LCW should have a better structural interaction. To assess the LCW force distribution a new Structural Interaction assessment criterion has been developed, which is described below.

Structural Interaction (SI) Criterion

The Structural Interaction (SI) criterion has been developed to resolve issues with the previous Homogeneity Criterion [3]. 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.

The SI criterion 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 corresponds to a B-pillar displacement of approximately 550 mm for most cars [Figure 3].

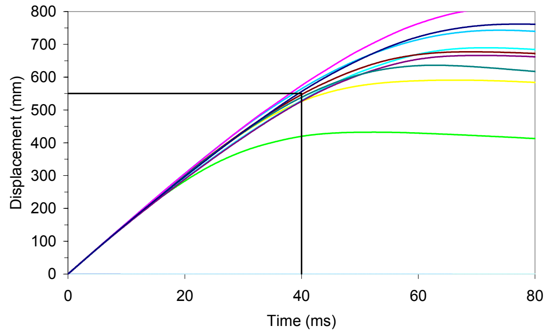

Figure 3. B-pillar displacement vs time plots for FWDB tests. Outlier is a supermini car with unique short stiff frontal structure which restricts its deformation.

Based on the assumption that structure which only crushes the 150 mm softer front layer of the barrier

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

will not apply sufficient load to the LCW to be adequately detected, this should allow the detection of structures up to 400 mm (550 mm -150 mm) from the front of the vehicle. This is adequate for detection of most Secondary Energy Absorbing Structures (SEAS), such as subframes, that interact with the partner vehicle in a crash. In addition, 400mm aligns with a recent NHTSA proposal to assess the Average Height of Force (AHOF) over the initial 400mm vehicle displacement.

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 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.

Each part of 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 part (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 [7].

Vertical Component (VSI)

Area 1 (rows 3 & 4)

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 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 row load target.
- VSI Area 1 is equivalent to the negative deviation.

Examination of the FWDB test data set available at TRL shows that a minimum row load requirement of 100 kN (i.e. target load of 100 kN with VSI area 1 score of 0) is a good indicator that vehicles have structure in alignment with rows 3 and 4, (the common interaction zone).

Area 2 (rows 2 to 5)

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 (minimum load) and Coefficient of Variance (load balance).

An example of how the VSI Area 2 distinguishes between vehicles is seen by examining the FWDB test data set in Figure 4. VSI Area 2 can correctly distinguish between two small family cars with different structures labelled ‘small family 1’ and ‘small family 2’. ‘Small family 1’ was a multi-load path level design which showed better structural interaction performance in car to car tests compared to ‘small family 2’ which was a single load path design [8]. However, if a performance limit was set to distinguish between these cars, large SUV type vehicles may find it difficult to achieve because their design requires large approach angles which makes it difficult to design them to 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.

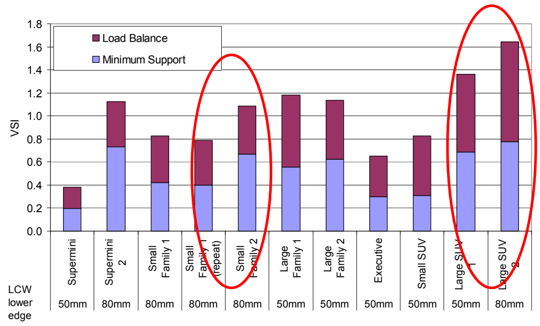

Figure 4. VSI Area 2 scores for VC-COMPAT FWDB test data set. (Note: lower score is better.)

Horizontal Component (HSI)

Area 1 and Area 2

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 [9], an option exists for the HSI component to be used to encourage wider structures for better structural interaction in lower overlap impacts. However, this part of the component is not currently included in the assessment and will not be included 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 target cell load is limited to a maximum [20kN], independent of vehicle mass. Crossbeams cannot apply loads greater than this to a cell without bottoming out the barrier because of the limit imposed by the crush strength of the barrier rear layer.
- 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: (currently not part of assessment but option for future)

- 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.

Examination of the FWDB test data set shows that HSI Area 1 can correctly distinguish between two small family cars with different crossbeam structures labelled ‘small family 1’ and ‘small family 2’ in Figure 5. ‘Small family 2’ had a stronger crossbeam than ‘small family 1’ and showed better structural interaction performance in car to car tests [8].

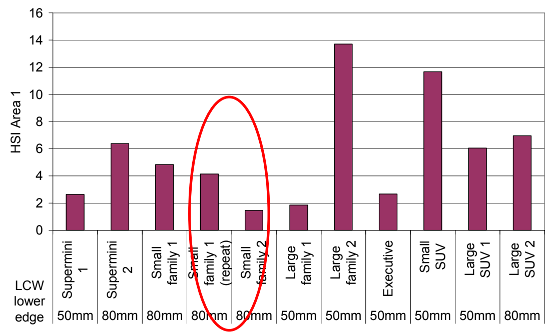

Figure 5. HSI Area 1 scores for VC-COMPAT FWDB test data set. (Note: lower score is better.)

HSI Area 1 also correctly ranks the bumper crossbeam strength correctly for a series of FWDB tests performed by ACEA with a large family car with different strength bumper crossbeams [Figure 6].

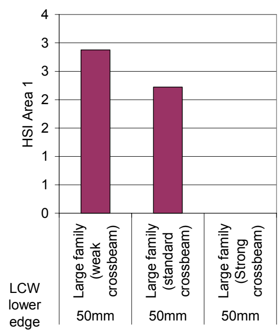

Figure 6. HSI Area 1 scores for FWDB tests performed by ACEA with large family car with different strength bumper crossbeams.

For implementation of the SI criterion the following two phases are proposed to allow manufacturers to gradually adapt vehicle designs to become more compatible:

- 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.

Repeatability

In the FWDB test the vehicle alignment with the Load Cell Wall (LCW) at the point of impact can vary from test to test, which can cause changes in the loads measured on the individual cells on the wall, which in turn can affect test repeatability. Change of the vehicle alignment with the wall can be caused by two factors. These are changes in the ride height of the vehicle and the test impact accuracy. It has been estimated that a vertical impact alignment tolerance of +/-10mm is required to achieve acceptable test repeatability with current vehicle designs that demonstrate poor compatibility. As the compatibility of vehicles improves and they spread their load more homogeneously over the LCW it should be possible to relax this tolerance.

Two tests within the +/-10mm impact alignment tolerance with a small family car were performed to assess repeatability. Also flat rigid plate impactor tests were performed to test the response of the deformable element and LCW to uniform loading.

For the car tests, the difference in the impact alignment was less than 1 mm in the vertical direction and 7 mm in the horizontal direction. The peak load cell wall (LCW) force was similar for the two tests, 549kN for the repeat test compared to 557kN for the first test. A difference in the B-Pillar displacement for the two tests resulted in a 22kJ difference in the absorbed energy [Figure 7]. However, in both tests the absorbed energy was within +/- 5% of the change in the vehicle kinetic energy. A +/- 5% difference, given the assumptions made when calculating the absorbed energy, was considered to be acceptable when considering energy balance.

The test results showed the majority of peak cell loads were within 5kN, whilst the row and columns loads were within 10kN indicating good repeatability of the force measurement [Figure 10].

The Structural Interaction criterion difference was 4% for VSI Area 2 [Figure 4] and 15% for HSI Area 1 [Figure 5] indicating reasonable repeatability. Note car is labelled ‘small family 1’ in these figures.

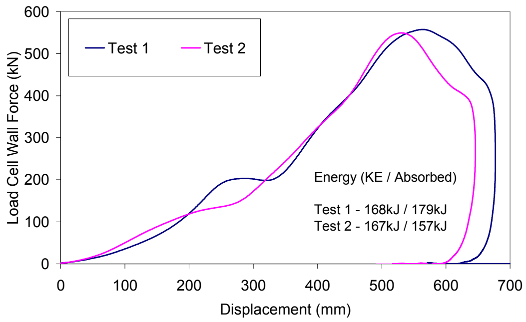

Figure 7. Load Cell Wall force against B pillar displacement for repeat tests with ‘small family 1’ car.

For the rigid impactor tests, an impactor (size 500 mm x 500 mm) was mounted on a sled, aligned with 16 load cells and impacted into the barrier as shown [Figure 8].

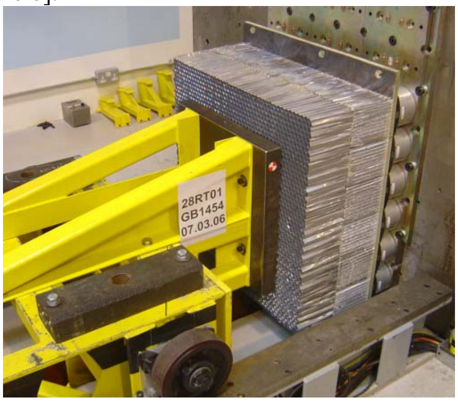

Figure 8. Sled test set-up, showing the sled, impactor face, deformable element and LCW.

The results of 2 tests showed that the LCW global force measurement was repeatable [Figure 9].

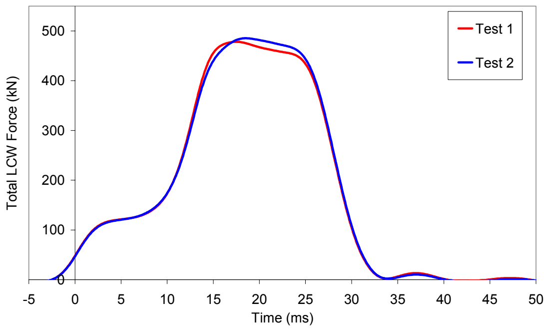

Figure 9. Comparison of total LCW force from sled tests showing good repeatability. (Note: Data filtered at CFC60 which causes non-zero load at time zero).

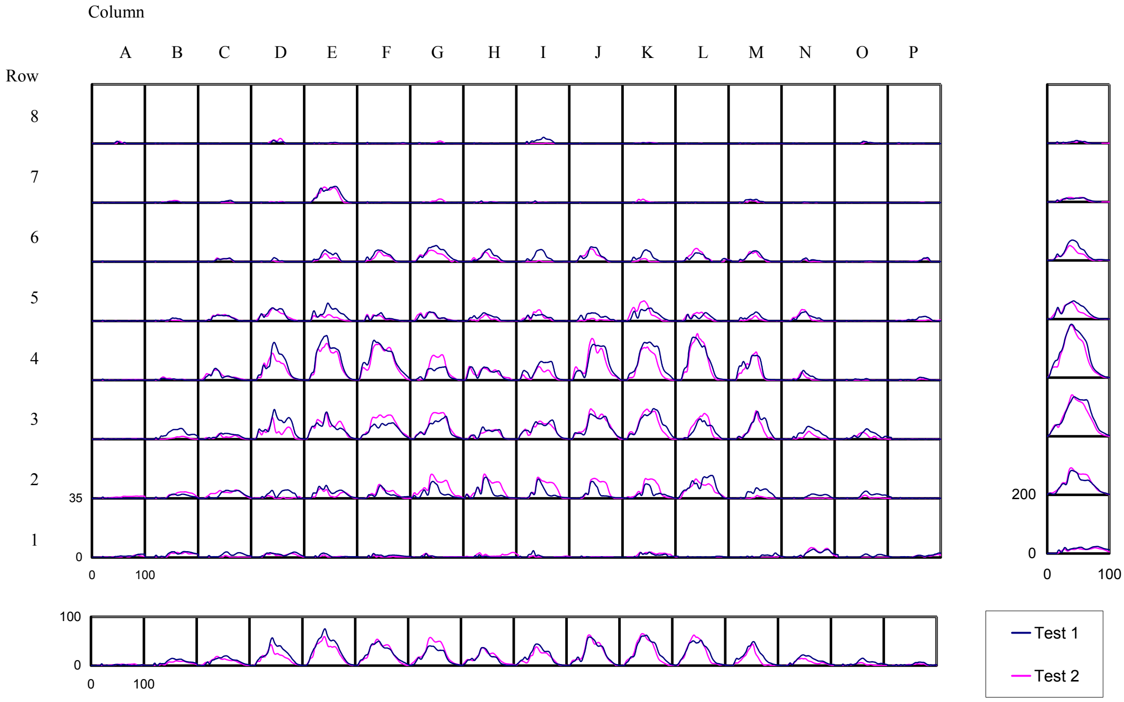

Figure 10. Load (scale 0 –35 kN) against time (scale 0-100ms) curves for complete Load Cell Wall for repeat tests with 'small family 1' car.

However, in both tests a greater than expected difference was observed between the peak cell loads recorded for the 16 load cells in alignment with the impactor [Figure 11].

Test2	A	B	C	D	E	F
3	2	3	4	5	2	1
4	0	26	27	28	26	1
5	3	31	29	30	29	4
6	1	27	28	35	28	0
7	0	28	28	30	31	0
8	2	2	0	1	2	0

Figure 11. Peak cell loads sled test 2. The shaded area indicates the cells which were in alignment with the impactor.

The reason for this is unclear and could be due to a number of factors, such as load spreading by the rear face of the barrier. However, differences of this magnitude should not substantially effect a vehicle's Structural Interaction criterion score, as they are much smaller than the differences seen with a car structure. Even so, further work is recommended to identify the cause of them and ideally reduce them.

In summary, from the work performed to date 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 tests with a flat rigid impactor.

WAY FORWARD

This section proposes a route map for the implementation of the FWDB set of tests into regulatory and/or consumer testing in Europe. It also outlines the main outstanding issues for compatibility, in particular for the FWDB test, and the work recommended to address them.

Route Map

A possible route map for the implementation of the FWDB set of tests in Europe is described below:

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

At present 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.

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 what 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

- Option 1 plus improvement of 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

- Option 2 plus further improvement of structural interaction by ensuring that vehicles spread their load better vertically using enforcement of the VSI Area 2 criteria 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 LCW force measured in ODB test.

Option 2

- Replace ODB test with PDB test and improve self protection and frontal force levels using measures as proposed in PDB approach.

Main Outstanding Issues

The main outstanding issues for compatibility, in particular for the FWDB test, and the work recommended to address them are:

Accident analysis

- Thoracic injury

In the GB benefit analysis it was observed that a high frequency of moderate (AIS2) and life threatening (AIS 3+) thoracic injuries were sustained by car occupants due to seat belt induced loading. The benefit models did not predict a significant reduction in these injuries. As thoracic injuries are known to be associated with fatal outcomes further work is recommended to understand more precisely the nature and cause of these injuries and their relationship to compatibility and its benefit. This work should consider the influence of improved restraint systems, in particular load limiters, on these injuries.

- Vehicle structural width

In laboratory testing a vehicle's structural width has been shown to have a large influence on its performance in vehicle to vehicle tests [9]. However, its relevance in real-world accidents is not known, so a decision whether or not tests should assess it cannot be made. Further accident analysis is recommended to answer this question.

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.

Cost Benefit

A cost benefit analysis for the implementation of the chosen procedures will be required.

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Further information on CCIS can be found at http://www.ukccis.org

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