# DEVELOPMENT OF NEW UNDERRIDE GUARDS FOR ENHANCEMENT OF COMPATIBILITY BETWEEN TRUCKS AND CARS

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## ABSTRACT

As a consequence of the lack of effective rear underride guards attached to trucks, trailers and semi-trailers, rear underride crashes are responsible for thousands of deaths every year throughout the world. In an attempt to reverse this situation, cooperative work was started between a Brazilian university and local car and truck industries, whose main goals were to design, construct and test reliable underride guards and to present solutions to government authorities. To meet these goals, to date two new retractile underride guards have been designed and three crash tests carried out. Based on the results obtained so far, the Brazilian Association of Technical Standards (ABNT) has elaborated a new Brazilian standard for rear underride guards.

## INTRODUCTION

It is known that thousands of people throughout the world are killed or seriously injured in rear underride collisions every year [1, 3]. The rate of fatalities is high in this kind of crash because the truck bed and chassis can penetrate the car passenger compartment, hitting its occupants at the head and chest level. In this case, all the modern developments in automotive safety technology like airbags, seat belts and the energy absorption capability of the car by crushing are virtually worthless. These facts served as motivation to start cooperative work between the State University of Campinas and Brazilian automotive industries, whose primary objective was to save thousands of lives in collisions with rear ends of trucks by introducing effective underride guards.

This cooperative work, denominated "The Impact Project," was initiated about four years ago as a partnership between UNICAMP (State University of Campinas), General Motors do Brazil and Mercedes-Benz do Brazil.

In order to accomplish the main objective of the Impact Project, it was necessary to design, construct and test rear underride guards for trucks, trailers and semi-trailers and to provide suggestions to government authorities. Besides the technical activities, the Impact Project has also embraced a social-political-juridical-educational front, whose activities have included alerting the judicial system, media and society to the mortal threat posed by the rear ends of heavy vehicles and exerting pressure on the government to introduce a new regulation on underride guards. The strategy has consisted of presentations at Brazilian and international congresses and safety seminars [2-12], publication of reports in local newspapers and magazines, local radio and television interviews, creation and maintenance of an Internet web site (www.fem.unicamp.br/~impact), denunciation of the problem to the Brazilian Federal Attorney for Citizens Rights, sending of a detailed project to the Brazilian National Congress, participation in the committee which elaborated a new Brazilian standard for underride guards and presentation of a technical project to DENATRAN (Brazilian National Department of Traffic) in January of 1997.

## DESIGN REQUISITES FOR A RELIABLE REAR UNDERRIDE GUARD

To be able to avoid underride, a truck rear guard must meet some geometrical and strength requisites. Because the rear ends of trucks usually present an aggressive profile to passenger vehicles, the correct positioning of the rear guard is of extreme importance, with ground clearance and distance from truck or trailer bed being factors that determine its effectiveness [7].

To take maximum advantage of the energy absorption capability of the car front structure and to avoid the wedge effect (the effect obtained when the car front end slides under the truck rear guard and lifts the cargo bed), the ground clearance should never exceed 500 mm, with 400 mm being preferable [1, 4 and 13]. To reduce the penetration of the car underneath the truck or trailer chassis, it is necessary to position the guard as rearmost as possible, i.e., flush with the truck or trailer bed rear end [7].

Concerning the strength requisites, BEERMANN [14] and RECHNITZER et al. [1, 15] have postulated that an underride guard able to withstand the impact at about 50 km/h of a hypothetical medium-sized car should be designed to resist the static loads of P1 = P3 = 100 kN and P2 = 150 kN (Figure 1).

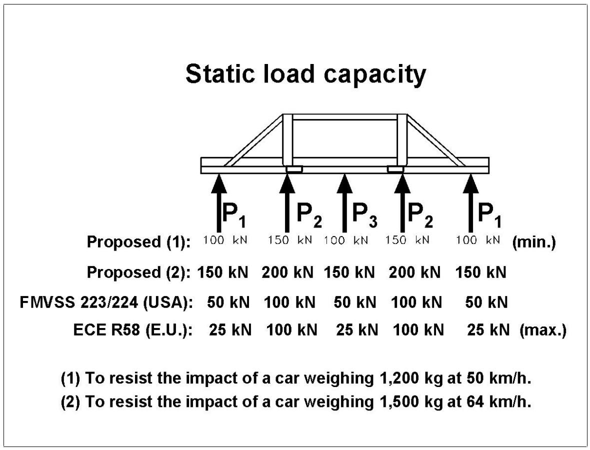


**Figure 1**
**Top view of an underride guard, showing test locations P1, P2 and P3 and the values of static load capacity required by the American FMVSS 223 and European E.C.E. R 58 regulations together with the values proposed by the Impact Project.**

## UNDERRIDE GUARDS DESIGNED BY THE IMPACT PROJECT

In order to fulfill the technical objectives of the Impact Project, two different underride guards have been designed and tested so far: the articulated underride guard and the conceptual pliers underride guard.

### The articulated underride guard

The first underride guard of the Impact Project team was designed so it could be easily manufactured using materials currently found on the market and easily attached to the truck. Furthermore, it should be as light as possible and not expensive. Since it is virtually impossible to meet all these requirements, the actual design had to include a concession regarding the final weight [7].

**Design Parameters -** With the aim of withstanding the impact of a 1,200 kg car at 50 km/h, this guard was designed to resist the static loads of P1 = P3 = 100 kN and P2 = 150 kN [1] (Figure 1). It was mounted with a ground clearance of 410 mm and flush with the truck's rearmost extremity. In order to avoid impairing the truck's maneuverability, the guard was attached to the chassis beams by means of two articulations, which gave the structure the ability to move upwards and backwards when hitting a ground obstacle [7] (Figure 2).

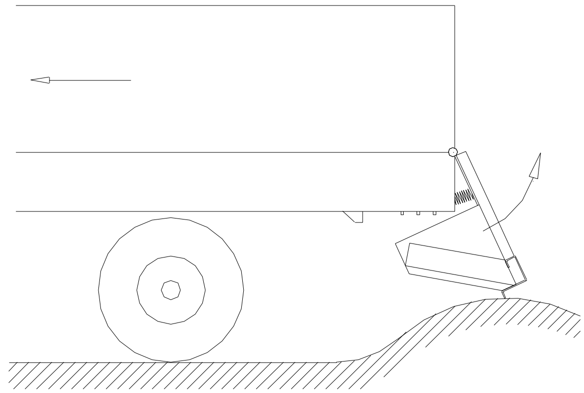

**Figure 2**
**The articulated underride guard moves upwards and backwards when it hits a ground obstacle [7].**

**Features -** The guard was manufactured using sheets and U-beams of SAE 1020 steel. Figures 3 to 6 present schematic drawings of the guard and some of its features. In essence, the guard consisted of a main beam (A in Figures 3 and 5) press-brake formed from a 5 mm thick steel sheet (beam cross-section shown in Figure 4), welded into two lateral supports (B) made of 7 mm thick steel sheets. These sheets were press-brake formed to provide the lateral supports with two flanges, one of which was designed to face the lower edge of the truck chassis beams (G). The other formed one of the guard drop arms. Two angle braces (C) and a transversal reinforcement (D), both made of tubular 100 X 45 X 5 mm beams, strengthened the structure. Two more reinforcements (E) of U 98 X 58 X 8 mm beams were welded onto the drop arm flange of each lateral support. The structure was fixed to the chassis beams by means of two articulations (F) with a diameter of 30 mm, which gave the guard the ability to articulate. The whole structure weighed about 75 kg.

To provide articulation capability to the guard structure, its fixation points had to lie on the same straight line. This kind of fixation, however, could not be effective in avoiding rotation of the whole structure about the vertical axis in the case of offset collisions. For that reason, it became necessary to provide the guard with additional supporting points that would work only the in case of impact. To avoid the sliding of the structure beneath the truck chassis beams if one of the articulations failed, two small steel blocks were welded onto the lower edge of the chassis (refered as "stop" in Figure 6). The lateral displacement that could occur in the case of offset collision should be prevented by three steel pins with a diameter of 20 mm, welded onto the lower edge of the chassis beams. These pins fit into oblong holes drilled into the lateral supports, allowing free articulation of the structure but blocking lateral displacements (Figure 6). Two springs, linking the drop arms to the chassis beams, were responsible for returning the structure to its rest position and for preventing guard oscillations during the ride [7].

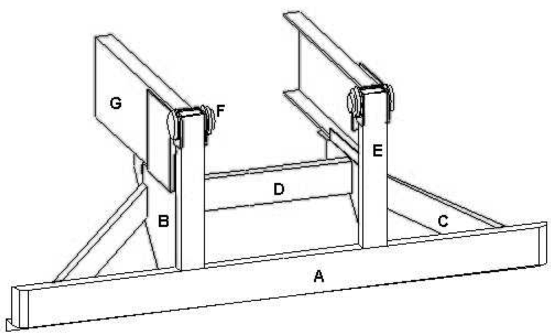


**Figure 3**
**Schematic drawing of the articulated underride guard.**

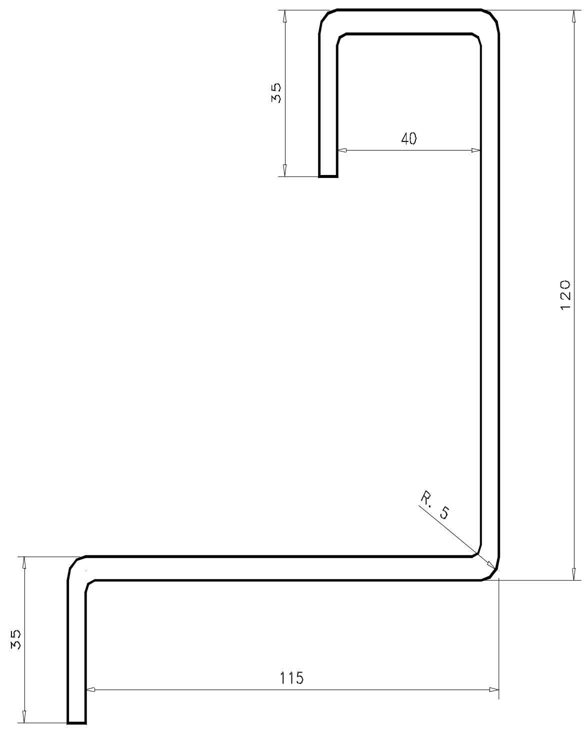


**Figure 4**
**Cross-section of the guard's main beam (A in Figures 3 and 5) [7].**

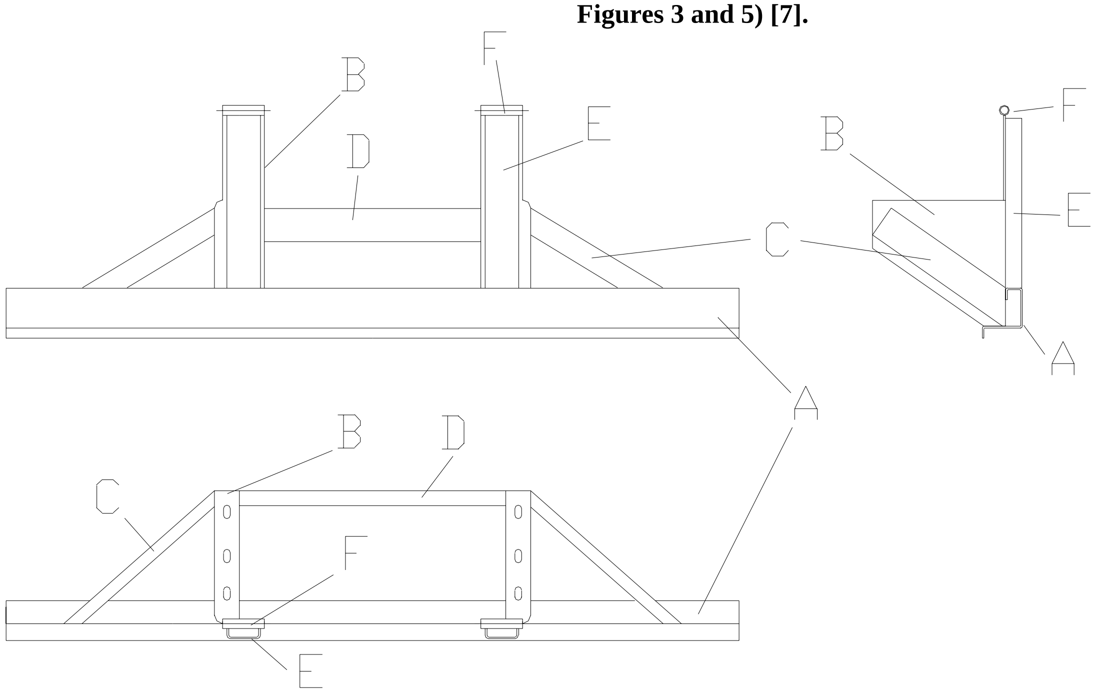


**Figure 5**
**Orthographic projections of the articulated underride guard [7].**

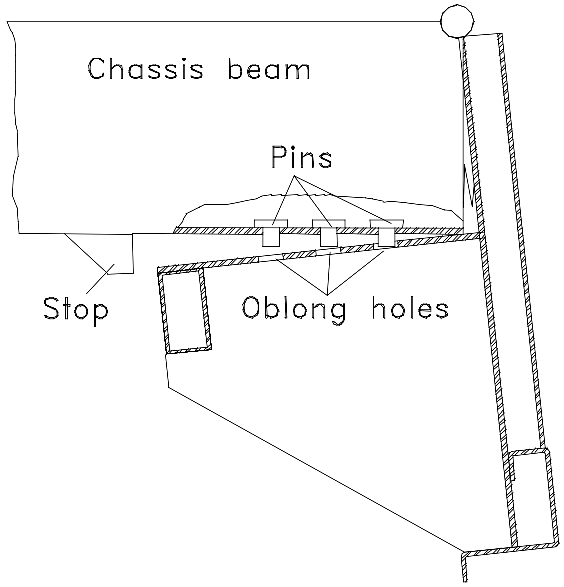


**Figure 6**
**Detail of the pins and stop used to restrain sliding and lateral displacement of the articulated underride guard during an impact [7].**

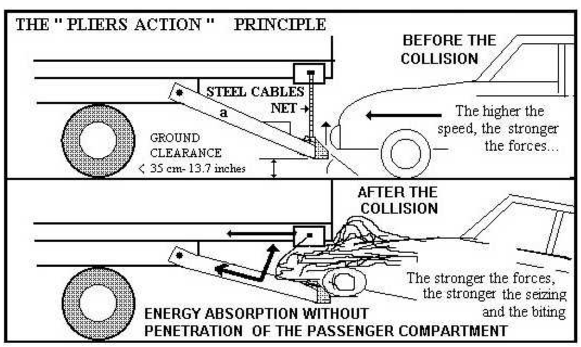


**Figure 7**
**Principle of the pliers underride guard [2, 4].**

**The pliers underride guard**

**<u>Principle</u> -** Based on the mechanical principle of a simple pliers tool, this underride guard proposed by SCHMUTZLER [2, 4] basically consists of a hanging frame held by a steel cable net. The frame is attached to the truck chassis beams by means of two articulations, which allows its upward movement if the truck hits a ground obstacle and also facilitates ground clearance adjustment in the case of large differences in height due to loading/unloading. In the event of a collision, the car front bumper will first touch the steel cable net, stretching the cables and consequently tending to lift the frame. The car front will be "bitten" by the frame and chassis beams, as if by a pliers (Figure 7). The compression of the car front end will avoid underride and the wedge effect. If the cables break, the frame will fall to the ground, preventing underride by working as a rigid barrier [10]. This principle would also make it possible for the car's front tires to collide with the guard, thereby giving rise to an additional way for energy to be absorbed not present in traditional underride guards.

**<u>Design Parameters</u> -** With the aim of preventing underride of a car weighing 1,500 kg at 64 km/h, this guard was designed to resist the following static loads: P1 = P3 = 150 kN and P2 = 200 kN (Figure 1). Unlike traditional underride guards, the forces arising from the impact would not act on the guard's main beam at first, but on the cables. Hence, for the purpose of calculations, the forces were considered to be acting on the middle point of the four vertical cables nearest points P1, P2 and P3. The guard was mounted with a ground clearance of 315 mm and flush with the truck's rearmost extremity [10].

**<u>Features</u>** [10] **-** The guard frame, shown schematically in Figure 8, was manufactured using SAE 1020 steel U-beams. Figure 9 shows the whole pliers underride guard attached to the truck before the crash test.

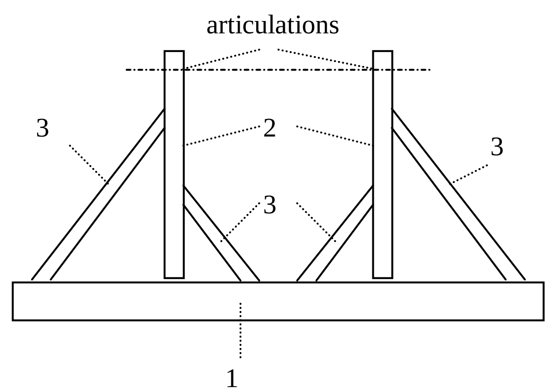


**Figure 8**
**Top view of the guard frame.**

A U 6" X 2" X 0.2" beam was used as the guard main beam (1 in Figure 8). This beam was mounted with an inclination of $60^0$ relative to a vertical line to facilitate the engaging of the car within the cables net during the impact. Two box-beams (made by welding two U 4" X $1^5/_8$" X 0.25" beams together (2) connected the guard main beam to the truck chassis beams by means of two articulations. Four angle braces made of U 4" X $1^5/_8$" X 0.18" beams (3) were welded between the guard main beam and the two box-beam arms. The steel cables net consisted of twenty-four cables, being twenty-two mounted vertically and two horizontally. Four cables (the two outermost vertical cables at each side of the net) had a diameter of 1/2" (12,7 mm), as long as the other eighteen cables had a diameter of 5/16" (8 mm). Since the wooden truck's cargo bed was not be strong enough to hold the cables during the impact, it became necessary to fasten the cable ends to an extra box-beam, made of two U 6" X 2" X 0.3" beams welded together. Additionally, two U 4" X $1^{5}/_{8}$" X 0.18" beams were assembled as angle braces between the chassis beams and this cables holder beam.

The only manufacturing operations required to construct the pliers underride guard were welding, turning and drilling. The overall weight of the first prototype was about 200 kg.

**Figure 9**
**Pliers underride guard before the crash test.**

## CRASH TESTS CARRIED OUT

Three crash tests have been carried out so far. Besides the two underride guards designed within the scope of the Impact Project, another one constructed in accordance with the current Brazilian regulation on the matter (CONTRAN Regulation No. 805/95 [16], which is a copy of European E.C.E. Regulation No. 58 [17]) was tested. The tests were carried out at the test site of General Motors do Brazil (*Campo de Provas da Cruz Alta* - *Indaiatuba* - *Brazil)*.

### Methodology

**Common Parameters** - The same Mercedes-Benz LK-1217 truck was used in the three tests. The truck was always ballasted to 10,000 kg and had its parking brake engaged during the impact. The impact always occurred at 50% offset on the car driver's side, and the three cars had their front suspensions lowered to simulate an emergency braking. Accelerometers attached to the tunnel of the cars measured the accelerations occurring during the test. A high-speed camera (1,000 frames per second) recorded the crashes [7, 10].

**Articulated underride guard** - The test was conducted with a GM Corsa Wind vehicle weighing 1,200 kg, including four water ballasts used to simulate passengers. The ballasts were restrained by conventional car seat belts. The car was accelerated to a nominal speed of 50 km/h by means of a steel cable system and released shortly before impact [7].

**Brazilian standard guard** - As test car a GM Corsa Station Wagon weighing 1,400 kg, including the four water ballasts, was used. As in the former test, the nominal impact speed was 50 km/h. The guard tested was constructed by a workshop accredited by the Brazilian National Institute for Standardization, Metrology and Industrial Quality *(INMETRO)* to manufacture underride guards according to CONTRAN Regulation No. 805/95. The workshop was not informed of the purpose for which the guard was destined [7].

**Pliers underride guard** - The test was conducted with a GM Vectra CD vehicle carrying four Hybrid 3 dummies and weighing 1,490 kg, including the dummies. The nominal impact speed was 64 km/h. Test data were acquired on fourteen channels. Accelerometers and load cells measured accelerations at the car and the dummies and forces at the dummies [10].

### Results

Table 1 presents some data from the three crash tests. The particularities of each test are described below.

**Articulated underride guard** - Figure 10 shows the final position of the car after the test. The car did not penetrate underneath the truck bed or chassis, thus no passenger compartment intrusion occurred. The impact occurred at the level of the car radiator. Although the weld that joined the articulation to the truck chassis beam on the impact side failed, the stops and pins shown in Figure 6 were able to prevent the structure from sliding beneath the truck bed. No other rupture was observed on the deformed guard structure. However, the truck chassis beams suffered significant bending. Only light damages to the car were observed. The windshield was not broken, the structural integrity of the passenger compartment was preserved, penetration of the steering column was negligible, no deformation of the instrument panel was observed and no intrusion of the pedals into the passenger compartment occurred [7].

**Brazilian standard guard -** The final status of the test can be seen in Figure 11. This guard could not prevent underride. It failed instantly after being touched by the car engine hood, permitting penetration of the car until hitting the truck rear tires, which functioned as the real underride guards. The car penetrated altogether 1.1 m underneath the truck chassis.

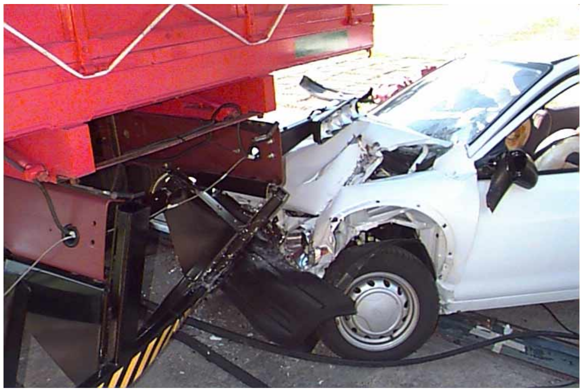

**Figure 10**
**Final position of the car after testing the articulated underride guard.**

**Figure 11**
**Final position of the car after testing the Brazilian standard guard (constructed according to CONTRAN Regulation No. 805/95 / E.C.E. R 58).**

Much more damage to the car was observed here than in the preceding test. The windshield was broken, the A-pillars deformed and the roof structure was not cut off only because the relative short overhang limited the intrusion. The instrument panel and the steering column of the car were pushed toward the driver's seat. If it had been a real accident, the driver would have at least broken both legs [7, 9].

**Pliers underride guard -** Figure 12 shows car and guard after the test. Contrary to the original idea, the car was not lifted by the guard frame, but rather the truck chassis beams were bent down. Nevertheless, the car front end was "bitten" by the structure as expected, which made it possible to take maximal advantage of the car's crushing capability. The guard frame suffered little plastic deformation and the steel cables did not rupture. On the other hand, the truck's chassis beams were severely bent down and its rear suspension damaged. The car's windshield and passenger compartment remained intact after the test. Yet no displacement or penetration of pedals, steering column or instrument panel was observed.

Some data obtained on the Hybrid 3 dummies during the test can be seen in Table 2. The HIC (Head Injury Criterion) value of 381 is noteworthy. This value can be regarded as low for an impact occurring at 64 km/h [18].

**Figure 12**
**Final position of the car after testing the pliers underride guard.**

**Comparison between the guards tested**

It became evident from the crash test that the CONTRAN/ECE guard is ineffective in avoiding underride at 50 km/h [9].

The articulated underride guard was able to avoid underride under the same conditions and could be considered ready to use after a few design modifications.

Despite having exhibited an excellent performance in the crash test, the pliers underride guard would require in-depth modifications to become commercially feasible, especially because of its weight; nevertheless, the technical feasibility of the principle could be verified.

The underride guards presented here were not object of any patent requirement.

**Table 1**
**Data obtained from the three crash tests carried out [11]**

| Guard type | CONTRAN /ECE [7] | Articu-lated [7] | Pliers [10] |
|---|---|---|---|
| Car type | GM Corsa Station Wagon | GM Corsa Wind | GM Vectra CD |
| Total car mass (kg) | 1,400 | 1,200 | 1,490 |
| Impact speed (km/h) | 50.0 | 50.1 | 63.9 |
| Dummies | Water ballast | Water ballast | Hybrid 3 |
| Car's kinetic energy at the impact (kJ) | 135 | 116 | 235 |
| Maximum longitudinal car accel. | -13G | -61G | -32G |
| Maximum vertical car acceleration | -17G | -17G | -18.1G |
| Maximum lateral car acceleration | -14G | -4G | +29.2G |
| Impact time (ms) | 250 | 200 | 200 |
| Underride | YES | NO | NO |
| Broken windshield | YES | NO | NO |

**Table 2**
**Data obtained on the Hybrid 3 dummies during the pliers underride guard test [11]**

| | |
|---|---|
| Maximum belt chest driver force | 6,768 N (at 84.5 ms) |
| Maximum belt pelvis codriver force | 8,310 N (at 77.4 ms) |
| Maximum driver head longitudinal acceleration | 53.6G (at 75.5 ms) |
| Maximum driver head vertical acceleration | 26.3G (at 117.6 ms) |
| Maximum driver head transversal acceleration | -24.7G (at 68.6 ms) |
| Maximum driver head resultant acceleration | 55.8G (at 75.4 ms) |
| Driver's HIC-36 | 381 |
| HIC-36 interval | $t_1$ = 102.7 ms $t_2$ = 138.7 ms |
| 3 ms peak within the interval $t_1$ - $t_2$ | 50.3G (at 117.6 ms) |

## THE NEW BRAZILIAN PROPOSED REGULATION FOR UNDERRIDE GUARDS

Thanks to the claims of the Impact Project that a new regulation on underride guards was needed, together with the technical results we were able to present, the Brazilian Association of Technical Standards (ABNT) formed a committee, on which one of the authors of this paper (L.O.F.S.) participated, with the scope of elaborating a Brazilian standard on the matter. At the same time, DENATRAN (the Brazilian National Department of Traffic) committed itself to issuing a new regulation as soon as the ABNT standard had been approved, in order to replace the current CONTRAN Regulation No. 805/95, which is a copy of E.C.E. Regulation R58. After working for about one year, the committee released proposal ABNT 39:002.01-002:1999 – *"Pára-choque traseiro para caminhões e veículos rebocados com massa total máxima acima de 4,6 t – Requisitos e métodos de ensaio"* (Rear guard for trucks and trailers with a gross vehicle weight of over 4.6 t – Requirements and test procedures) [18]. Based on this proposal, the Brazilian National Department of Traffic elaborated the new proposed regulation on rear underride guards. At the time of writing, DENATRAN is requesting comments on its proposal. The final standard has not yet been approved.

### Technical requisites

Tables 3 and 4 compare the most important technical requisites established by the new Brazilian proposed regulation with those of the existing regulations and with the proposals of the Impact Project.
The geometrical parameters established by the new Brazilian proposal (ground clearance of 400 mm max. and position of the rear guard flush with the rear extremity of the cargo bed) are in agreement with those advocated by the Impact Project, and it is apparent that they will bring considerable improvement in terms of safety compared to the existing standards.
Concerning the static load capacity of the underride guard, the new Brazilian proposal divides trucks into four groups according to weight and establishes different test loads for each group (Table 4). As already demonstrated by RECHNITZER [1], truck weight exercises very little influence on the necessary load capacity of the guard. So it does not seems to be reasonable to lower the strength requirements for the guard for lighter trucks.

**Table 3**
**A comparison between the geometrical requisites of different underride guard regulations (dimensions in millimeters)**

| Regulation | Ground clearance | Maximal distance from truck bed rear end |
|---|---|---|
| **New Brazilian proposed regulation [18]** | **400** | **0** |
| E.C.E. R58 [17] (Europe) / CONTRAN 805/95 [16] (Brazil) | 550 | 400 |
| FMVSS 224 [20] (U.S.A.) | 560 | 305 |
| Proposed by the Impact Project | 400 | 0 |

**Table 4**
**The quasistatic strength required by the new Brazilian proposal in comparison with that specified by other standards and the suggestion of the Impact Project (location of points P1, P2 and P3 according to Figure 1).**

| Standard | Truck and trailer maximum mass (M) (tons) | P1 (kN) | P2 (kN) | P3 (kN) |
|---|---|---|---|---|
| **New Brazilian proposed regulation [18]** | **4.6–6.5** | **50** | **75** | **50** |
| | **6.5–10** | **60** | **90** | **60** |
| | **10–23.5** | **80** | **120** | **80** |
| | **>23.5** | **100** | **150** | **100** |
| E.C.E. R58 [17] (Europe) / CONTRAN 805/95 [16] (Brazil) | < 20 | 12.5% of M | 50% of M | 12.5% of M |
| | > 20 | 25 | 100 | 25 |
| FMVSS 223 [19] (U.S.A.) | > 4.536 | 50 | 100 | 50 |
| Proposed by the Impact Project | all | 100 | 150 | 100 |

The strength values required by the new Brazilian proposal are satisfactory for trucks and trailers heavier than 23,500 kg. For this weight category, the new proposal complies with the claims of BEERMANN [14], RECHNITZER [1] and the Impact Project [7, 9]. For trucks between 10,000 and 23,500 kg the new proposal exceeds the specifications of the existing standards, but the strengths required are still below the minimum recommendable to guarantee the safety of car passengers. Regarding trucks lighter than 10,000 kg, the new proposal establishes values of P2 below those of the American FMVSS 223. The fact that the required values for P1 and P3 have been raised relative to the current CONTRAN regulation (from max. 25 kN to 50 kN or 60 kN, according to truck weight) contributes to minimizing the detrimental effect of this lowered strength. Since P2 is located at the strongest point of the structure, a guard designed to resist 50 kN or 60 kN at the weaker points, P1 and P3, will probably be able to resist at least 100 kN at P2.

There are two points in CONTRAN Regulation No. 805/95 that should have been modified, but have remained unchanged in the new proposal: the admission of a distance of up to 600 mm above the ground for test locations P1, P2 and P3 and the conduction of the strength test exclusively with the guard installed in the complete truck or trailer.

Concerning the first item, the value of 600 mm is meaningful under the current CONTRAN Regulation No. 805/95 because it specifies a ground clearance of up to 550 mm. Since the new proposal establishes a maximum ground clearance of 400 mm, keeping this dimension of 600 mm unchanged permits replacement of the main beam by a skirt made of a thin metal sheet that could be attached to the guard structure 600 mm above the ground, and which in the case of collision would easily bend and allow underride. Therefore, the distance from the ground of points P1, P2 and P3 should be limited to 450 mm.

Regarding the second item cited above, it is our opinion that the new proposal should also include the possibility of testing the guard attached to a rigid test fixture, as the American FMVSS 223 [19] does. Since the goal of the test is to verify the strength of the guard and its attachment hardware, and not the strength of the truck chassis, the use of a rigid test fixture could reduce test costs, eliminating the risk of damaging an entire truck or trailer.

## CONCLUSIONS

The campaign to highlight the problem and press government authorities, together with the technical results we were able to present, was successful in impelling the Brazilian National Department of Traffic to propose a new regulation on rear underride guards. Although this new proposal did not include all suggestions made by the Impact Project, it represents a substantial improvement over the current legislation on the matter. We hope that the new proposal will eventually be approved and that the Brazilian experience can then be of aid in the revision of other rear underride guard standards.

**ACKNOWLEDGMENTS**

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