DEVELOPMENT OF A REAR UNDERRIDE GUARD SPECIFICATION FOR HEAVY VEHICLES

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Abstract

This paper summarizes results of a large research program intended to develop a draft rear underride guard specification for heavy vehicles. Results of a series of laboratory and full-scale crash tests performed at the Transport Canada Research Center were used in the development of these specifications. A total of eleven full-scale crash tests was carried out to evaluate the effectiveness of different underride guards. The first ten of these tests were performed on a simulated trailer attached guard. Inteh final crash test, an actual trailer was used to attach the underride guard. Four different underride guard designs were used in the full-scale crash tests. Three different vehicle models traveling at 48, 56 and 65 km/h speeds were used to impact underride guards head on. Results of the first ten crash tests show that the current US FMVSS 223 standard is not adequate in preventing rear underride. Based on findings obtained from these crash tests, an improved guard design was developed and tested using a 16-meter trailer. The final crash test verified the effectiveness of improved guard design in reducing the undesirable effects of rear underride crashes. Based on the results, a draft heavy vehicle rear underride guard specification was developed for Turkey.

Keywords: Underride; Crash test; Heavy vehicle; FMVSS 223; Standard; Safety
Topic Area: C2 Safety Analysis and Policy

1. Introduction

Rear underride accidents take place when a relatively small vehicle, such as a passenger car, collides with the rear end of a much larger, heavier and stronger vehicle. During the collision, the front portion of the smaller vehicle slides partially or completely under the rear of the larger vehicle. In the worst case, the smaller vehicle underrides the large vehicle long enough that the rear extremity of large vehicle enters the passenger compartment of the smaller vehicle. This phenomenon, referred to as "passenger compartment intrusion (PCI)", frequently results in fatalities.

Heavy vehicle rear underride guards (HVRUG) can be categorized as passive protective devices and are utilized on the rear-end of heavy vehicles to minimize the amount of vehicle underride, crash severity and amount of PCI during passenger car-large truck collisions (see Figure 1). The U.S. National Highway Traffic Safety Administration (NHTSA) requires that most heavy-duty trailers and semi-trailers manufactured for sale in the U.S. on or after 26 January 1998 be fitted with a rear impact guard meeting the requirements of Federal Motor Vehicle Safety Standard (FMVSS) 223 (NHTSA 1998). In most countries, including Canada, and Turkey, there is not an adequate specification or standard that exists for heavy vehicle manufacturers to equip their trailers with a rear impact guard, with the exception of tanker trailers designed to transport dangerous goods which was developed primarily to protect the tank and its valves rather than the occupants in the colliding vehicle. This shows the level of consciousness in these countries toward this important transportation safety concern (Atahan 2003).

To review the issue of rear impact protection for heavy vehicles and to develop a set of HVRUG specifications for Turkey and Canada, a large research project was initiated at Transport Canada Research Center (Boucher 2000a). A major objective of this research project was to determine the minimum performance levels that HVRIG systems should have and whether participating countries should adopt the same performance requirements that are mandated in FMVSS 223.

Figure 1. Picture of rear underride guards

2. Test plan

2.1 Underride guards

Four different guard designs were evaluated in full-scale crash tests: a 560 mm high guard, a 480 mm high guard, a 480 mm high guard with stopper and a 560 mm high slanted guard. Each of these guards was positioned so that the face of the horizontal member was approximately 300 mm behind the structure foremost surface. In other words, this placement allowed the striking vehicle to advance 300 mm under the simulated trailer before it contacts the guard. This distance represents the most forward position allowed by FMVSS 223 and represents the worst placement of the guard. The 560 mm guard is designed to have a ground clearance of 560 mm when mounted on the back of a trailer. The design of this particular guard is based on the concept developed by the Canadian Transportation Equipment Association (CTEA). For the research program, CTEA guard had to be weakened so that it would conform minimally with the strength and energy absorption requirements of the US FMVSS 223 (NHTSA 1995). As shown in Figure 2, the 560 mm guard consists of two sections; its triangulated top part is very rigid and does not deform easily while the weaker bottom part is designed to deform under load and absorb energy through plastic deformation.

The 480 mm guard is identical to the 560 mm guard, with two exceptions. The vertical supports have been elongated by 80 mm so that the guard ground clearance is reduced to 480 mm. Also, the back brace is longer than that in the 560 mm guard so that the distances between the top of the horizontal member and the point at which the back brace connects to the support are identical in both guards.

The 480 mm displacement limiting guard is a modification of the 480 mm guard; a very rigid piece of steel mounted vertically (see Figure 3) was added to limit the travel of the horizontal member. The stopper was sized and positioned so that the horizontal member would contact it once it had raised 70 to 80 mm through rotation; the lower part of the stopper was angled to ensure a good contact between the stopper and the horizontal member. This modification was designed to investigate the effect of limiting the vertical displacement in a 480 mm guard, especially in crashes involving either very low vehicles or speeds of the order of 65 km/h.

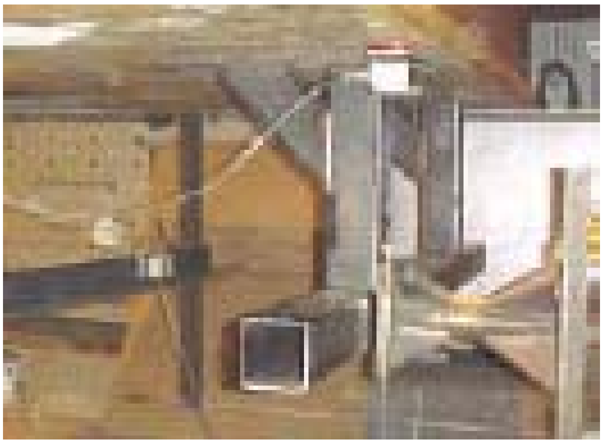

Figure 2. FMVSS 223 Minimally Compliant Guard

Finally, the 560 mm slanted guard is also a modification of the original CTEA design; the slanted design was used to minimize the increase in ground clearance experienced with a vertical guard design when it is deformed during a crash. The original CTEA design was not weakened as was done for the 560 mm guard. The vertical supports were slanted towards the rear of the simulated trailer and elongated so that the horizontal member still had a ground clearance of 560 mm when undeformed. This resulted in a stiffer guard, which could maintain a quasi-constant ground clearance of 560 mm during the displacement of the horizontal member. Figure 4 shows this guard in its pre-test conditions.

Figure 3. 480 mm displacement limiting guard

Figure 4. 560 mm slanted guard

2.2 Test vehicles

Three test vehicles were used in the test program, each representing a specific vehicle category. The 1998 Ford Windstar represented the light truck and van category. The 1998 Chevrolet Cavalier represented the compact cars and the 1998 Honda Civic represented the sub-compact vehicle class. Each of these vehicles with different frontal properties represented a specific challenge for the various underride guards being tested.

The Windstar, at over 1900 kg, is the heaviest vehicle used in the test program. Good engagement of the guard by the vehicle frontal features of the vehicle, such as bumper, engine compartment and suspensions is expected because of the vehicle height. Its hood, however, is quite short compared to conventional automobiles and there is some concern that the distance needed to stop the vehicle might produce PCI.

The Cavalier is close to the average vehicle both in size and weight, and plans called for this vehicle to be tested at speeds as high as 65 km/h, thus providing good information about the performance of various underride guards with this size of vehicles at impact speeds higher than those used in the original NHTSA test program (Elias and Monk 1993).

The Civic was the lightest of the three vehicles tested and should therefore not represent a challenge to the structure of the underride guard, even at higher speeds (when compared to Cavalier, for example). The specific challenge with this vehicle is the low height of its structure; the concern was that the deformation of the underride guard might reduce the overlap between the guard and the stiff parts of the vehicle structure, thus hindering its capacity to slow the vehicle down (Atahan et al. 2003).

2.3 Crash test matrix

“A total of 10 crash tests were performed using simulated trailer mounted underride guard setup. The test matrix summarizing some of the characteristics, such as the test number, vehicle model, test mass, guard type and test speed is depicted in Table 1.

Table 1. Summary of Crash Test Vehicles and Crash Test Conditions

Test No	Vehicle Model	Test Mass (kg)	Guard Type	Test Speed (Nominal)
1	Ford Windstar	1943	560 mm MCG	48 km/h
2	Chevrolet Cavalier	1386	480 mm MCG	48 km/h
3	Chevrolet Cavalier	1391	560 mm MCG	48 km/h
4	Chevrolet Cavalier	1389	480 mm MCG	65 km/h
5	Chevrolet Cavalier	1387	480 mm DLG	65 km/h
6	Honda Civic	1223	480 mm MCG	48 km/h
7	Honda Civic	1231	480 mm DLG	48 km/h
8	Honda Civic	1267	560 mm MCG	56 km/h
9	Honda Civic	1229	480 mm DLG	56 km/h
10	Honda Civic	1236	560 mm SG	48 km/h

2.4 Simulated trailer and crash area

A support structure, shown in Figure 5, was used to simulate the rear of a trailer and to support the rear underride guards being tested. As shown in Figure 5, the ground clearance of the simulated trailer was 1105 mm. The support structure consisted of four horizontal steel girders, a thick reinforced concrete slab, four vertical steel columns and two diagonal steel pipes connecting setup to the rigid wall on the back. The underride guards were attached to the support structure using four bolts at each connection to provide a rigid connection. As described later during crash tests the simulated trailer remained rigid and no members showed sign of yielding.

A powerful cable and towing mechanism was used to accelerate vehicles to a pre-determined speed. A fixed ground barrier was used to detach the towing mechanisms from the vehicle to allow free wheeling just prior to impact.

Figure 5. Support structure and simulted trailer attached underride guard

3. Test results

Full-scale crash tests were performed to evaluate the acceptability of underride guards in reducing crash severity of vehicular impacts. Also, these tests were intended to understand how an underride guard meeting the minimum US FMVSS 223 standards would perform in stopping various classes of vehicles at different speeds.

As shown in Table 1, a total of ten crashes were performed using simulated trailer. For each test, the total displacement and speed were computed from the recorded deceleration. Since some vehicles were tested with barriers at two heights (480 and 560 mm), the total displacement was computed as the sum of the distance traveled by the vehicle after the first contact and its original longitudinal offset. This longitudinal offset is the distance the front bumper travels under the underride guard before the guard contacts the vehicle. This offset was computed from pre-test measurements with the test vehicle in contact with the underride guard. Figures 3 and 4 show the Honda Civic resting against a guard with a ground clearance of 480 mm and 560 mm respectively. The figures show that the bumper will travel further under the horizontal member in the case of the 560 mm guard. The various longitudinal offsets are depicted in Table 2 below. Some test results are tabulated in Table 3.

Table 2. Test vehicle longitudinal offset at various guard height

Vehicle Type	560 mm Ground Clearance (mm)	480 mm Ground Clearance (mm)
Ford Windstar	179	128
Chevrolet Cavalier	119	99
Honda Civic	80	Not Tested

3.1 560 mm guard

Three vehicles were tested against this guard: the Ford Windstar as a representative of light truck and vans, the Chevrolet Cavalier as a representative of compact automobiles and the Honda Civic as a representative of sub-compact automobiles.

The 560 mm guard provided good protection to the passenger compartment of the Windstar. As shown in Figure 6, there was very little intrusion inside the passenger compartment. The vehicle was decelerated to a stop in 178 ms with a total displacement of 1422 mm. The maximum deceleration measured was 16.3 g's. There was no damage (or very little) inside the passenger compartment.

Table 3. Summary of test results by type of underride guard

Underride Guard Type	Vehicle Type	Test Speed (km/h)	Total Computed Displacement (mm)	Maximum Measured Deceleration (g's)
560 mm	Ford Windstar	48	1422	16.3
560 mm	Chevrolet Cavalier	48	1965	12.7
560 mm	Honda Civic	56	2374	17.5
560 mm SG	Honda Civic	48	1319	25.4
480 mm	Chevrolet Cavalier	48	1441	17.4
480 mm	Chevrolet Cavalier	65	2209	19.3
480 mm	Honda Civic	48	1775	16.6
480 mm DLG	Chevrolet Cavalier	65	1388	30.0
480 mm DLG	Honda Civic	48	1457	19.8
480 mm DLG	Honda Civic	56	1605	21.4

The 560 mm guard was also tested with the Cavalier. In that test, the maximum deceleration rate recorded was 12.7 g's. The vehicle was decelerated to a stop in 238 ms and the total displacement was 1965 mm. There was passenger compartment intrusion and the steering wheel dropped, pinching the lead bags used as weight. The guard support structure came in contact with the top of the windshield and the horizontal member of the guard with the A-pillar on the driver's side. Pictures taken from this crash test are shown in Figure 7.

The FMVSS 223 compliant 560 mm guard failed to stop the Honda Civic before the vehicle collided with the concrete rigid wall. The Civic was traveling at approximately 40 km/h when its roof struck the rearmost surface of the barrier and at approximately 22 km/h when it struck the concrete wall. The wall is located approximately 2.4 m from the rearmost surface of the structure and the total displacement at that time would have been 2.25 m. Prior to contacting the concrete wall, the maximum vehicle deceleration had only reached 17.5 g's. The collision with the wall generated a vehicle deceleration of 21.1 g's. Figure 8 shows post test pictures for this crash. As shown in Figure 8, damage to the passenger compartment was severe and the roof was pushed down by the underside of the guard.

3.2 560 mm slanted guard

The 560 mm slanted guard provided relatively acceptable protection to Honda Civic when impacted at 48 km/h. There were no contact between the structure and the vehicle or windshield. No PCI was observed during the test. The vehicle was decelerated to a complete stop in 193 ms with a total displacement of 1319 mm. The maximum vehicle deceleration was 25.4 g's. There was no visible damage inside the vehicle. Close examination of the guard after the test revealed that it had moved more than 125 mm in the horizontal direction; the final ground clearance of the guard was 600 mm. It was also noted that the guard had rotated so much that its rest position was higher than the vehicle suspension posts. This means that at a higher vehicle speed this guard could have allowed underride. It is doubtful that this guard could have provided acceptable passenger compartment protection at a speed of 56 km/h which represents a 36% increase in kinetic energy at impact compared to 48 km/h impact. Figure 9 shows post test pictures for this crash.

Figure 6. Ford Windstar after crash test into 560 mm guard at 48 km/h

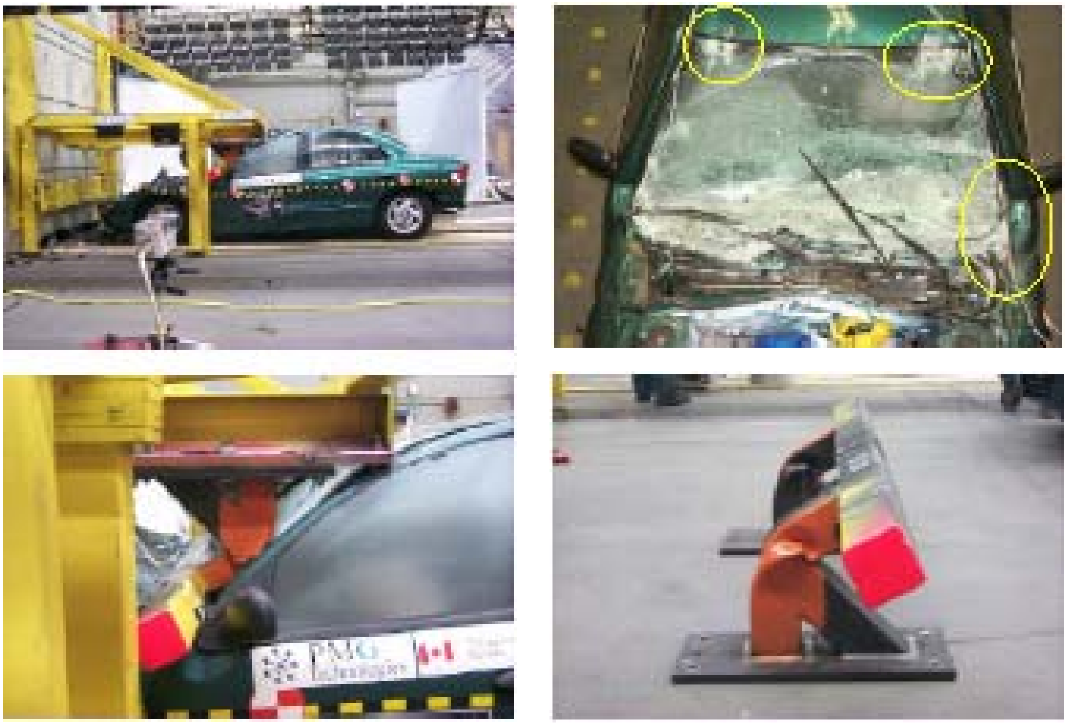

Figure 7. Chevrolet Cavalier crash test into 560 mm guard at 48 km/h

Figure 8. Honda Civic crash test into 560 mm guard at 56 km/h

Figure 9. Honda Civic Crash test into 560 mm slanted guard at 48 km/h

3.3 480 mm guard

Three tests were performed with the 480 mm guard. In two of those tests Chevrolet Cavaliers traveling at 48 and 65 km/h were used to evaluate compact automobile impacts. In one test, a Honda Civic traveling at 48 km/h was used to evaluate sub-compact automobile impact behavior.

The 480 mm guard provided good protection to the passenger compartment of the Cavalier in the test at 48 km/h. The vehicle was decelerated to a stop in 212 ms with a total displacement of 1441 mm. The maximum deceleration measured was 17.4 g's. There was no visible contact between the windshield and the structure, and there was no damage inside the passenger compartment as well. As shown in Figure 10, the test was judged to be successful.

Although the 480 mm guard provided good protection to the passenger compartment of the Cavalier in the test at 48 km/h, it was not capable to do so in the test at 65 km/h. As shown in Figure 11, a serious passenger compartment intrusion was observed during the test. The maximum vehicle deceleration was measured to be 19.3 g's, and vehicle came to a complete stop at 247 ms after initial contact with the guard.

The 480 mm guard did not provide a good protection to the passenger compartment of the Honda Civic, in large part due to the frame of the vehicle sliding under the horizontal member of the guard. By the time the horizontal member was contacted by the engine, it had rotated such that it just struck the top of the intake manifold. The horizontal member then skipped over the engine, contacted slightly the suspension post and came to rest on the A-pillars, deforming those slightly. The driver and passenger side widows shattered, as did a large portion of the windshield. The base of the windshield was pushed inside the passenger compartment. The vehicle was decelerated to stop in 222 ms with a total displacement of 1775 mm. The measured maximum vehicle deceleration was 16.6 g's. Figure 12 shows the post test pictures for this crash test. Note that given that poor performance of the 480 mm guard in this test, necessity for a stronger guard became apparent to safely stop particularly Honda Civic.

Figure 10. Chevrolet Cavalier cash test into 480 mm guard at 48 km/h

Figure 11. Chevrolet Cavalier crash test into 480 mm guard at 65 km/h

Figure 12. Honda Civic crash test into 480 mm guard at 48 km/h

3.4 480 mm displacement limiting guard

A total of three tests were performed with the 480 mm displacement limiting guard. In one of those tests a Chevrolet cavalier traveling at 65 km/h was used. The other two tests were performed using Honda civics traveling at 48 and 56 km/h. The purpose of these tests was mainly to evaluate the performance of a guard whose vertical motion was limited so that the ground clearance never exceeds 560 mm. This performance was evaluated by repeating the two tests where the 480 mm guard without displacement limiting mechanism had not provided adequate protection to the passenger compartment. These tests represented, as shown in table 1, crash tests 4 and 6 which were involved Chevrolet cavalier at 65 km/h and Honda civic at 48 km/h, respectively.

The Chevrolet Cavalier was the first vehicle tested with the 480 mm displacement limiting guard. This guard design provided much better protection to the passenger compartment of the Chevrolet Cavalier than did the 480 mm guard without displacement limiting property at 65 km/h impact. There was no contact between the support structure and the vehicle of windshield throughout the test. The vehicle was decelerated to a complete stop in 113 ms with a total displacement of 1388 mm. The maximum measured vehicle deceleration was 30 g’s. Figure 13 shows post test pictures for this crash. It should be noted that the crash resulted some damage inside the passenger compartment on the driver’s side.

For the test with Honda Civic the severity of impact was less than that of the Cavalier mainly due to reduced vehicle weight and speed. At 48 km/h, Honda Civic crashed the 480 mm displacement limiting guard head on. Guard provided good protection to the passenger compartment. There was no contact between the support structure and the vehicle or windshield. The vehicle was decelerated to a complete stop in 182 ms with a total displacement of 1457 mm. The maximum vehicle deceleration was 19.8 g’s. There was no visible damage inside the passenger compartment, except for the cracked windshield (caused by the hood folding during the crash). Figure 14 shows post test pictures for this crash.

The 480 mm displacement limiting guard provided good protection to the passenger compartment of Honda Civic when impacted at 56 km/h. There was little or no contact between the structure and the vehicle or windshield. The vehicle was decelerated to a stop in 183 ms with a total displacement of 1605 ms. The maximum vehicle deceleration was 21.4 g’s. As shown in Figure 15, there was no visible damage inside the vehicle.

4. Summary of crash test results

When the results of the simulated trailer mounted underride guard tests are reviewed, the following can be mentioned for each of the three categories of vehicles tested:

4.1 Light trucks and vans

The representative for this vehicle category was the Ford Windstar, and it was tested against only the 560 mm guard. Test results showed that the guard worked well against this size of vehicle. The Windstar was large enough that rotation of the underride guard around its supports at the simulated trailer did not impair its ability to slow the vehicle down and stop it prior to passenger compartment intrusion (PCI). This vehicle was only tested at 48 km/h.

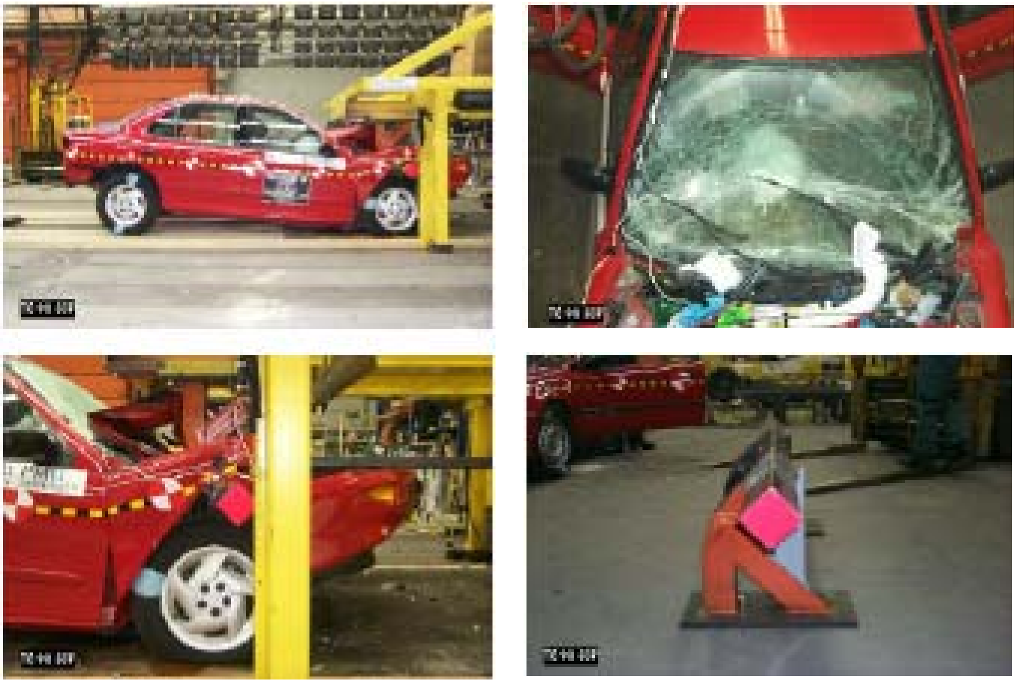

Figure 13. Chevrolet Cavalier crash test into 480 mm displacement limiting guard at 65 km/h

Figure 14. Honda Civic crash test into 480 mm displacement limiting guard at 48 km/h

Figure 15. Honda Civic crash test into 480 mm displacement limiting guard at 56 km/h

4.2 Compact automobiles

This vehicle category was represented by the Chevrolet Cavalier. Tests were performed with the 560 mm guard at 48 km/h, the 480 mm guard at 48 and 65 km/h and the 480 mm displacement limiting guard at 65 km/h. The test results show that:

1. the 560 mm guard could not stop the vehicle in time to prevent PCI and therefore did not provide acceptable protection to the occupant compartment,
2. the 480 mm guard offered adequate passenger compartment protection for the crash at 48 km/h but could not prevent severe PCI at 65 km/h,
3. the 480 mm displacement limiting guard prevented PCI at 65 km/h, at the expense of higher vehicle decelerations (30 g's).

4.3 Sub-compact automobiles

This vehicle category was represented by the Honda Civic, and a total of 5 tests were performed. It was found that this vehicle, being the lowest of those tested, provided the toughest challenge for the underride guard. Three of these tests were performed at 48 km/h using 480 mm guard, 480 mm displacement limiting guard and 560 mm slanted guard. Two other tests were performed at 56 km/h using 560 mm guard and 480 mm displacement limiting guard. The test results show that:

1. the 560 mm guard could not stop the vehicle and consequently it crashed into the rigid wall supporting the simulated trailer structure. The vehicle underride was significant and so was the damage to vehicle. At the moment of impact vehicle was traveling at 22 km/h. This test conclusively shows the inadequacy of FMVSS 223 standards in providing acceptable protection to the passenger compartment intrusion.
2. the 480 mm guard could not offer adequate protection for the crash at 48 km/h and as a result PCI occurred. Video of the crash shows the vehicle body structure sliding under the horizontal member of the underride guard, causing it to rotate around its pivot points.

3. the 480 mm displacement limiting guard provided good passenger compartment protection at both 48 and 56 km/h impacts.
4. the 560 mm slanted guard provided good passenger compartment protection at 48 km/h. A test was not performed at 56 km/h on this guard.

Test results for Honda Civic showed that a stiffer guard will stop a vehicle more quickly, thereby reducing the risk of PCI. This behavior was very similar to test results obtained from the Chevrolet Cavalier tests. In addition, occupants of a modern sub-compact vehicle can survive a collision at speeds of 56 km/h despite the increased deceleration levels. Finally, it is possible to design guards that will have a pre-crash ground clearance of 560 mm and still provide sub-compact vehicle occupants with a satisfactory level of protection at 48 km/h, if the guard is stiff enough and maintains good engagement with the vehicle structure.

5. Final crash testing

After the 10 full-scale crash tests described above, an additional crash test was performed using a 1998 Honda Civic and a 16 meter long semi-trailer (Boucher 2000b). The rear of the trailer was fitted with an improved underride guard design expected to stop sub-compact Honda Civic in a acceptable manner. A sketch of the guard showing its members and their dimensions is depicted in Figure 16. The most important improvement for the new guard was the location. Instead of moving the guard under the trailer, in the improved design the guard was flushed with the rearmost surface of the trailer. This automatically reduced the amount of vehicle underride during a collision. The ground clearance of the guard when vehicle unloaded was 520 mm. The guard is consisted of 3 mm thick hollow steel members. A 101 mm wide x 101 mm deep x 2860 mm long horizontal member was used to support two 76 mm wide x 101 mm deep and 480 mm long vertical members. Two diagonal 50 mm wide x 50 mm deep x 680 mm long members were used to connect horizontal member to vertical members as shown in Figure 16. These diagonals are intended to strengthen the horizontal member against impact forces. The vertical members were also supported by 35 mm wide x 35 mm deep x 750 mm long struts. Struts were attached to trailer and intended to reduce the rearward deflection of vertical members during vehicle impact by increasing their flexural strength.

The trailer and the Honda Civic were aligned for rear impact at an outdoor facility in Transport Canada Laboratory. The purpose of this final crash test was to evaluate the strength, energy absorption characteristics of underride guard and compare vehicle deceleration, amount of vehicle underride with acceptable criteria. The crash speed was selected to be 56 km/h to represent moderate impact. The test weight of the Honda Civic was 1229.5 kg. Two dummies were used in the test; one representing the driver and the other for the passenger to quantify the severity of impact on the occupants.

During the impact the semi-trailer moved forward a distance of 185 mm. As shown in Figure 17, there was no contact between the trailer frame and the Honda Civic. Damage inside the passenger compartment was minimal. The maximum vehicle deceleration was 24 g's, which is acceptable. The guard was received minor damage and it is decided that it can resist another similar magnitude impact with confidence. The Civic was decelerated to a complete stop in 149 ms with a total displacement of 1310 mm. Table 4 summarizes the test results.

The data recorded by the crash dummies were compared to the suggested Injury Assessment Reference Value (IARV) for several criteria. Results were within the acceptable limits. Based on the crash test results, it appears likely that this crash would have been survivable. It was concluded that this guard could be a good representation of acceptable underride guard properties and could be used to develop a draft specification.

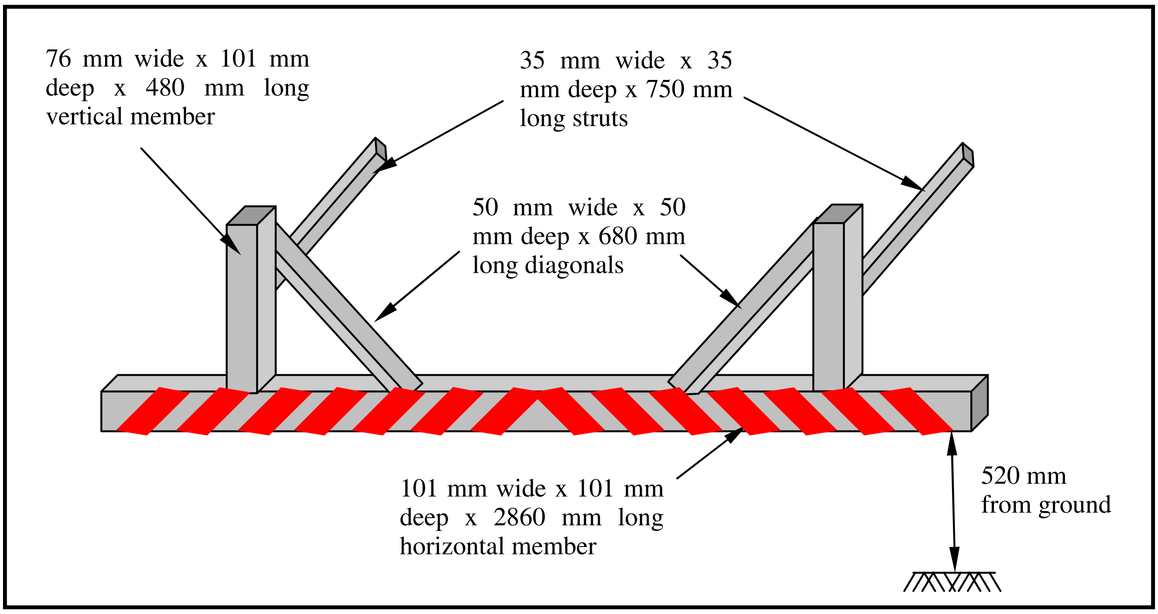

Figure 16. Sketch of underride guard used in the final crash test

Table 4. Test results – Honda Civic Crashes at 56 km/h

Test Number	Test 1	Test 2	Test 3
Vehicle Weight (kg)	1236	1266	1229.5
Guard Type	560 mm Guard	480 mm DLG	520 mm
Stopping Distance (m)	> 2.37	1.61	1.31
Maximum Vehicle Deceleration (g's)	17.5	21.4	24.3
Test Result	Failure	Acceptable	Acceptable

Figure 17. Final crash test on trailer mounted underride guard

6. Draft underride guard specification

Scope:

To establish minimum requirements for the manufacture and installation of rear underride guards to be attached to trucks, trailers and semi-trailers with gross vehicle weight rating (GVWR) above 4,536 kg.

Purpose:

To prevent material damage to the upper and lower parts of the passenger's compartment of vehicles colliding with the rear end of trucks, in order to avoid or minimize trauma on the upper and lower parts of the victim's bodies.

Application:

All trucks, trailers and semi-trailers with a gross vehicle weight rating above 4,536 kg, except the vehicles described below.

i. Incomplete of unfurnished
ii. Tractor trucks
iii. Military and collector's vehicles

Specific requirements:

The rear underride guards must comply with the requirements specified in 1 through 7 below:

1. The lowest height of the rear guard's horizontal member shall not exceed 520 mm when vehicle is unloaded.
2. As shown in Figure 18 below, the horizontal member of the guard will be flush with the rearmost surface of the truck.
3. The length of the rear guard's horizontal member shall neither be shorter than 100 mm on either side, nor exceed the largest dimension of the cargo bed width.

4. The guard shall be straight, uniform in shape, seamless, without holes and made from a single type of material.
5. The welding material shall be compatible with the material of the chassis beams.
6. The guard should not hinder visibility in terms of the vehicle's rear warning lights and license plate according to the respective requirements.
7. The guard shall be painted with reflective red and white stripes, inclined at a 45 degree angle as shown in Figure 19. The quality and reflectivity of stripes shall conform to government standards.

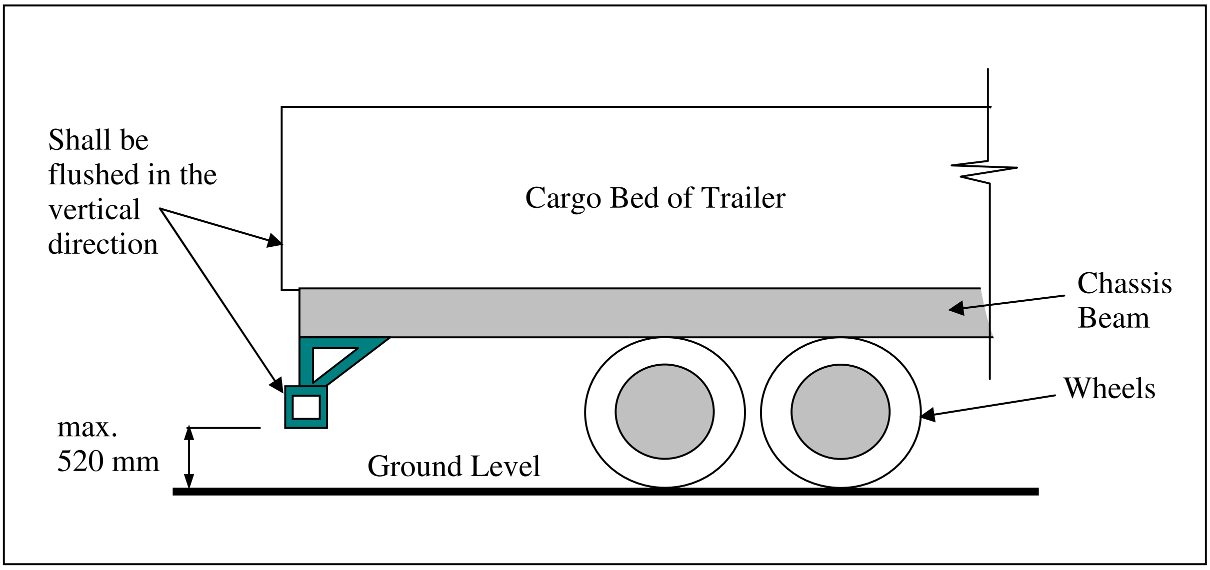

Figure 18. Position and alignment of proposed rear underride guard in a typical heavy vehicle

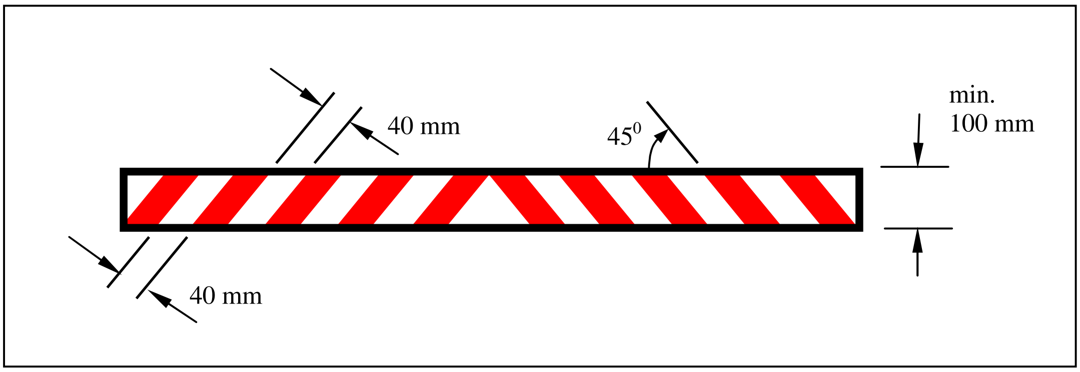

Figure 19. Reflective red and white stripes on the horizontal member of the guard

Test procedure

A candidate underride guard should be tested in a static manner. A candidate guard shall be attached to a simulated trailer setup and loaded in static manner. The magnitude and distribution of loads shall be equivalent to dynamic loads applied by impacting vehicle. An appropriate conversion method shall be selected to determine the static load equivalents and its application points. The maximum load shall be applied on the guard and load-displacement data shall be recorded.

Desired performance:

The performance of the underride guard after testing shall conform the following criteria:

i. The deflection of the horizontal member during the static loads, as specified in the FMVSS 223 standard, shall not be in excess of 125 mm in the direction of impact when full static load was applied.

ii. The guard structure, its components and welds used to hold the guard in place shall not exhibit any signs of fracture during the loading.

iii. To reduce the overall weight of the guard, light materials will be used as much as possible.

Approval and refusal of approval

i. Regarding its dimensions. The guard is considered approved if it meets the requirements specified in this draft specification.

ii. The maximum permanent deformation of the guard horizontal member after the static test shall not be greater than 125 mm relative to its original position.

iii. Cracks at the welds or fractures at the guard or chassis beams produced during the test will not be allowed. The final approval of the guard shall be made by the transportation officials.

7. Conclusions

Based on this study it was determined that the height of underride guard from ground, the position of guard with respect to rearmost surface of trailer and deformation potential of guards during vehicle impact have significant effect on the acceptability of underride guard crash performance. It was clearly demonstrated that FMVSS 223 compliant guards with a ground clearance of 560 mm did not provide acceptable crash behavior. Moreover, FMVSS 223 compliant guard with a 480 mm ground clearance was unable to prevent occurrence of severe PCI. It was concluded that a guard complying with FMVSS 223 standard was inadequate and an improved guard with increased flexural strength and impact resistance was necessary to safely stop vehicles that tend to underride heavier vehicles.

Full scale crash test results show that improved guard was a promising alternative for FMVSS 223 compliant guards and can be used for the development of a draft standard for underride guards.

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