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A Discussion on Rear Underride Protection in Canada

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INTRODUCTION

Rear underride occurs when a relatively small vehicle, such as a passenger car, collides with the rear of a much larger and heavier vehicle, and the front of the smaller vehicle slides under the rear of the larger vehicle. In the worst case, the smaller vehicle underrides the large vehicle sufficiently that the large vehicle's rear extremity enters the passenger compartment of the small vehicle. This effect, referred to as "passenger compartment intrusion" (PCI), frequently results in fatalities.

Canada currently does not require rear impact guards, with the exception of some tanker trailers designed to transport dangerous goods; these must be fitted with a rear impact guard meeting the requirements of Canadian Standards Association (CSA) standard B-620-1998 [6]. It should be noted, however, that this rear impact guard is essentially designed for the protection of the tank valves rather than for the protection of the occupants in the colliding vehicle.

A test programme was undertaken to verify the performance of a rear impact guard built to comply with the requirements contained in FMVSS 223/224 when impacted by representative vehicles sold in Canada.

UNDERRIDE GUARDS

Three guard designs were used in this test programme, all based on the design developed for the Canadian Trucking Equipment Association (CTEA) [11]. The base guard consisted of a CTEA-guard weakened so that it barely met the minimum strength requirement specified in S5.2.1 of FMVSS 223 (referred to as the minimally compliant guard or MCG). The second guard was a MCG that included a device to limit the vertical displacement of the horizontal member once it had reached a ground clearance of 560 mm as shown in Figure 1 (displacement limiting guard or DLG). The third guard consisted of a CTEA-guard where the vertical posts had been slanted so that they rotated through an arc, thus having an initial and final ground clearance of 560 mm as shown in Figure 2 (stronger slanted guard or SSG). Two sizes of MCG were used in the tests, one with a ground clearance of 560 mm and the other with a ground clearance of 480 mm.

CRASH TESTING

Three test vehicles were used in this programme, each representing a specific vehicle category. A 1998 Ford Windstar represented the light truck and vans category, a 1998 Chevrolet Cavalier represented compact vehicles and a 1998 Honda Civic represented sub-compact vehicles. These models were selected because of their sales volume in Canada in 1994, 1995 and 1996. Table 1 shows some of the characteristics of each of the test vehicles, as well as the test matrix; tests 8, 9 and 10 (shaded) were performed with Anthropomorphic Test Devices (ATD). The ATD in the driver position was a 5th percentile female Hybrid III while the ATD in the passenger position was a 50th percentile male Hybrid III.

Table 1. Information on Test Vehicles and Test Conditions

Test No.	Vehicle Model	Engine	Transmission	Test Mass [kg]	Guard Type	Test Speed (nominal)
1	Windstar	3.0 L	A4	1943	560 mm MCG	48 km/h
2	Cavalier	2.2 L	M5	1386	480 mm MCG	48 km/h
3	Cavalier	2.2 L	M5	1391	560 mm MCG	48 km/h
4	Cavalier	2.2 L	M5	1389	480 mm MCG	65 km/h
5	Cavalier	2.2 L	M5	1387	480 mm DLG	65 km/h
6	Civic	1.6 L	M5	1223	480 mm MCG	48 km/h
7	Civic	1.6 L	M5	1231	480 mm DLG	48 km/h
8	**Civic**	**1.6 L**	**M5**	**1267**	**560 mm MCG**	**56 km/h**
9	**Civic**	**1.6 L**	**M5**	**1229**	**480 mm DLG**	**56 km/h**
10	**Civic**	**1.6 L**	**A4**	**1236**	**560 mm SSG**	**48 km/h**

TEST RESULTS

Ford Windstar - The 560 mm MCG provided good protection to the passenger compartment of the Windstar and there was very little damage inside the passenger compartment. This test demonstrated that a minimally complying guard could offer good protection to occupants of a minivan in a collision at 48 km/h. Figure 3 shows the Windstar in the post-test condition.

Figure 1. Detail of displacement limiting device on DLG

Figure 2. Close-up of SSG

Figure 3. Ford Windstar, 560 mm MCG, 48 km/h

Chevrolet Cavalier - A total of four tests were performed with this vehicle; two tests were performed at 48 km/h and two others at 65 km/h.

560 mm MCG, 48 km/h - The 560 mm MCG did not provide good protection to the passenger compartment; the guard contacted and deformed the A-pillar on the drivers-side. The test structure came in contact with the top of the windshield (see Figures 4 and 5). Also, the steering wheel was displaced downward, pinching the lead bags used as weight between its rim and the seat.

480 mm MCG, 48 km/h - The 480 mm MCG provided good protection to the passenger compartment. There was no contact between the structure and the windshield and there was no damage inside the passenger compartment. This test showed that a MCG with a reduced ground clearance to 480 mm could provide good protection to occupants of compact vehicles in a collision at 48 km/h.

480 mm MCG, 65 km/h - The 480 mm MCG did not provide good protection to the passenger compartment of the Cavalier in the test at 65 km/h. The vehicle came to rest only after undergoing severe intrusion and extensive deformation of the A pillars (see Figures 6 and 7).

480 mm DLG, 65 km/h - For this test only, a 25 mm solid square rod was welded behind each of the stoppers, between the stopper itself and the concrete barrier at the rear. This was done to prevent any movement of the stopper during the crash. The 480 mm DLG provided much better protection to the passenger compartment of the Chevrolet Cavalier than the 480 mm guard did; there was no contact between the structure and the vehicle or windshield. Some damage was evident inside the passenger compartment on the driver side, but none on the passenger side.

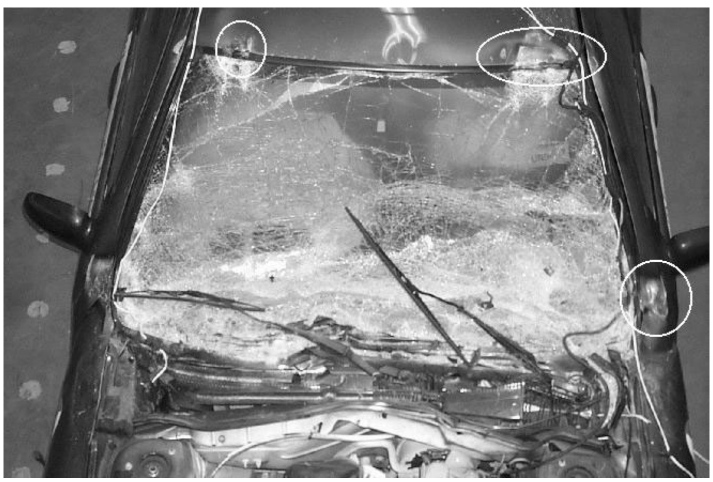

Figure 4. Exterior damage to Chevrolet Cavalier, 560 mm MCG, 48 km/h

Figure 5. Detail of damage to A-pillar, Chevrolet Cavalier, 560 mm MCG, 48 km/h

Figure 6. Chevrolet Cavalier, 480 mm MCG, 65 km/h

Figure 7. Details of damage to A-Pillar, Chevrolet Cavalier, 480 mm MCG, 65 km/h

Honda Civic - A total of five tests were performed with this vehicle.

480 mm MCG, 48 km/h - The 480 mm MCG did not provide good protection to the passenger compartment of the Honda Civic. This was in large part due to the frame of the vehicle sliding under the horizontal member of the guard. By the time the horizontal member of the guard was contacted by the engine, it had rotated such that it struck the top of the intake manifold. The horizontal member then skipped over the engine, contacted slightly the suspension posts and came to rest by deforming the A-pillar. The driver-side and passenger-side windows shattered, as did a large portion of the windshield. The base of the windshield was pushed inside the passenger compartment.

480 mm DLG, 48 km/h - The square rods were not used in this test, because of the reduced velocity and weight of the Civic compared to those of the Cavalier. The 480 mm DLG provided good protection to the passenger compartment; there were no contact between the structure and the vehicle or windshield. There were no visible damage inside the passenger compartment, except for the cracked windshield (caused by the hood folding during the crash).

560 mm MCG, 56 km/h - The 560 mm MCG failed to stop the Honda Civic before it collided with the concrete wall supporting the structure. The Civic was travelling at approximately 22 km/h when it struck the concrete barrier. This barrier is located approximately 2.4 m from the rearmost surface of the structure. The post-test ground clearance of the guard was 660 mm. The necks of both ATDs were damaged beyond repairs. Damage to the passenger compartment was severe; the roof was pushed down by the underside of the structure (see Figures 8 and 9).

480 mm DLG, 56 km/h - The 480 mm DLG provided good protection to the passenger compartment. There was little or no contact between the structure and the vehicle or windshield (see Figure 10). There was no visible damage to the passenger compartment. The post-test ground clearance of the guard was 555 mm.

560 mm SSG, 48 km/h - The test with the 560 mm SSG was performed at 48 km/h since no previous quasi-static or dynamic testing had been performed with this guard; the guard designer originally believed that the guard could withstand 320 kN but, when tested in the full-width test, it could only withstand 287 kN. The 560 mm SSG provided good protection to the passenger compartment; there were no contact between the structure and the vehicle or windshield (see Figure 11). There was no visible damage to the passenger compartment. The post-test ground clearance of the guard was 600 mm. Close examination of the guard after the test revealed that it had moved more than the expected 125 mm in the longitudinal direction. Also, the guard had rotated such that it was now resting on the vehicle structure; it is doubtful that this guard could have provided acceptable passenger compartment protection at a speed of 56 km/h (36% more kinetic energy at the beginning of the crash).

GUARD STRENGTH AND ENERGY ABSORPTION TESTS - These tests were performed at the Centre for Surface Transportation and Technology (CSTT) in Ottawa; for logistical reasons, these tests could only be performed after all the vehicle crash tests had already been completed. The three designs were tested. The MCG was tested in accordance with the P3 test of the Laboratory Test Procedure for FMVSS 223. Both the DLG and the SSG were tested in accordance with a newly developed Transport Canada test procedure; this new test procedure is similar to the FMVSS test except that loads are applied uniformly across the entire width of the rear impact guard.

Figure 8. Honda Civic, 560 MCG, 56 km/h

Figure 9. Front View, Honda Civic, 560 MCG, 56 km/h

Figure 10. Honda Civic, 480 mm DLG, 56 km/h

Figure 11. Honda Civic, 560 mm SSG, 48 km/h

GUARD TEST -Test results on the 480 mm DLG showed that the FMVSS Laboratory P3 test results could not be directly compared to those obtained in the full-width test (i.e., the full-width test does not result in loads twice as large as in the P3 test). The 480 mm DLG, which is essentially identical to the 560 mm guard for this type of test, offered a resistance of 171 kN while the maximum load in the P3 test was 121 kN; thus, the full width test resulted in a maximum load of only 1.4 times the load obtained in the P3 test. The load-displacement curves for both guards are shown in Figure 12.

It should be noted that the two test curves are not parallel, although their shape has similarities. The main reason for this behaviour appears to be the contribution of the “untested” vertical support in the P3 test. If the horizontal member is stiff enough, it will load the vertical support that is not being tested. For example, in Figure 13, the ram pushed on the post that is in the foreground and it can be seen that the untested support in the background was also deformed plastically. The resistance to load in a P3 test can exceed that for the full-width test (for the same ram displacement) if the untested support resistance is large enough, particularly if there is a twisting effect. This, of course, does not occur in a full-width test, due to the uniform loading of the underride guard along the entire length of the horizontal member.

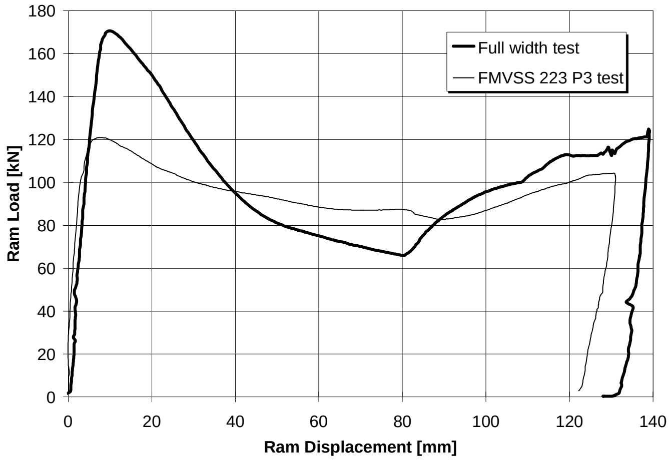

Figure 12. Results of full-width test on 480 mm DLG and FMVSS 223 P3 test on 560 mm MCG

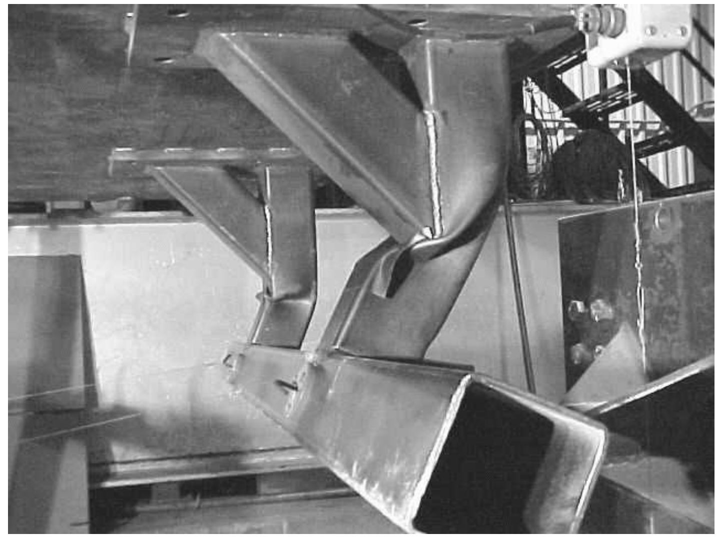

Figure 13. Close-up, 560 mm MCG in FMVSS 223 P3 test

CONCLUSION

The testing programme yielded the following conclusions:

1. The current Laboratory Test Procedure for FMVSS 223 does not permit the estimation of the total load that can be withstood by the whole guard. The guard design greatly influences the relationship between the resistance to a push on one support and that obtained in a full-width test. If the horizontal member is very stiff, the second support will contribute to the resistance of the tested support in a P3 test.

2. The minimally compliant guard mounted at 560 mm provided good protection to the passenger compartment of the Windstar at 48 km/h but could not provide good protection to the passenger compartment of the Cavalier at 48 km/h. This guard was not tested on a Civic at 48 km/h, but was tested at 56 km/h. The MCG was not capable of stopping the Civic without extensive PCI. The necks of the two ATDs used in that test were damaged beyond repair and had to be replaced; several of the ATD responses were greater than the IARV threshold for severe injury, indicating that both occupants would have likely been severely injured or killed.

3. The minimally compliant guard mounted at 480 mm ground clearance provided good protection to the passenger compartment of the Cavalier at 48 km/h but was not able to prevent PCI for the Civic at 48 km/h. Also, this guard was not able to prevent PCI for the Cavalier at 65 km/h.

4. The 480 mm guard with the displacement-limiting stopper provided good protection to the passenger compartment of the Cavalier at 65 km/h, and to the Civic at 48 and 56 km/h.

5. The 560 mm stronger slanted guard provided good protection to the passenger compartment of the Civic at 48 km/h. This guard demonstrates that a properly designed guard can protect occupants in a sub-compact vehicle even with an initial ground clearance of 560 mm, provided it is capable of absorbing the energy of the impacting vehicle.

RECOMMENDATIONS

The results of this programme have shown that it is possible to build a guard meeting, and even exceeding, the performance requirements specified in the US FMVSS 223 that cannot provide acceptable protection to the passenger compartment of compact and sub-compact automobiles. Since these vehicle classes represents approximately 35% of the light-duty fleet registered in Canada, it is important that improvements be made to the current FMVSS 223 requirements to provide protections to the occupants of these smaller vehicles.

The NHTSA (Table V-1 of [2]) found that 30% of the fatal crashes involving underride had occurred with a speed differential (Delta V) of 48 km/h or less; an additional 27% of these crashes occurred with a Delta V of 48 to 56 km/h, and a further 16% involved crashes with a Delta V of 56 to 64 km/h. This type of data does not exist for Canada; at best, speed limit at the scene of the collision is available. The Canadian data show that an estimated 80 to 90% of the fatal rear impact collisions involving trailers occur at posted road speeds at or above 80 kph.

Given that there is a significant portion of fatal collisions involving underride where the Delta V is between 48 and 56 km/h and that modern automobiles are built to withstand Delta Vs of 56 km/h (US New Car Assessment Programme), it is recommended that the safety standard for Canada require underride guards that will be able to prevent PCI at speeds up to 56 km/h.

To achieve this goal, it is recommended that;

1. The Test Method for CMVSS 223 specify an additional full-width test in its compliance procedure.

2. The full width uniform load test should have a minimum requirement of 350 kN before the ram displacement has reached 125 mm.

3. As the post collision guard deformed ground clearance is of paramount importance, it is suggested that an additional requirement be added that the guard ground clearance after the ram has displaced by 125 mm be no more than 560 mm.

4. The guard be capable of absorbing significantly more energy, potentially in the order of 20 kJ during a full-width test.

A guard meeting all these requirements is commercially and technically feasible. Accepting these requirements would also allow for easy harmonisation of US and Canadian requirements by allowing manufactures to install underride guards at 560 mm ground clearance.

FOLLOW-UP WORK

As a follow-up of the work described above, an additional test was performed using a 1998 Honda Civic and a 16-metre (53-foot) semi-trailer constructed by Manac; the rear impact guard fitted to the Manac trailer was designed to meet the requirements specified in the above recommendation. The purpose of the test was to validate the strength and energy absorption requirements and demonstrate the feasibility of building such a rear impact guard.

The crash speed was 56.5 km/h; under the impact the tractor-trailer combination vehicle moved forward a distance of 185 mm, despite the fact that the tractor and trailer parking brake had been set. There was no contact between the trailer frame and the Honda Civic and the damage inside the passenger compartment was minimal (see figures 14 and 15). The maximum vehicle deceleration was 24.3 G.

Figure 14. Honda Civic, Manac Guard, 56 km/h

Figure 15. Passenger compartment damage, Honda Civic, Manac Guard, 56 km/h

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