IMPROVED CRASHWORTHY DESIGNS FOR TRUCK UNDERRIDE GUARDS

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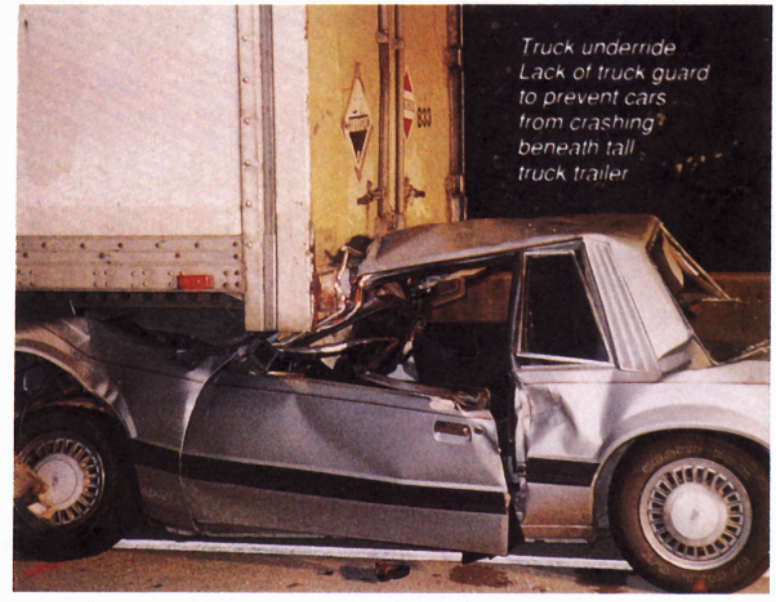


ABSTRACT

When a passenger vehicle collides with a large truck or trailer rig, this mismatch is further aggravated when the passenger vehicle continues beneath the rear or side of the taller truck. These are called ***truck underride*** crashes ... and often decapitate the upper half of the passenger vehicle and its occupants.

In the United States, there is a new federal motor vehicle safety standard requiring a rear underride prevention guard for newly manufactured truck trailers beginning in January 1998. The 22-inch maximum permitted height was based on 30 mph crash tests, yet contradicts prior NHTSA 35-to-40 mph crash test research that recommended an 18-to-20 inch height as necessary to protect smaller vehicles in 40 mph crashes. The guard strength is minimal, and the test is only a slow-push on an exemplar guard.

The new regulation also totally ignores the side underride hazard, which accounts for almost half of the U.S. fatalities in underride accidents each year.

Using existing technology, there are many feasible designs for rear underride guards and side underride guards that are effective, light-weight, and economical.

Such guards can be utilized on new trucks and trailers, as well as being capable of being retrofit to existing in-use trucks and trailers. Among the explored designs are (A) the use of Belleville spring-washer stacked pistons, (B) the use of rigid foam-filled convoluted tube structures, (C) the use of recycled non-metallic synthetics, and (D) cable entrapment platforms.

And what of the requirement for ***harmonization*** of vehicle safety standards, so that all member nations utilize the same underride guard requirements, and thereby impose a reduced burden for variety among the vehicle manufacturers?

Can there be a singular international safety standard for truck underride guards, and if so, it should be based on the most effective requirements, rather than compromised to meet the least-challenging requirements?

INTRODUCTION:
The Truck Underride Decapitation Epidemic

When a passenger vehicle crashes into and continues beneath.. or *underrides*... the rear or side of a large truck or trailer, the consequences to the vehicle's driver and passengers are often the extreme ripping into and crushing of the passenger compartment *"survival space"*, and severe or fatal head injuries or even decapitation. The prevention of passenger compartment intrusion (PCI) is clearly the primary purpose of having an underride prevention guard. Though estimates have varied over the years, there are likely about 200-to-300 fatalities in underride accidents each year in the U.S.

There is also the parallel issue of the front of a large truck crashing over... or *overrriding...* the lower structures of a passenger vehicle. Thus, there is a need for energy-absorbing and lower-to the-road frontal bumpers and overall design considerations to try to reduce the often lethal consequences of a massive truck colliding head-on with a smaller passenger vehicle. (The front override issue has been addressed in prior ESV papers, and continues as a major focus for needed safety improvements. This paper will focus on the truck rear underride and side underride issues and designs.)

In the United States, there has recently been a new requirement for an improved rear underride prevention guard for all newly-manufactured trailers and semi-trailers, as of January 26th, 1998. The new Federal Motor Vehicle Safety Standards are "Rear Impact Guards", FMVSS No. 223, and "Rear Impact Protection", FMVSS No. 224. The need for such underride prevention guards for trucks and trailers was initially proposed in 1967, some thirty years ago, as one of the initial standards promulgated by the then-newly- created National Highway Safety Bureau (NHSB).

After a laborious and often-delayed thirty-year process from its inception as a proclaimed safety need, until its enactment in 1995 and its implementation in 1998, there is concern that the long gestation period did not give birth to an optimal safety standard. Admittedly, the process was on-again, off-again, on-again, off-again to such a perplexing extent, that merely having "some standard at last" seems better than continuing that thirty-year delay even more. **Yet, the new NHTSA regulation has many shortcomings:**

- The regulation applies only to new trailers, and does not also include single-unit trucks, dump trucks, or other trucks with lethal designs.
- The permissible guard height above the ground can be up to 22 inches, but should be 16 to 18 inches to protect smaller vehicles.
- The guard's strength requirements are too weak, and were derived from 30 mph crash tests, but should have been based on 40-plus mph requirements.
- Does not address the side underride hazard, which accounts for almost 50-percent of all underride fatalities.

The NHTSA fixation on fatalities does not take into account the merits of underride guards in reducing the severity of injuries, or preventing them completely. Severe brain trauma, extensive facial fractures, and the loss of eyes, are notable injuries that can be prevented with underride guards.

In many years of investigating car-into-truck collision accidents and evaluating the crashworthiness of the involved vehicles, the authors have noted many truck underride accidents in which the ICC rear bumper was grossly ineffective in its failure to prevent the

intrusion into and crushing of the passenger compartment of the car, pickup, or van. In some cases, there was no rear or side guard or bumper at all.

In the United States, coal dump trucks and trash-hauling trucks typically do not have any rear underride guards or bumpers at all. In Brazil, and in many other nations as well, virtually all trucks are without underride guards,

or there is the pretense of a makeshift rear bumper that is totally ineffective. With or without governmental regulations, there is also neglect by truck and trailer manufacturers and operators to voluntarily and compassionately correct the underride hazard by designing and implementing safer trucks and trailers with effective underride prevention guards.

The truck industry in many nations, including the United States, has well known of the underride hazard and its toll of death and injury, but has delayed and argued and been indifferent to moving ahead constructively to help solve the underride hazard problems.

Many European nations, beginning with Sweden in the mid-1970's, have adopted rear underride guards. The European Economic Community (EEC) Commission Directive 79/490/EEC concerns rear underrun (underride) protection, and was enacted in 1979.

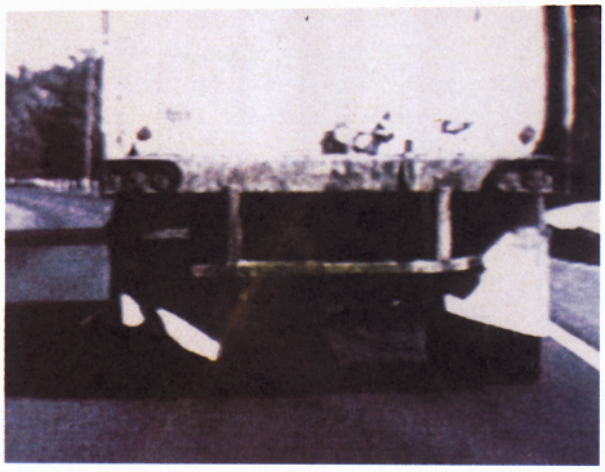
With regard to side underrun protection, ECE/TRANS/505 Regulation No. 73 was enacted in January 1988. While initially intended primarily to prevent pedestrians, cyclists, and motorcyclists from getting trapped beneath the long open sides of large trucks and trailers, the side underride guards have also been beneficial to help prevent cars from underriding, especially with angular crashes.

THE ICC REAR BUMPER IS OBSOLETE AND INEFFECTIVE

The 1953 ICC regulation for "Rear End Protection" has been demonstrated to be grossly ineffective. The vast majority of the ICC bumpers at the rear of trucks and trailers are too high off the ground (typically in the 24 to 28 inch range), are too narrow across the rear of the truck, and are too weak. These deficiencies of the ICC rear bumper have been shown in actual car-into-truck accidents and crash tests to fail to prevent a passenger car, minivan, compact pickup truck, sport utility vehicle, or van from penetrating deeply beneath the truck… resulting in passenger compartment intrusion (PCI) that causes severe to fatal injuries.

Nothing has prevented a truck or trailer manufacturer from designing rear bumpers that were safer, and were less than the "shall not exceed" maximums. Many years ago, they could have designed and installed rear bumpers that were **18 inches above the ground** (notably below the 30-inch maximum), and **full-width** across the truck's rear, and that had **strength and energy-absorbing features** that optimized the prevention of the underride hazard for vehicles that might crash into the rear of the truck or trailer.

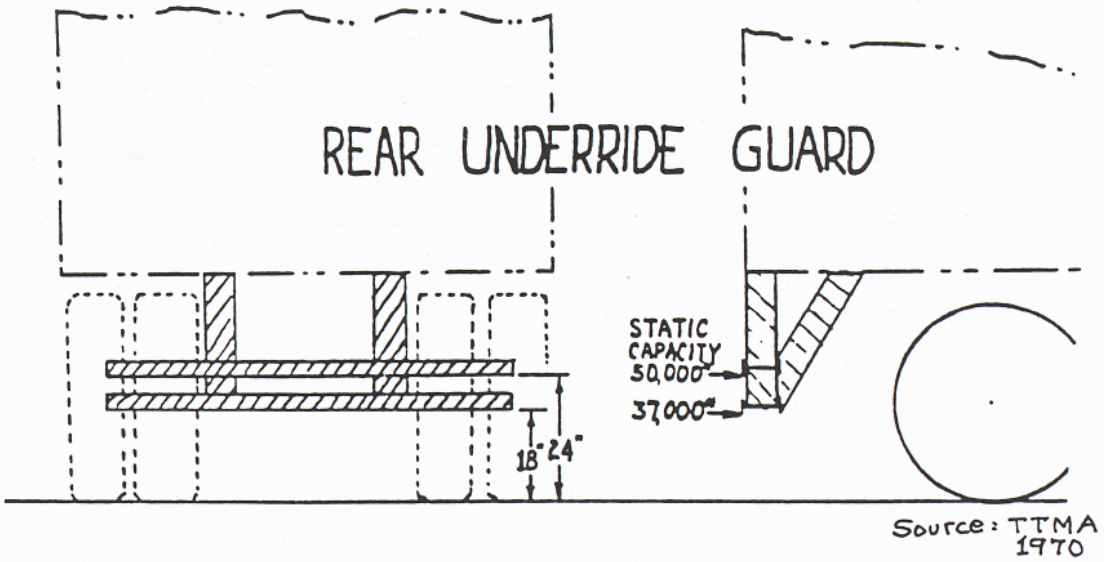
Over the past thirty years, safer rear underride guard designs have been discussed and described, but they have been largely ignored.

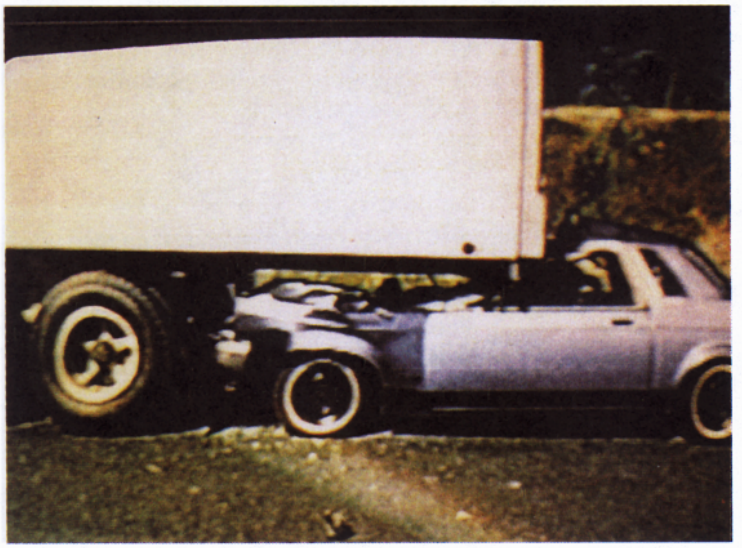


For example, the Truck Trailer Manufacturers Association (TTMA) back in 1970 noted that:

> ***"…it is within our competency to design and and mount on new trailers an underride guard capable of withstanding the test loads described in the DOT proposal and at a height of 18 inches above the road." "It is possible to provide the dual capability of 50,000 (pounds) at the 24-inch height and 37,000 (pounds) at the 18-inch height using the same structure. (See enclosed sketch)."***

Yet, in the subsequent 25 years since that 1970 proclamation, the TTMA did not recommended nor require that its trailer-manufacturer members actually implement such safer rear underride guards.





NHTSA STANDARD SHOULD ALSO APPLY TO TRUCKS

The new rear underride prevention guard requirement applies only to trailers and semi-trailers with a gross vehicle weight rating (GVWR) of 10,000 pounds or more. The standard does not apply to single-unit trucks, dump trucks, truck tractors, pole trailers, low chassis trailers, special purpose vehicles, or wheels back vehicles. A "special purpose vehicle" is defined as a trailer or semi-trailer that has work-performing equipment at the lower rear and whose function would be significantly impaired by a rear impact guard. The arbitrary weight requirement for excluding trucks and trailers below 10,000 pounds contradicts the fact that many light-duty and medium-duty and cab-chassis trucks are equipped with truck bodies that present the same lethal underride hazard as do the larger, heavier trailers and semi-trailers.

In its Final Regulatory Analysis of December 1995, NHTSA noted that over the past 13 years, total car-into-truck rear-end fatalities have averaged 421 per year, with 73-percent (308) due to collisions with combination truck-trailers, and the remaining 27-percent (113) due to collisions with straight trucks (GVWR greater than 10,000 lbs.). NHTSA noted that about 1.5 times more straight body trucks are manufactured each year compared to trailers (250,000 straight body trucks versus 162,000 trailers).

The fixation on fatalities does not take into account the merits of underride guards in reducing the severity of injuries, or preventing them completely. Severe brain trauma, extensive facial fractures, and the loss of eyes, are notable injuries that can be prevented with underride guards.

Because of NHTSA's abdication of setting a safer standard for straight trucks, it is important for the manufacturers and/or their trade association to voluntarily adopt a requirement similar to or preferably superior to FMVSS 223 and 224. Such a "Recommended Practice" should be issued by the Truck Trailer Manufacturers Association (TTMA), the American Trucking Associations (ATA), and the Truck Body Equipment Association (TBEA), and urged upon its members for immediate implementation.

Thus, the U.S. now has two different sets of regulations. For new trailers only, effective in 1998, there are FMVSS 223 and 224. But for all other new trucks, the old 1953 ICC regulation is applicable. And for all existing trucks and trailers, they are also still regulated by the old ICC regulation, since there is no retrofit requirement. Thus, there is truly a "double-standard" conflict for new trucks versus new trailers. Yet, the underride hazard is the same.

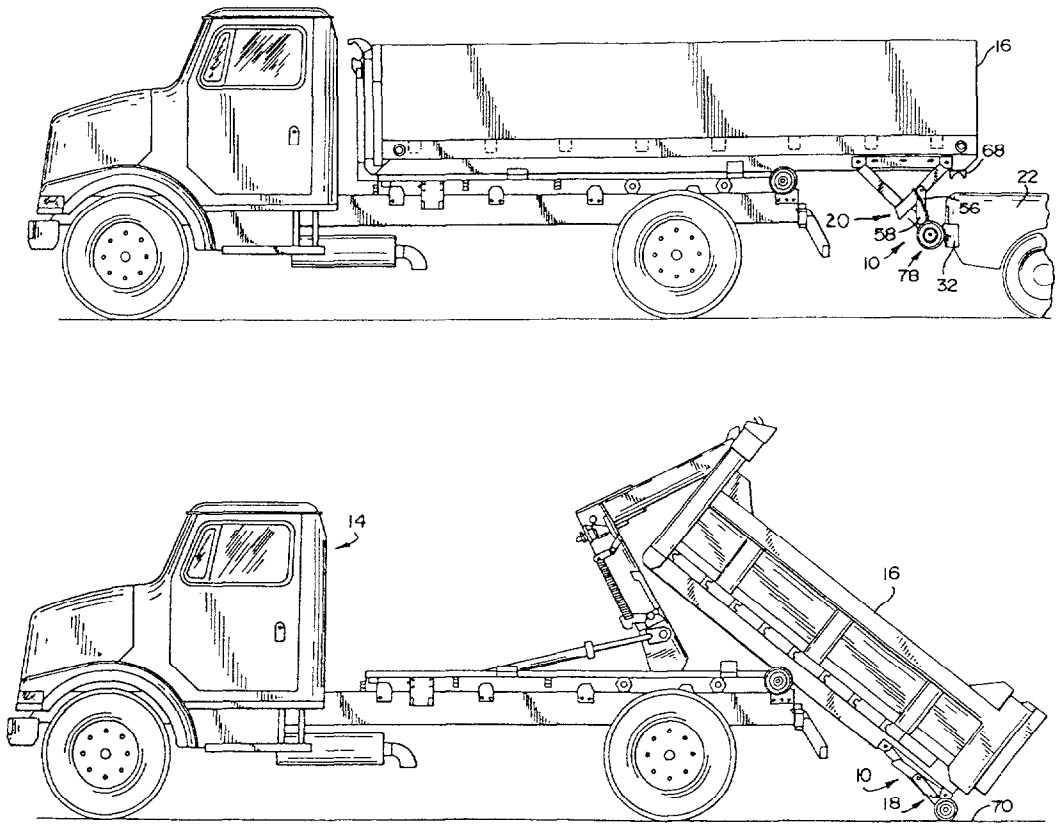
If you're a truck manufacturer, here's your dilemma... Let's assume you manufacture straight van trucks with a load floor or bed height at 36 inches, and city delivery van trucks with a bed height of 44 inches. Do you continue to use an ICC rear bumper that's permissibly (albeit unsafely) up to 30 inches above the ground, and is inboard about 18

inches from each side ? Or instead, do you incorporate a design that complies with the newer requirements as specified in FMVSS 223 and 224 which are specifically applicable to trailers. The decision should clearly be to adopt a lower, wider, stronger rear underride guard for all trucks.

Trucks come in all sizes, shapes, and weights... and they all should be designed to minimize the underride hazard if at all possible. There are coal dump trucks with extensive rear overhangs of about 6 feet, and they clearly present a lethal underride hazard.

Coal dump trucks and tilt-bed tow trucks and others can be feasibly equipped with rear underride guards that automatically pivot and fold rearward beneath the truck body as it tilts in performing its work function. Shown below is an example of a United States patent for a rear underride guard that can be retracted upward when the truck dump function is utilized, and then is returned down to an effective height to serve as an underride prevention guard when the dump truck is traveling on the road.

There are tow trucks with tiltable car-carrying platforms that project rearward like an ax blade. There are straight body trucks which have frame rails or bed heights in the 36-to-48 inch range, presenting an underride hazard virtually identical to that of a trailer. There are large trucks with tuck-under lift gates that are sloped beneath the rear of the truck and can thus accentuate the underride hazard by "funneling" the car even lower as it continues beneath the rear of the truck.



These drawings are from a United States patent that shows a rear underride guard for dump trucks. The guard is normally in a down position when the truck is traveling on the roads, but can be retracted pivotally upward when the truck is performing its dump functions at a work site.

DESIGN FOR CRASHES ABOVE 30 MPH AND LOWER GUARD HEIGHT

NHTSA's most recent crash test program to evaluate the underride situation involved the use of the subcompact GM Saturn and Honda Civic, and the compact-size Ford Tempo and Chevrolet Corsica sedan and Beretta coupe. The car crashed into either a rigid guard or a moderate-strength guard, which were mounted to either a 1988 Fruehauf 48-foot-long trailer, or a specially-constructed Rigid Test Fixture that had a ground-to-floor-bottom height of about 49 inches. (Refer to "Heavy Truck Rear Underride Protection," VRTC-82-0267, Vehicle Research and Test Center, East Liberty, Ohio, June 1993, Final Report, DOT HS 808-081.)

The 30 mph crash level for the new NHTSA regulation is grossly inadequate, since the technical capability exists to exceed at least a 40-plus mph level. Accident data and case evaluations indicate that the vast majority of truck underrides occur in the 30-to-50 mph range. And prior crash tests programs, such as Cornell in 1971 and Dynamic Science in 1980, demonstrated that a 40-plus mph rear underride guard was feasible, it seems short-sighted of NHTSA to settle for the unrealistically low level of 30 mph. Truck and trailer manufacturers should recognize that the new NHTSA regulation #223 and #224 are only "minimums" that should be significantly exceeded by the installation of production guards with a notably higher capability.

In contrast to this most-recent 30-to-35 mph crash test series conducted at VRTC in 1993-94, previous NHTSA crash test programs (e.g., 1979-80 at Dynamic Science) for developing and evaluating rear underride prevention guards have included crash tests in the realistic 35-to-40 mph range... [Note that a 40 mph crash test is about 1.8 times more severe than a 30 mph crash test. The energy varies as the square of the velocity... the ratio is $(40)^2$ over $(30)^2$, or 1600/900 = 1.8]

The application of a slowly-applied force to the underride guard exemplar may not adequately test impact strength. Some underride guard designs that may be capable of withstanding gradually applied loads may fail when the same amount of force is applied abruptly. Similarly, the attachment of the guard to the frame structure of the truck or trailer may transfer the applied loads in an actual crash accident to what may be a weaker frame rail. The applied load requirement of 22,480 lbs. is also notably below the previously-recommended 50,000 lbs. that was derived from crash tests in the 35-40 mph range, including larger passenger vehicles than the Saturn-Civic-Tempo-Corsica range.

The slowly-applied loads also do not necessarily account for offest and angular impacts that occur in real-world accidents, and which may tend to overwhelm a vertical support and cause it to catastrophically fail or break-away... thereby allowing the car to continue to dangerously underride beneath the taller truck or trailer..

The 1971 Cornell crash test program for NHTSA, in its report titled "A Study of Heavy-Vehicle Underride Guards" (SAE 710121), described the twelve car-into-truck crash tests with guard heights of 18 inches and 24 inches. Their conclusion was that an 18 inch guard height provides protection for the smaller cars. Small VW Beetles and full-size Fords were used in most tests.

The 1980 Dynamic Science crash test program for NHTSA, in its report titled "Development of Compliance Test for Truck Rear Underride Protection" (DOT HS-805-564), noted among its Recommendations:

> ***"To prevent excessive underride, it is recommended that the guard height***

not exceed 20 inches at the impact speeds from 30-40 mph and 22 inches below 30 mph to ensure adequate structural engagement of the car (engine) with the guard."

However, when the new FMVSS 223 and 224 requirements were issued in the mid-1990's, the prior recommendations for the 18-inch maximum height and the 20-inch maximum height were both ignored. The new requirement is for a 22-inch maximum height, which is too high in view of the 16-to-20 height of many vehicle bumpers and supporting structures.

THE CRITICAL NEED FOR *SIDE* UNDERRIDE PROTECTION

The new NHTSA regulation totally ignores the need to require side underride prevention guards.

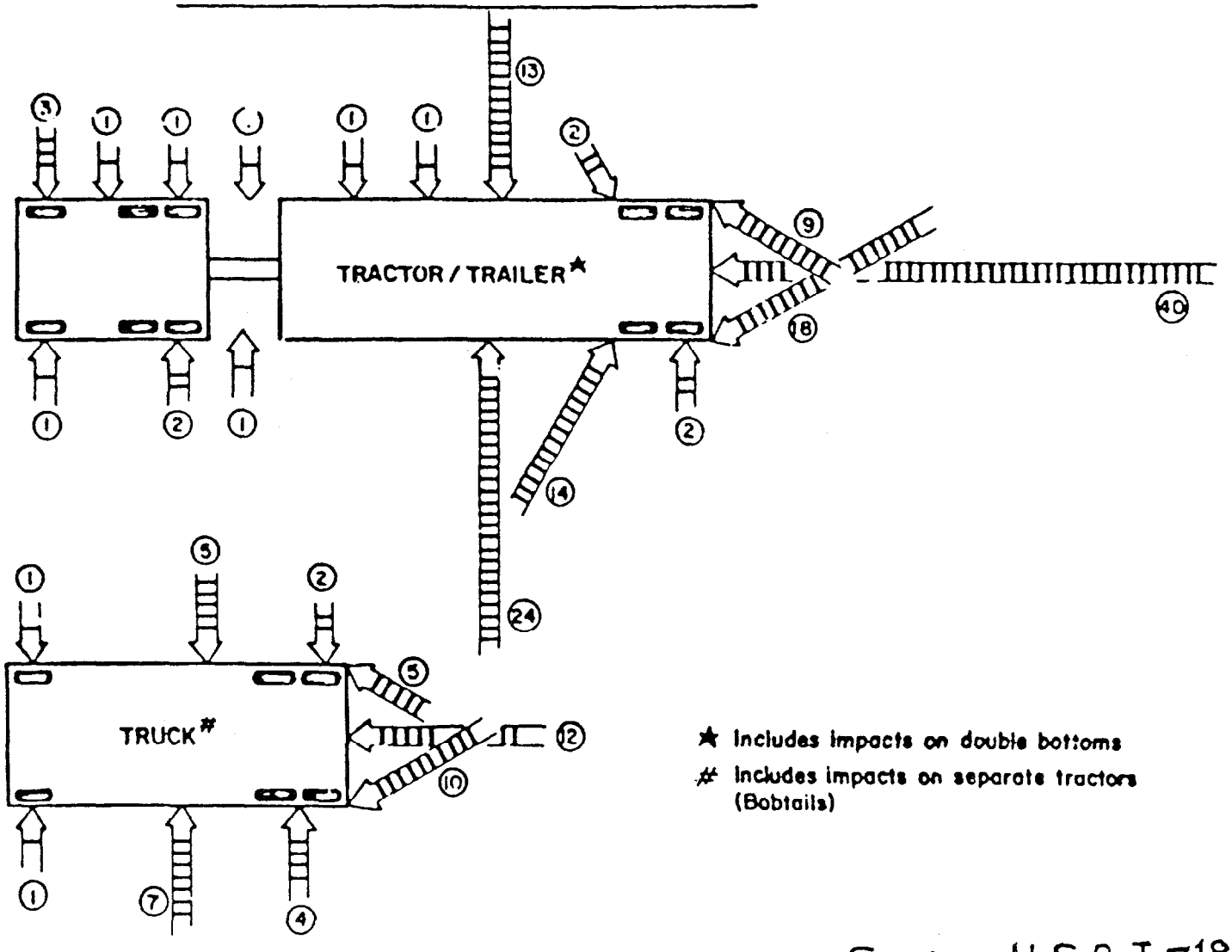
Back in 1968, the National Highway Safety Bureau (which became NHTSA in 1971), funded a study entitled "Development of Standards for a Heavy Vehicle Underride Guard". The research was conducted by Aerospace Research Associates (ARA) of California. Various side underride guard designs were discussed, including those with energy-absorbing features. The report noted that *"If a heavy vehicle is struck from the rear or side by a light vehicle, serious injury can be incurred by the occupants of the smaller vehicle. It would appear that equipping such heavy vehicles with rear and side underride guards would result in a reduction of a number of fatalities and the severity of injuries."*

Then in 1970, as the NHSB proceded further with rule-making efforts for rear underride guards, they noted that further consideration would be given, after ompleteion of technical studies, to underride protection for the sides of large vehicles. Despite those good intentions, the side underride efforts were essentially put in llimbo following the 1971 White House directive to cancel or shelve various then-pending vehicle safety regulations.

In the 1977 research report "Car-Truck Fatal Accidents in Michigan and Texas", by the Highway Safety Research Institute (HSRI), at the University of Michigan, U.S. Dept. of Commerce PB-274-111, a study was conducted of car-into-truck and car-into-trailer accidents. As a rough **estimate, the researchers noted that there would be 261 rear-end underride car-into-truck fatal collisions per year, and 195 side underrides per year.**

The distribution of points of impact for 181 car-truck/trailer fatal crashes were illustrated as shown in this excerpt drawing from the HSRI report. The report notes not only the large quantity and percentage (almost half) that are side and side-angular crashes, and also notes the majority (65 out of 87) were in the 30-to-50 mph range

Figure 1. DISTRIBUTION OF POINTS OF IMPACT
181 CAR-TRUCK/TRAILER FATAL CRASHES



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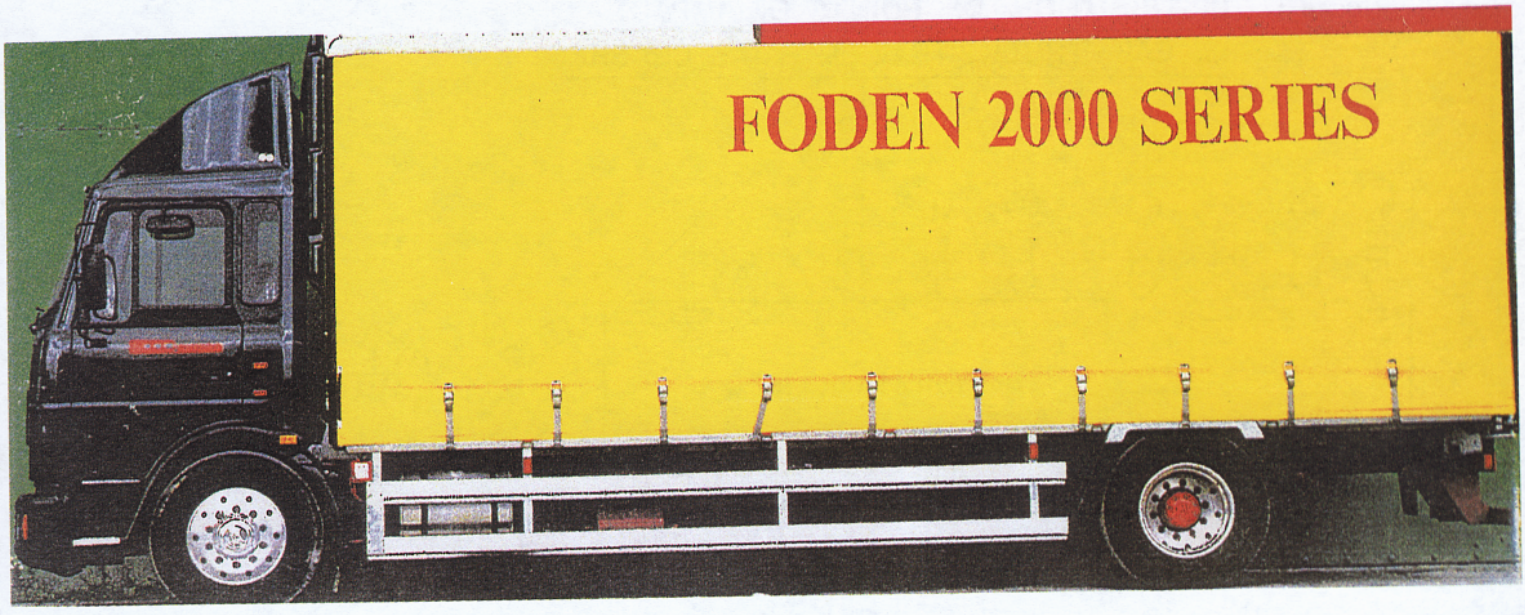


In England and other European nations, side underride guards were implemented beginning in the early to mid 1980's to protect motorcyclists, bicyclists, and pedestrians from becoming entrapped in the open space along the sides of the trucks and trailers. Discussions with European colleagues indicate that such side underride (or "underrun") guards have also demonstrated effectiveness in helping prevent cars from underriding.

Similar to a guard rail along the highway, such side underride guards also can be effective in helping deflect cars from unsafely underriding into and beneath the tall sides of trucks and especially long trailers. When a large tractor-trailer rig makes a lane change on the highway, an adjacent car may not be readily perceived by the truck driver... and the car gets trapped in the long-open side of the trailer and crushed by the trailer's rear wheels, as well as having the trailer's side structures crush into the car's roof.

Other side underride accidents have occurred when a tractor-trailer makes a turn at an intersection or pulls out onto the highway in front of oncoming traffic. Others occur at night, for example, when the Headlights of the tractor create glare to an oncoming driver and thereby camouflages the visual perception that the tractor's long trailer is still diagonally straddling the road ahead.

The use of retro-reflective tape along the sides and rear of trucks and trailers is exteremely beneficial in enhancing their *"conspicuity"* or perception and identification at night and in inclement weather, so that motorists can see and understand the nature of the large truck danger ahead, and thereby hopefully avoid the accident from occurring in the first place, or at least reduce the severity of any collision that might occur.

It is imperative for NHTSA to immediately focus on rulemaking for a side underride prevention safety standard. This would be a

logical companion standard to FMVSS 223 and 224.

It is interesting to note that NHTSA, back in 1970, noted they soon would be giving consideration to the subject of underride protection for the sides of large trucks and trailers. Virtually nothing has been done since then. There is also a need for a federal safety standard to address heavy truck frontal aggressivity and front underride prevention.

IMPROVED CRASHWORTHY DESIGNS

Most rear underride guards have been of a simple design, with two vertical struts and a single horizontal bar. As guard designs have become stronger and full-width across the rear of the truck or trailer, additional vertical struts and diagonal braces and gussets have been added to help prevent the guard from bending forward too easily, or even breaking a strut completely away from its anchorage.

While the use of energy-absorbing mechanisms has been attempted, few current designs utilize any such features. Therefore, the typical guard will begin to yield and bend forward under the load from a rear-ending car... which can cause the adverse effect of "funneling" the car downward, compressing the front suspension downward, and aggravating the underride hazard.

It is also preferable to utilize rear underride guard designs that engage the passenger vehicle at a lower height, preferably in the 16-to-18 inch height above the road surface, so as to more effectively engage the front bumper structures, front suspension, and tires. This lower engagement will help reduce the adverse effect of the rear structures of the truck loading essentially downward on the car's sloping hood.

THE BRAZILIAN PLYER GUARD

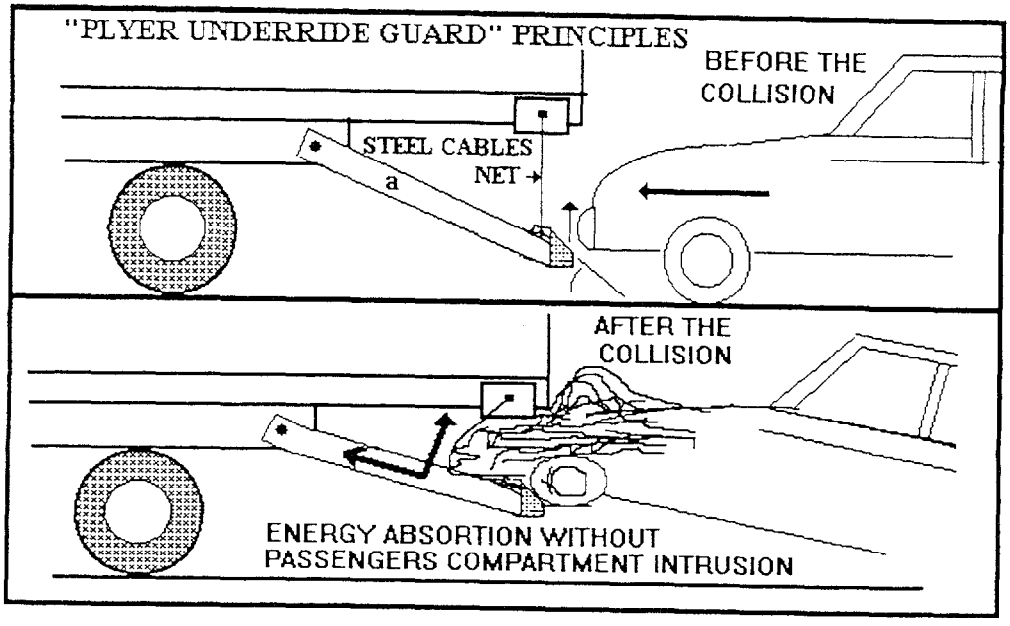
A novel design for an underride prevention guard was conceived at the Biomechanics Engineering Laboratory, at Unicamp State University, in Campinas, Brazil. The particular design is referred to as the "Plyer Underride Guard", denoting its relationship to the mechanical principles of a simple pliers tool.

As the passenger vehicle or car engages the low-mounted crossbar, the car becomes entrapped. As the car continues forward, it progressively deforms the "net" of steel cables. As this engagement takes place, it also allows the vehicle's designed-in frontal "crush zone" to deform and absorb the collision forces as well. Thus, the passengers are receiving the dual safety benefits of the car's frontal crush zone doing its work, and also the elimination of the unsafe underride penetration into the passenger compartment.

The Brazilian Plyer Guard was successfully crash-tested on April 14, 1998, at the General Motors crash laboratory facilities near the city of Indaiatuba, Sao Paulo State. The car was a GM Vectra that crashed into the rear of the target truck at 40 mph in a 50% offset collision.

The Vectra's front bumper was the first part of the car to impact the Plyer Guard's steel cables, which assured that the Vectra's designed-in energy-absorption capabilities, its frontal "crush zone", was fully employed. The Vectra's windshield was not touched by any part of the truck. The front doors could be easily opened, which would thus facilitate the exiting or rescue of the passengers.

In this initial crash test of the Plyer Guard, the main goal of preventing intrusion into the passenger compartment was fully achieved. An initial review of this demonstration crash test of the prototype Plyer Guard indicates that it would likely perform well with regard to higher



impact speeds or forces. The project staff will continue to optimize the design.

For further details of the Brazilian Plyer Guard Project, including the crash test results, please refer to the internet website as follows:

http://www.cte.unicamp.br./impact

There are other energy absorbing techniques that can be readily applied to underride guards.

Belleville Spring Washer Concept:
Belleville spring washers are like thin-metal "pie plates" of varying strengths and concave/convex contours. These "pie plates" can be strategically stacked within a chamber, so that a movable piston will react into the stack. By selecting the strength and contour of these "pie plates", they can absorb energy progressively so that smaller cars of lighter weight can be allowed a progressive "ride down" as it crashes into the guard at 30 mph or at 50 mph... since the higher-speed crash will also engage the stiffer, stronger pie plates. Heavier cars will similarly be accommodated by the varying energy-absorbing deformability of the differing pie plates that have been stacked within the piston chamber.

Rigid Foam Filled Structures Concept:
The use of high-density rigid polyurethane foam inside of tubular or compartmented structures has been shown to triple the bending strength and compressive strength of that structure. Thus, the foam-filled design concept enables a light-weight, economical, and efficient technique to be applied to the design of rear and side underride guards. For example, the foam-filled strengthening can be applied within the diagonal struts that are typically used to brace the vertical members of a rear underride guard.

Recycled Non-Metallic Synthetics
The rubber from used tires is often recycled. The rubber tires are initially shredded and powdered, and can be mixed with bonding agents to create a moldable basic material. The molding of underride guard members or

rails can be accomplished in large molds, with inserts of reinforcements such as wires, cables, or interwoven fibreglas-type sheets.

The freedom to explore many different and novel design for rear underride guards and side underride guards should be encouraged. An early concept of a dual-level and dual-strength rear underride guard was shown by the Truck Trailer Manufacturers Association (TTMA) back in 1970. Quinton-Hazell of England demonstrated an energy-absorbing rear underride guard that utilized hydraulics and pistons. Tube Industries of England demonstrated a novel concept of inverted tubes to absorb energy (the larger tube inverted over the smaller tube in a manner somewhat akin to peeling a stocking off of a leg).

CONCLUSION

The truck underride issue will continue to be of vital concern. The truck underride regulation must be made applicable to all trucks and trailers that may present an underride risk, primarily due to their extended rear overhang profile and side underride dangers as well.

We can encourage progress in developing and implementing side underride guards, and in improving the rear underride guards that will be installed in conformance with the new NHTSA regulation. We can also encourage progress in developing and implementing safety measures to alleviate the hazards of heavy truck frontal aggressivity and underrun.

Manufacturers and operators of trucks and trailers should maximize their efforts and implement the safest available designs, and not settle for the minimum levels of compliance. Thus, the continuing epidemic of underride accidents will be reduced, many of the underride fatalities and severe injuries will be prevented, and the industry will reduce its risks and costs of litigation and liability.

Many nations, such as Brazil, must move ahead expeditiously and adopt regulations to require that all large trucks and any other vehicles that present an underride hazard, be equipped with effective underride prevention guards.

REFERENCES

1. Rear End Protection, 49 Code of Federal Regulations (CFR), Paragraph 393.86, effective January 1, 1953. Established first rear guard rquirements.

2. Amendments to the Initial Federal Motor Vehicle Safety Standards, 32 Federal Register 14278 (October 14, 1967). Consideration of a Federal Motor Vehicle Safety Standard for Rear Underride Guards for Trucks, Buses, and Trailers. Established the NHTSA Docket No. 1-11.

3. "Development of Standards for a Heavy Vehicle Underride Guard." Aerospace Research Associates, Inc. (ARA) Prepared for the National Highway Safety Bureau (NHSB became NHTSA). Dec. 1968. Describes rear and side underride guard requirements.

4. Rear Underride Protection, 34 Federal Register 5383, March 19, 1969. Proposed 18-inch maximum height of guard above road, and movable guards if necessary.

5. Rear Underride Protection, 35 Federal Register 12956, August 14, 1970. Proposed 50,000 pounds static force be applied as test, and consideration for underride protection for the sides of large trucks.

6. Truck Trailer Manufacturers Association (TTMA), "Rear Underride Protection", Oct. 21, 1970. Noted dual-bumper configuration of 18-

inch and 24-inch guards, at 37,000 and 50,000 pounds static force capacity respectively.

7. N. DeLays and M. Ryder, "A Study of Heavy-Vehicle Underride Guards", Cornell Aeronautical Laboratory. SAE 710121. 1971. For the National Highway Safety Bureau (NHSB became NHTSA).

8. L. Zaremba, J. Wong, C. Moffatt, "Eliminating Automobile Occupant Compartment Penetration in Moderate Speed Truck Rear Underride Crashes: A Crash Test Program", Insurance Institute for Highway Safety (IIHS).

9. D. Minahan and J. O'Day, "Car-Truck Fatal Accidents in Michigan and Texas," Highway Safety Research Institute (HSRI) of the University of Michigan. Oct. 1977.

10. R. Baczynski, N. Johnson, S. Davis, "Development of Compliance Test for Truck Rear Underride Protection", Dynamic Science, Inc. DOT HS-805-564. Sept. 1980. Under Contract to NHTSA.

11. G. Rechnitzer and F.C. Wai, "Fatal and Injury Crashes of Cars into the Rear of Trucks", Monash University Accident Research Centre, Australia. May 1991.

12. "Automotive Safety: Are We Doing Enough to Protect America's Families?", U. S. Congressional Hearing, Washington, D.C., Dec. 4, 1991. Testimony on truck underride hazards, and delay by NHTSA and industry to implement effective underride prevention guards.

13. ABC News "Primetime Live" televised report and transcript of report on truck underride hazards, its regulatory history, accident examples, comparison with European adoption of underride guards, and U.S. industry neglect. January 1992.

14. B. Bloch and E. Wolfe, "Truck Underride Tragedies", TRIAL Magazine, Association of Trial Lawyers of America (ATLA). Feb. 1993. Describes legal basis for liability if manufacturer fails to equip trucks with underride guards.

15. Congressional Report on Truck Underride Guards, by NHTSA Office of Vehicle Safety Standards, Nov. 1993. Included summary of car-into-truck crash tests conducted at VRTC.

16. G. Rechnitzer, "Fatal and Injury Crashes of Cars and Other Road Users with the Front and Sides of Heavy Vehicles", Monash University Accident Research Centre, Australia. Feb. 1993.

17. "Final Regulatory Evaluation, Rear Impact Guards, FMVSS No. 223, and Rear Impact Protection, FMVSS No. 224." Office of Regulatory Analysis, NHTSA. Dec. 1995.

18. B. Bloch, "Underride Guards: Is the New NHTSA Regulation Good Enough?" SAE Heavy Vehicle Underride Protection TOPTECH. April 1997.

19. G. Rechnitzer, "Design Principles for Underride Guards and Crash Test Results," Monash University Accident Research Centre, Australia. SAE Heavy Vehicle Underride Protection TOPTECH Conference. April 1997.

20. L. Schmutzler, "An Underride Guard Design for the Brazilian Traffic Environment", Unicamp State University, Campinas, Brazil. SAE Heavy Vehicle Underride Protection TOPTECH Conference. April 1997

21. J. Tomassoni, "Additional Insights to the Underride Problem and Concerns." SAE Heavy Vehicle Underride Protection TOPTECH Conference. April 1997.

22. F. Hope, "Safety Rear Underride Bar with an Optional Reverse Impact Braking System". SAE Heavy Vehicle Underride Protection TOPTECH. April 1997.