Effectiveness of rear underrun protection devices in trucks for reducing passenger car fatalities and serious injuries in India

Rohan Govardhan, Vishal Waykar, Muddassar Patel, Ravishankar Rajaraman, Jeya Padmanaban

Abstract The objective of this study was to evaluate the real-world effectiveness of RUPDs in India using accident data collected from field investigations under Road Accident Sampling System – India (RASSI) initiative. The analysis of field data indicates that RUPDs show a higher effectiveness in reducing fatalities for belted car drivers even at relatively higher impact speeds but are not effective for unbelted car drivers. While RUPD fitment rates and compliance to dimensional requirements were found to be poor, the crashes involving trucks with RUPDs were examined for deformation extent and height of initial contact on passenger cars, relative impact speeds and impact energies. Post-impact condition of RUPDs and calculation of impact energies indicate that the impact energy experienced by bent or sheared RUPDs is more than six times higher than when the RUPD remained intact. A multipronged approach involving compliance to seatbelt laws in passenger cars and RUPD fitment in heavy trucks, improvements in heavy truck RUPD design, and implementation of accident avoidance and mitigation technologies in passenger cars, through a data-driven approach aided by on-scene scientific crash investigations of real-world crashes, can help improve the effectiveness of RUPDs in reducing passenger car fatalities and serious injuries.

Keywords India, IS 14812, RASSI, Rear Underrun Protection Device, Underrun crashes

I. INTRODUCTION

The Society of Automotive Engineers (SAE) defines underrun as the instance in which a light vehicle is positioned at least partially underneath a large truck at some time during a crash [1]. Underrun crashes are severe in terms of injuries sustained by occupants in the passenger car as the front bumper and the longitudinal structural members of passenger cars slide underneath the truck, while the bonnet and A-pillars engage with the rear structure of the truck. An example of a rear underrun crash is shown in Fig. 1.

Fig. 1. Example of a rear underrun crash of a car with a heavy truck (Source: RASSI Case ID: 91-2014-010-0017)

To understand the underrun crashes in the Indian scenario, the crashes in the RASSI database were studied. RASSI crash data are collected through on-scene crash investigations across five different locations in India, covering state highways, national highways, urban and semi-urban roadways, and expressways [2]. The data considered for this study included crashes from 1 April 2011 to 31 March 2019 that were investigated and included in the RASSI database. To date, about 5,000 crashes from five locations across India have been

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investigated in-depth and information on detailed on-scene examination, vehicle inspection, crash reconstruction, injury analyses and contributing factors is available in the RASSI database.

For data collected in the RASSI database, vehicles are typically examined at the crash site or at police stations. The vehicle examination includes detailed photography of vehicle and damage evidence, identification of damage areas, their measurements, checks of additional fitment on the vehicle, determining passenger safety system usage and identification of occupant contact evidence on the vehicle. Details of occupant seating positions and injury severity are derived from police investigation documents, victim interviews and witness statements and are corroborated with each other to arrive at information with a higher degree of certainty.

A total of 1,314 heavy trucks were investigated for the RASSI database. Of these, passenger cars accounted for 21% of the collision partners for trucks. A study of 276 crashes between passenger cars and trucks showed that 33% of crashes involved frontal impacts between passenger cars and trucks, 22% involved side impacts on the truck and 45% of the crashes involved a car rear-ending a truck. All of the 124 rear-end crashes were underrun crashes. It was also seen that 60% of the rear-end crashes led to fatal injuries as compared to 42% in head on crashes between cars and trucks and 11% in side impacts to trucks. Hence, the higher fatality rate for crashes involving a car rear-ending a truck needs further study.

Past studies on car crashes have highlighted the risk and severity of underrun crashes in India [3-4]. It is therefore crucial that measures be provided in the heavy vehicles to ensure effective engagement of the load-bearing structural part of a car to prevent it from sliding under. A Rear Underrun Protection Device (RUPD) is one such measure that increases the crash compatibility between passenger cars and trucks by preventing the cars from sliding underneath the trucks. An additional property of a RUPD is to absorb the impact energy of the passenger car and thus reduce the severity of the impact forces experienced by the car occupants.

The Government of India mandated the installation of RUPDs on trucks from 1 May 2003, through an amendment to Rule 124 of the Central Motor Vehicle Rules (CMVR). The rule requires RUPDs to be installed in heavy trucks as per the specifications and testing requirements mentioned in IS 14812:2000 of the Bureau of Indian Standards (BIS). The dimensional requirements of the RUPDs as per IS 14812:2005 [5] are given in Fig. 2 below.

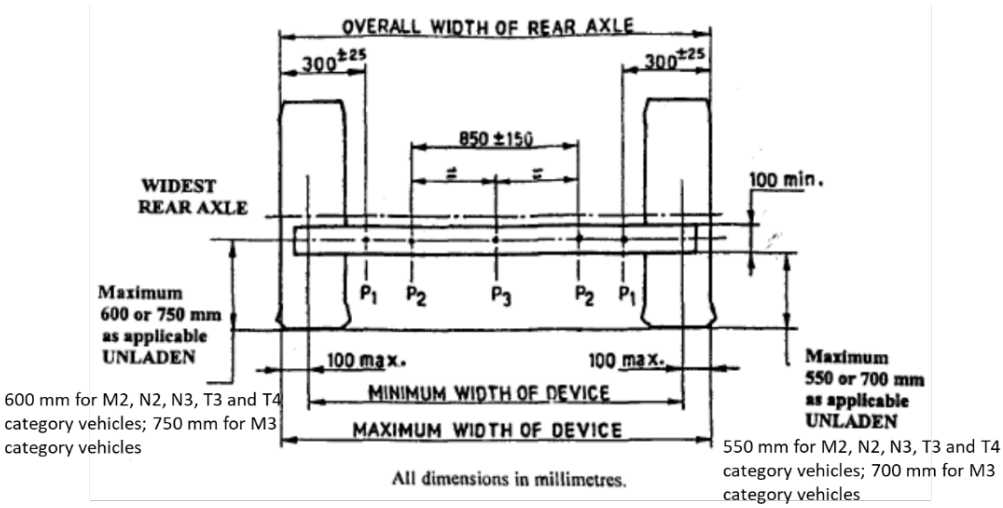

Fig. 2. Dimensional Requirements of RUPDs in India (Source: IS 14812:2005).

Studies from the National Highway Traffic Safety Administration (NHTSA) [6], the Fédération Internationale de l'Automobile (FiA) [7], Monash University Accident Research Centre, Australia [8] have shown that RUPDs help to reduce fatalities in crashes where passenger cars impact the rear-end of heavy vehicles. NHTSA estimated rear underrun guard will be about 10–25% effective in reducing fatalities due to passenger compartment intrusions seen in underrun crashes in the United States of America (USA) [9].

The objective of this study was to evaluate the real-world effectiveness of RUPDs in India using accident data collected from field investigations under the RASSI initiative. Based on the results, recommendations and possible areas of further research are suggested.

II. METHODS

For this study, a sample of 124 crashes were selected from the RASSI database, which involved a car rear-ending a truck. These 124 crashes were further filtered based on two criteria: (1) the first crash event should involve a passenger car impacting a truck from rear; and (2) the impacting passenger car and impacted truck should be available for inspection. The "BodyType" variable in RASSI was used to choose vehicle types. Details of the "BodyType" variable in RASSI are given in Appendix A. For passenger cars, "BodyType" 1 to 9 were used, while for trucks "BodyType" 22 to 29 were selected. This yielded a sample of 73 crashes. All 73 crashes were underrun crashes.

An initial study of the 73 crashes was carried out to check the availability of RUPD in impacted trucks involved in underrun crashes. Further, the injury severity rate for car drivers of the impacting passenger cars was studied in crashes with and without RUPD availability to determine the benefit of belt usage in underrun crashes. The percentage effectiveness [10-12] of RUPD in reducing the risk of fatalities for belted car drivers was calculated as:

$$Percentage\ Effectiveness = \frac{(fatality\ risk\ for\ belted\ drivers\ in\ Non\ RUPD\ trucks - fatality\ risk\ for\ belted\ drivers\ in\ RUPD\ trucks)}{(fatality\ risk\ for\ belted\ drivers\ in\ Non\ RUPD\ trucks)} \times 100 \quad (1)$$

The RUPD effectiveness was then checked for any influence of relative impact speed between the truck and the passenger car. As part of RASSI crash investigation and in-depth crash data collection, all crashes are reconstructed using PC-Crash accident reconstruction software to determine the impact speeds for the vehicles. The impact speed data of the involved vehicles were used to calculate the difference in impact speeds of the involved car and truck, which was noted as the relative impact speed for the crash. Crashes where the impact speed of either or both the colliding vehicles were unknown were not considered in the relative impact speed calculation. Based on the relative impact speeds obtained, the effectiveness of the RUPDs was calculated for low relative impact speed and high relative impact speed crashes.

A major factor in rear underrun crashes is the higher probability of the back of the heavy truck intruding into the passenger compartment. For this study, a Passenger Compartment Intrusion (PCI) is considered to occur when the back of the truck enters into the passenger compartment of the car in a rear-end crash. A PCI reduces the space available for the car occupants and thus increases the likelihood of the occupants sustaining severe injuries. The analysis for PCI in passenger cars was done using the Collision Deformation Classification (CDC) given by the Society of Automotive Engineers (SAE) manual J224 [13]. This is a seven-digit alphanumeric code to describe the location, type, and extent of deformation in a car or similar light vehicle. The seventh character provides the longitudinal extent of deformation into the passenger car as a result of impacting the rear of the truck. The seventh character was used to determine the extent of the longitudinal deformation caused to the passenger car and is divided into nine deformation zones, as shown in Fig. 3. Based on the seventh character of the CDC, the influence of the RUPD on PCI was determined.

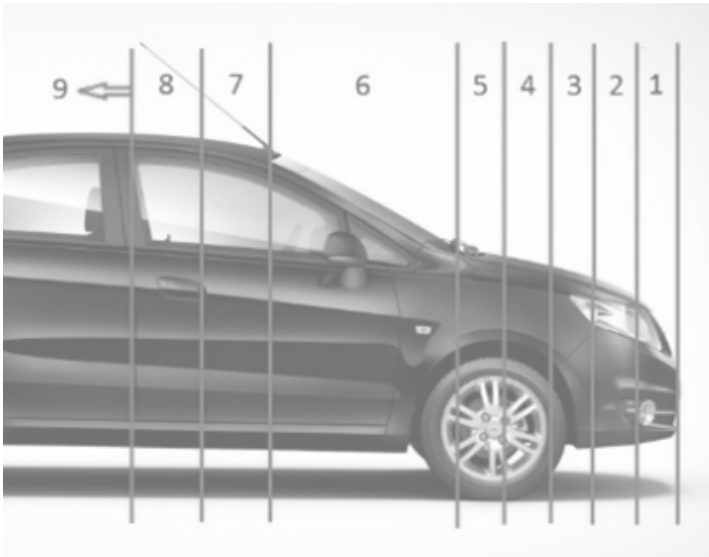

Fig. 3. Sections of seventh character of CDC - Deformation Extent.

For crashes involving RUPDs, the height of the initial contact of the RUPD on the car was also checked. The vertical height of the car was divided into three sections viz. Bumper, Front grill/bonnet, and Pillar, as shown in Fig. 4. This was also compared with the maximum unladen height of the RUPD from the ground, as per the IS 14812:2005, which is also marked in Fig. 4. The influence of relative impact speed was also checked by height of initial contact of the RUPD.

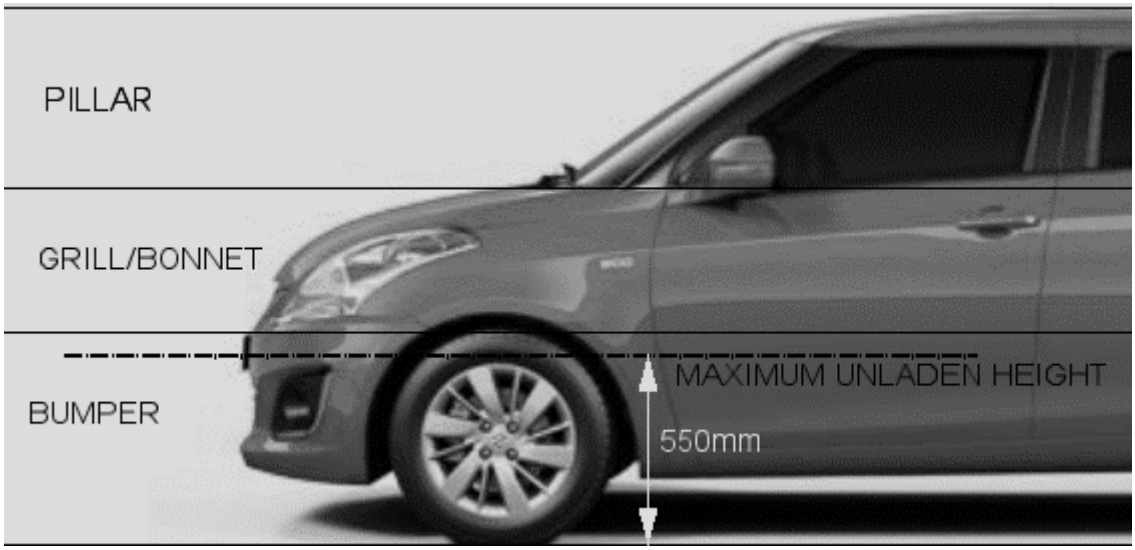

Fig. 4. Sections of height of initial contact of the RUPD with the car

Finally, the photographs of the trucks involved in the crash, with RUPD fitted, were examined to check dimensional conformity of RUPDs to the IS 14812:2005 and the post-impact RUPD condition. Considering the post-impact conditions, the relative impact speed between the vehicles was used to calculate the impact energy experienced by the RUPDs. The impact energy was calculated for each crash in kilojoules (kJ) using the formula given below:

$$Impact\ Energy\ (kJ) = \frac{0.5 * Mass\ of\ passenger\ car\ in\ kilograms * (relative\ impact\ speed\ in\ metre\ per\ sec)^2}{1000} \quad (2)$$

All the parameters used for this analysis and the data sources from RASSI database are listed in Appendix B.

III. RESULTS

The results of the analysis performed on the 73 underrun crashes are described in the sections below.

Availability of RUPD in impacted trucks

First the fitment rate of RUPDs in the heavy trucks was checked. The overall fitment rate for the years 2011–2019 showed that RUPDs were fitted in 38% of trucks, thereby indicating non-compliance. A directive was issued by the Ministry of Road Transport and Highways, Government of India, in September 2015 [14], for the states to check for installation of RUPDs in heavy trucks as a part of the renewal of vehicle fitness certificate. The directive also makes it mandatory for the trucks manufactured even before 2005 to be retrofitted with RUPDs at the time of the vehicle fitness certification. The examination of trucks involved in crashes from April 2011 to March 2016 showed a RUPD fitment rate of 34%. A similar study done for trucks involved in crashes from April 2017 to March 2019 showed a fitment rate of 52%. This indicates a considerable increase in fitment rates after the Government directive.

Effectiveness of RUPDs in reducing fatality and serious Injury

The fatality and serious injury rates of car drivers in underrun crashes with trucks fitted with and without RUPDs are shown in Fig. 5 and Fig. 6 by belt use.

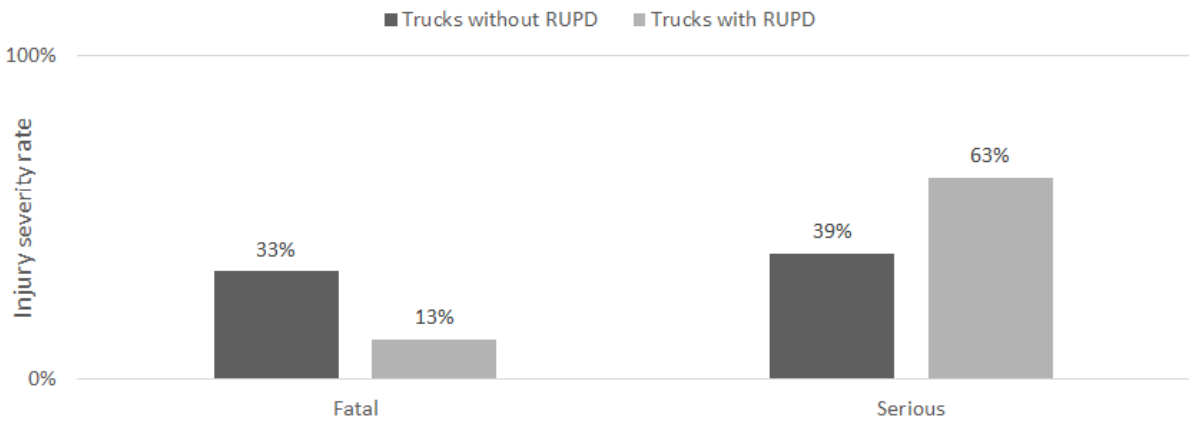

Fig. 5. Fatality and Serious injury rates for belted car drivers in crashes with and without RUPD fitment in trucks.

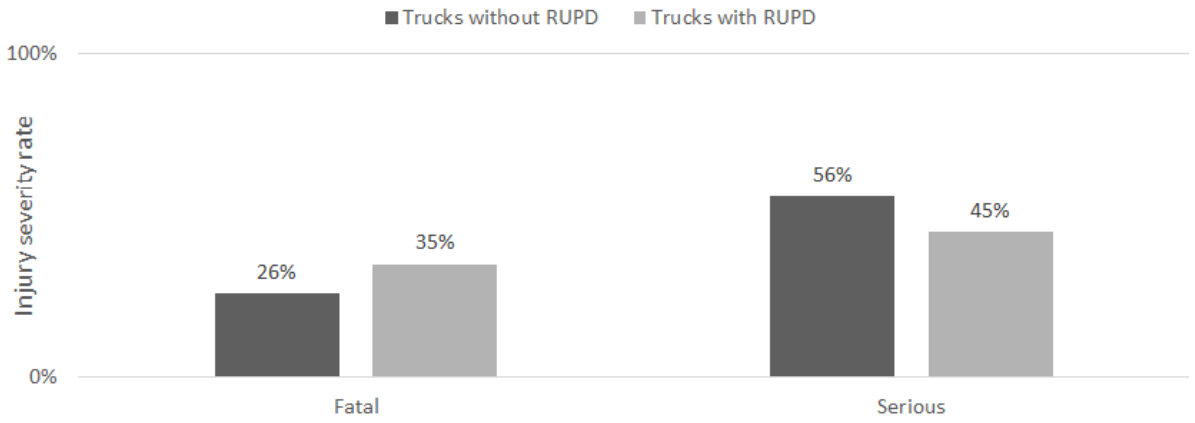

Fig. 6. Fatality and Serious injury rates for unbelted car drivers in crashes with and without RUPD fitment in trucks.

While Fig. 5 shows that RUPDs helped in reducing the injury severity from fatal to serious for belted car drivers, fig. 6 clearly shows that the presence of a RUPD did not make much difference if the drivers were unbelted. Based on the fatality rates in Fig. 5, the effectiveness of RUPD in reducing fatalities is calculated to be 61% for belted car drivers:

$$(0.33 - 0.13 / 0.33) * 100 = 61\% \qquad \text{(Eq. 1)}$$

With regards to the serious injuries, it can be seen that the belted car driver injury percentage was lower for non-RUPD trucks as compared to the trucks fitted with RUPD. The definition of serious injuries in the RASSI database includes AIS≥2 injuries that require hospitalisation for more than 24 hrs. All the serious injuries involving belted car drivers in crashes with RUPD trucks were AIS≥2 upper extremity injuries. All the serious injuries involving belted car drivers in crashes with non-RUPD trucks were AIS≥2 abdomen and spine injuries.

The fatality rates of belted car drivers in crashes with trucks fitted with and without RUPDs was checked by relative impact speeds between the vehicles. At relative speeds till 50 kph, there were no crashes where belted car drivers sustained fatal injuries. However, at relative speeds above 50 kph the fatality rate for crashes with RUPD was 20% as compared 63% with crashes involving no RUPDs. Thus, the effectiveness of RUPDs in reducing fatalities is 68% for belted car drivers in crashes with relative speed above 50 kph as per Equation 2:

$$(0.63 - 0.2 / 0.63) * 100 = 68\% \qquad \text{(Eq. 2)}$$

For unbelted drivers, at relative speed above 50 kph the fatality rates were 71% for crashes with RUPD and 40% for crashes without RUPD. This indicates that RUPDs were effective in reducing fatalities for belted car drivers but were not effective for unbelted car drivers. However, fatalities were also observed for belted car drivers. Hence the underrun crashes were further examined to determine the effect of factors affecting crash severity viz. extent of deformation on passenger cars, impact location of RUPD, RUPD compliance with standards and relative impact speed and impact energies.

Passenger Compartment Intrusion in rear-end underrun crashes.

To determine the influence of RUPDs in preventing PCI during rear-end underrun crashes, the deformation extent (seventh character of CDC) of the passenger cars rear-ending trucks with RUPD and without RUPD were analysed and the results are shown in Fig. 7.

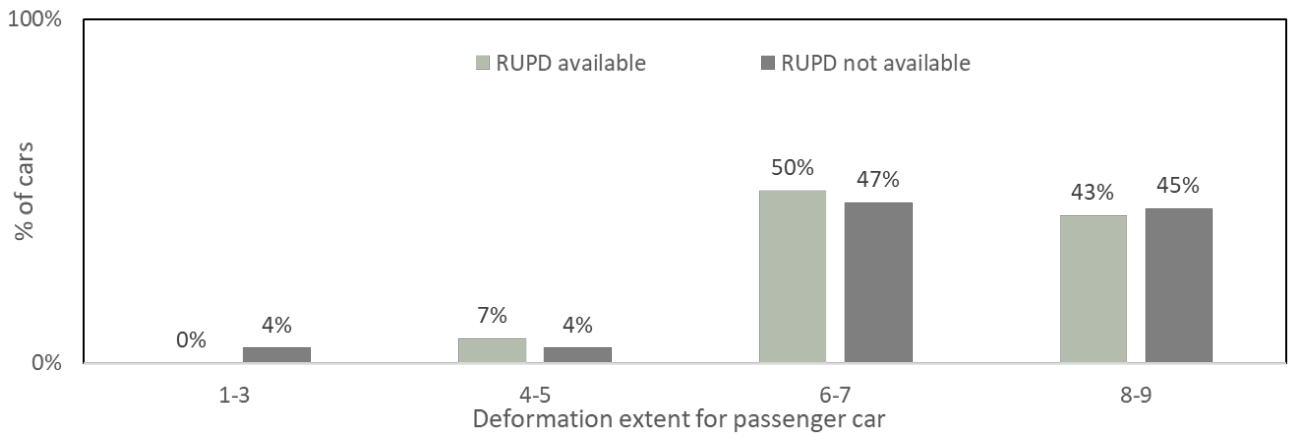

Fig. 7. Severity of underrun crashes by deformation extent.

Fig. 7 shows that a deformation extent of 6 or more, i.e. involved a PCI as a result of the back of the heavy truck intruding into the passenger compartment, was observed in 93% of the cars rear-ending trucks with RUPD and 92% of cars rear-ending trucks without RUPD. When the underrun crashes were examined by deformation extent and injury severity, all fatal crashes had a PCI. Thus, the occurrence of PCI has a major effect on the injury severity in underrun crashes.

As PCI was seen in crashes with RUPD involvement, the crashes with RUPD involvement were checked further to determine the height of initial contact of the RUPD on the impacting passenger cars. It was observed that in 50% of the cars, the height of initial contact was on the grill/bonnet section of the car, and in the remaining 50%, the height of initial contact was in the bumper section of the car. On checking the relative impact speeds at different sections of initial contact it was seen that for cars where the initial contact was in the bumper region, the minimum relative speed leading to PCI was 40 kph. Whereas, for cars where the initial contact area was above the bumper section, even a relative speed as low as 15 kph led to PCI. Thus, the height of initial contact on the car and the relative impact speed play an important role in determining the occurrence of PCI in rear-end crashes.

Conformity of RUPD installation to standard dimensions as set out in IS 14812:2005

The dimensional specifications of the RUPD of trucks (sample size) were checked against the Indian standard IS 14812:2005 for compliance. This standard dictates the dimensional criteria of a RUPD. The following were the specifications against which involved trucks in each of the crashes were assessed.

1. Maximum height of lower end of RUPD from ground should not exceed 550 mm.
2. Maximum difference between half of width of RUPD to half-width of truck should not exceed 100 mm.

The percentage of trucks with RUPDs complying with the standards is shown in Table I. Only 4% of the RUPDs covered the width of the truck as per the standard requirement. An average deviation of 223 mm was noted between the width of the RUPDs in the study and the standard requirement. An average deviation of 84 mm was noted between the height of the RUPDs in the study and the standard requirement. Therefore, the overall dimensional compliance of RUPDs with regard to the IS 14812:2005 was low.

TABLE I
TRUCK RUPD CONFORMITY TO STANDARDS AS PRESCRIBED IN IS 14812:2005

		(Width of truck/2) – (Width of RUPD/2) is ≤ 100mm?	
		Yes	**No**
Height of lower end of RUPD from ground is ≤ 550mm?	**YES**	0%	64%
	NO	4%	32%

Post-impact condition of the RUPD

Based on the analysis of photos of the RUPDs taken during on-site crash investigations, it was found that the RUPDs remained intact only in 7% of the crashes. In the rest of the crashes, the RUPD had either sheared off or was bent due to impact forces. Examples of the post-impact condition of RUPD are shown in Fig. 8. The passenger cars experienced a PCI in 96% of the crashes in which the RUPD did not remain intact.

RUPD Bent. (RASSI Case ID: 91-2013-010-0099) RUPD Sheared. (RASSI Case ID: 91-2015-010-0068) RUPD Intact. (RASSI Case ID: 91-2015-011-0022)

Fig. 8. Example crashes for post-impact condition of RUPD. (Source: RASSI database)

Impact Energy by area of damage on trucks

The impact energy was calculated for each case and the mean value of impact energy for crashes with intact RUPD was calculated as 29 kJ and for bent/sheared RUPD was calculated as 190 kJ. Hence, impact energy is over six times higher for crashes with bent/sheared RUPDs.

For crashes where the RUPDs got bent or sheared post-impact the severity of impact energy at different location on the RUPDs was checked by plotting the mean impact energy by the area of damage on the truck. The Truck Deformation Classification (TDC) [1] provided by the SAE J1301 manual was used to categorize the impact energy as per the location of impact on the rear of the truck, as shown in Fig. 9. As can be observed in Fig. 9, a high impact energy is applied to the whole width of the truck, D (282 kJ), and on the zones at the outer edge of the truck, R (211 kJ) and L (140 kJ). Consequently, RUPDs must be designed to withstand and absorb equal amount of impact energy at any point across the entire width of the truck.

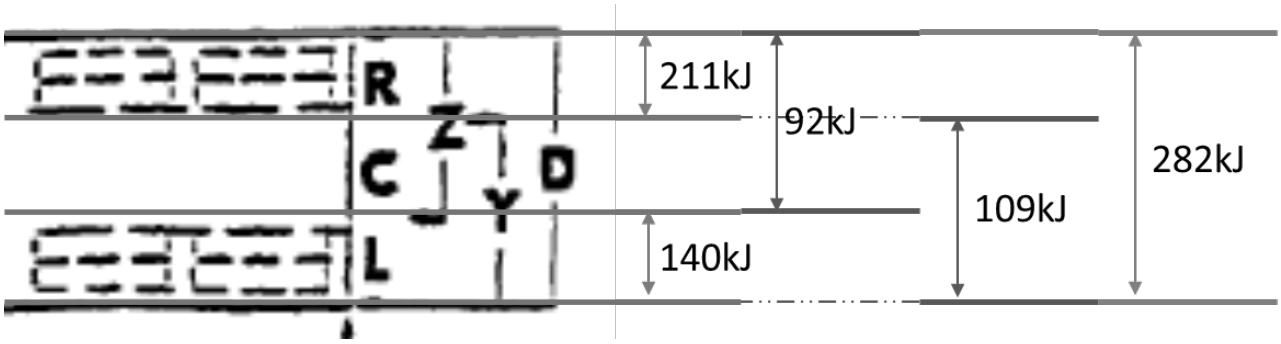

Fig. 9. Mean impact energy values at different locations of the rear of the truck.

IV. DISCUSSION

The study clearly highlights a positive benefit of wearing seatbelts in reducing fatalities during underrun crashes, especially when the heavy trucks are equipped with RUPDs. The presence or absence of RUPDs did not seem to affect passenger car fatalities in crashes where car drivers were not belted. The positive benefit of RUPDs is also seen at higher values of relative impact speeds between the vehicles. Thus, seat belt usage needs consideration while determining the effectiveness of RUPDs in crashes involving cars rear-ending trucks. There was also a notable increase in belted car drivers having the highest injury severity as “serious”. The increase in the serious injury rate can be attributed to the location of injuries, as belted drivers in crashes with trucks equipped with RUPDs have sustained injuries primarily to the extremities. Thus, even though the belted drivers in such crashes have sustained injuries leading to a hospitalization of more than 24hrs, the overall survivability is higher if the driver is belted in crashes with RUPD availability.

With a RUPD fitment rate of only 38% in all the trucks in this study, the RUPD fitment rate is much lower than what is observed in countries like the UK [15]. Though the level of compliance has seen an upward trend over the last few years, primarily because of a Government directive to check for RUPDs during vehicle fitness certification, the fitment rate still needs to increase further. Additional interventions such as regular checks on roads by enforcement authorities and easy availability of RUPD in the aftersales market needs consideration. Benefits of RUPDs can also be included in driver training and awareness programs.

The study also shows that fatalities of belted occupants occur when the back of the truck intrudes into the passenger compartment of the car, leading to a passenger compartment intrusion (PCI). The rate of PCIs was similar irrespective of the availability of RUPDs in crashes. Two reasons were identified for the ineffectiveness of RUPDs in preventing PCI. The first reason for the occurrence of PCI can be attributed to the initial height of contact of RUPD being above the bumper section of the passenger car. A major observation is that the RUPDs examined in the study did not comply with the dimensional requirements mentioned in the standards. This reduced the crash compatibility of the RUPDs and led to passenger compartment intrusions even in crashes with low impact severity. Hence, it is recommended that fitness tests for heavy vehicles should also include check for dimensional compliance of RUPDs. The second reason for the occurrence of PCI can be attributed to the amount of energy that a RUPD can withstand or absorb. The RUPDs remained intact in only 7% of crashes. The post impact condition of the RUPDs can be directly correlated with the high number of PCIs seen in passenger cars. It was found that the likelihood of a PCI in passenger cars increases with the increase in relative speed between the passenger car and the truck. This indicates that the RUPDs are unable to withstand or absorb the impact energy seen in real world crashes. The finding is in line with similar studies conducted using real world crash data in the United Kingdom (UK) [15] and the USA [16]. Crashes where RUPDs were bent/sheared experienced impact energy that was more than six times higher than crashes where the RUPDs remained intact. Thus, impact energy plays a major role in determining the injury severity of occupants in passenger cars rear-ending trucks. For crashes where shearing/bending of RUPDs was observed, high impact energy values were measured at all locations across the width of the truck where the passenger cars impacted. This indicates that design and performance standards of RUPDs need to consider the impact energies seen in real world crashes, and consequently, RUPDs must be designed to absorb equal amounts of impact energies across the entire width of the truck. This is an area for future research towards improving effectiveness of RUPDs.

Based on the above two reasons, the effectiveness of RUPDs during impact can be improved through the

following methods viz. a) improving the dimensional compliance of RUPDs, and b) improving the ability of the RUPD to withstand or absorb impact forces. Alternatively, reducing the relative impact speeds between the vehicles during the pre-impact phase of the crash would also be beneficial. Implementation of technologies in passenger cars such as Forward Collision Warning (FCW), Adaptive Cruise Control (ACC) and Autonomous Emergency Braking (AEB) may help in preventing or mitigating such crashes, and the effectiveness of such technologies needs to be assessed.

This study demonstrates the influence of RUPDs in crashes involving passenger cars rear-ending trucks. However, due to a small sample the data is currently limited to be able to provide a strong conclusion regarding the effectiveness of RUPDs in reducing fatalities and serious injuries in rear underrun crashes. With the continuation of the RASSI crash investigation study, more underrun crashes are expected to be investigated and with more data for RUPD-compliant trucks, a repeat of this study is warranted. In addition, as none of the RUPDs in the study conformed to dimensional requirements of the standards, the performance of the RUPDs meeting dimensional requirement of the standard warrants a separate study. Though the sample size is small, this is a pioneering initiative using on-scene crash investigation to determine the effectiveness of RUPDs and to identify the factors leading to fatalities in underrun crashes on Indian roads. The results of the study provide significant information for stakeholders and policy makers to influence the design, testing and enforcement of RUPDs.

V. CONCLUSIONS

This initial study of a limited sample of underrun crashes indicates that RUPDs show a higher effectiveness in reducing fatalities for belted car drivers, even at high relative impact speeds between the vehicles. To enhance the effectiveness of RUPDs, the following steps have been identified under this study:

1. Promoting seatbelt use in passenger cars through effective education and enforcement.
2. The fitment rate of RUPDs needs to be increased further. While data indicates that the fitment rate is increasing, further steps needs to be taken to encourage complete compliance through driver training, awareness, and enforcement.
3. The RUPDs fitted on the trucks should also be checked for dimensional conformity with the standard specified during vehicle fitness certification, as this has a major influence on the occurrence of PCI.
4. Further data-driven studies on underrun crashes are required to ensure that the design standards for RUPDs consider impact energies experienced in real-world crash conditions.
5. Alternatively, technologies such as FCW, ACC and AEB in passenger cars need to be assessed for their effectiveness in reducing the relative impact speed of the passenger car prior to rear-ending a truck.

Hence, the effectiveness of RUPDs in reducing passenger car fatalities and serious injuries can be further improved through a multipronged approach involving compliance to seatbelt laws in passenger cars and RUPD fitment in heavy trucks, improvements in heavy truck RUPD design, accident avoidance and mitigation technologies in passenger cars, through a data-driven approach aided by on-scene scientific crash investigations of real-world crashes.

VI. ACKNOWLEDGEMENTS

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VIII. APPENDIX

Appendix A

List of body types in "BodyType" variable RASSI for passenger cars and trucks.

BODYTYPE ID	BODYTYPE
1	01 - Hatchback
2	02 - Sedan
3	03 - Station wagon
4	04 - Coupe
6	06 - MUV
7	07 - SUV
8	08 - Van
9	09 - Unknown Car
22	22 - Straight Truck - 2 Axle
23	23 - Straight Truck - 3 Axle
24	24 - Tanker
25	25 - Tipper
26	26 - Tractor without trailer
27	27 - Tractor with trailer
28	28 - Truck other
29	29 - Truck unknown

Appendix B

PARAMETERS FOR ANALYSIS AND THE CORRESPONDING DATA SOURCE

Parameter for analysis	Data source
1. Availability of RUPD in impacted trucks	RASSI variable “RTUNDER”
2. Post-crash condition of the RUPD, where available	Inspecting crash vehicle pictures
3. Conformity of RUPD installation to IS 14812:2005	Inspecting crash vehicle pictures
4. Highest injury severity rate of the passenger car drivers	Calculations based on RASSI variable “HISP”
5. Relative impact speed between the vehicles	RASSI variable “VC_1st”
6. Curb weight for impacting passenger cars	RASSI variable “CURBWGT”
7. Deformation extent in cars	RASSI variable “EXTENT” based on SAE J224
8. Seat-belt usage for passenger car drivers	RASSI variables “SEATPOS” and “MANUSE”
9. Lateral area of damage on trucks	RASSI variable “SHL” based on SAE J1301

Erratum

Effectiveness of rear underrun protection devices in trucks for reducing passenger car fatalities and serious injuries in India

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Based on the feedback received from members of the RASSI Consortium, the authors have updated the "**Discussion**", "**Conclusions**" and "**Acknowledgements**" section of the paper. It should be noted that the changes only involve the rewording of the respective sections and do not have any consequence on the research, findings and conclusions made by the authors. Please consider that the **last sentence of paragraph 4 of "Discussion", point no 5 of "Conclusions"**, and **the entire** "**Acknowledgements**" section mentioned below replace the respective sections in the above paper.

IV. DISCUSSION (PAGE 108)

Technologies such as Forward Collision Warning (FCW), Adaptive Cruise Control (ACC) and Autonomous Emergency Braking (AEB) in passenger cars can be assessed for their effectiveness in reducing the relative impact speed of the passenger car prior to rear-ending a truck.

V. CONCLUSIONS (PAGE 108)

5. Alternatively, technologies such as FCW, ACC and AEB in passenger cars can be assessed for their effectiveness in reducing the relative impact speed of the passenger car prior to rear-ending a truck.

VI. ACKNOWLEDGEMENTS (PAGE 108)

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