PDB BARRIER FACE EVALUATION BY DSCR AND NHTSA'S JOINT RESEARCH PROGRAM

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ABSTRACT

Vehicle compatibility combines aspects of both self and partner protection. Self protection involves a vehicle's compartment strength and occupant protection systems. Partner protection involves vehicle design attributes that work towards providing occupant crash protection of a vehicle's collision partner. Research has suggested that crush force matching (or good engagement of the front structures) and high compartment strength are essential components for improving compatibility between passenger cars and other vehicles [1]. However, recent trends have shown that incompatible force distributions and greater relative front end stiffness are prevalent in the fleet. To research this issue, the Progressive Deformable Barrier (PDB) face was evaluated for its ability to assess the compatibility between the front end force of heavier vehicles with the compartment strength of lighter ones.

The paper investigates the feasibility of a high energy absorption PDB in full frontal and offset frontal crash test configurations. A joint research program was carried out at the Union Technique de l'Automobile du Motocycle et du Cycle (UTAC) in conjunction with the Directorate for Road Traffic and Safety (DSCR) in France and the National Highway Traffic Safety Administration (NHTSA) of the United States (U.S.) to investigate whether barrier deformation using the PDB could differentiate compatibility performances between two different U.S. light trucks and vans (LTVs).

INTRODUCTION

Safety researchers around the world, including the U.S. and France, have been concerned with vehicle compatibility in crashes for many years. NHTSA has conducted studies on vehicle aggressiveness (injury risk vehicles pose to drivers of other vehicles with which they collide) and methods for measuring it for over 25 years [2]. Examination of U.S. crash statistics shows a disparity in fatality risk for passenger car occupants in vehicle-to-vehicle collisions with LTVs. Past studies have shown that LTVs, as a class, were found to be twice as aggressive toward their collision partners as passenger cars [2]. This mismatch in crash performance has considerable consequences for the traffic safety environment, as approximately half of all passenger vehicles sold in the U.S. are LTVs.

While LTVs are not nearly as prevalent in Europe, vehicle compatibility has been a growing concern for its countries as well. Researchers have observed that European vehicles have been generally produced with greater mass, stiffer front ends and higher compartment strengths to provide occupant crash protection in fixed offset barrier crash tests [1]. However, as vehicles get heavier and stiffer, the deformable barriers used for the evaluation of frontal offset crash protection begin bottoming out. As a consequence, the test becomes more severe for the stiffer, heavier vehicles, and they become more incompatible with smaller collision partners.

In 1996, European Enhanced Vehicle-Safety Committee Working Group 15 on vehicle compatibility was established in order to explore methodologies to assess vehicle compatibility, and develop test procedures to address it. In March 2002, vehicle compatibility was included as an area of focus for the exchange of information in the program of work adopted under the World Forum for the Harmonization of Vehicle Regulations (WP.29) 1998 Global Agreement. Both the U.S. and France are signatories to that agreement, and have been concurrently active participants in international research collaborations, such as the International Harmonized Research Activities on vehicle compatibility [3].

In 2004, NHTSA and the DSCR signed a bilateral agreement to enhance cooperation and increase the efficient use of resources. One form of this cooperation includes conducting joint analyses to promote the development of improved vehicle safety programs and related regulations. The two parties decided that one area of focus would relate to issues of vehicle compatibility. A joint research program was initiated to investigate the use of a PDB in discerning levels of partner and self protection of heavy passenger vehicles in full width and offset test configurations. Based on its own research program on vehicle compatibility, NHTSA identified two sets of LTVs with differing levels of aggressiveness for the PDB study [4]. UTAC was selected as the site location for conducting the tests.

DSCR has been researching the PDB test procedure approach for over 8 years as a means to address vehicle compatibility [1]. The PDB progressively increases in stiffness in depth and upper and lower load levels, which contributes to its name, PDB, as a Progressive Deformable Barrier. Its characteristics were designed to represent an actual vehicle structure with sufficient force level and energy absorption capacity to mitigate any occurrences of bottoming out. In doing so, the PDB may be able to better harmonize test severity among vehicles of different masses. The approach aims to encourage lighter vehicles to be stronger without increasing the force levels of large vehicles [1]. By its design, the PDB is also able to detect all frontal structures involved in a crash (i.e. cross members, subframes, blocker beams, and longitudinal frame rails). By detecting the impact deformations, the test procedure can encourage vehicle designs to incorporate structures that distribute homogeneous force levels over large surfaces.

METHOD OF TEST EVALUATION

Test Severity

One approach toward evaluating both self protection and partner protection is to normalize the test severity for all vehicles, large and small by using the PDB. The test velocity alone is not a good indication of the severity of the event because, unlike a rigid barrier test, a portion of the test energy is absorbed by the deformable element of the barrier. The energy absorbed by the barrier is a factor of the vehicle's mass, design and stiffness. Therefore, the parameter used to equate the test severity for different vehicles at a common speed using the PDB is the Energy Equivalent Speed (EES).

$$EES(km/h) = 3.6 \times \sqrt{\frac{2 \times Eabs}{M}}$$

Eabs = energy absorbed by the vehicle (J)
Eabs = Kinetic energy – Energy in the barrier
M = mass of the vehicle (kg)

$$Ebarrier = \int_{x_{min}}^{x_{max}} F dx \qquad F = P * S$$

P = barrier stiffness (MPa) S = crushed surface (m^2)

Self protection

The concept of self protection is the ability to protect the occupants within the striking vehicle in a vehicle-to-vehicle crash. Many of the crashworthiness regulations around the world are directed toward evaluating a vehicle's "self protection," or how the vehicle protects its own occupants. To achieve good self protection, front end design must limit intrusion and acceleration levels in the passenger compartment as well as limit occupant injury criteria. The following parameters were measured to evaluate the level of self protection the vehicles offered:

- Compartment intrusion
- Dummy injury criteria
- Vehicle acceleration

Partner protection

The concept of partner protection involves vehicle design attributes that function to maximize protection of the occupants within the collision partner (struck) vehicle. In order to take advantage of the potential energy absorption of a vehicle front end in a vehicle-to-vehicle crash, good engagement of the vehicle structures must occur. To achieve this result, the deformation of the front end must be distributed over a large surface. In this study, barrier digitization is used to examine the different barrier engagement patterns. The study also compares the following parameters that have been identified in previous research as influential in the evaluation of partner protection [5]:

- Average Height of Deformation (AHOD): height at which the median deformation occurs, (evaluates the frontal geometry of a vehicle)
- Average Depth of Deformation (ADOD): average deformation over the barrier, (evaluates the frontal stiffness of a vehicle)
- Maximum Deformation (Dmax)

<u>Calculation method</u>:

- Average Height of Deformation (AHOD):

For a given rectangular investigation region, the "depth profile" is computed as a function of height.

$$\rho(z) = k \int_{y_{min}}^{y_{max}} X(y,z) dy$$

Where k is a normalization constant ensuring that:

$$\int \rho(z)dz = 1$$

The AHOD is then obtained as a mean value:

$$AHOD = \int z\rho(z)dz$$

- Average Depth of Deformation (ADOD):

For a given investigation region with an area S:

$$ADOD = \frac{1}{S}\int X(y,z)dydz$$

TEST CONFIGURATION

PDB+ Offset Test configuration

	PDB+ Offset	
	Barrier	PDB + 50%
	Speed	60km/h
	Overlap	50%
	Dummies	H3 50% male H3 5% female + Leg Lx

Figure 1: Vehicle in front of the offset PDB

This test procedure is based on the current PDB test protocol (Figure 2) [6]. The only difference is in the barrier construction itself. In order to avoid bottoming out the barrier with large and heavy LTVs, a layer of 90 mm honeycomb at 1.71 MPa was added to the back of the barrier (Figure 2). The stiffness of other barrier parts were similar to the current PDB. For the purposes of this study, this modified barrier, with a rear layer, is called "PDB+."

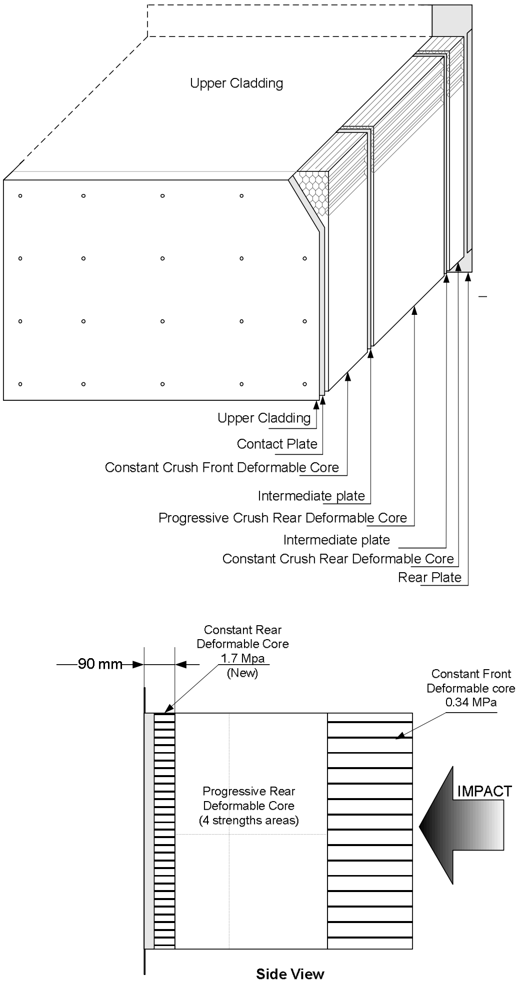


Figure 2 : PDB + barrier specification.

PDB+ Full Width test configuration

	PDB+ Full Width	
	Barrier	PDB + 100%
	Speed	60km/h
	Overlap	100%
	Dummies	H3 50% male H3 5% female + Leg Lx

Figure 3: Vehicle in front of the full width PDB

The "full width" test configuration used a full width PDB+ (Figure 4). This barrier was built as a standard PDB, considering stiffness and layers, but it is 2 meters wide instead of 1 meter. This barrier was also built with a rear layer of 90 mm of honeycomb at 1.71 MPa. The test speed was fixed at 60 km/h to ensure that the test would be sufficiently severe for LTVs and the results could be compared with previous offset PDB tests [1] and full width rigid wall tests.

Figure 4: Full width PDB+

A belted Hybrid III 50th percentile male dummy was in the driver position and a belted Hybrid III 5th percentile female dummy was seated in the right front passenger position. Both dummies were instrumented with lower leg instrumentation.

VEHICLE SELECTION

To evaluate the performance of the PDB+, the 2003 Chevrolet Silverado pickup truck (Figure 5 and Figure 6) and the 2005 Chrysler Town & Country minivan (Figure 7 and Figure 8) were selected for this study based upon their design, construction geometry, test weight, frontal stiffness and force matching height, collected as part of the United States New Car Assessment Program (USNCAP). In this test program, vehicles equipped with belted 50th percentile male dummies are impacted into a rigid barrier at 56 km/h, and load cell data is collected from the test.

The intent of the vehicle selection was to identify those that had similar force matching heights during impact, but also had a difference in frontal structural stiffness, which could represent two incompatible vehicles. The Silverado and Town & Country vehicles also represent two distinct vehicle design approaches. The Silverado used a separate body on frame construction whereas the Town & Country was built with a unibody structure. From USNCAP test data, it was determined that the average height of the force when impacting an instrumented rigid barrier was similar for both the Silverado and the Town & Country. However, the Silverado's front structure was estimated to be over 40 percent stiffer. Since the vehicles had similar force matching heights, they were identified as good candidates to evaluate how the PDB discriminates not only different front structural stiffness, but also differing frame construction. Figure 6 and Figure 8 provide details on the mass, width, and structure.

Figure 5: Silverado

Silverado	
Test Mass	2293 kg
Width	1994 mm
Structure	Body on frame

Figure 6: Silverado Specifications

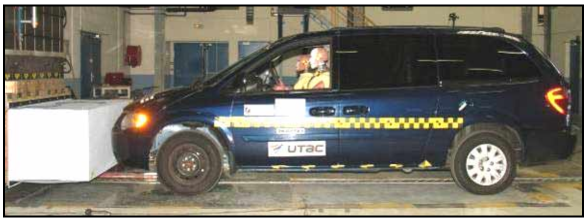


Figure 7*: Town & Country*

Town & Country	
Test Mass	1950 kg
Width	1920 mm
Structure	Unibody

Figure 8: Town & Country Specifications

TEST RESULTS

Four tests were performed according to the matrix below (Figure 9). The following sections describe the test results based on test severity, self protection and partner protection.

Test Matrix		
	50% Offset PDB+	**Full Width PDB+**
Silverado	√	√
Town & Country	√	√

Figure 9: Test Matrix

PDB+ Offset test

Town & Country

Test severity

The amount of energy absorbed in the offset PDB+ was 73 kJ for the Town & Country test. The calculated EES for this test is 51 km/h, which is 9 km/h less than the test speed.

Self protection

In terms of self protection, the Town & Country maintained its occupant compartment integrity (Figure 10). The front end crushed uniformly without any undeformed load paths.

Figure 10: Town & Country PDB+ offset

The injury measures for the 50th percentile male driver and 5th percentile female passenger are reported in Figure 11.

	Driver	Pass.
HIC36	450	295
HIC15	265	217
Chest Def (mm)	36	29
Chest Gs	47	42
Left Femur (kN)	1.98	1.57
Right Femur (kN)	1.56	0.17
UL Tibia Index	0.559	0.112
UR Tibia Index	0.337	0.390
LL Tibia Index	0.237	0.250
LR Tibia Index	0.296	---

Figure 11: Town & Country PDB+ offset – Dummy Injury Measures

None of the occupant injury measures were elevated in this test. Intrusion measures in this test (Figure 12) were low, except for the footwell area on the driver's side. However, the dummy lower leg injury measures were not significantly affected.

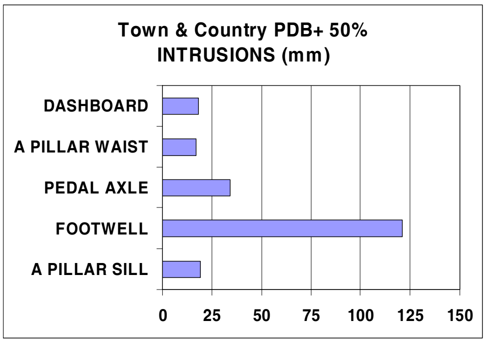


Figure 12: Town & Country PDB+ Offset – Driver side intrusions

The maximum acceleration measured was 31 g at 93 ms, corresponding to 1.023 m of displacement (Figure 13). The average acceleration was 17.6 g.

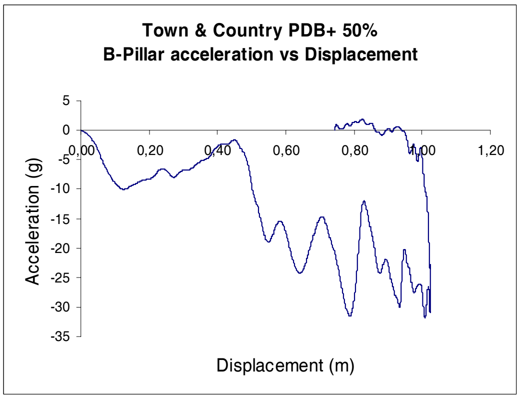


Figure 13: T&C PDB+ offset – Acceleration pulse

Partner protection

In the PDB+ offset test, the forces generated by the longitudinal and lower load paths of the Town & Country are distributed, resulting in homogeneous deformation (Figure 14 and Figure 15). There was good engagement between the front of the vehicle and the barrier. No bottoming out of the barrier was observed.

Figure 14: Town & Country PDB+ offset – front end deformation

Figure 15: Town & Country PDB+ offset – barrier deformation

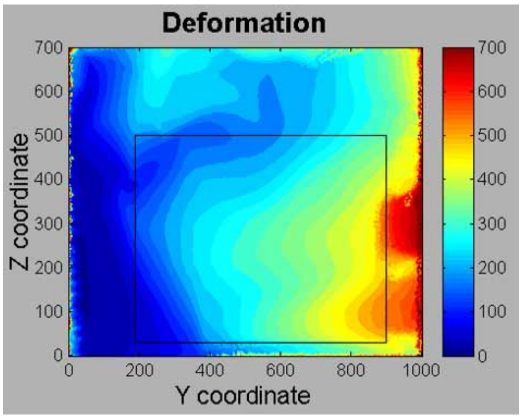


Figure 16: Town & Country PDB+ offset – barrier digitization

In Figure 16, the barrier was able to detect the lower load path of the vehicle. The calculated parameters based on barrier digitization analysis are presented in Figure 17. The energy absorbed in the barrier is 73 kJ which represent 27% of the total kinetic energy.

Partner protection	
ADOD (X)	275 mm
AHOD (Z)	404 mm
Dmax	570 mm

Figure 17: Partner Protection Parameters for the Town & Country PDB+ offset test

Silverado

Test severity

The amount of energy absorbed in the offset PDB+ was 85 kJ for the Silverado test. The calculated EES for this test is 51 km/h, which is 9 km/h less than the test speed.

Self protection

In terms of self protection, the Silverado resulted in significant deformation of the roof and sill between the A- and B-Pillar in the PDB+ offset test. The rear door of the extended cab even exhibited structural deformation (Figure 18).

Figure 18: Silverado PDB+ offset

The injury measures for the 50^{th} percentile male driver and 5^{th} percentile female passenger are reported in Figure 19. The head and chest injury measures of the dummies were relatively low; however, some of the driver leg injury measures were elevated.

	Driver	Pass.
HIC36	505	358
HIC15	285	201
Chest Def (mm)	28	15
Chest Gs	40	35
Left Femur (kN)	5.54	3.20
Right Femur (kN)	6.12	2.62
UL Tibia Index	**0.987**	0.419
UR Tibia Index	**0.929**	0.446
LL Tibia Index	0.668	0.475
LR Tibia Index	0.671	0.237

Figure 19: Silverado PDB+ offset Dummy Injury Measures

This is consistent with the high intrusion levels exhibited in the footwell area (Figure 20).

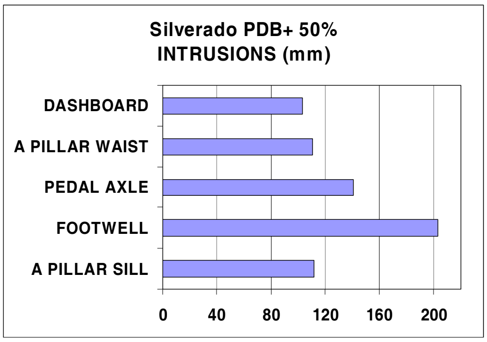


Figure 20: Silverado PDB+ Offset – Driver side intrusions

The maximum acceleration measured is 36 g at 88 ms, corresponding to 1.150 m of displacement (Figure 21). The average acceleration is 14.4 g.

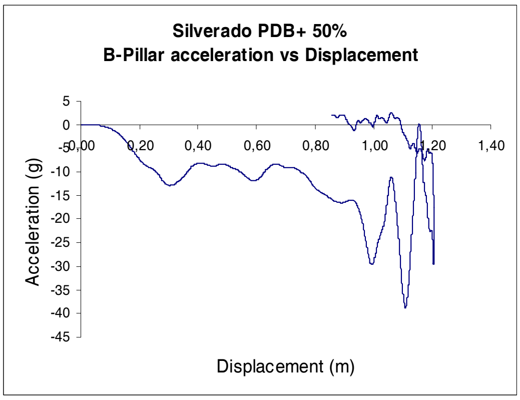


Figure 21: Silverado PDB+ offset – Acceleration

Partner protection

There was good integrity and no bottoming out of the PDB+ after the Silverado test. However, the deformation was largely inhomogeneous since the deformation was localized in front of the longitudinal and connecting beam (Figure 22). The PDB+ was able to detect the unique load path of this vehicle (Figure 23).

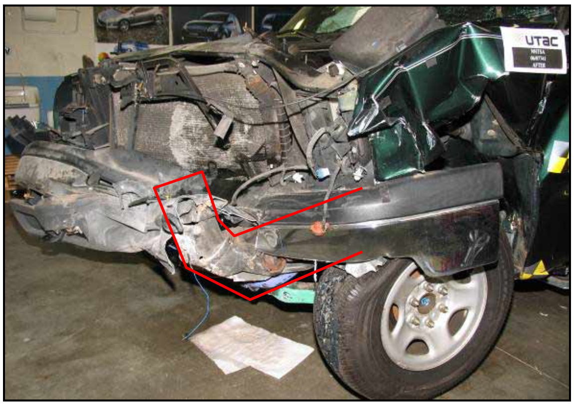


Figure 22: Silverado PDB+ 50% - front end deformation

Figure 23: Silverado PDB+ 50% - barrier deformation

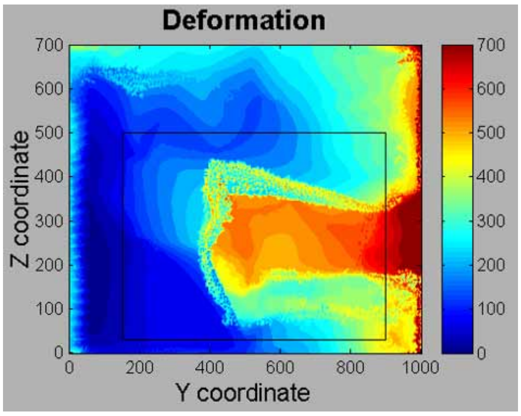


Figure 24: Silverado PDB+ 50% – barrier digitization

The calculated parameters based on barrier digitization analysis (Figure 24) are presented below (Figure 25). The energy absorbed in the barrier was 85 kJ which represents 27% of the total kinetic energy.

Partner protection	
ADOD (X)	289 mm
AHOD (Z)	414 mm
Dmax	654 mm

Figure 25: Partner Protection Parameters for the Silverado PDB+ offset test

PDB+ Full Width test

Town & Country

Test severity

In the PDB+ full width test of the Town & Country, the amount of energy absorbed in the barrier was 33 kJ. The calculated EES for this test was 56 km/h which is 4 km/h less than the test speed, but comparable with the severity of a full frontal rigid barrier test at 56 km/h.

Self protection

The Town & Country minivan exhibited good structural integrity after the full width PDB+ test (Figure 26).

Figure 26: T&C PDB+ Full Width

The injury measures for the 50th percentile male driver and 5th percentile female passenger dummies are reported in Figure 27. Head injury measures for both dummies were low; however, the chest acceleration measurement for the passenger dummy was high.

	Driver	Pass.
HIC36	437	419
HIC15	229	281
Chest Def (mm)	51	30
Chest Gs	49	**57**
Left Femur (kN)	1.68	3.94
Right Femur (kN)	1.67	1.49
UL Tibia Index	0.452	0.526
UR Tibia Index	0.477	0.500
LL Tibia Index	0.371	0.532
LR Tibia Index	0.516	0.338

Figure 27: Town & Country PDB+ full width – Dummy Injury Measures

Intrusions were relatively low, except in the footwell area, where there was more than 125 mm of intrusion (Figure 28).

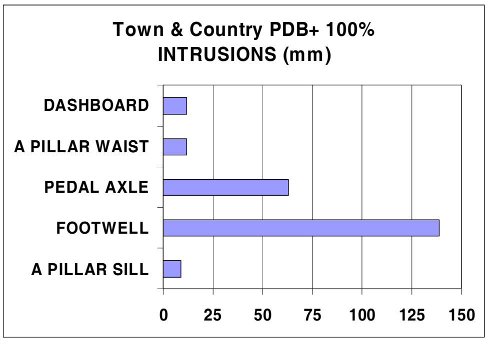


Figure 28: Town & Country PDB+ Full Width – Driver side intrusions

The maximum acceleration measured in the test was 44 g at 60 ms, corresponding to 0.775 m of displacement (Figure 29). The average acceleration was 21.6 g.

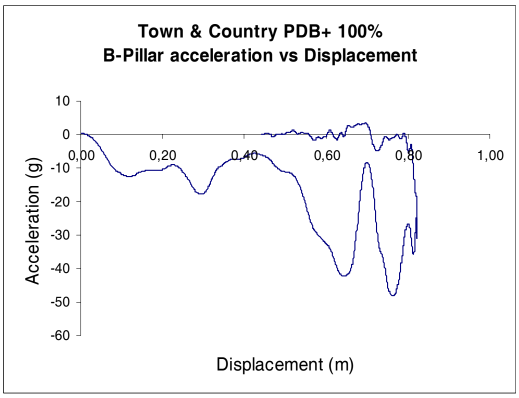


Figure 29: Town & Country PDB+ offset – Acceleration

Partner protection

In the Town & Country full width PDB+ test, there was very good integrity of the barrier and good engagement with the barrier; no bottoming out was observed. The deformation was large and homogeneous. The front end of the vehicle fitted with two levels of load paths, was able to distribute the loads (Figure 30 and Figure 31).

Figure 30: Town & Country PDB+ Full Width - front end deformation

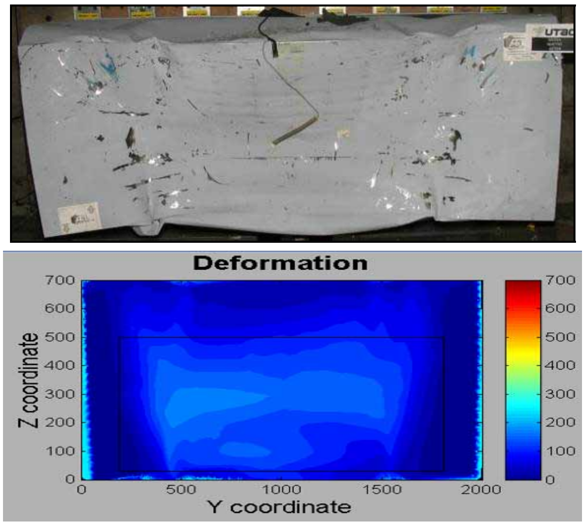


Figure 31: Town & Country PDB+ Full Width - barrier deformation and digitization

The calculated parameters based on barrier digitization analysis (Figure 31) are presented in Figure 32 below. The energy absorbed in the barrier was 33 kJ which represents 12% of the total kinetic energy.

Partner protection	
ADOD (X)	105 mm
AHOD (Z)	425 mm
Dmax	174 mm

Figure 32: Partner Protection Parameters for the Town & Country PDB+ Full Width

Silverado

Test severity

In the PDB+ full width test of the Silverado, the amount of energy absorbed in the barrier was 68 kJ. The calculated EES for this test was 53 km/h which is 7 km/h lower than the test speed and lower than the severity of a full frontal rigid barrier test at 56 km/h.

Self protection

There was good structural integrity of the Silverado after the full width PDB+ test (Figure 33).

Figure 33: Silverado PDB+ Full Width

The injury measures for the 50th percentile male driver and 5th percentile female passenger are reported in Figure 34.

	Driver	Pass.
HIC36	727	**988**
HIC15	410	**787**
Chest Def (mm)	35	23
Chest Gs	43	42
Left Femur (kN)	5.24	3.38
Right Femur (kN)	6.99	5.08
UL Tibia Index	0.605	0.498
UR Tibia Index	0.534	0.463
LL Tibia Index	0.391	0.311
LR Tibia Index	0.454	0.312

Figure 34: Silverado PDB+ Full Width – Dummy Injury Measures

The driver dummy had relatively low injury measures; however, the passenger dummy had high head injury measures. There were low levels of intrusion in the driver compartment, except in the footwell area where there was nearly 80 mm of deformation (Figure 35).

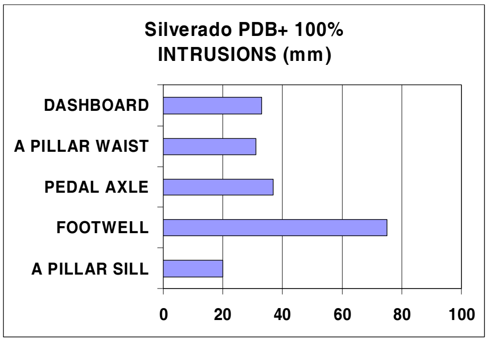


Figure 35: Silverado PDB+ Full Width – Driver side intrusions

The maximum acceleration measured was 33 g at 74 ms, corresponding to 0.887 mm of displacement (Figure 36). The average acceleration was 16.5 g.

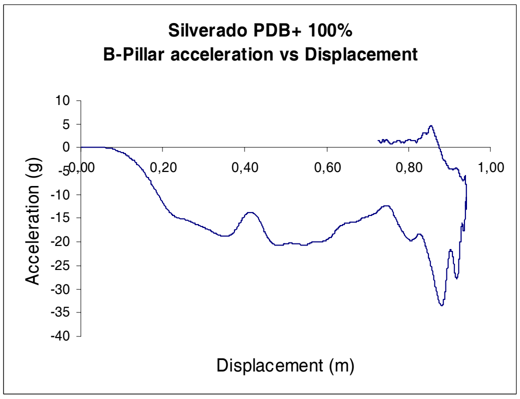


Figure 36: Silverado PDB+ Full Width – Acceleration

Partner protection

There was good integrity and no bottoming out of the full width barrier in the Silverado full width test. However, the deformation was inhomogeneous and localized in front of the longitudinal (Figure 37).

Figure 37: Silverado PDB+ Full Width - Front end deformation

The imprint of the connecting beam was not well detected, as it was positioned back from the front of the longitudinal and the deformation was not enough to detect this device (Figure 38).

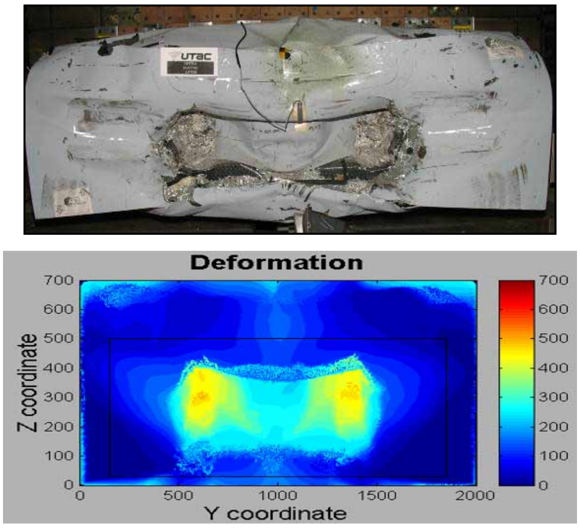


Figure 38: Silverado PDB+ Full Width - barrier deformation and digitization

The calculated parameters based on barrier digitization analysis are presented in Figure 39 below. The energy absorbed in the barrier was 68 kJ which represents 21% of the total kinetic energy.

Partner protection	
ADOD (X)	163 mm
AHOD (Z)	423 mm
Dmax	516 mm

Figure 39: Partner Protection Parameters for the Silverado PDB+ full width

DISCUSSION

Test severity

The test severity in the offset test configuration is similar for the Town and Country and Silverado; even with 350 kg differences in car mass, the evaluation of the EES is 51 km/h for both cars. Considering full width configuration, EES for the Silverado is slightly lower than for the Town and Country (53 km/h vs. 56 km/h).

The PDB barrier shows good capability for absorbing different amounts of energy. Thus it seems possible to normalize test severity with the use of a deformable element, which will allow for controlling other parameters, such as partner protection. Test severity harmonization could encourage heavier vehicles to be less stiff and result in less disparity between heavy and light vehicles because of the test set-up. Thus it has the potential of reducing the front end force difference.

Self protection

In the offset PDB+ tests, both vehicles demonstrated good performance in protecting the head and chest of the dummy. The injury numbers were not elevated in these tests. Similarly, most of the head and chest injury performance measures were relatively low in the full width PDB+ tests. However, there were a few notable exceptions. In the Town & Country full width PDB+ test, the passenger dummy resulted in a high chest acceleration measure, and in the Silverado test, the 5th percentile passenger dummy resulted in a high head injury reading.

It is interesting to note that when compared to the injury measures from the USNCAP full width rigid barrier tests of the same vehicle models (Figure 40 and Figure 41), it was found that the elevated passenger head injury criteria in the Silverado test was consistent with elevated passenger head injury criteria in the USNCAP program (in spite of it using a different dummy size). However, the elevated passenger chest acceleration in the Town & Country test was not found in the USNCAP test. Most other injury measures were comparable between the two test procedures.

	Town & Country Driver		Silverado Driver	
	Full PDB+	US NCAP	Full PDB+	US NCAP
Dummy	50th	50th	50th	50th
HIC36	437	482	727	738
HIC15	229	284	410	523
Chest Def (mm)	51	39	35	29
Chest Gs	49	44	43	45
L Femur (kN)	1.68	3.21	5.24	4.09
R Femur (kN)	1.67	2.09	6.99	4.35

	Town & Country Passenger		Silverado Passenger	
	Full PDB+	US NCAP	Full PDB+	US NCAP
Dummy	5th	50th	5th	50th
HIC36	419	385	**988**	**990**
HIC15	281	204	**787**	**629**
Chest Def (mm)	30	31	23	32
Chest Gs	**57**	46	42	49
L Femur (kN)	3.94	3.55	3.38	4.64
R Femur (kN)	1.49	3.45	5.08	4.36

Figure 40 and Figure 41: Comparison of PDB+ and USNCAP Dummy Injury Measures

Based upon this limited data, the measured self-protection of the vehicles in the full width PDB test was nearly equivalent to a full frontal rigid barrier crash test.

In terms of intrusions, the Town & Country produced relatively low levels in both the full width and offset configurations (Figure 42). Footwell intrusions were the exception to this. The values were 122 mm and 140 mm for the offset and full width tests, respectively. Though, in spite of the noted footwell intrusions, none of the dummy lower leg injury readings were elevated in these tests.

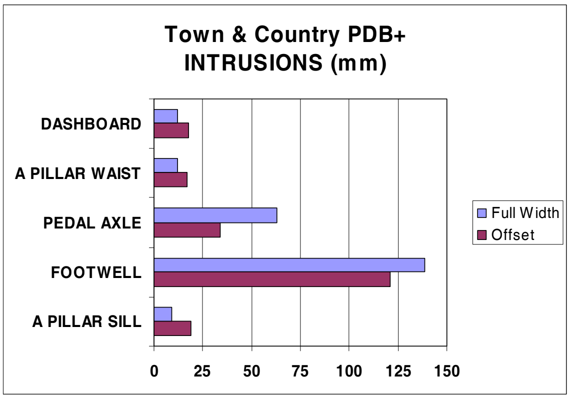


Figure 42: Comparison of driver side intrusions – Town & Country

All of the intrusion levels in the Silverado were higher in the offset test than the full width test (Figure 43). This is not unexpected, given the nature of the test configuration. The driver footwell intrusion in the Silverado offset test was over 200 mm. This was consistent with the elevated lower leg injury measures for the driver dummy in this test. The tibia indexes were 0.987 and 0.929 for the left and right legs, respectively.

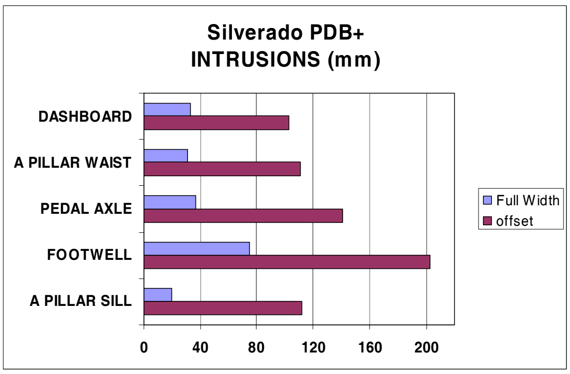
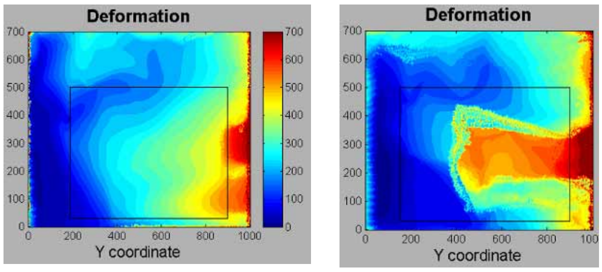


Figure 43: Comparison of driver side intrusions – Silverado

Aside from the footwell and pedal axle intrusions, the structural intrusions in the Silverado were generally greater than the Town & Country.

Partner protection

The test results showed that structural differences between the two vehicles are detected by the PDB+ in the offset test configuration (Figure 44). The Silverado barrier deformation is localized in front of the lower rail. The vehicle's crossbeam is also detected. In contrast, the deformation of the Town & Country barrier is large and homogenous.



Town & Country Silverado

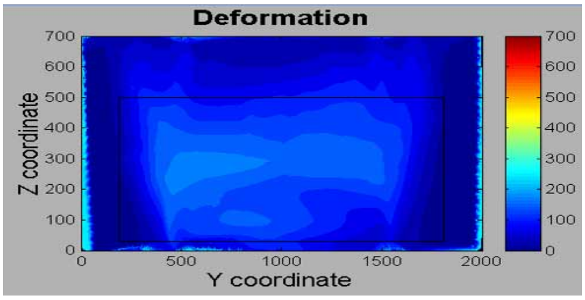
Figure 44: Comparison of barrier deformation – Offset

Figure 45 summarizes the parameters calculated for this test configuration. As expected from the vehicle selection, the AHOD values for the Town & Country and Silverado were within 2 percent of each other. This is consistent with USNCAP tests that similarly found the average height of force (AHOF400) values to be 476 mm, and 475 mm for the Town & Country and Silverado, respectively [7]. The ADOD and Dmax were slightly higher in the Silverado, as expected from the digitization.

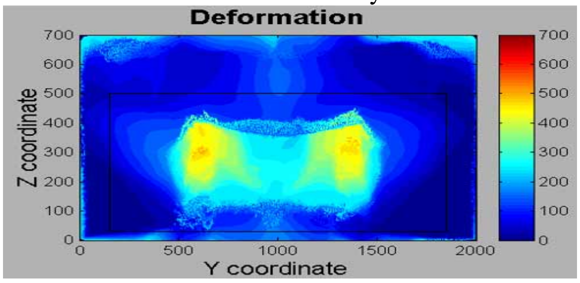
PDB+ Offset			
	T&C	Silverado	Δ %
ADOD (X) (mm)	275	289	5
AHOD (Z) (mm)	404	414	2
Dmax (mm)	570	654	13

Figure 45: Comparison of Partner protection Parameters in the Offset Tests

Similarly, in the full frontal barrier tests, the deformation patterns were very different between the two tested vehicles. The Silverado, fitted with a stiff single load path, created an inhomogeneous deformation, localized in front of the lower rail. On the other hand, the Town and Country resulted in a more homogeneous deformation pattern due to the front cross beam and lower load paths. The forces were distributed over a large area (Figure 46).



Town & Country



Silverado

Figure 46: Comparison of barrier deformation – Full Width

Figure 47 summarizes the parameters calculated in the full width test configuration. Again, the AHOD values for the Town & Country and Silverado were very close in magnitude (within 1 percent) and consistent with USNCAP findings. On the other hand, the Dmax values were considerably different for the two vehicles in the full width PDB+ tests. The Town & Country resulted in only 174 mm of deformation, whereas the Silverado resulted in 516 mm.

PDB+ Full Width			
	T&C	Silverado	Δ%
ADOD (X) (mm)	105	163	35
AHOD (Z) (mm)	425	423	1
Dmax (mm)	174	516	66

Figure 47: Comparison of Partner protection Parameters in the Full Width Tests

NHTSA is also evaluating the merits of a stiffness metric, KW400, in its compatibility research program [4]. As part of this research, NHTSA conducted two full frontal vehicle-to-vehicle crash tests using both the Town and Country and Silverado. Each vehicle was impacted by a standard collision partner, the 2002 Ford Focus. The results showed that the Silverado imparted higher head and chest injury measures to the driver dummy of Ford Focus than did the Town & Country. Head and chest injury measures were increased 15 and 18 percent, respectively. The crash test results are directionally consistent with the partner protection findings in this study.

Future considerations of the PDB+ test procedure

The PDB+ test configuration was able to discriminate between the Silverado's body on frame vehicle structure and the unibody construction of the Town & Country. Future research could include evaluating the PDB+'s ability to identify secondary energy absorbing structures, or other novel designs, and assess their partner protection performance for crash compatibility. Research can also be expanded to appraise how the PDB+ performs with vehicles that have similar frontal stiffness and force matching to identify additional design factors that may play a roll in crash compatibility. Finally, additional full width PDB+ testing could be conducted to verify if there is a correlation with the self-protection measurements of a rigid barrier.

The DSCR is developing a parameter to assess the homogeneity of the vehicle crush pattern using the barrier digitization analysis. It will be based on the shape of the deformation, discriminating between localized deformation and homogeneous deformation. This parameter has the potential to be very useful in differentiating the crash characteristics of the two vehicles.

In this testing, a load cell wall was installed behind the PDB+ to measure the global front end force. The PDB+ procedure is able to measure this force with a high level of accuracy. Although the global force is reported for informational purposes in this paper, with further research it could be used for evaluating self and partner protection. (See test results in the Appendix).

CONCLUSIONS

- Different frontal designs, in terms of force and geometry were well detected by both the full width and offset PDB+ test configurations.
- The deformable element of the PDB+ absorbs different amounts of energy, so that the concept of force matching appears to be obtainable.
- In the four tests, no bottoming out or instability of the PDB+ was observed. The size and stiffness seemed to be appropriate for these heavier vehicles.
- In this test series, the Silverado demonstrated crash protection concerns that were well identified by the PDB+ test procedure both in terms of self and partner protection. The barrier forces were transmitted through the stiff Silverado front to a relatively soft occupant compartment, which led to higher compartment intrusion particularly in the footwell area.
- The full width and offset test configurations were also able to evaluate the self protection of a vehicle in addition to its partner protection.
- The testing showed that the measured self-protection in the full width PDB+ test was reasonably equivalent to that achieved in a full frontal rigid barrier for the two vehicles evaluated.

- The results from these PDB tests are consistent with vehicle-to-vehicle crash tests.
- Under the bilateral agreement between NHTSA and DSCR, resources were leveraged to carry out a joint research program on vehicle compatibility. Results and knowledge gained from this test procedure evaluation proved to be useful to both countries.

ACKNOWLEGDEMENTS

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APPENDIX

Global force

PDB+ Offset test - Town & Country

The maximum global force is 436 kN at 1 meter displacement of the B-Pillar (Figure 48).

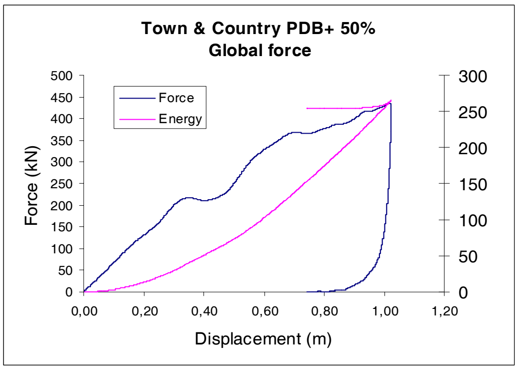

Figure 48: Town & Country PDB+ offset – Global force

PDB+ Offset test - Silverado

The maximum force was 495 kN at 1.150 m displacement of B-Pillar (Figure 49).

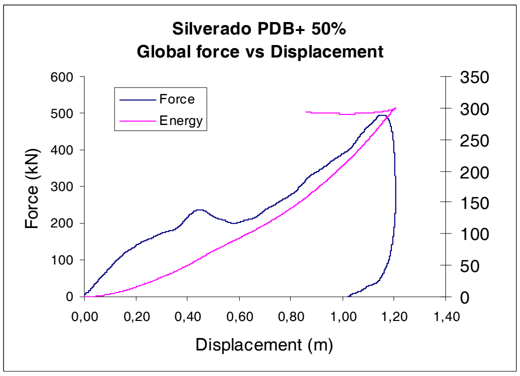

Figure 49: Silverado PDB+ offset – Global force

PDB+ Full Width test - Town & Country

The measured global force (Figure 50) could not be validated. The calculated energy was 10% higher than the kinetic energy. An investigation was conducted, but no explanation was found. Therefore, for this test, the force measurement can not be interpreted, as it is probably overestimated.

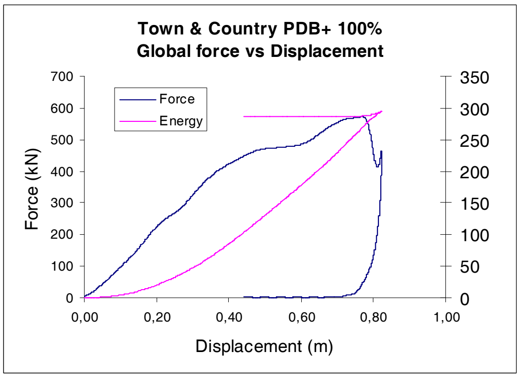

Figure 50: Town & Country PDB+ Full Width – Global force

PDB+ Full Width test - Silverado

The maximum force was 541 kN at 0.801 m displacement of the B-Pillar (Figure 51).

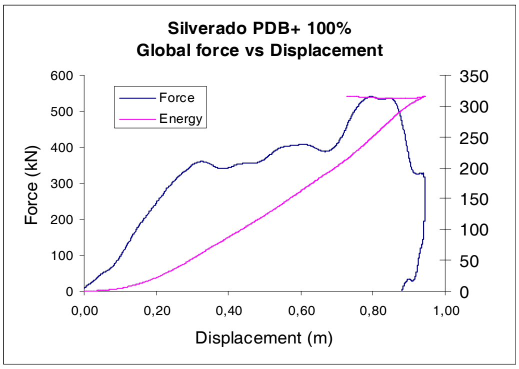

Figure 51: Silverado PDB+ Full Width – Global force