Enhanced Vehicle Collision Compatibility – Report of Front-to-Front US Technical Workgroup on Test and Simulation Work Performed in 2006 / 2007 to Investigate use of a Load Cell Wall Approach for Assessing an LTV's Compatibility

Executive Summary

The Enhanced Vehicle-to-Vehicle Crash Compatibility (EVC), a commitment for continued progress by leading automakers, front-to-front Technical Work Group (TWG) was created in order to develop solutions for improving compatibility between passenger cars and light truck based vehicles (LTVs) in frontal impacts. Initial studies of the TWG resulted in the development and implementation of the Phase I requirements that were announced on December 3 2003, as a first step towards improving geometrical compatibility. Following this, an amendment to the agreement was submitted to NHTSA on May 10 2006, which added a strength requirement for secondary energy absorbing structure.

Research continues by TWG members to develop further recommendations to improve the compatibility of LTVs without significant reductions in their self protection capability. Currently, three distinct research paths are being pursued, one of which is the assessment of LTVs' compatibility using a fixed barrier with Load Cell Wall (LCW) measurements. Previous work done by the members of the technical workgroup has been presented to NHTSA in the previous technical exchanges and some of it has also been published externally.

In 2006 / 2007 the TWG performed an integrated series of tests to develop this approach further with the following objectives:

- To understand the effect of vertical geometrical changes to improve an LTV's compatibility in LTV-to-car impact.
- To evaluate the ability of the Full Width Deformable Barrier (FWDB) test to assess these changes using LCW measurements and associated metrics.
- To correlate the assessment of an LTV's compatibility using the FWDB test with the performance of the car in an LTV-to-car impact and set performance requirements.

Three series of tests were performed to investigate the following LTV geometric parameters:

- Height of Primary Energy-Absorbing Structure (PEAS) – this was achieved by altering the ride height of the LTV.
- Presence of BlockerBeam® type Secondary Energy-Absorbing Structure (SEAS)
- Presence of Subframe type SEAS

This report details the results and observations from this work.

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1 Introduction

The Enhanced Vehicle-to-Vehicle Crash Compatibility (EVC), a commitment for continued progress by leading automakers, front-to-front Technical Work Group (TWG) was created in order to develop solutions for improving compatibility between passenger cars and light truck based vehicles (LTVs) in frontal impacts. Initial studies of the TWG resulted in development and implementation of the Phase I requirements that were announced on December 3 2003, as a first step towards improving geometrical compatibility [1]. These requirements state beginning September 1, 2009, 100 percent of each participating manufacturer's new LTVs up to 10,000 pounds Gross Vehicle Weight Rating (GVWR), with limited exceptions, intended for sale in the United States and Canada, will be designed in accordance with one of the following two geometric alignment alternatives:

OPTION 1: The LTV's primary frontal energy-absorbing structure shall overlap at least 50 percent of the Part 581 zone[1] AND at least 50 percent of LTV's primary frontal energy-absorbing structure shall overlap the Part 581 zone (if the primary frontal energy-absorbing structure of the light truck is greater than 8 inches tall, overlap of the entire Part 581 zone is required).

OPTION 2: If a LTV's structure does not meet the criteria of Option 1, there must be a secondary energy-absorbing structure (SEAS), connected to the primary structure, whose lower edge shall be no higher than the bottom part of the Part 581 bumper zone.

Following this, an amendment to the Phase 1 agreement was submitted to NHTSA on May 10 2006, which added a strength requirement for the SEAS. This requirement states that the SEAS shall withstand a load of least 100 kN exerted by a loading device as described in reference [2], Appendix A, before this loading device travels 400 mm from the forward-most point of the significant vehicle structure.

An accident analysis based study performed by the IIHS estimated that the benefit that could occur from LTV's conforming to these requirements is substantial [3]. For LTV-to-car frontal collisions a reduction in the risk of fatality for the car drivers of 16 percent was calculated for SUVs and 20 percent for pickups. For collisions where the LTV strikes the side of a car a reduction in the risk of fatality of 30 percent was calculated for SUVs and 10 percent for pickups.

Even with this predicted improvement, research continues by TWG members to develop further recommendations to improve the compatibility of LTVs without significant reductions in their self protection capability. Currently, the following three distinct research paths are being pursued:

- Assessment of LTV's compatibility using a fixed barrier with Load Cell Wall (LCW) measurements.
- Assessment of LTVs compatibility using a car surrogate Mobile Deformable Barrier (MDB) with deformation measurements and decelerations.
- Assessment of LTVs compatibility using a CAE approach by simulating LTV impacts into a Finite Element model of a representative car or cars.

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

The TWG members have performed several series of tests and simulations to evaluate the fixed barrier LCW approach over the years which have been presented in several publications. This report describes only the results from the work done during 2006-2007, which was funded by the EVC Management Committee.

2 Background to Fixed Barrier Approach

The aim of this approach is to develop a dynamic test procedure to evaluate the collision compatibility of LTVs with a car using a fixed barrier and a metric based on Load Cell Wall (LCW) measurements. Ideally, to keep the number of additional tests to a minimum, this test should be an adaptation of a current test.

The work to date has focused on the Full Width Deformable Barrier (FWDB) test proposed by the International Harmonisation of Research Activities (IHRA) compatibility working group [4], which is an adaptation of the US FMVSS No. 208 and NCAP test. However, it should be noted that research to evaluate an approach using a rigid wall may still be performed at a later date. The reason for the focus on a test with a deformable element is that it offers the following advantages over a rigid wall:

- Improved detection of Secondary Energy-Absorbing Structures (SEAS), which can be set back from the front of the vehicle and undetectable in an impact with a rigid wall.
- Reduction of engine dump loading and force spikes caused by small protruding local features forming preferential load paths that may otherwise confound the measured force distribution.
- Improved detection of crossbeam structures which may not be strained in an impact with a rigid wall.
- Reduction of the high decelerations that can result from the stress wave effects at the front of the rails in rigid wall impacts with the effect that the initial phase of the impact is more representative of vehicle-to-vehicle crashes.

The following work plan was drawn up to investigate the effect of an LTV's geometry and stiffness characteristics on its compatibility in impacts with cars, and to develop metrics for the FWDB test to control them:

1. Geometry – vertical
    - Understand the effect of vertical geometrical changes to an LTV, such as height of PEAS or addition of SEAS, on its compatibility performance.
    - Develop and validate metrics with performance limits to control these characteristics.
2. Geometry – horizontal
    - Repeat (1) but for horizontal geometrical changes to LTV such as improved crossbeam structures.
3. Repeatability / reproducibility
    - Check that test repeatability and reproducibility is acceptable and set tolerances for test parameters such as vehicle to LCW alignment.
4. Stiffness matching
    - Investigate stiffness matching issue and develop metrics to control it.

The work described in this report relates to step (1), to investigate vertical geometrical changes to an LTV. As part of this work the following candidate metrics to assess the LTV's compatibility potential were evaluated:

Metric 1
This metric is based on the sum of the peak cell loads for rows 3 and 4 of the LCW and is similar to the VNT metric proposed by IHRA [4]. Please note that peak cell loads are calculated independent of time and could occur at any time in the impact. The principle of the metric is to ensure the vehicle has adequate structure in alignment with the CFR49 Part 581 Zone using enforcement of a minimum load requirement on both rows 3 and 4, as these rows encompass the Part 581 Zone. Earlier work by the group has suggested that a minimum load requirement of about 100 kN is needed [2]. In summary Metric 1 is:

> Sum of peak cell loads at any time during crash on rows 3 and 4 with proposed minimum load of 100 kN for each row.

Metric 2
This metric is a modification of the one above; the modification being that the peak cell loads are calculated for the first 40 ms of the impact as opposed to the whole impact. It is equivalent to the VSI metric proposed by TRL [5]. The purpose of the modification was to ensure that the loads from structures located more than about 400 mm rearwards of the front of the vehicle, such as the engine, would not be assessed by the metric. This also helped to align this metric with the AHOF400 and KW400 metrics proposed by NHTSA which also only assess structures up to 400 mm from the front of the vehicle. In summary Metric 2 is:

> Sum of peak cell loads during first 40 ms of crash on rows 3 and 4 with proposed minimum load of 100 kN for each row.

Metric 3
Average Height of Force (AHOF) as proposed by NHTSA [6]. AHOF can be calculated up to any point (time or vehicle B-pillar displacement) during the impact. NHTSA have calculated AHOF up to the end of the impact and up to a B-pillar displacement of 400 mm (AHOF400). However, NHTSA have only calculated AHOF for rigid barrier tests, whereas the tests performed for this study have a deformable element. This results in the vehicle having a greater displacement in the test. Hence, AHOF400 in a test with a rigid barrier is not equivalent to AHOF400 in a test with a deformable element. So, for this study instead of comparing AHOF400 values, a comparison of how AHOF varied throughout the impact was made.

In addition, for test series 1 and 2 variations of Metric 1 and Metric 2 were examined to investigate the effect of different ways of calculating the row load. Further detail is given in the results sections.

3 Objectives

The overall objectives of the work performed were:

- To understand the effect of vertical geometrical changes to improve an LTV's compatibility in LTV-to-car impact.
- To evaluate the ability of the FWDB test to assess these changes using LCW measurements and associated metrics.
- To correlate the assessment of an LTV's compatibility using the FWDB test with the performance of the car in an LTV-to-car impact and set performance requirements.

4 Description of Test Series

Three integrated series of tests, which are summarised in Figure 1, were performed to investigate the following LTV geometric parameters:

- Height of Primary Energy-Absorbing Structure (PEAS) – this was achieved by altering the ride height of the LTV.
- Presence of BlockerBeam® type Secondary Energy-Absorbing Structure (SEAS)
- Presence of Subframe type SEAS

Each series of tests consisted of at least 2 LTV-to-car tests and 2 FWDB tests to allow a comparison of the performance of the baseline and modified LTV in an impact with a car and in the FWDB test.

	Research Goal	Bullet Vehicle	vs	Target	Diagram
TEST					
1	Understand the effect of ride height in V-t-V collision and evaluate ability of FWDB and various metrics to detect this change.	Full-sized PU at normal ride height [Option 1 compliant]	vs	Mid-sized PC1	
		Full-sized PU raised by 10 cm [Option 1 non-compliant]	vs	Mid-sized PC1	
		Full-sized PU at normal ride height [Option 1 compliant]	vs	FWDB-LCW	
		Full-sized PU raised by 10 cm [Option 1 non-compliant]	vs	FWDB-LCW	
2	Understand the effect of BlockerBeam® type SEAS in V-t-V collision and evaluate ability of FWDB and various metrics to detect this type of SEAS.	Heavy Duty PU with standard BlockerBeam® SEAS [Option 2 compliant]	vs	Mid-sized PC2	
		Heavy Duty -PU with BlockerBeam® SEAS removed	vs	Mid-sized PC2	
		Heavy Duty PU with standard BlockerBeam® SEAS [Option 2 compliant]	vs	FWDB-LCW	
		Heavy Duty PU with BlockerBeam® SEAS removed	vs	FWDB-LCW	
SIMULATION					
3	Understand the effect of subframe-type SEAS in V-t-V collision and evaluate ability of FWDB and various metrics to detect this type of SEAS.	SUV with standard subframe raised by 12.5 cm [Option 2 non-compliant]	vs.	Mid-size PC3	
		SUV with elongated subframe raised by 12.5 cm [Option 2 compliant]	vs.	Mid-size PC3	
		SUV with standard subframe raised by 12.5 cm [Option 2 non-compliant]	vs.	FWDB-LCW	
		SUV with elongated subframe raised by 12.5 cm [Option 2 compliant]	vs.	FWDB-LCW	
		SUV with standard subframe [Option 1 compliant]	vs.	Mid-size PC3	
		SUV with elongated subframe [Option 1 over-compliant]	vs.	Mid-size PC3	
		SUV with standard subframe [Option 1 compliant]	vs.	Mid-size PC3	
		SUV with elongated subframe [Option 1 over-compliant]	vs.	FWDB-LCW	

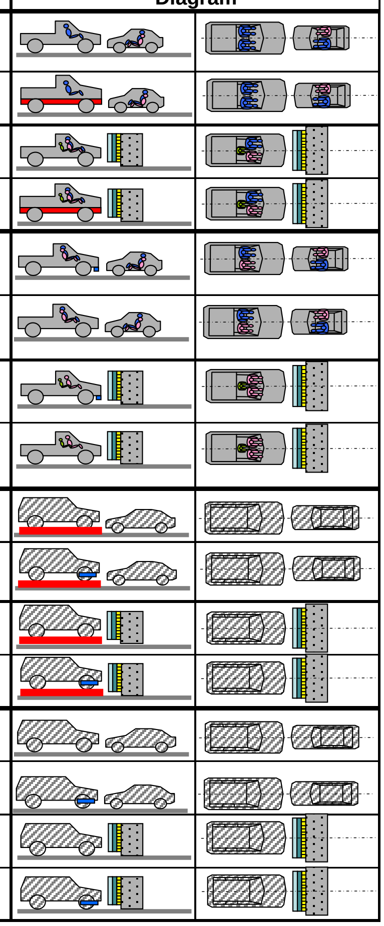

Figure 1: Description of three test series performed to investigate effect of changing an LTV's geometric parameters on its compatibility potential and ability of FWDB test to detect them. Note: Test series 3 was performed using Finite Element simulation.

Test Series 1 – Height of PEAS
The aim of this test series was to understand the effect of a LTV's PEAS height in an LTV-to-car collision and evaluate the ability of the FWDB test and associated metrics to detect a change.

The effect of the height of an LTV's PEAS on its compatibility potential was investigated by performing tests with a standard (baseline) full-sized pickup whose PEAS conforms to the 'option 1' criteria and a modified one whose ride height had been increased by 10 cm. The raised pickup's PEAS did not conform to the 'option 1' criteria. This height was chosen to give a substantial difference whilst still being representative of current vehicles on the road.

Test Series 2 – Presence of BlockerBeam® type SEAS
The aim of this test series was to understand the effect of a BlockerBeam® type SEAS in an LTV-to-car collision and evaluate the ability of the FWDB test and associated metrics to detect this change.

The effect of the presence of a BlockerBeam® type SEAS on its compatibility was investigated by performing tests with a standard (baseline) 'option 2' compliant heavy duty pickup and a modified one from which the SEAS had been removed.

Test Series 3 – Presence of subframe type SEAS
This series of tests was performed using Finite Element simulation. The aim of the series was to understand the effect of a subframe type SEAS in an LTV-to-car collision and evaluate the ability of the FWDB test and associated metrics to detect this change.

Two sets of simulations were performed. The first set investigated the effect of adding a subframe type SEAS to an 'option 1' non-compliant SUV. The baseline 'option 1' non-compliant SUV was 'made' by raising the ride height of an 'option 1' compliant SUV by 125 mm by raising the ground plane in the simulation. To investigate the effect of the presence of subframe type SEAS the baseline SUV was modified to make it 'option 2' compliant by adding an elongated subframe to it. The second set of simulations investigated the effect of adding a sub-frame type SEAS to an already 'option 1 compliant' LTV.

In all three series the configuration of the LTV vs car tests was 100% overlap with a closing speed calculated to impart a change of velocity on the car of 35 mph assuming an inelastic collision. The FWDB test was 100% overlap with a test speed of 35 mph. The load cell wall and deformable element used have been described previously [7] but in summary are:

- Load Cell Wall (LCW)
  Nominal resolution 125 mm x 125 mm mounted 80 mm above ground level so that the Part 581 Zone spans two rows (3 and 4) to enable better detection of structure at this height.
- Deformable element
  Two 150 mm deep layers of aluminium honeycomb, the front layer with a crush strength of 0.34 MPa, the rear layer with a crush strength of 1.71 MPa and segmented along each load cell row and column to prevent spreading of load between cells.

Further details for the configurations of the tests performed are reported with the test results.

5 Results of Test Series

The results of each test series and a summary of the main observations are described below.

5.1 Test Series 1 – Height of PEAS

5.1.1 LTV vs Car Tests

Two tests were performed between a full sized pickup and a small passenger car. The tests were identical except one test was performed with a standard pickup and the other with the ride height of the pickup raised 100 mm [Figure 2].

	Test 1		**Test 2**	
	Full Sized Pickup	Small Passenger Car	Full Sized Pickup	Small Passenger Car
Vehicle Details	Model Year 2006	Model Year 2005	Model Year 2006 Raised by 100mm	Model Year 2005
Dummy type (Driver/Pass)	H-III 50% / H-III 50%	H-III 50% / H-III 5%	H-III 50% / H-III 50%	H-III 50% / H-III 5%
Test Mass	2598 kg	1297 kg	2604 kg	1300 kg
Ride Height (Left/Right)	Front 875 / 883 mm Rear 911 / 912 mm	Front 653 / 660 mm Rear 645 / 652 mm	Front 976 / 978 mm Rear 1019 / 1023 mm	Front 646 / 658 mm Rear 636 / 644 mm
Impact Velocity	28.0 km/h	56.4 km/h	27.8 km/h	56.5 km/h
Test accuracy	Car was 53 mm Right Vertical accuracy unknown		Car was 43 mm Right Vertical accuracy unknown	

Figure 2: Test configuration for full sized pickup to car tests

For the LTV vs car tests, the alignment of the LTV PEAS and car rails, is shown [Figure 3]. The PEAS of the standard pickup overlapped well with the car PEAS but there was no overlap for the raised pickup.

Figure 3: Pre-test alignment of standard (top) and raised (bottom) pickup with car.

Examination of the test film showed greater engagement between the vehicles in the test with the standard pickup, whereas in the test with the raised pickup there was override, with the front wheels of the pickup lifting off the ground [Figure 4].

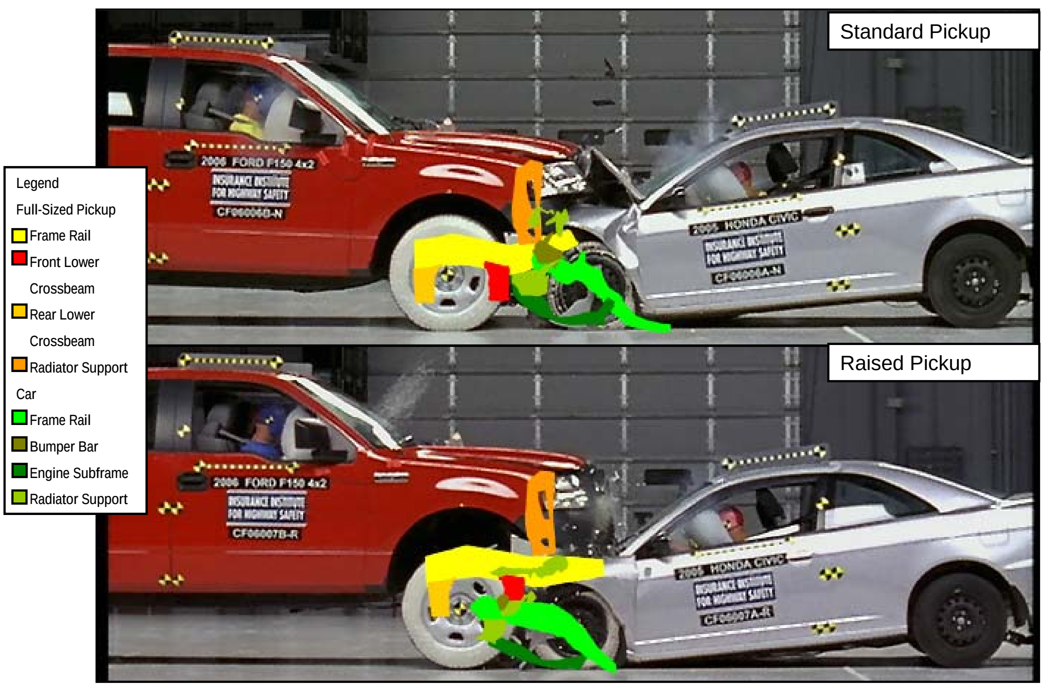

Figure 4: Pickup vs Car tests showing showing greater structural engagement for standard pickup (upper) and override for raised pickup (lower).

The amount of override seen was quantified by comparing the difference between curves representing the relative displacement between points on the B-pillar rocker of the pickup and the car for both tests [Figure 5]. These curves were derived from video analysis. The relative displacement includes the deformation of the vehicles and the override. Comparing the plots it is evident that the maximum relative displacement for the test with the raised pickup is 160 mm greater than for the test with the standard pickup. This gives an indication of the amount of override in the test with the raised pickup.

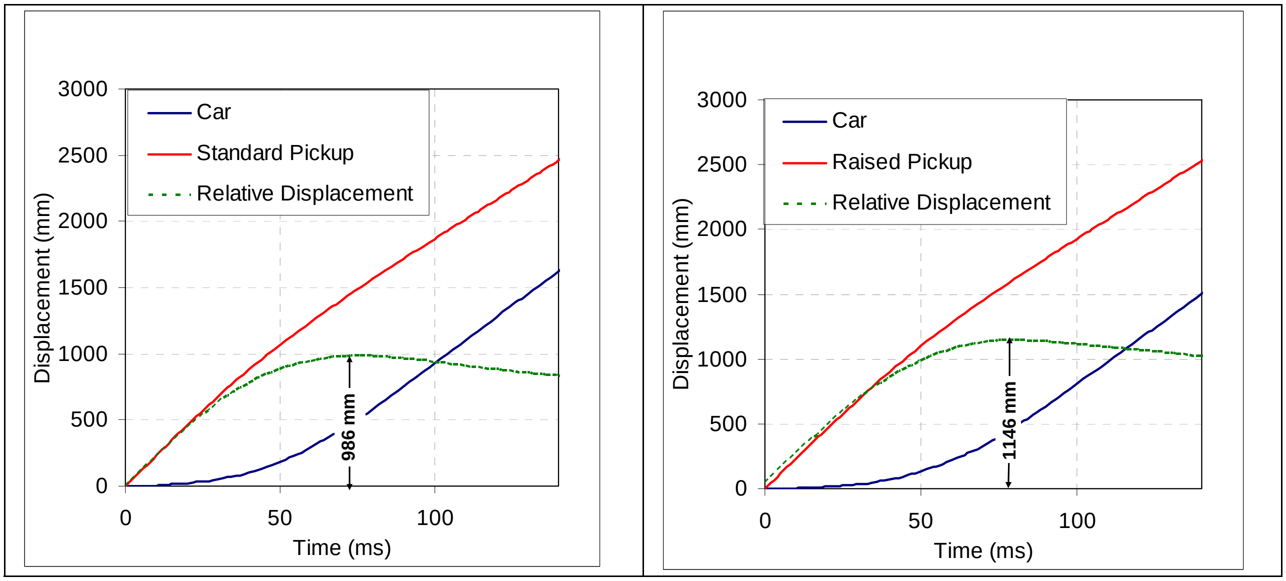

Figure 5: Relative displacement time histories for car and pickup for tests with standard pickup (left) and raised pickup (right).

Detailed examination of the vehicles post-test indicated that the override on the raised pickup was most likely limited by interaction between the car's bumper beam and the pickup's front lower crossbeam located below and approximately 500 mm rearward of the front of the PEAS [Figure 6].

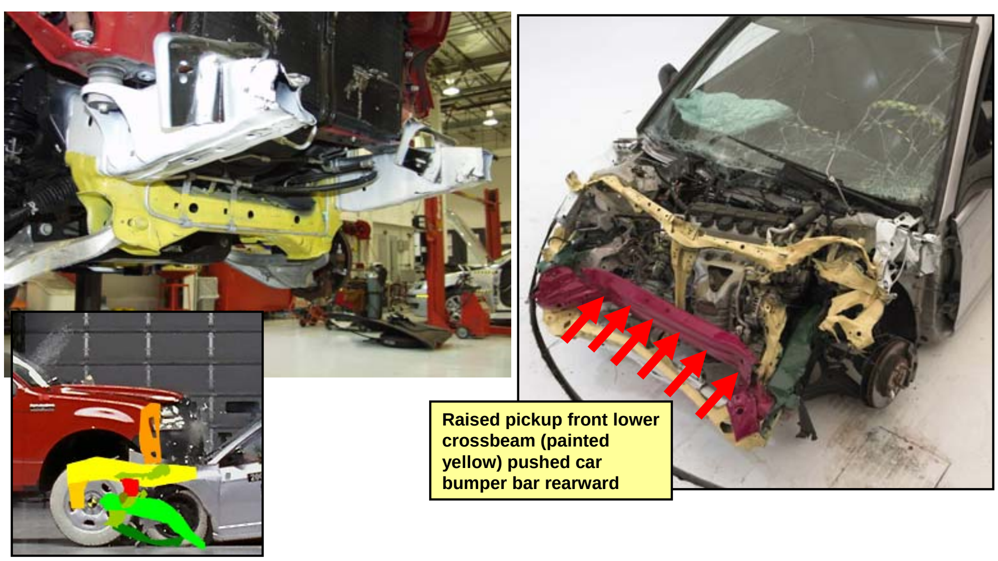

Figure 6: Interaction front lower crossbeam on raised pickup and car's bumper crossbeam.

The difference in the structural engagement between the tests with the standard and raised pickups was clearly illustrated by comparison of the final deformation of the vehicles [Figure 7 and Figure 8]. For the raised pickup test there was much less deformation of the car and pickup

PEAS showing that structural engagement was not as great as in the standard pickup test where there was more deformation of both the car and pickup rails.

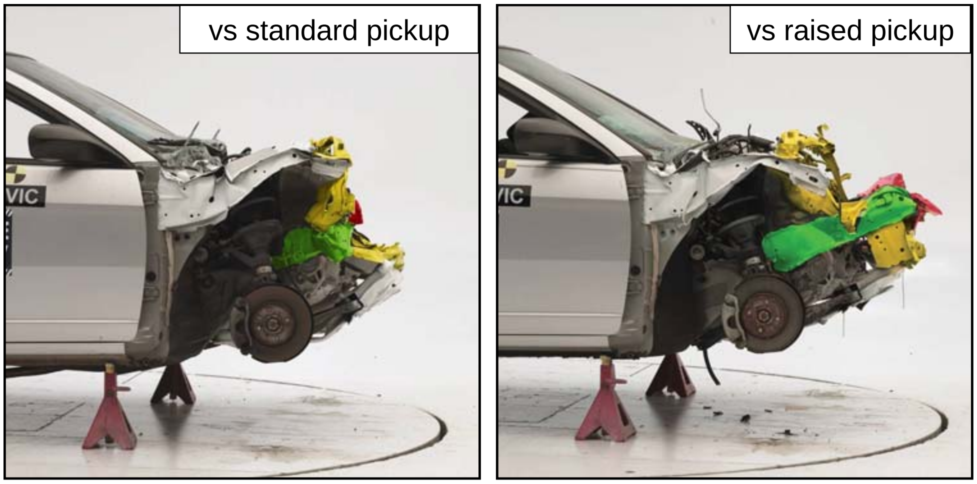

Figure 7: Comparison of car deformation in tests with standard and raised pickups.

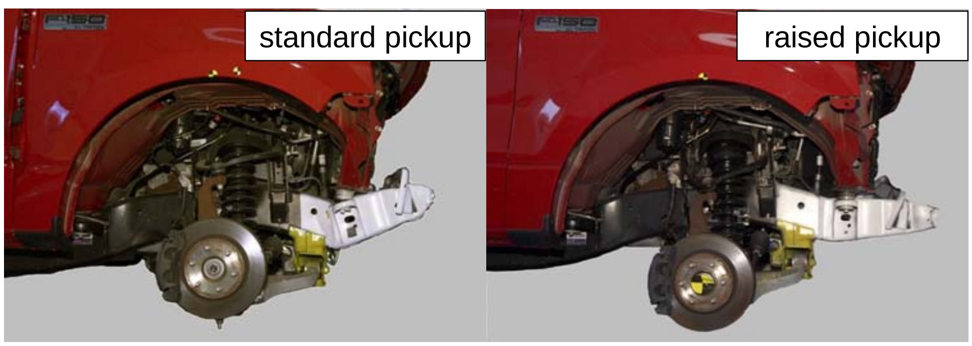

Figure 8: Comparison of deformation of standard and raised pickups.

The cars' compartment intrusions were measured based on the IIHS intrusion procedure, which gives a resultant displacement with respect to the average seat bolt movement for all points, apart from those on the instrument panel for which a longitudinal displacement is given [Figure 9]. They were low and similar in both tests (8 cm or less apart from brake pedal), even though the cars were loaded differently as a result of the different structural engagement. It is interesting to note that the intrusions at the toe pan and footrest level were slightly lower for the raised pickup, indicating a reduction in the loading of the car structure at this height for the test with the raised pickup.

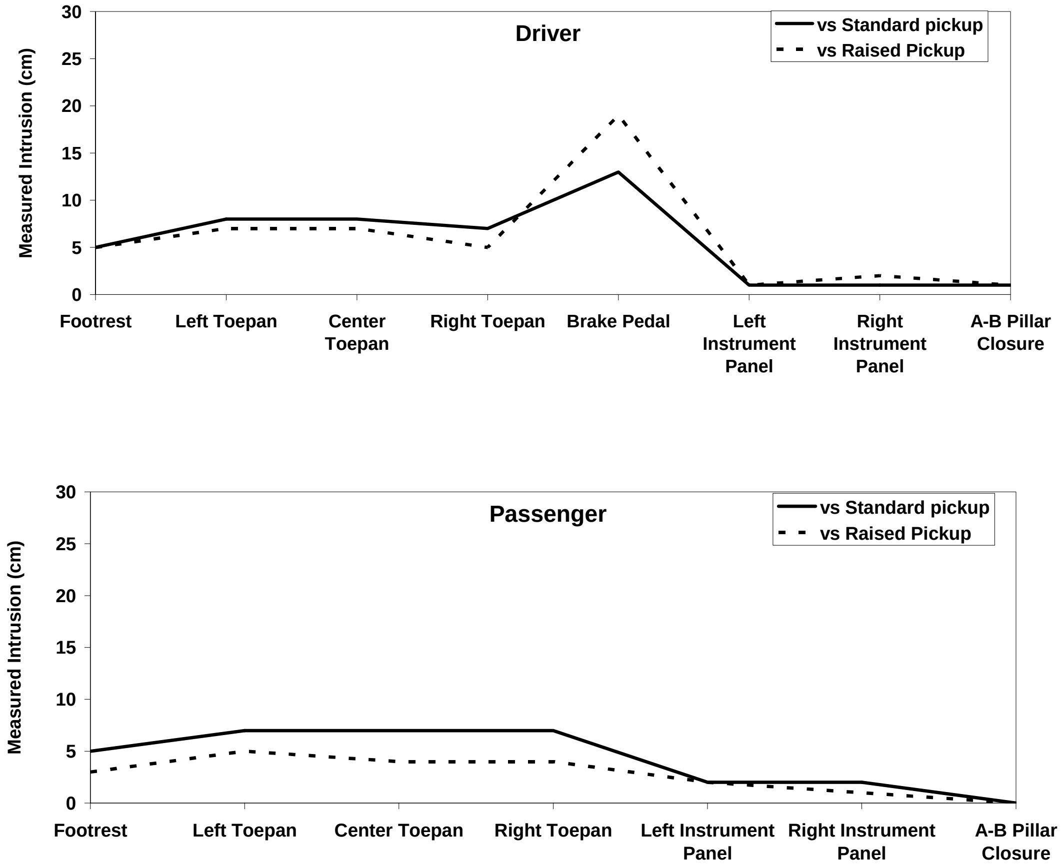

Figure 9: Car compartment intrusion measured using IIHS methodology for driver (top) and passenger (bottom) against standard and raised pickups.

Detailed intrusion profiles of the floor and dash panel were measured at the driver and passenger centrelines [Figure 10]. Comparison of the profiles for the standard and raised pickups shows that there was slightly less deformation of the floor / toe pan area for the impact with the raised pickup, which confirms the results of the point measurements shown above.

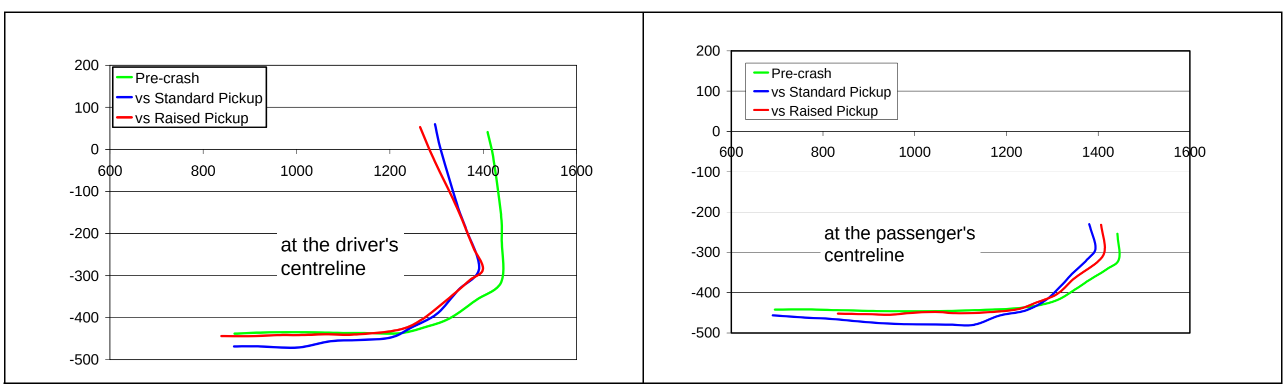

Figure 10: Floor and toe pan intrusion of car impacted by standard and raised pickups.

The effect of the different structural engagement between the tests can be seen by comparing the car compartment deceleration pulses. For the test with the standard pickup, where there was greater structural engagement, the initial cabin deceleration rose to about 25g in the first 10 ms of the impact. This compared to about 10g in the test with the raised pickup in which override occurred.

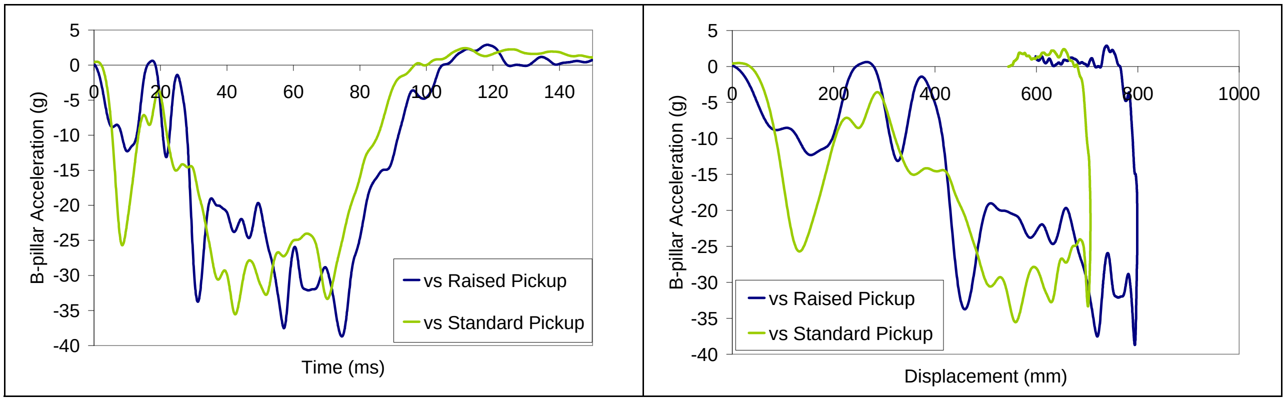

Figure 11: Car compartment deceleration vs time (upper) and displacement (lower) showing effect of override.

This difference in the deceleration pulses resulted in a difference in the deployment of the car's Supplementary Restraint System (SRS). In the test with the standard pickup, the high initial car cabin deceleration caused the SRS to fire in "high severity" crash mode at 14 ms, which is similar to the typical high-speed flat barrier response. In contrast, in the test with the raised pickup the lower initial car cabin deceleration caused the SRS to fire in "low severity" mode at 22 ms. This mode deploys the 1st stage of the airbags immediately, but delays deployment of 2nd stage by 20 and 40 ms for driver and passenger, respectively.

For both dummies in the cars the ATD injury measures were all below the standard regulatory limits, apart from the tibia index, but generally higher for the test against the raised pickup, in particular for the head and right tibia index [Figure 12]. A contributory factor to the higher head injury values for the test against the raised pickup could have been the difference in the triggering of the SRS. However, it should be noted that the injury values were well below the standard regulatory limits. No clear explanation for the high right tibia index values in the test against the raised pickup could be found.

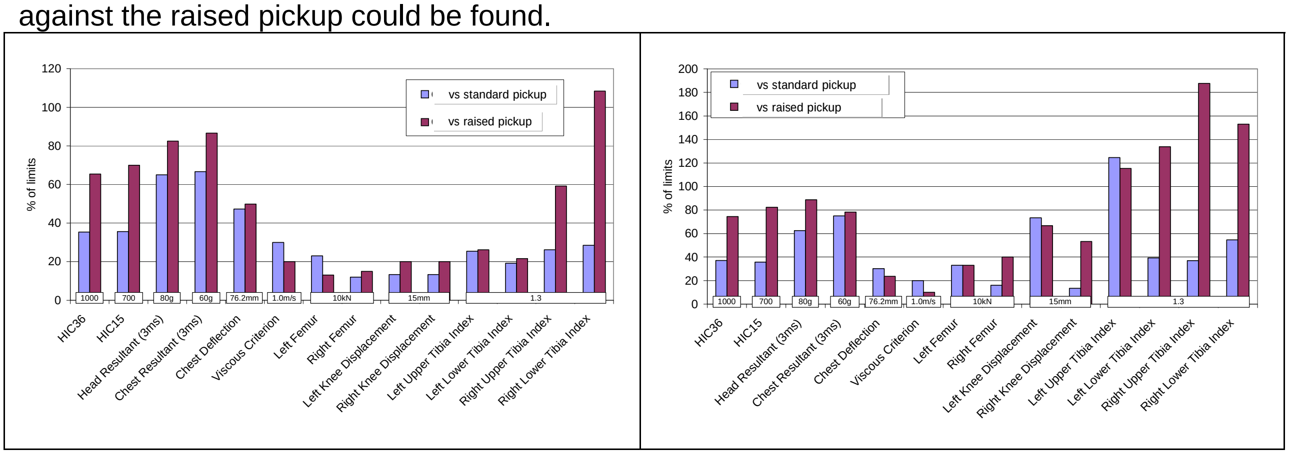

Figure 12: 50th percentile HYBRIDIII driver ATD (right) and 5th percentile HYBRIDIII passenger ATD (left) responses for car.

In summary:

- A visual comparison of the results showed a difference in the structural engagement behaviour between the tests. For the standard pickup, the leading edge of its PEAS engaged the PEAS of the car and no wheel lift of the pickup was observed indicating that no override occurred. For the raised pickup, the leading edge of its PEAS did not engage the PEAS of the car and wheel lift of the pickup was observed indicating that override occurred.
- This difference in structural engagement behaviour led to a difference in the cars' occupant compartment deceleration, especially at the beginning of the impact. For the standard pickup the compartment deceleration rose to about 25g in the first 10 ms of the impact. In contrast, for the raised pickup the compartment deceleration rose to only 10g in the first 10 ms.
- In turn, this difference in compartment deceleration caused the SRS to deploy differently between the tests. For the standard pickup the SRS deployed in a 'high severity' mode similar to that seen in a high speed flat barrier test. In contrast, for the raised pickup the SRS deployed in a 'low severity' mode at a later time. The different way in which the SRS deployed may have affected the dummy injury measures.
- The cars' compartment intrusions were low and similar in both tests (8 cm or less apart from brake pedal).
- The ATD injury values were all below the standard US regulatory limits, apart from the tibia index, but generally higher for the raised pickup, especially for the head and tibia index.

5.1.2 LTV FWDB Tests

Two FWDB tests were performed with standard and raised full sized pickups [Figure 13].

	Standard Full sized pickup	Raised full sized pickup
Vehicle Details	**Model Year 2006**	**Model Year 2006 Raised by 100mm**
Dummy type (Driver/Pass)	**H-III 50% / H-III 5%**	**H-III 50% / H-III 5%**
Test Mass	**2597 kg**	**2590 kg**
Ride Height (Left/Right)	**Front 877 / 878 mm Rear 905 / 912 mm**	**Front 976 / 979 mm Rear 1006 / 1014 mm**
Impact Velocity	**56.96 km/h**	**57.14 km/h**
Impact Accuracy	**~ 30 mm Left N/A Vertical**	**36 mm Left 0 mm Vertical**
LCW Height above Ground	**205 mm**	**205 mm**

Figure 13: Test configuration for full sized pickup FWDB tests.

Figure 14 shows the post impact deformation of the standard and raised pickups, showing that they deformed in a similar manner in both tests.

Figure 14: Post impact deformation of standard full size pickup (left) and raised pickup (right) and corresponding barriers.

A comparison of the Load Cell Wall (LCW) total force for the standard and raised pickups shows similar traces indicating that, overall, both pickups performed in a similar manner [Figure 15].

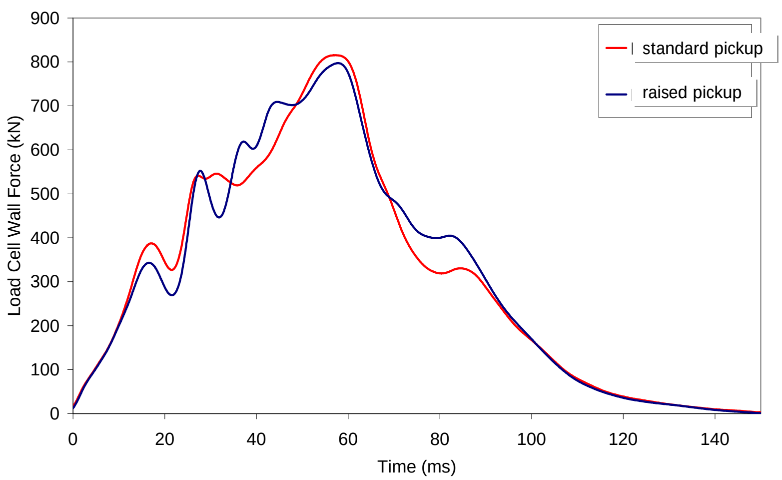

Figure 15: FWDB test LCW total force for standard and raised pickups.

The LCW force distributions for the standard and raised pickups are shown in Figure 16 and Figure 17 respectively. It is clearly seen that the raised pickup applies less load to row 3 and more load to row 4 than the standard pickup.

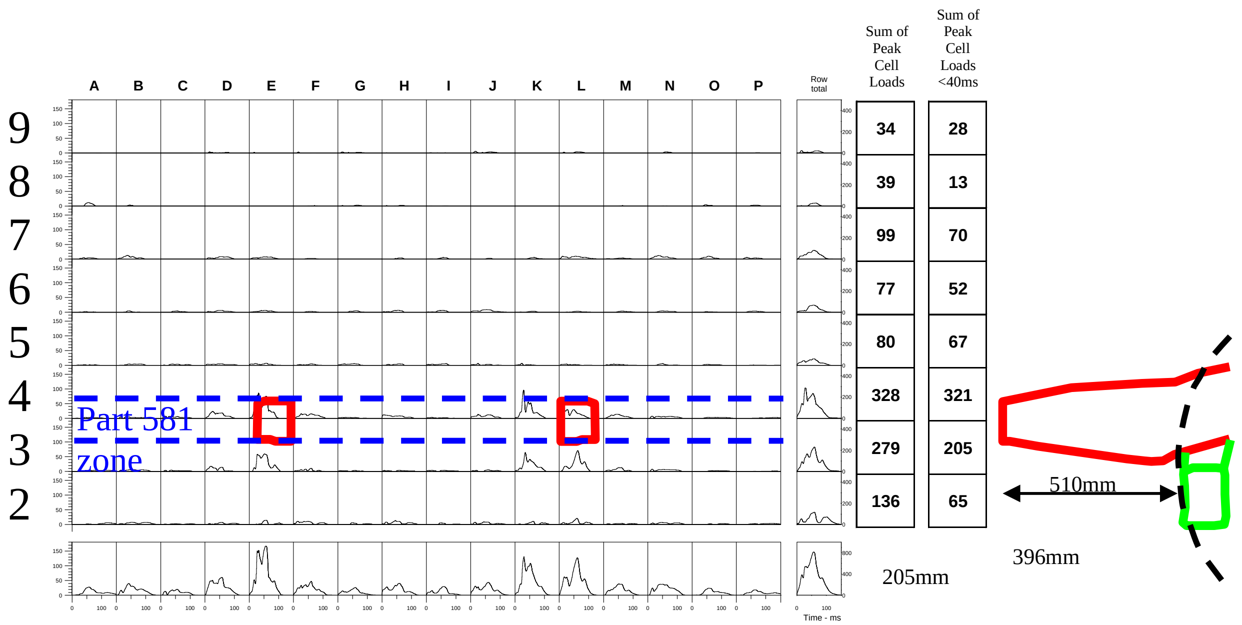

Figure 16: Standard pickup: Load (scale 0 –180kN) / time (scale 0-150ms) curves for complete load cell wall. Alignment of vehicle at impact, row loads, column loads and sum of peak cell loads in row for whole impact and up to 40 ms also shown. Part 581 Zone marked with blue dashed lines.

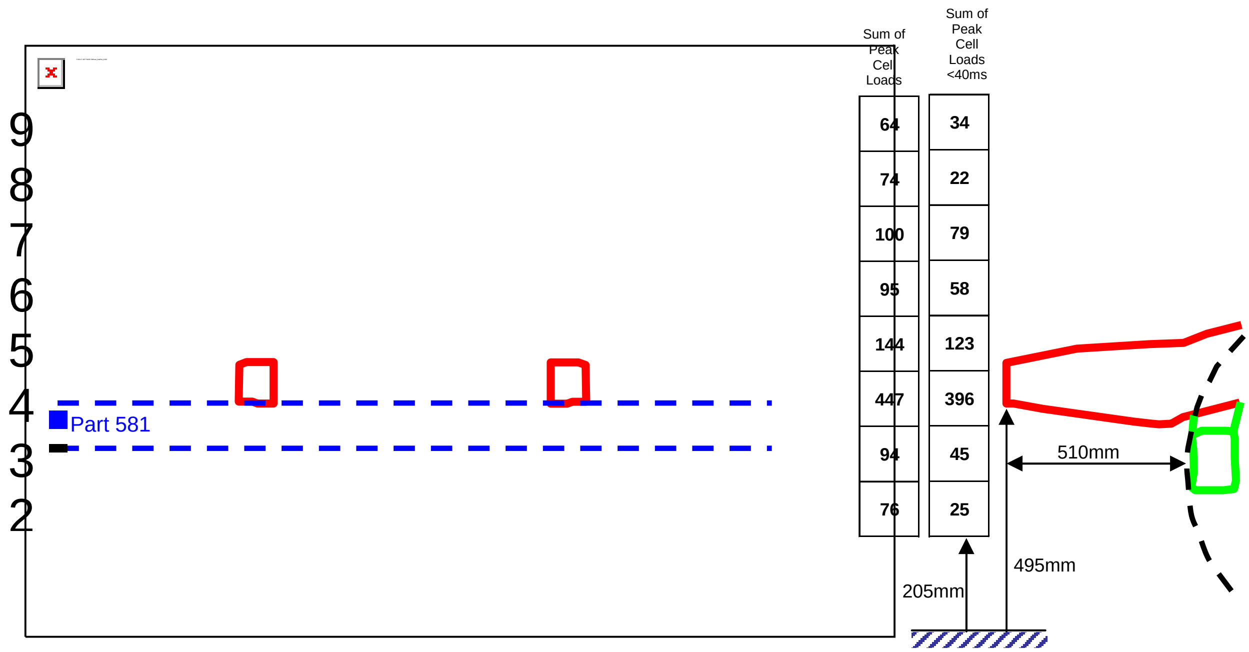

Figure 17: Raised pickup: Load (scale 0 –180kN) / time (scale 0-150ms) curves for complete load cell wall. Alignment of vehicle at impact, row loads, column loads and sum of peak cell loads in row for whole impact and up to 40 ms also shown. Part 581 Zone marked with blue dashed lines.

The total maximum force appearing in a certain row, e.g. row$_i$, can be characterised using two different methods. Firstly, the force time histories from all load cells within row$_i$ are combined to form a row$_i$ total force time history, whose maximum value for a given time period is taken denoted by 'Peak load for row$_i$'. Secondly, the peak loads in each load cell within row$_i$ are first found irrespective of the precise time they occur and then summed, this force is denoted as 'Sum of Peak Cell Loads for row$_i$'. In each method described, the values denoted by either

‘Peak Load for row_i’ or “Sum of Peak Cell Loads for row_i’ was also calculated within a 40 ms time window. This leads to four different measures for a row_i force.

Figure 18 indicates that, for the standard pickup, the loads seen in rows 3-6 gradually increase and then decrease in approximately a 100-200-300-50 KN pattern. For the raised pickup, as seen in Figure 18, the loads in rows 3-6 increase and decrease in approximately a 50-75-400-100 KN pattern. A shifting of load mainly from row 3 to row 4, of approximately 100 kN, occurs when the pickup is raised. It should be noted that this load pattern is the same regardless of the method of calculation (Sum of Peak Loads vs. Peak Row) indicating that the metrics are not likely to be significantly affected by changing the methodology to calculate the row load from ‘Sum of Peak Loads’ to ‘Peak Load’.

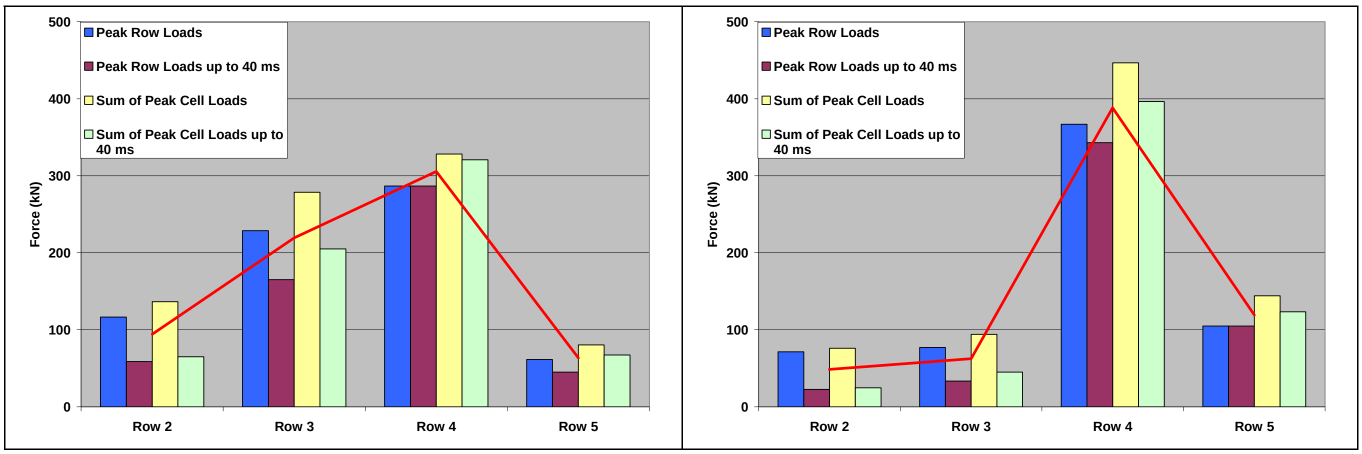

Figure 18: Comparison of peak row load distribution for standard (left) and raised (right) pickups.

The capability of the 3 metrics to assess the differences between the standard and raised pickups was evaluated. The metrics are described in detail in the ‘Background’ section but in summary are:

<u>Metric 1</u>

Sum of peak cell loads <u>at any time during crash</u> on rows 3 and 4 with proposed minimum load of 100 kN.

<u>Metric 2</u>

Sum of peak cell loads <u>during first 40 ms of crash</u> on rows 3 and 4 with proposed minimum load of 100 kN.

<u>Metric 3</u>

Average Height of Force (AHOF).

A comparison of the Metric 1 and 2 row loads shows that for the raised pickup the loads on row 3 are less than 100 kN whereas for the standard pickup they are greater than 100 kN [Figure 19]. However, for Metric 1 the load calculated is close to 100 kN, indicating that if this metric were used, the suggested performance limit of 100 kN may need to be raised.

Pickup	**Metric 1** Sum peak cell loads (kN)		**Metric 2** Sum peak cell loads up to 40 ms (kN)	
	Row 3	**Row 4**	**Row 3**	**Row 4**
Standard	279	328	205	321
Raised	94	447	45	397

Figure 19: Comparison of peak cell loads on rows 3 and 4 for standard and raised pickups.

A comparison of the AHOF against B-pillar displacement shows that the AHOF metric detects the difference in ride height between the vehicles at the end of the impact (549 mm cf 639 mm) and to within about 20 percent throughout the impact. However, its value does not correspond to the actual height of the PEAS [Figure 20].

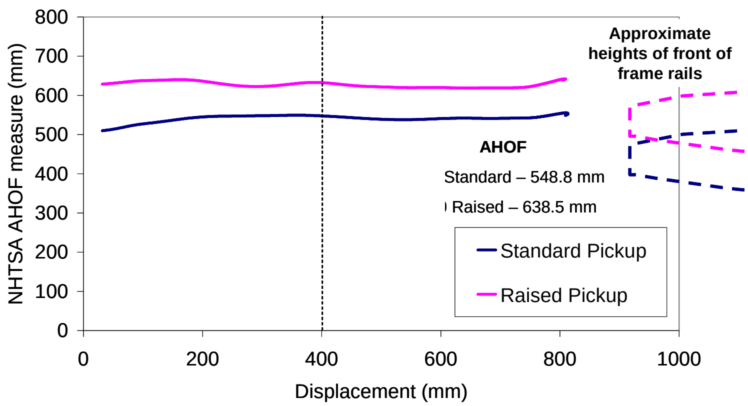

Figure 20: Comparison of AHOF against B-pillar Displacement for standard and raised pickups.

In summary:

- Row load based metrics 1 and 2 can discriminate difference in rail heights of the standard and raised pickups using the proposed minimum load of 100 kN.
- AHOF as measured using a 125 mm resolution load cell wall can indicate relative ride height differences between standard and raised pickups at the end of the impact (549 mm cf 639 mm) and within 20 percent throughout the impact.

5.1.3 Summary of Observations

- The pickup vs car tests showed that alignment of the pickup's PEAS with the CFR49 Part 581 zone resulted in greater structural engagement with the test car's PEAS. This caused a SRS deployment more similar to a flat barrier test and reduced most ATD measures, although compartment intrusions remained similar.
- Metrics based on peak cell loads on rows in alignment with the Part 581 zone (rows 3 and 4) with an example requirement of 100 kN discriminated the change (~ 10 cm) in height of the pickup's PEAS.

- The Average Height of Force (AHOF) metric also detected this change at the end of the impact (549 mm cf 639 mm) and within 20 percent throughout the impact.

5.2 Test Series 2 – BlockerBeam® type SEAS

5.2.1 LTV vs Car tests

Two tests were performed between a heavy duty pickup and a small passenger car. The tests were identical except one test was performed with a standard pickup with SEAS and the other with the SEAS removed [Figure 21].

	Test 1		Test 2	
	Heavy-Duty Pickup with SEAS	Small Passenger Car	Heavy-Duty Pickup **without** SEAS	Small Passenger Car
Model Year	2007	2005	2007	2005
Vehicle Weight	3191 kg	1531 kg	3186 kg	1538 kg
Vehicle Ride Height (mm, RH / LH)	1010 / 1000	647 / 641	1002 / 994	658 / 654
Impact Velocity	82.55 kph	0.0	83.05 kph	0.0
Velocity Change	26.71 kph	55.84 kph	27.04 kph	56.02 kph

Figure 21: HD pickup vs car test configuration details.

Unfortunately, most of the driver dummy's and some of the passenger dummy's channel recordings were lost in the test of the heavy-duty pickup with SEAS against a passenger car due to a high voltage anomaly. Therefore, only vehicle decelerations, displacements, and intrusions could be used for the correlation with the FWDB tests results and conclusions.

Figure 22 shows a simplified CAD representation of the pickup's passenger side front rail, lower radiator support, and BlockerBeam® (along with the associated attachment bracket). For the test without SEAS both the BlockerBeam® and the BlockerBeam® attachment bracket were removed, but the lower radiator support was not removed.

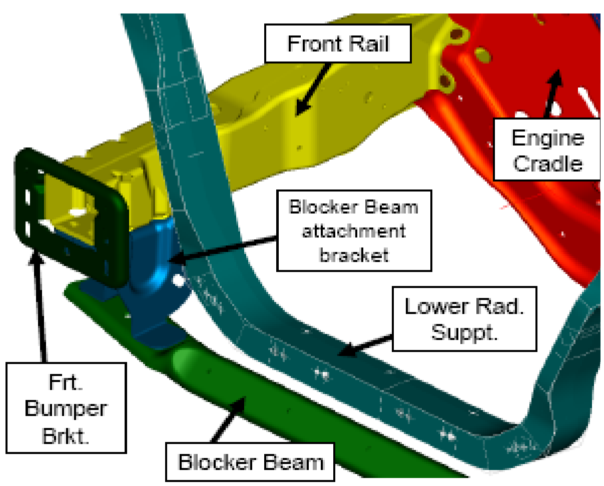

Figure 22: Front structure components in the heavy duty pickup.

Figure 23 shows the alignment of the heavy duty pickup PEAS and SEAS structures with the passenger car structures prior to the tests.

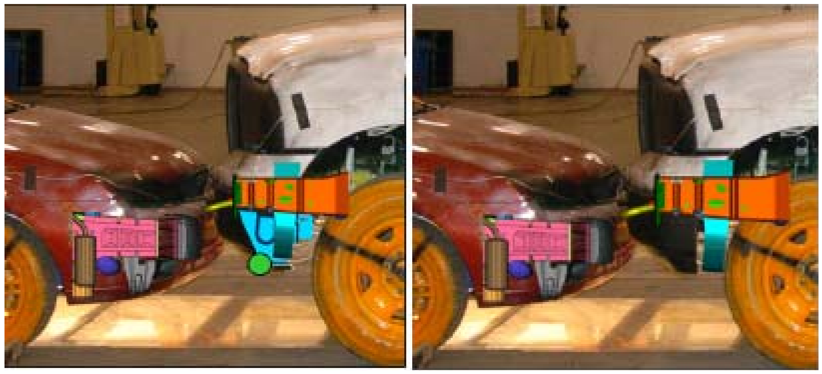

Figure 23: Alignment of heavy duty pickup and car structures for pickup with SEAS (left) and without SEAS (right).

Examination of the test film showed that there was less override of the car for the heavy duty pickup with SEAS compared to the one without SEAS [Figure 24].

Figure 24: Pickup vs car tests showing less override for HD pickup with SEAS (upper) compared to HD pickup without SEAS (lower).

This was confirmed by examining the difference between curves representing the relative displacement between points on the B-pillar / rocker on the bullet (pickup) and target (car) vehicles involved in the crash [Figure 25]. These data were obtained from a double integration of data from accelerometers mounted at these points. This difference includes deformation and override. Comparing the plots it is evident that the maximum relative displacement in the absence of SEAS is 184 mm more than that with SEAS (1529 mm vs. 1345 mm). This indicates that there was more override over the target vehicle in the case of no SEAS compared to that with SEAS.

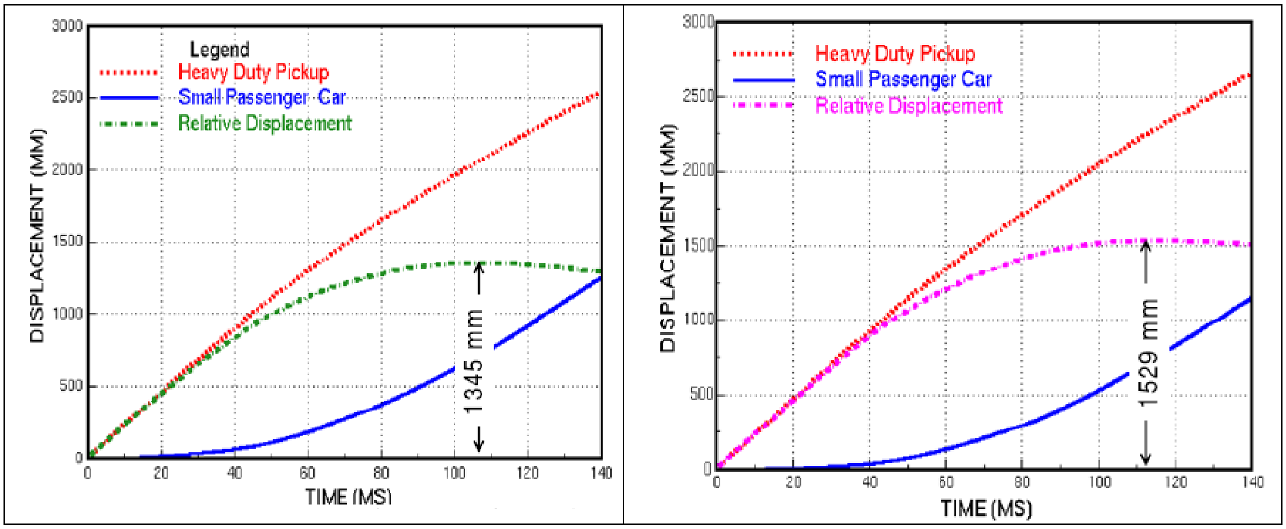

Figure 25: Relative displacement time histories obtained from target and bullet vehicles for HD pickup with SEAS (left) and HD pickup without SEAS (right).

The target car impacted by the HD pickup with SEAS has less overall deformation compared to the one impacted by HD pickup without SEAS [top of Figure 26]. This is very clear in the deformation zone around the A-pillar/roof rail and B-pillar/roof rail joints. This is due to a greater override of the bullet vehicle onto the target car when the SEAS is removed. The bottom of Figure 26 shows the specific collapse modes of the target car's PEAS impacted by the bullet vehicle with and without SEAS. In the test with SEAS, axial collapse is first observed in the car's fore-rail followed by a bending collapse near the engine mount due to the presence of SEAS and greater structural interaction. In the second test with the SEAS removed, there is less engagement of the front portion of the car's rail, leading to more override that resulted in considerable rotation and bending of the aft rail of the target vehicle.

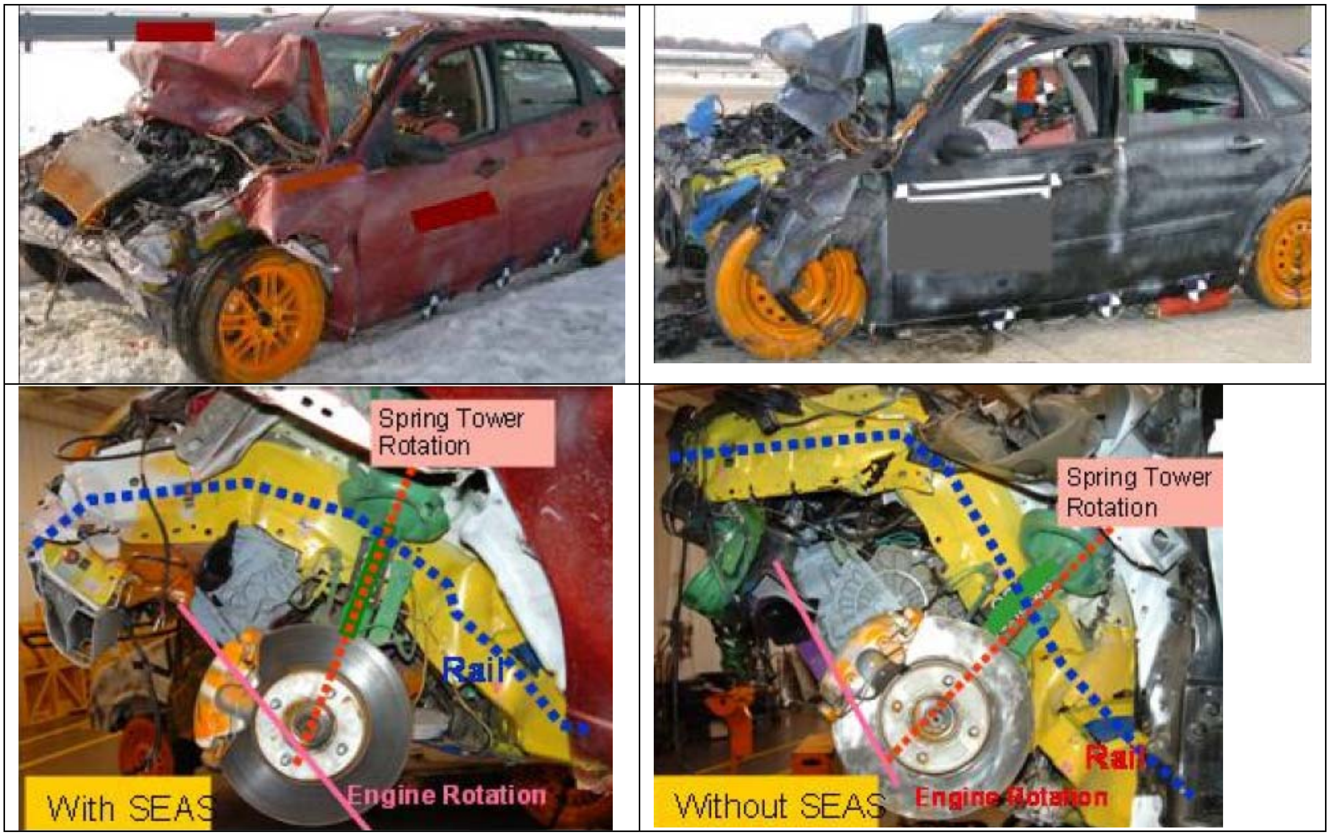

Figure 26: Car deformation for tests with SEAS (left) and without SEAS (right).

Figure 27 shows a dimensional analysis of the pre- and post-crash of the car's passenger compartment. In Figure 27, A represents a point at the A-pillar/roof joint, B represents a point at the B-pillar/roof joint, C represents a point at B-pillar/beltline, D represents a point at the B-pillar/rocker joint, E represents a point at the A-pillar/rocker joint, and F represents a point at the A-pillar/beltline. It is indicated from this figure that the presence of SEAS provided some reduction in the override, which led to less overall deformation and intrusions in the passenger compartment of the car.

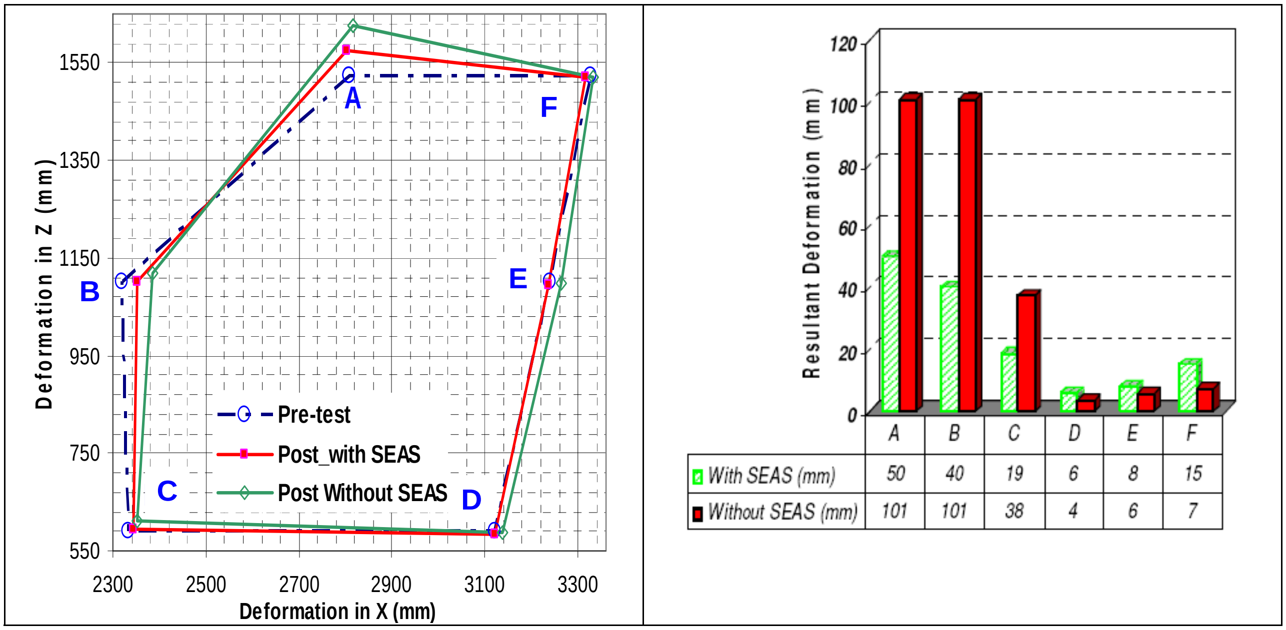

Figure 27: Car occupant compartment deformation in impacts with HD pickup with and without SEAS.

Pre-and post-crash dimensional analyses on target vehicles impacted by bullet vehicles with and without SEAS were carried out to obtain car compartment intrusion profiles shown in Figure 28. Intrusion profiles represented by sections from the cowl top to the floor panel at the driver centerline, vehicle centerline and passenger centerline are shown. For the driver centreline it was evident that having the SEAS on the bullet vehicle significantly reduced cabin intrusions, specifically at the instrument panel area due to increased structural interactions and reduced override. Higher engine rotation in the target vehicle when impacted by the bullet vehicle without SEAS caused larger upper dash intrusions. For the vehicle centreline, a small difference between the dash intrusion profiles on the car was seen. For the passenger centerline intrusions, mixed results were seen. Intrusions were improved in the lower part of the cabin at the foot pedal and foot rest areas with the presence of SEAS. Intrusions at the upper part got worse near instrument panel area. Very careful examination of the post-crashed target vehicles was conducted to better understand this observation. The engine is transversely mounted and is pivoted at a point approximately one-third of its transverse dimension towards the driver side and two-third towards the passenger side. In the case of the pickup with SEAS impact, higher forces were transmitted to the engine in the interaction zone compared to that without SEAS. This caused more rotation of the intruded engine towards the passenger side.

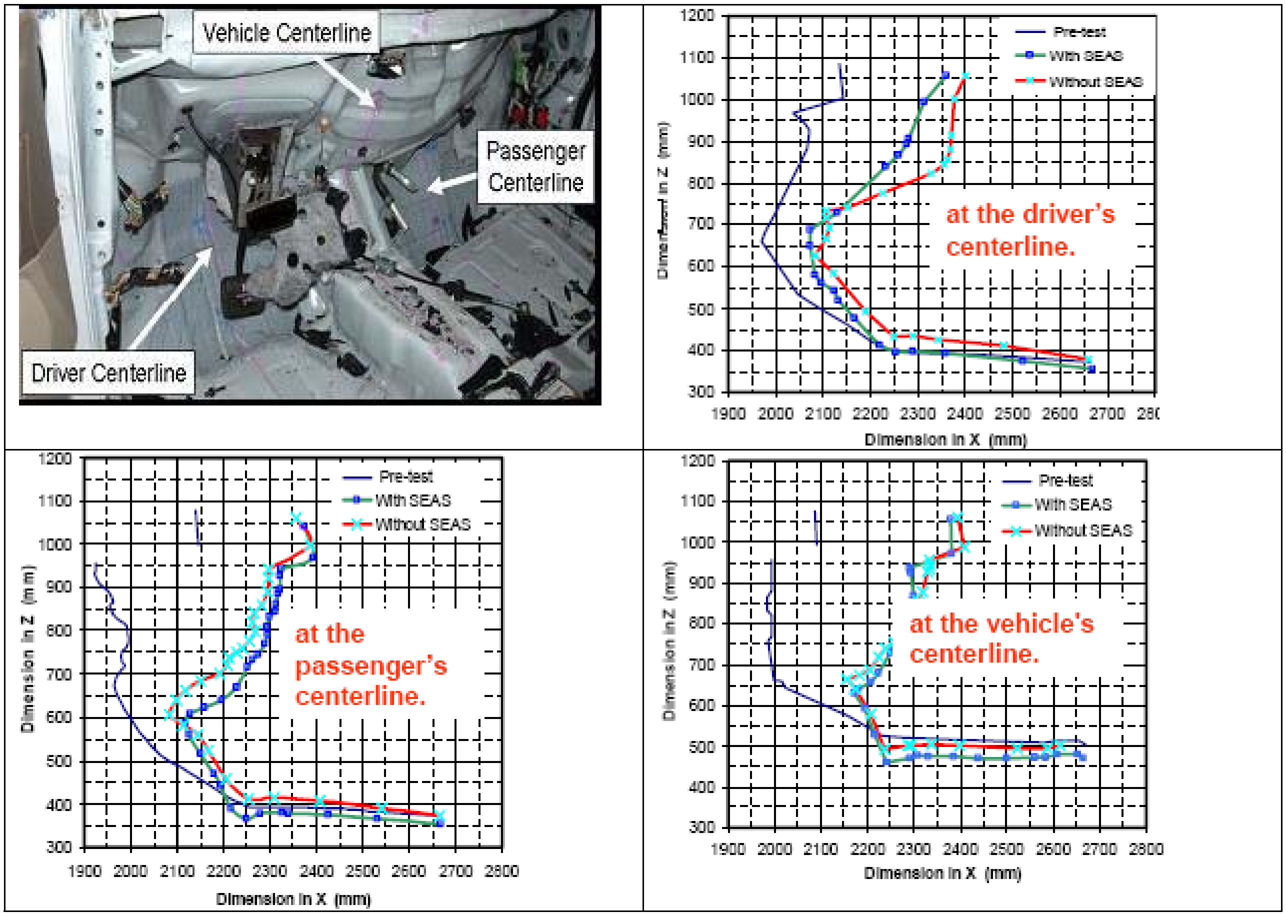

Figure 28: Dash intrusion of car impacted by HD pickup with and without SEAS.

Figure 29 shows a comparison of the deceleration pulses for the target car and bullet HD pickup for tests with and without SEAS. The effect of the presence of SEAS is quite obvious. The SEAS on the striking heavy-duty pickup engages the front end PEAS of the passenger car and transmits a larger force to the target vehicle early in the impact event, less than 20 ms, as seen in Figure 29. The SEAS caused the 20 G deceleration at approximately 20 ms experienced by the target car. From Newton's law, by considering the mass times the deceleration, approximately 304 KN of force is acting between the vehicles at this particular time. Such a force level was observed in the interaction zone (rows 3 and 4) in the FWDB test impacted by the heavy-duty pickup with SEAS (see next section). The target car experienced a much lower deceleration level when impacted by the heavy-duty pickup without SEAS. This means that within 20- 25 ms of initial impact, the HD pickup without SEAS missed engagement with the passenger car PEAS and contacted the passenger car's engine at approximately 30 ms. This is evident from the sudden jump of the crash pulses in both the target and bullet vehicles as seen in Figure 29.

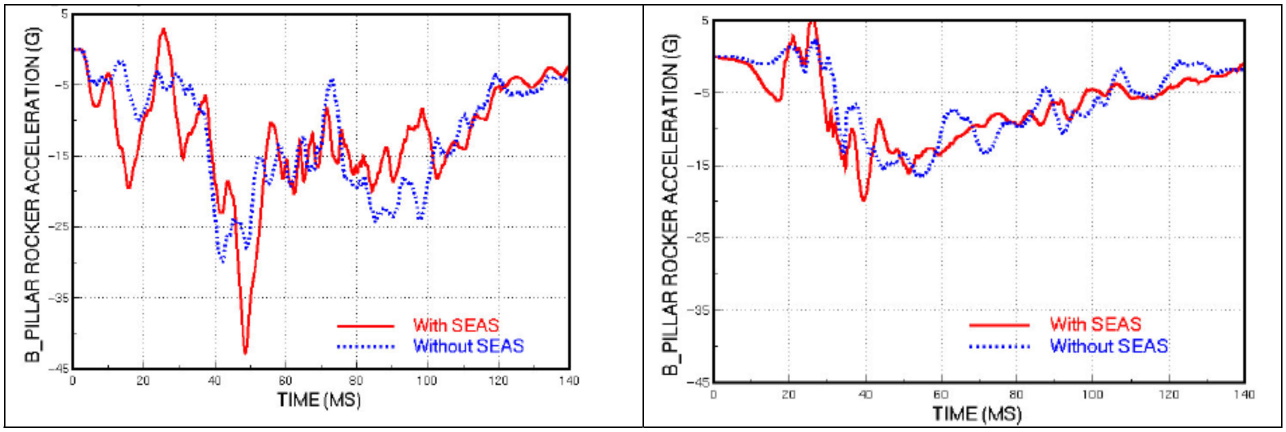

Figure 29: A comparison of the B-pillar deceleration pulses for the target car (left) and bullet HD pickup (right) for tests with and without SEAS.

In summary:

- The presence of the SEAS on the Heavy Duty pickup provided greater interaction with the PEAS of the target car. This led to reduction in override of the target car that resulted in reduction of the overall deformations and intrusions in the target vehicle's occupant compartment.

5.2.2 FWDB Tests

Two FWDB tests were performed with the heavy duty pickup, one test with a standard pickup with SEAS and the other with the SEAS removed as for the tests versus the small passenger car described above [Figure 30].

		Heavy Duty Pickup with SEAS	Heavy Duty Pickup without SEAS
Vehicle Configuration	Mass (kg)	3185.6	3184.6
	Impact velocity (kph)	57.47	57.39
	Ride Height (mm) (Left / Right)	Front 995 / 995 Rear 1018 / 1020	Front 994 / 999 Rear 1017 / 1025
Height of the first row of Load Cell Wall		330 mm	330 mm

Figure 30: Test configuration for FWDB tests with Heavy Duty Pickup.

The total LCW force should ideally be the same. However, the LCW force profiles are different, which indicates a different collapse mechanism of the structure [Figure 31]. In the case where SEAS are present, LCW cells around those structures will record more load as compared to the case without SEAS.

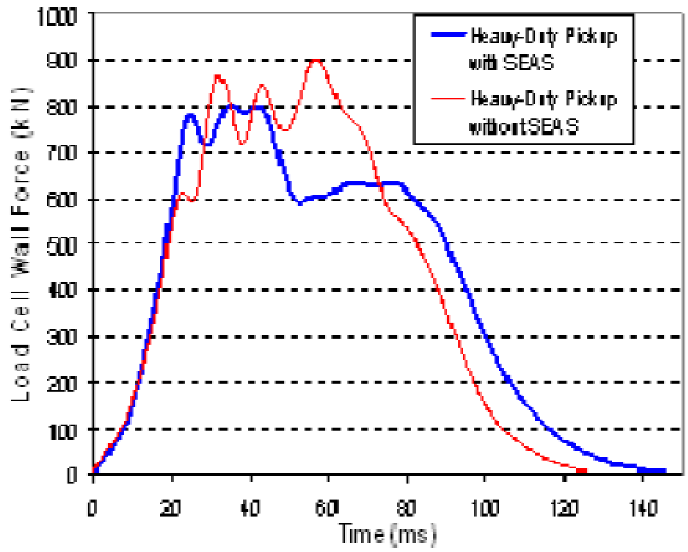

Figure 31: Time history plots for total barrier force in FWDB tests of heavy duty pickups with and without SEAS.

The LCW force distributions for the standard and raised pickups are shown in Figure 32 and Figure 33 respectively.

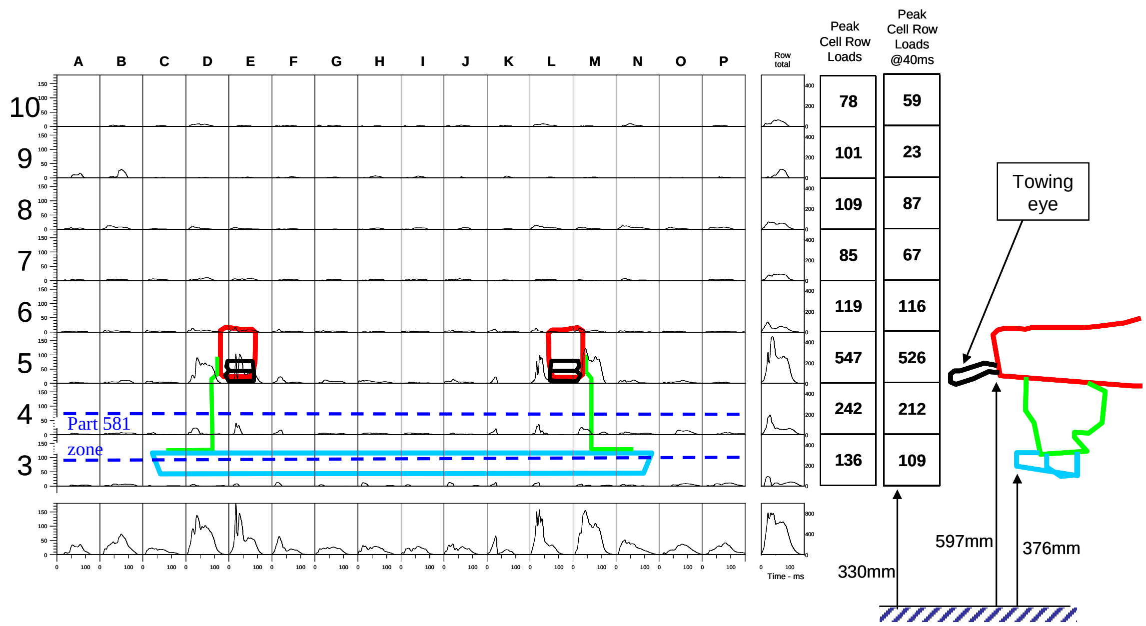

Figure 32: Standard heavy duty pickup with SEAS: Load (scale 0 –180kN) / time (scale 0-150ms) curves for complete load cell wall. Alignment of vehicle at impact, row loads, column loads and sum of peak cell loads in row for whole impact and up to 40 ms also shown. Part 581 Zone marked with blue dashed lines.

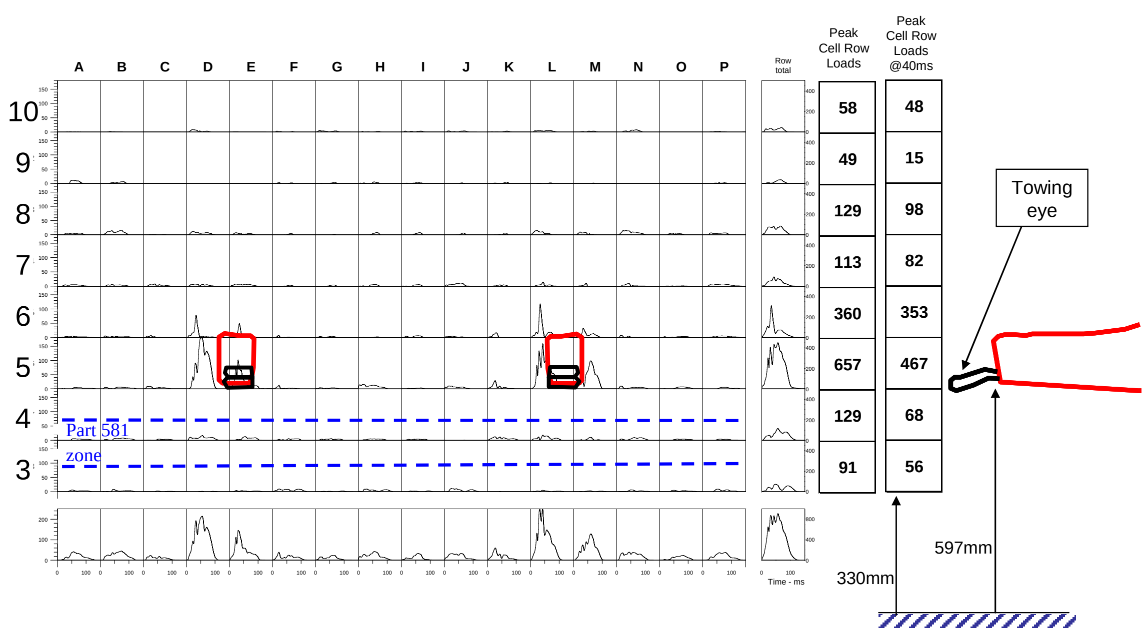

Figure 33: Modified heavy duty pickup with SEAS removed: Load (scale 0 –180kN) / time (scale 0-150ms) curves for complete load cell wall. Alignment of vehicle at impact, row loads, column loads and sum of peak cell loads in row for whole impact and up to 40 ms also shown. Part 581 Zone marked with blue dashed lines.

Examination of the deformed vehicles and barrier faces [Figure 34] and the LCW force distribution [Figure 32 and Figure 33] showed that the pickup with SEAS applied more load to the lower part of the barrier in alignment with rows 3 and 4 and resulted in less penetration into the deformable face with more load distribution.

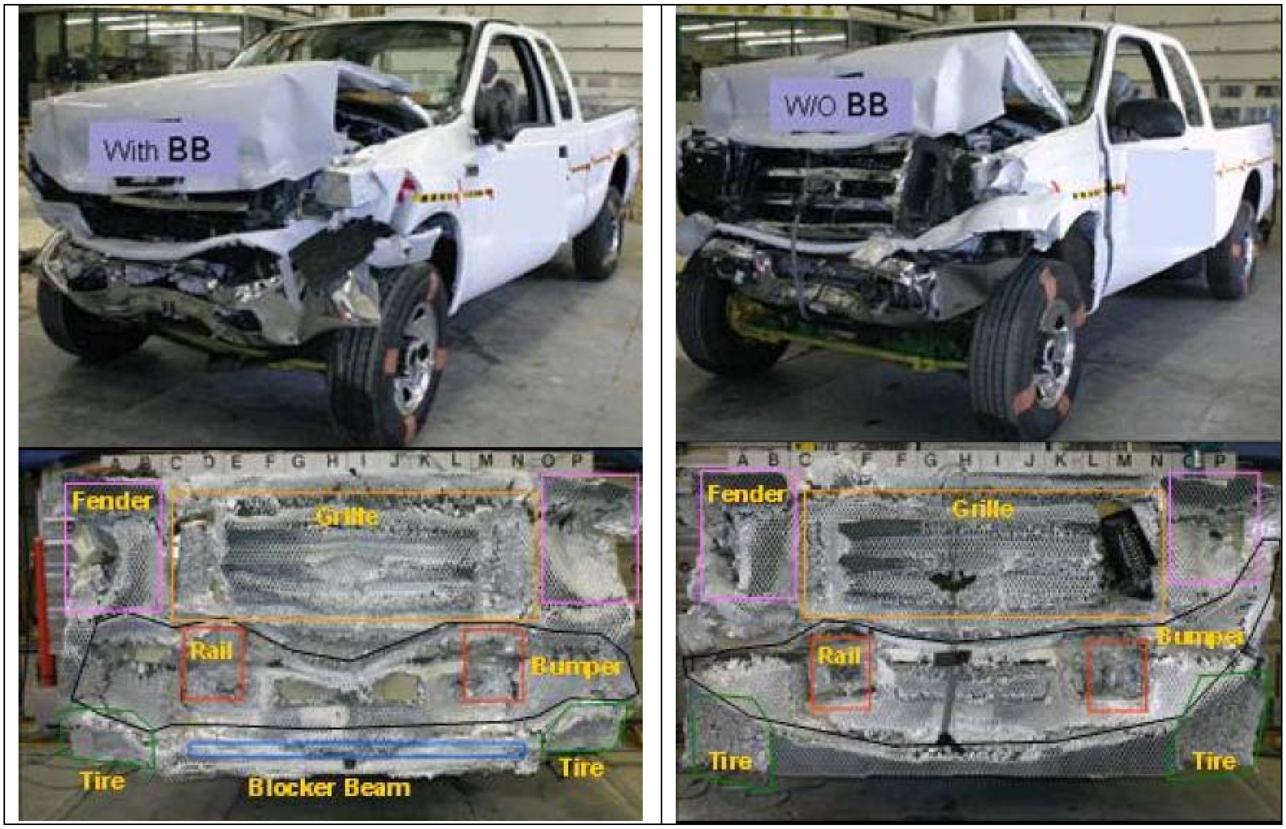

Figure 34: Post impact deformation of heavy duty pickup with SEAS (left) and without SEAS (right) and corresponding barriers.

Figure 35 shows the force time histories for rows 3 and 4 of the LCW for the heavy duty pickup with and without SEAS. It is seen that rows 3 and 4 carry a significantly higher load when the SEAS structure is present. It is also seen that the maximum force level of rows 3 and 4 combined occurs much later (at 55.8 ms as compared to 30.2 ms) without SEAS than with SEAS respectively. From this observation, it is suggested that a compatibility metric should aim to assess forces due to early interaction of energy-absorbing structures rather than those due to engine engagement which occurs later in the event.

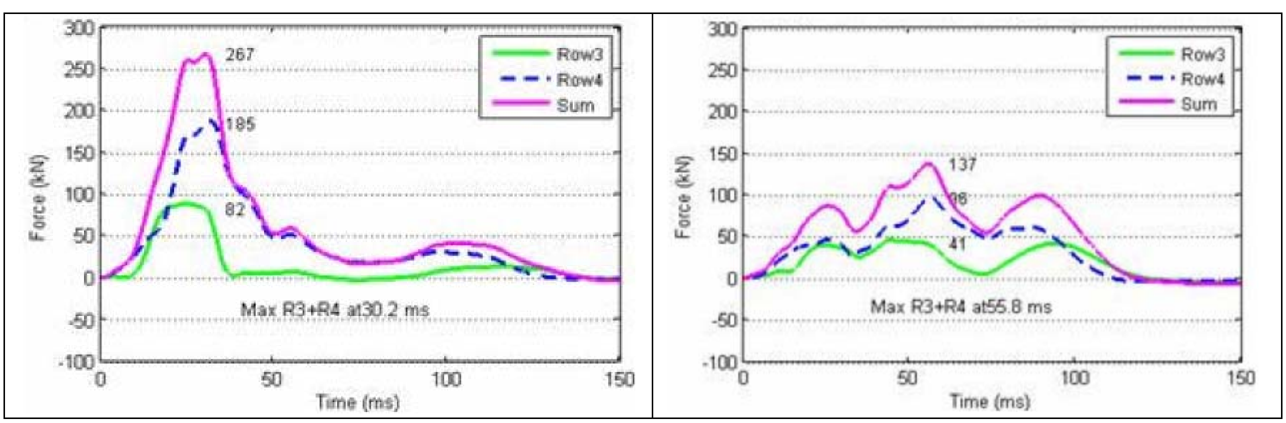

Figure 35: Comparison of Force time histories for LCW rows 3 and 4 for the heavy duty pickup with SEAS (left) and without SEAS (right).

It is also seen that the difference in the total load supported by rows 3 and 4 has a maximum magnitude of 130 kN. This is believed to be the force provided by the SEAS structure.

The total maximum force appearing in a certain row, e.g. row_i, can be characterised using two different methods. Firstly, the force time histories from all load cells within row_i are combined to form a row_i total force time history, whose maximum value for a given time period is taken denoted by ‘Peak load for row_i’. Secondly, the peak loads in each load cell within row_i are first found irrespective of the precise time they occur and then summed, this force is denoted as ‘Sum of Peak Cell Loads for row_i’. In each method described, the values denoted by either ‘Peak Load for row_i’ or “Sum of Peak Cell Loads for row_i’ was also calculated within a 40 ms time window. This leads to four different measures for a row_i force.

Figure 36 indicates that, for the heavy-duty pickup with SEAS, the loads seen in rows 3-6 gradually increase and then decrease in approximately a 100-200-500-100 KN pattern. For the heavy-duty pickup without SEAS, as seen in Figure 34, the loads in rows 3-6 build up gradually and in approximately a 50-50-450-300 KN pattern. A shifting of load from rows 3 and 4 occurs when SEAS are absent since the total barrier load in both cases must remain the same (the impacting vehicle mass and velocity are the same). A noticeable increase occurs in row 5 due to the pickup's frame or PEAS impact at this location. It should be noted that this load increase pattern is the same regardless of the method of calculation (Sum of Peak Loads vs. Peak Row), the only difference being the higher variability when the SEAS is not present. This indicates that the metrics are not likely to be significantly affected by changing the methodology to calculate the row load from ‘Sum of Peak Loads’ to ‘Peak Load’, but it could be more stable.

In the previous section describing the results of the pickup to car tests for this series, the force acting on the pickup’s SEAS structure was calculated from the deceleration of the car [Figure 29]. Using Newton’s law this was calculated to be about 304 kN. Figure 36 shows that the force exerted by the SEAS structure (including attachment brackets) in the FWDB test on the LCW rows 3 and 4, which are in alignment with this structure, were around 100 kN and 200 kN respectively. This adds to a total of about 300 kN which correlates with the load exerted on the pickup’s SEAS in the equivalent vehicle to vehicle test [Figure 37].

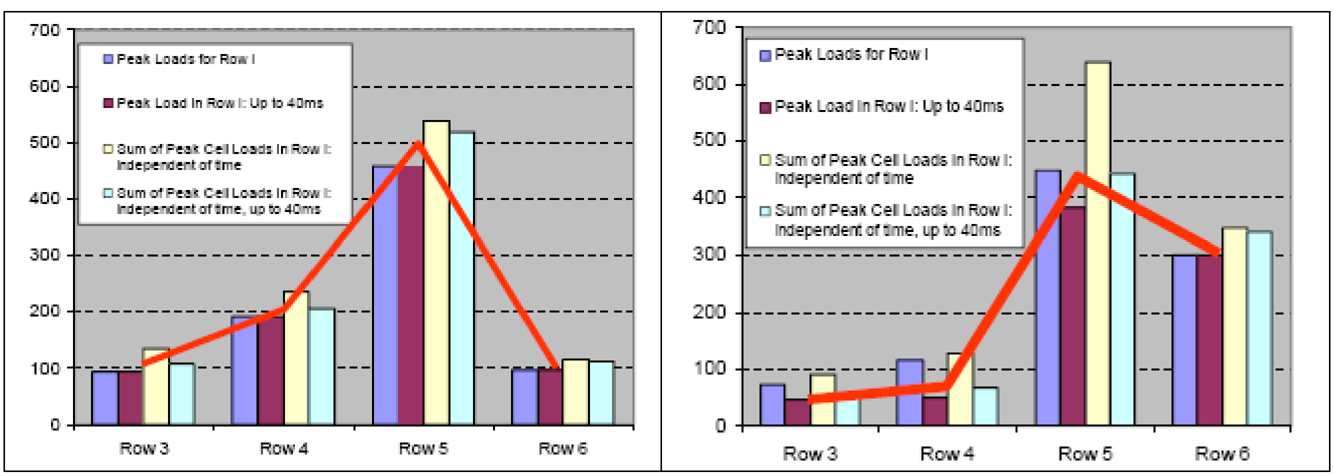

Figure 36: Comparison of peak row load distribution for heavy duty pickup with SEAS (left) and without SEAS (right).

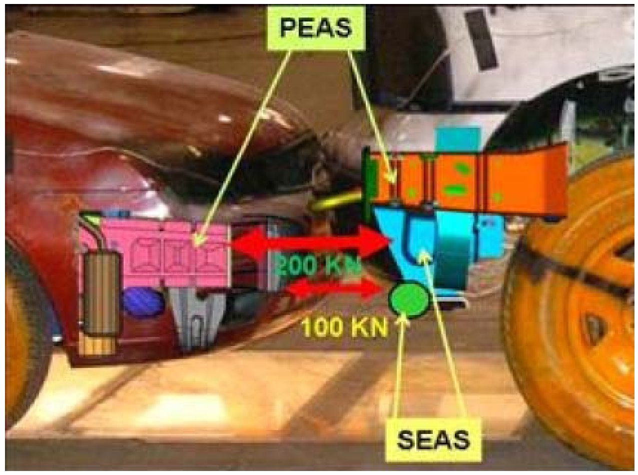

Figure 37: Forces in interaction zone (rows 3 and 4) between target car and bullet HD pickup.

The capability of 3 metrics to assess the differences between the heavy duty pickups with and without SEAS was evaluated. The metrics are described in detail in the 'Background' section but in summary are:

Metric 1

Sum of peak cell loads at any time during crash on rows 3 and 4 with proposed minimum load of 100 kN.

Metric 2

Sum of peak cell loads during first 40 ms of crash on rows 3 and 4 with proposed minimum load of 100 kN.

Metric 3

Average Height of Force (AHOF).

A comparison of the metric 1 and 2 row loads shows that for the heavy duty pickup without SEAS the loads on all rows were > 100 kN for the standard pickup with SEAS and < 100 kN on at least one row for the pickup without SEAS [Figure 38]. However, for Metric 1 the load calculated for the pickup without SEAS is close to 100 kN, indicating that if this metric were used, the suggested performance limit of 100 kN may need to be raised. It should be noted that since in vehicle-to-vehicle impact compatibility is most affected by front-end structural interactions and not those from the engine, a window of 40 ms, i.e. Metric 2, may be preferable.

Heavy Duty Pickup	Metric 1 Sum of peak cell loads (kN)		Metric 2 Sum of peak cell loads up to 40ms (kN)	
	Row 3	**Row 4**	**Row 3**	**Row 4**
Standard	136	242	109	212
No SEAS	91	129	56	68

Figure 38: Comparison of loads on rows 3 and 4 for heavy duty pickup with and without SEAS.

A comparison of the AHOF at the end of the impact shows a lower value for the test in which the SEAS was removed (719 mm cf 743 mm), which was unexpected [Figure 39]. However, comparison of AHOF throughout the impact shows that the AHOF was up to about 6 percent higher for the test in which the SEAS was removed for a B-pillar displacement of about 300 mm to 600 mm.

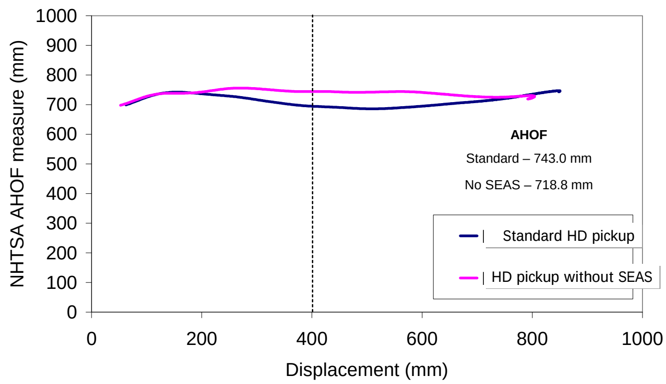

Figure 39: Comparison of AHOF for heavy duty pickup with and without SEAS.

The results of the FWDB tests show that metrics based on the loads on rows in alignment with the Part 581 zone can discriminate the presence of the BlockerBeam® using a minimum row load requirement of about 100 kN.

In summary:

- Metrics based on peak cell loads on rows in alignment with the Part 581 zone (rows 3 and 4) with an example requirement of 100 kN discriminated between the heavy duty pickup with SEAS and without SEAS. If focus on front-end structural interactions and not those from the engine is required, a window of 40 ms, i.e. metric 2, may be preferable.
- The Average Height of Force (AHOF) metric at the end of impact showed a lower value for the test in which the SEAS was removed (719 mm cf 743 mm) which was unexpected. However, at some points throughout the impact (B-pillar displacement 300 mm to 600 mm) AHOF was up to about 6 percent higher for the test in which the SEAS was removed.
- During the first 40 ms in vehicle-to-vehicle impact when the bullet vehicle has SEAS, approximately 304KN of force acts on the vehicles in the interaction zone. This force level was correlated to that observed in the interaction zone (rows 3 and 4) in the FWDB test impacted by the heavy-duty pickup with SEAS.
- LCW results showed that the heavy duty pickup with SEAS helped in transferring dynamic force to lower portions (rows 3 and 4) of the LCW. Results obtained from pickup impacts with and without SEAS identified a difference in total load supported by rows 3 and 4 of 130 kN. This force may be attributed to the SEAS structure.

5.2.3 Summary of Observations

- The presence of the SEAS on the heavy duty pickup increased the interaction with the PEAS of the target car. This resulted in greater deformation of the PEAS and a reduction of the overall deformations and intrusions in the target vehicle's occupant compartment.

- Metrics based on peak cell loads on rows in alignment with the Part 581 zone (rows 3 and 4) with an example requirement of 100 kN discriminated between the heavy duty pickup with SEAS and without SEAS. If focus on front-end structural interactions and not those from the engine is required, a window of 40 ms, i.e. metric 2, may be preferable.
- The Average Height of Force (AHOF) metric at the end of impact showed a lower value for the test in which the SEAS was removed (719 mm cf 743 mm), which did not correlate with the better performance of the heavy duty pickup with SEAS seen in the LTV vs car tests. However, at some points throughout the impact (B-pillar displacement 300 mm to 600 mm) AHOF was up to about 6 percent higher for the test in which the SEAS was removed.
- During the first 40 ms in vehicle-to-vehicle impact when the bullet vehicle has SEAS, approximately 304KN of force acts on the vehicles in the interaction zone. This force level was correlated to that observed in the interaction zone (rows 3 and 4) in the FWDB test impacted by the heavy-duty pickup with SEAS.
- Finally, the LCW with deformable face investigated in this test series has a potential to be used to assess the removal of SEAS from this vehicle.

5.3 Simulation Series – Subframe type SEAS

The aim of the series was to understand the effect of a subframe type SEAS in an LTV-to-car collision and evaluate the ability of the FWDB test and associated metrics to detect this change. Two sets of simulations were performed. The first set investigated the effect of adding a subframe type SEAS to an ‘option 1 non-compliant’ SUV. The second set of simulations investigated the effect of adding a sub-frame type SEAS to an already ‘option 1 compliant’ LTV.

5.3.1 Set 1 – addition of subframe type SEAS to ‘option 1’ non-compliant SUV

Two SUV vs car simulations were conducted with raised SUVs; one being an SUV with an elongated subframe type SEAS and the other one without SEAS. Both the SUVs were raised in the simulation by 125 mm above the standard height so that the vehicle with SEAS conformed to the ‘option 2’ criteria and the vehicle without SEAS did not conform. In the SUV vs car simulations, the car’s PEAS showed significant overlap with the elongated subframe, but not so for the SUV without the elongated SEAS [Figure 40 and Figure 41].

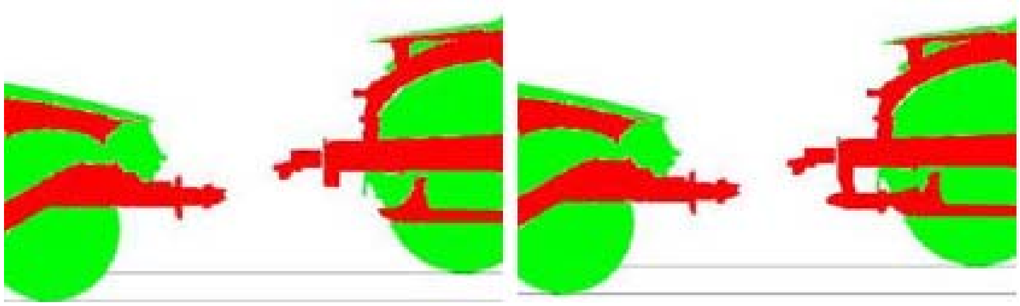

Figure 40: Alignment of raised SUV (left) and raised SUV with elongated subframe SEAS with car.

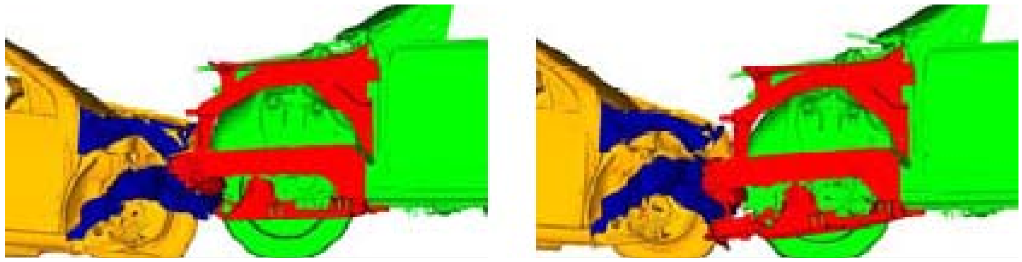

Figure 41: SUV vs car simulation at 75 ms showing increased structural interaction of raised SUV with elongated subframe SEAS (right).

The cars' compartment intrusions in the simulated impacts were all less than 5 cm [Figure 42]. A comparison of the results shows that the raised SUV with SEAS (option 2 compliant) caused approximately 14 percent less intrusion in the car than the raised SUV without the SEAS (option 2 non-compliant).

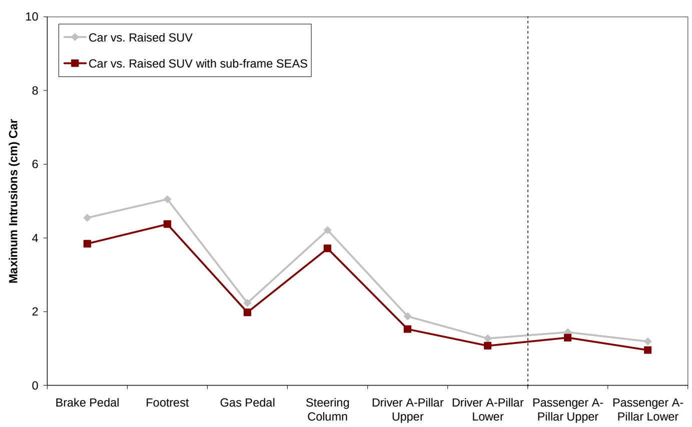

Figure 42: Car compartment intrusions in raised 'option 1' non-compliant SUV impacts.

However, the cars' compartment decelerations showed little difference except the peak acceleration occurred a little earlier for the SUV with subframe SEAS indicating greater structural engagement [Figure 43].

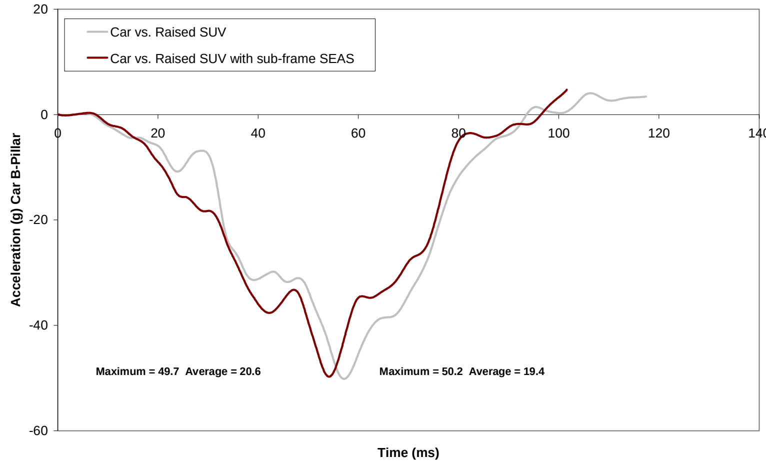

Figure 43: Car compartment decelerations in raised 'option 1' non-compliant SUV impacts.

The FWDB LCW results for Metric 1 and 2 are shown in Figure 44. The addition of the subframe SEAS increases the loading of row 3 to meet the 100 kN example requirement.

		Metric 1 Sum peak cell loads (kN)		**Metric 2** Sum peak cell loads up to 40 ms (kN)	
		Row 3	**Row 4**	**Row 3**	**Row 4**
Raised SUV	**Without SEAS**	75	154	38	130
	With sub-frame SEAS	237	248	135	150

Figure 44: Comparison of peak cell loads on rows 3 an 4 for raised SUV with and without subframe SEAS.

The AHOF at the end of impact showed a 9 percent difference (737 mm cf 667 mm) between the raised SUV and the raised SUV with a subframe SEAS. However, a plot of the AHOF against B-pillar displacement shows that the difference in AHOF is much less towards the beginning of the impact (about 3 percent at 200 mm B-pillar displacement) [Figure 45].

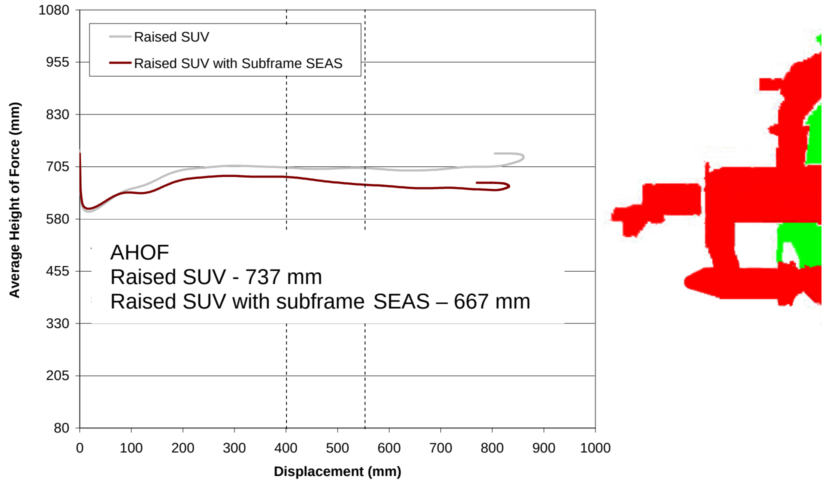

Figure 45: Comparison of AHOF vs B-pillar displacement for raised SUV with and without subframe SEAS.

5.3.2 Set 2 – addition of subframe type SEAS to 'option 1' compliant SUV

Similar simulations to the ones described in the section above were performed for SUVs at the standard ride height to investigate the effect of adding a sub-frame type SEAS to an already 'option 1 compliant' SUV [Figure 46]. The car compartment intrusions were less than 6 cm in impacts with both SUVs. The addition of a subframe increased the intrusions by an average of 51 percent. A similar trend was seen in the car's peak and average decelerations where the SUV with subframe causes higher values [Figure 47].

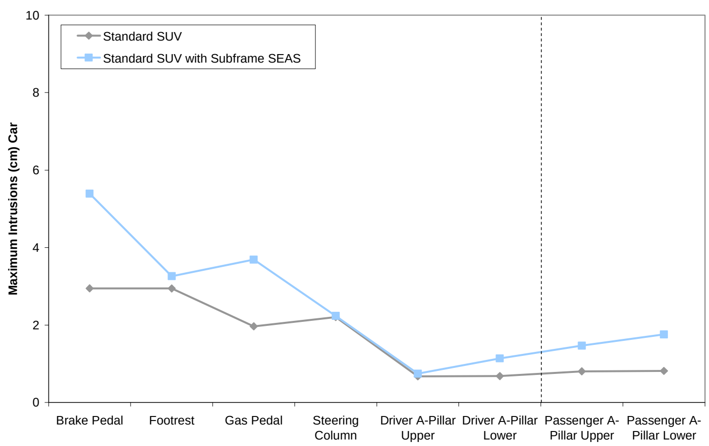

Figure 46: Car compartment intrusions in standard 'option 1' compliant SUV impacts.

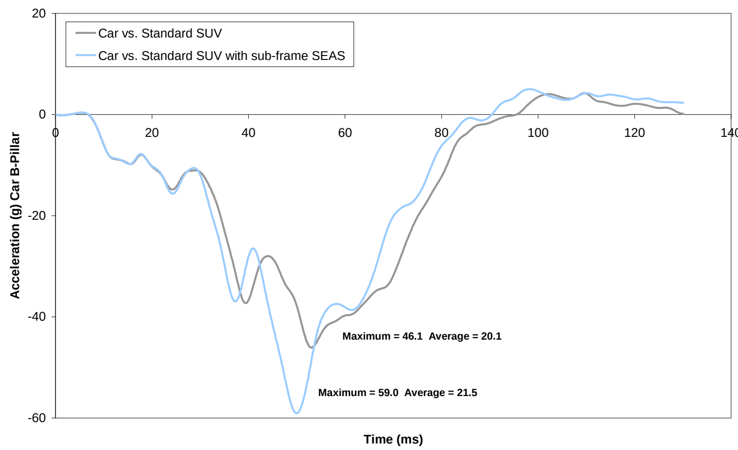

Figure 47: Car compartment decelerations in standard 'option 1' compliant SUV impacts.

For the FWDB tests, a comparison of the metric 1 and 2 row loads show that both configurations of the standard SUVs meet the 100 kN requirement for both rows 3 and 4 [Figure 48]. Hence, these metrics would not encourage the addition of SEAS to the baseline SUV.

		Metric 1 Sum peak cell loads (kN)		**Metric 2** Sum peak cell loads up to 40 ms (kN)	
		Row 3	**Row 4**	**Row 3**	**Row 4**
Standard SUV	**Without SEAS**	154	450	130	372
	With sub-frame SEAS	248	490	150	411

Figure 48: Comparison of peak cell loads on rows 3 an 4 for standard SUV with and without subframe SEAS.

The AHOF at the end of impact showed a 13 percent difference (612 mm cf 533 mm) between the standard SUV and the standard SUV with a subframe SEAS [Figure 49]. NHTSA have not yet given a firm indication that if they were to use the AHOF metric what the performance requirements would be. However, if a requirement for AHOF to be within the Part 581 zone was set (406 mm to 508 mm), this metric would encourage the addition of SEAS to the baseline SUV which could make it more aggressive in car impacts. Also, it should be noted that none of the other 'Option 1' compliant vehicles investigated in these test series would meet such a requirement either.

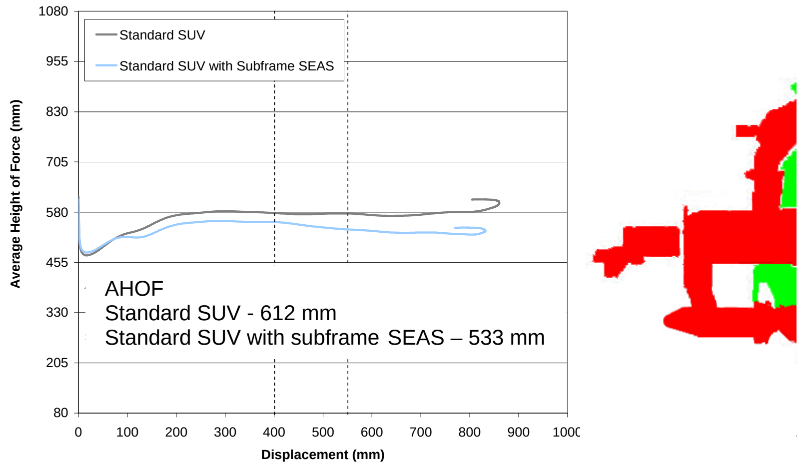

Figure 49: Comparison of AHOF vs B-pillar displacement for standard 'option 1 compliant' SUV with and without subframe SEAS.

5.3.3 Summary of Observations

- Metrics based on peak cell loads on rows in alignment with the Part 581 zone (rows 3 and 4) with an example requirement of 100 kN detected the addition of a subframe type SEAS to an 'option 1' non-compliant SUV. This correlated to reduced intrusion measures seen in the SUV vs car simulations.

- AHOF measured at the end of impact showed a difference of about 9 percent (737 mm cf 667 mm) between the raised SUV and the raised SUV with a subframe SEAS. However, this difference was not consistent throughout the impact and much less towards the beginning of the impact (about 3 percent at 200 mm B-pillar displacement).

- Addition of subframe SEAS to 'option 1' compliant SUV resulted in increased intrusion and deceleration to the car in the SUV vs. car simulation. This may indicate need to integrate SEAS design with overall front end design taking into account the global stiffness of the front end.

6 Summary of Observations

In each test series the vehicle that met the example requirement of 100 kN for metric 1 and 2 had greater structural engagement than the vehicle that did not meet the example requirement.

The LCW with deformable face investigated in these test series has a potential to be used to assess vehicle to vehicle interaction performance in full overlap front to front impacts based on the results of these test series which show that it was able to detect a 10 cm change in vehicle height and to assess the presence of SEAS in the vehicles studied.

<u>Test series 1: height of PEAS</u>

- The pickup vs car tests showed that alignment of the pickup's PEAS with the CFR49 Part 581 zone resulted in increased structural engagement with the test car's PEAS. This caused a SRS deployment more similar to that in a flat barrier test and reduced most ATD measures, although compartment intrusions remained similar.
- Metrics based on peak cell loads on rows in alignment with the Part 581 zone (rows 3 and 4) with an example requirement of 100 kN discriminated the change (~ 10 cm) in height of the pickup's PEAS.
- The Average Height of Force (AHOF) metric measured at the end of the impact (549 mm cf 639 mm) also detected this change and detected it within 20 percent throughout the impact.

<u>Test series 2: BlockerBeam® type SEAS</u>

- The presence of the SEAS on the heavy duty pickup increased the interaction with the PEAS of the target car. This resulted in greater deformation of the PEAS and a reduction of the overall deformations and intrusions in the target vehicle's occupant compartment.
- The FWDB tests showed that metrics based on peak cell loads on rows in alignment with the Part 581 zone (rows 3 and 4) with an example requirement of 100 kN, discriminated between the heavy duty pickup with SEAS and without SEAS.
- The Average Height of Force (AHOF) metric at the end of impact showed a lower value for the test in which the SEAS was removed (719 mm cf 743 mm), which did not correlate with the better performance of the heavy duty pickup with SEAS seen in the LTV vs car tests. However, at some points throughout the impact (B-pillar displacement 300 mm to 600 mm) AHOF was up to about 6 percent higher for the test in which the SEAS was removed.
- During the first 40 ms in vehicle-to-vehicle impact when the bullet vehicle has SEAS, approximately 304KN of force acts on the vehicles in the interaction zone. This force level was correlated to that observed in the interaction zone (rows 3 and 4) in the FWDB test impacted by the heavy-duty pickup with SEAS.

<u>Simulation series: subframe type SEAS</u>

- The FWDB simulations showed that metrics based on peak cell loads on rows in alignment with the Part 581 zone (rows 3 and 4) with an example requirement of 100 kN detected the addition of a subframe type SEAS to an 'option 1' non-compliant SUV. This correlated to reduced intrusion measures seen in SUV vs car simulations.

- AHOF measured at the end of impact showed a difference of about 9 percent (737 mm cf 667 mm) between the raised SUV and the raised SUV with a subframe SEAS. However, this difference was not consistent throughout the impact and much less towards the beginning of the impact (about 3 percent at 200 mm B-pillar displacement).

- Addition of subframe SEAS to ‘option 1’ compliant SUV resulted in increased intrusion and deceleration in the SUV vs. car simulation. This may indicate need to integrate SEAS design with overall front end design taking into account the global stiffness of the front end.

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