

# DEVELOPMENT OF A SPORT UTILITY FRONT BUMPER SYSTEM FOR PEDESTRIAN SAFETY AND 5 MPH IMPACT PERFORMANCE

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## ABSTRACT

A front bumper system for use on a Sport Utility Vehicle was designed by Honda R&D Americas, which meets the conflicting requirements for both pedestrian safety and 5 mph impact performance.

The requirements for both substantial “soft” crush space and limited barrier intrusion presented conflicting design directions. A sport utility front bumper system, which balances these design parameters, was developed using computer modeling. A pedestrian upper legform to bumper test was modeled using MADYMO, while 5 mph barrier test simulations utilized LS-DYNA3D. The virtually developed pedestrian bumper system’s performance was confirmed through physical testing.

This paper will outline the process and methods used for this pedestrian bumper system development. Some details of the new bumper design and its performance will be featured.

## INTRODUCTION

In the past decade, there have been a multitude of advancements for motor vehicle safety. From dual stage airbags and load limiting seatbelts to side airbags and head curtains, occupants of motor vehicles have never been more protected. However, pedestrians still have the same risks they have faced for years.

Automobiles are designed with the safety of their occupants in mind. The increasingly stronger structures that protect these occupants in high-speed frontal crashes have devastating effects when the object that is struck is an unprotected pedestrian. In the United States alone in 1997, there were 5,307 fatalities and some 77,000 injuries of pedestrians (1). Although pedestrian accidents only account for 2.4 percent of all automotive accidents in the U.S., they account for 12.6 percent of all automotive fatalities

(1). In addition to the 5,000 annual fatalities in the U.S., there were over 3,000 in Japan (2), 7,000 in the European Union (3), and 19,000 in China (4).

In order to address this global problem, the European Experimental Vehicles Committee (EEVC) working group established test procedures for evaluating the safety performance of motor vehicles with respect to pedestrians (5). These procedures include the evaluation of bumper systems.

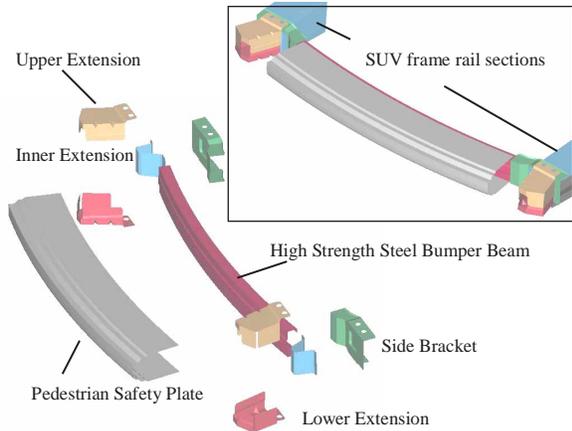
For some off-road and multi-purpose vehicles, an upper legform impactor test is used to evaluate the front bumper system. This test propels an upper legform impactor into a stationary vehicle at a velocity of 40 kph. Acceptance criteria are based on peak loads and bending moments measured on the impactor. Generally, substantial “soft” crush space is required for good performance.

On the other hand, a series of low speed barrier impact tests are conducted to evaluate vehicle repair costs. This includes frontal impact tests conducted at 5 mph on both flat and 30 degree angled barriers. Generally, limiting the amount of barrier intrusion minimizes repair costs.

This paper outlines the methodology used to develop an SUV pedestrian bumper system. The various test procedures and design targets are reviewed. The simulation results for several design concepts are presented. Finally, the test results of the final design are summarized and the new bumper system’s performance is discussed.

## DETAILS OF SUV PEDESTRIAN BUMPER SYSTEM DESIGN

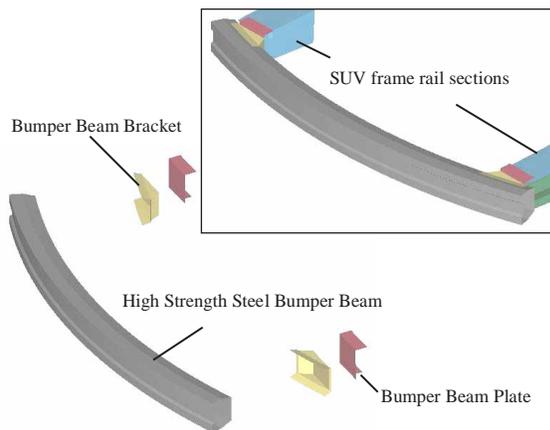
A new SUV front bumper system with two separate sub-systems was created to meet the conflicting requirements of pedestrian safety and low speed impact performance. A schematic of this pedestrian bumper system is shown in Figure 1.



**Figure 1. Exploded view of SUV pedestrian bumper system.**

A pedestrian safety plate of 0.65 mm thick mild steel, which is welded to a 1.2 mm thick high strength steel beam, occupies the region between the frame rails. This beam is in turn welded to 2.0 mm thick high strength steel side brackets, which bolt on to the vehicles frame rails. In front of the frame rails are three part extensions welded to the side brackets. These extensions are all 2.0 mm thick mild steel.

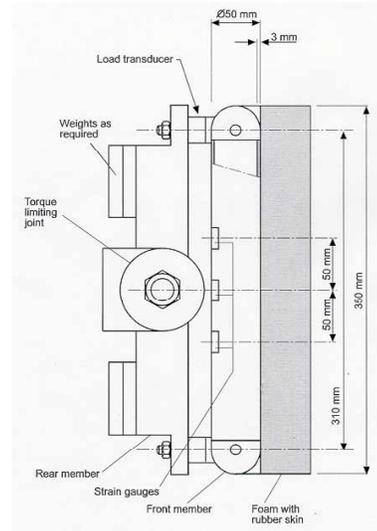
This pedestrian bumper system construction is significantly different from the typical SUV front bumper system shown in Figure 2. This standard SUV front bumper system features a 2.0 mm thick high strength steel bumper beam spanning the frame rails. This beam is welded to brackets, which are in turn welded to plates, which bolt on to the frame rails.



**Figure 2. Exploded view of SUV standard bumper system.**

## PEDESTRIAN SAFETY DEVELOPMENT

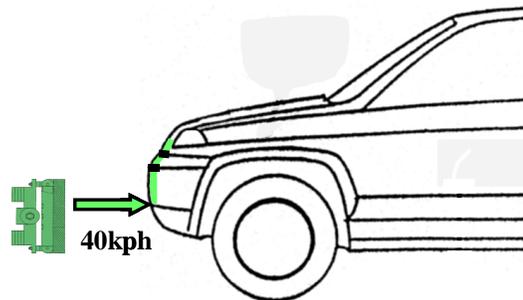
The main focus of the pedestrian safety development for this SUV front bumper system was the creation of a pedestrian safety plate structure. The purpose of the safety plate was to meet requirements for an alternative upper legform impactor (see Figure 3) to bumper test.



**Figure 3. Schematic of upper legform impactor.**

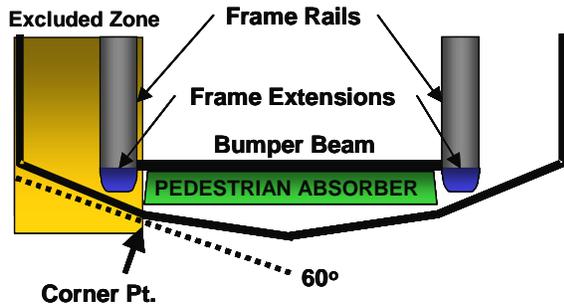
### Upper legform to bumper test procedure

An alternative upper legform test is used when a vehicles bumper system is more than 500 mm off the ground. At this height, the bumper would contact the femur portion of the lower leg form impactor. The alternative impact test uses the upper legform impactor, shown in figure 3, which is launched horizontally at 40kph. This setup can be seen in Figure 4.



**Figure 4. Alternate impactor to bumper test.**

The impact zone is constrained within the corner of each outside bumper edge. A vertical plane determines the bumper edges, which is 60 degrees from the centerline of the car. A layout of this pedestrian impact zone is shown in Figure 5.



**Figure 5. Layout of impact zone for pedestrian legform**

This pedestrian test is very demanding. Acceptance levels are based on AIS2+ femur injury risk.

### Review test targets and performance of standard SUV front bumper system

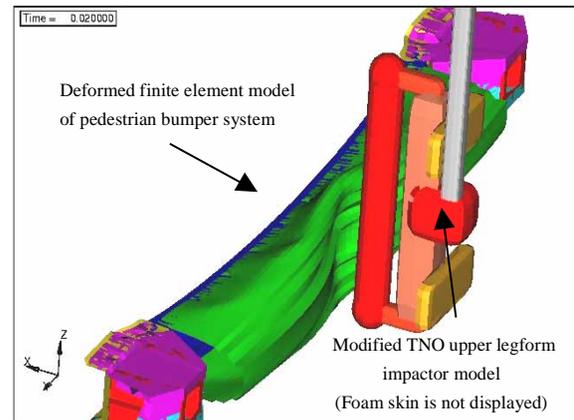
The first step in developing the pedestrian safe bumper system was to set certain performance targets. The standard SUV bumper, shown in figure 2, was evaluated using the alternate upper legform test to understand the baseline performance.

Test results showed a peak force of 26 KN and a peak moment of 1686 N\*m. As expected the forces were very high. The upper legform performance targets for the pedestrian safe bumper system development were set at less than 7.5 KN peak force and less than 510 N\*m for the peak moment.

### Details of the simulation model and techniques

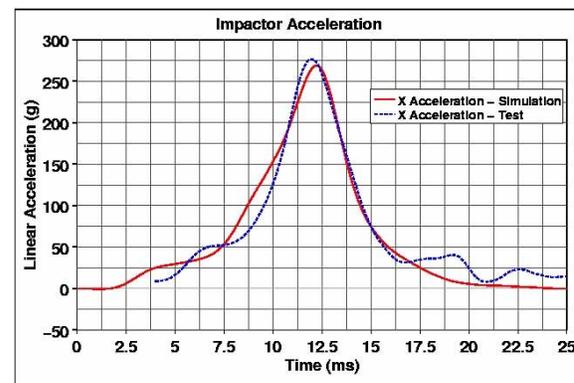
The upper legform to bumper test described above was simulated using the MADYMO 3D occupant simulation program developed by TNO. The partly finite element database of the EEVC upper legform impactor created by TNO was the starting point for our impactor model (6). Finite element models of the standard and pedestrian SUV bumper systems were created. The various parts were modeled using shell elements and rigid weld connections were created. A finite element model of a generalized SUV fascia was included for the simulations. Figure 6 shows one such MADYMO model at maximum intrusion of the impactor. The impactor foam and vehicle fascia are not displayed.

The bumper structure was fixed in space at the frame rails. The fascia was fixed in space at the mounting points and the impactor was given an initial velocity. Contact interfaces were created between the impactor and the safety plate and between the safety plate and the bumper beam.



**Figure 6. Upper legform to pedestrian bumper simulation model.**

The configuration and mass of the TNO impactor model was modified to represent the physical Honda test equipment. This modified impactor model was validated by simulating the legform certification test and correlating to results for the Honda rig (7). The upper legform to bumper test was first simulated for the standard SUV bumper system to gain further confidence in our methods. Figure 7 shows a comparison plot of impactor acceleration versus time between the test and simulation.

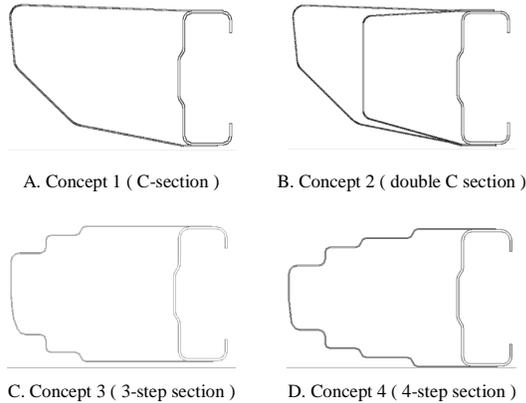


**Figure 7. Impactor acceleration for alternate legform to standard bumper test (7).**

### Development process for the pedestrian safety plate

Several different types of potential constructions and materials for a pedestrian safety plate were

evaluated. The goal was to develop a structure, which would absorb the kinetic energy of the impactor within the available space without causing a force peak above 7.5 KN. Concepts constructed of steel, plastic, and foam were considered for this application. Steel was selected for the development since it offered the best combination of performance, cost, and flexibility.



**Figure 8. Cross-sections of various safety plate concepts.**

Several different cross-sectional shapes for a steel pedestrian safety plate were evaluated using simulation. These different cross-sections are shown in Figure 8. The sweep of the standard bumper system was used for all of the initial pedestrian bumper concepts.

The simulated performance of these four concepts showed that none of these initial concepts met our targets. These results are provided in my associate’s paper (7). In all cases a force peak above 7.5 KN was produced when the impactor crushes the safety plate and strikes the beam behind it. However, the 3-step concept produced the most constant level of force before bottoming out.



**Figure 9. Impactor force versus stroke results for final 3 step safety plate at variable thickness (7).**

Therefore, a new pedestrian bumper system design was created based on the 3-step concept. The sweep of the bumper beam was reduced to create more crush space for the 3-step safety plate. Several more simulations were run to investigate the effects of thickness and different methods of fabrication on the performance of the 3-step design (7).

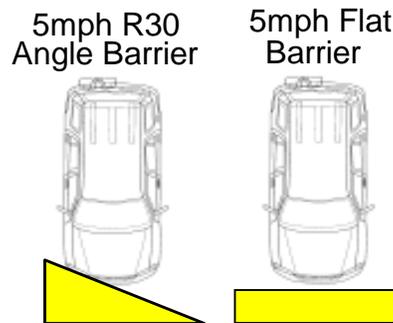
A comparison plot of impactor force versus stroke is provided in Figure 9. The final 3-step 0.65 mm thick pedestrian safety plate design shown in figure 1 was selected as the best possibility to meet all targets. The performance of this pedestrian safety plate design for impactor hits on the edge of the plate was also confirmed using simulation (7).

### 5 MPH BARRIER IMPACT DEVELOPMENT

The main focus of the 5 mph barrier development for this SUV pedestrian bumper system was the creation of the frame rail extensions to limit intrusion of the flat and 30 degree angled barriers.

#### Flat and angled barrier test procedure

The performance criteria for low speed bumper impact is judged based on two test modes. The first is a 5 mph flat barrier impact and the second is a 5 mph 30 degree angle barrier test. A schematic of each test setup is given in Figure 10.



**Figure 10. Low speed bumper test setup.**

The purpose of the bumper system for these tests is to limit intrusion and prevent damage to body parts.

#### Review test targets and performance of standard SUV front bumper system

Again, baseline data was obtained using a standard SUV bumper system. This baseline data was also used to develop the targets for the pedestrian system. With the standard bumper, the goal was to prevent damage to any parts except the bumper

system and to limit the repair cost of all damaged parts in both tests.

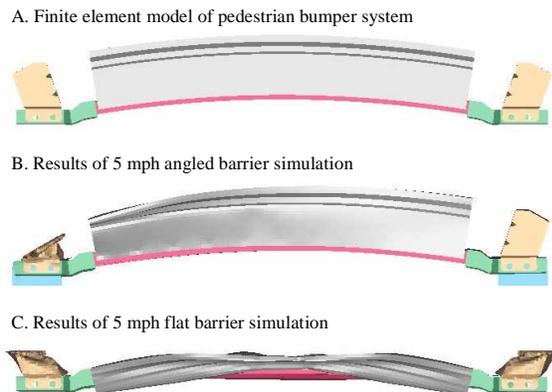
The standard bumper system allowed 110 mm of stroke in the flat 5 mph and 90 mm of stroke in the angled 5 mph test. To match the flat barrier performance exactly would be difficult because the leading bumper edge had to be pedestrian safe.

Since first contact of the pedestrian system is on the 'soft' safety plate, very little energy is absorbed before contact to the extensions. Therefore, some additional stroke is necessary. In order to achieve the previously discussed cost targets, intrusion for the flat barrier was set at less than 155 mm and for the angled barrier at less than 98 mm.

### Details of the simulation model and techniques

The 5 mph front flat and angled barrier tests described above were simulated using the LS-DYNA 3D crash simulation program developed by LSTC. The finite element models of the standard and pedestrian bumper systems and SUV fascia were adapted for LS-DYNA. The bumper systems were joined to finite element sections of SUV frame rail structure using rigid connections to represent bolts. The rear edges of these frame rail sections and the fascia mounting points were merged to a rigid body with the same general mass and inertia properties as an SUV. This combined body and bumper structure was given an initial velocity. An automatic contact between parts of the bumper structure was created. A contact between the bumper structure and a rigid wall was also created.

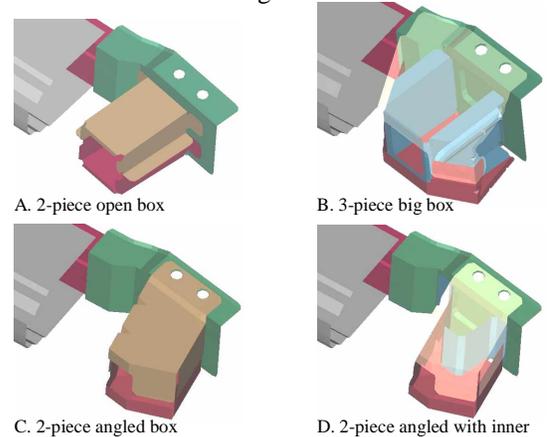
Figure 11 shows the pedestrian bumper model created for LS-DYNA and the deformed structure from the flat and angled barrier simulations. The vehicle fascia is not displayed.



**Figure 11. Low speed barrier impact simulation model.**

### Development process for frame rail extensions

The first concept for the frame rail extensions was an open box like structure in front of the SUV frame rails. This first extension concept and the later iterations are shown in Figure 12.



**Figure 12. Concepts for pedestrian bumper extensions.**

The goal for this structure was to limit the amount of barrier intrusion for the 5 mph flat and angled impacts. However, making the extensions excessively strong was not possible in order to balance with airbag sensor development.

The simulation results for the first concept showed the structure did not meet the intrusion target for the angled barrier. The box structure was crushed to the side by the angled barrier. A summary of the simulation results for all of the extension concepts is provided in Table 1.

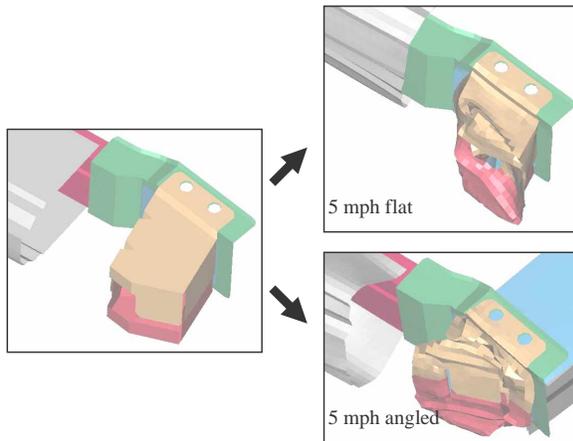
**Table 1. Results of 5 mph barrier simulations**

Extension	5 mph Flat		5 mph R30°	
	Peak Body G	Intrusion (mm)	Peak Body G	Intrusion (mm)
Targets	NA	<155	NA	<98
2-p open box	7.6	136	6.1	131
3-p big box	10.0	119	4.1	76
2-p angled box	6.5	140	4.3	107
2-p angled box with inner	6.5	128	3.8	95

Next, a bigger and stronger three-part box concept was created to improve angled barrier performance. This stronger extension met all the intrusion targets. But the high G peak it generated during the flat impact suggested it would have a negative impact on sensor development.

Therefore, the next extension concept, a two-part box, was angled outward to align the crush axis of the extension with the face of the angled barrier. This

was done to limit angled barrier intrusion but reduce the G spike produced during flat impact by the extensions. This design worked as intended but the angled barrier performance was slightly below target. Figure 12. shows the deformed shape of the angled box extension after the flat and angled 5 mph barrier impact simulations.



**Figure 12. Deformed shape of extension after low speed barrier impact simulations**

Therefore, a fourth concept was created by adding an inner extension to the two part angled box. This inner extension was added as a second stage of crush strength. Its purpose was to further limit the angled barrier stroke without adding to the flat barrier G peak that was created by the two-part box structure. This final 3-part angled extension concept met all intrusion targets and the amount of peak G increase was judged to be acceptable.

### TEST RESULTS OF PROTOTYPE SUV PEDESTRIAN BUMPER SYSTEM

The final step of development was to confirm the performance of the virtually designed bumper system with physical testing of prototype parts. The first test series was done on the pedestrian safety plate with the horizontal upper legform impact mode. These results were compared to the standard SUV bumper and the pedestrian bumper targets. A summary is given in Table 2.

Since all targets were met for the upper legform pedestrian test, the next step was to confirm low speed bumper impact performance. The second test series was done on the pedestrian bumper system mounted on an SUV with the 5 mph flat and angled barrier mode. Again, results were compared to the standard SUV bumper system and the pedestrian bumper targets. Once again all of the targets were

met for low speed barrier impact. A summary is provided in Table 3.

**Table 2. Results of upper legform pedestrian testing**

Test Description	Peak Force	Peak Moment		
	Total (N)	Upper (N-m)	Center (N-m)	Lower (N-m)
Targets	<7500	<510	<510	<510
Standard SUV (Center)	26090.1	949.1	1518.9	1685.7
Pedestrian SUV (Center)	5495.9	224.3	326.2	374.4
Pedestrian SUV (Off-center)	4704.5	265.4	334.8	324.7
Pedestrian SUV (Edge)	5186.2	284.9	363.9	365.9

**Table 3. Results of low speed barrier testing**

Bumper System	5 mph Flat		5 mph R30°	
	Peak Floor G	Intrusion (mm)	Peak Floor G	Intrusion (mm)
Targets	NA	<155	NA	<98
Standard SUV	5.7	110	5.1	90
Pedestrian SUV	8.2	130	4.4	67

### CONCLUSIONS

- An SUV front bumper system was virtually developed to meet the conflicting requirements of pedestrian safety and low speed impact performance using CAE.
- The peak force measured by the upper legform impactor for this pedestrian bumper system was a 79% reduction from the standard bumper.
- The 5 mph flat barrier intrusion for this pedestrian bumper system was 20 mm greater than for the standard bumper but below our target. This result correlated well with our simulation prediction.
- The 5 mph angled barrier intrusion for this pedestrian bumper system was 23 mm less than for the standard bumper, which was significantly less than our prediction. This was due to the prototype extensions being slightly stronger than anticipated and due to the flexibility of the vehicle structure, which was not modeled.
- The pedestrian bumper system was estimated to cost \$2.12 more than the

standard bumper system. However, it resulted in a 1.58 Kg mass reduction.

## **ACKNOWLEDGEMENTS**

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