A new approach for rear underrun protection systems – accident investigations & CAE based development

V. S. Gogate, V. A. Pachore, A. A. Thorat

Abstract The Tata Motors Accident Research Group (TMARG) has been involved in accident data recording on the Mumbai-Pune expressway since 2010. Analysis of accident statistics highlighted that 16% of the crashes were underrun of cars against heavy goods vehicles (HGVs) of which half were full-width underrun and the other half were offset underrun. Eight per cent (8%) of these crashes were fatal accounting for 33% of all fatal crashes. A detailed study of the data has shown that the conventional Rear Underrun Protection Device (RUPD), as per ECE R58, is not able to stop the smaller vehicle from riding under the larger vehicle in an offset impact. Further analysis was carried out to identify the severity of impact. As a result, a new load case to simulate this kind of crash was developed through CAE-based solutions. This paper explains the new system, its evaluation and recommendations for improvement in the rear underrun protection systems on heavy goods vehicles (HGVs).

Keywords Accident research, Underrun, ECE R58, IS 14812,

I. INTRODUCTION

India has reported nearly half a million road traffic accidents (RTA) in the year 2012 leading to about 140,000 fatalities [1]. The trend is continuously increasing. At present India does not have a comprehensive in-depth accident data recording system at the national level. The RASSI (Road accident sampling system India) database and the accident data recording system established by Tata Motors Ltd, in association with interested emergency medical services (EMS), are in operation [2]. The accident data, collected in the latter initiative, are managed by the Tata Motors Accident Research Group (TMARG). TMARG analysis of accident statistics since 2012 shows that 16% of the crashes were underrun in nature of which one half were full-width underrun and the other half were offset underrun. 8% of these crashes were fatal accounting for 33% of all fatal crashes.

A detailed study of the data has been carried out to understand the interaction of cars with a rear underrun protection device (RUPD) fitted to heavy goods vehicles (HGVs). A number of accident cases were studied to identify the sequence of events and the severity of the crash. Following is a brief description of the characteristics of this type of event.

The car impacts the overhanging end of the RUPD (Fig.1), bends it and continues to move forward (Fig. 1). The load platform installed on the HGV interacts either with the A pillar or the windshield of the car, or both. In some cases, the load platform interacts with the roof structure as well. This is not uncommon when the ground clearance of the bottom end of the chassis frame is ≥1000mm (Fig. 2).

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Fig 01
(The boxed text show the accident ID)

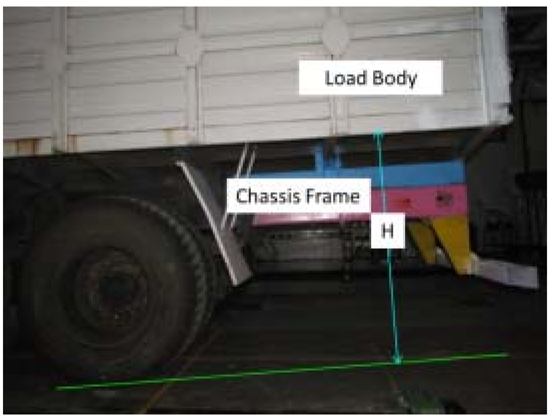


Fig 02

The car comes to a halt when some part of its structure (e.g. A pillar, roof) is sufficiently deformed and the kinetic energy is completely absorbed. Severance of the A pillar has also been recorded in rare cases. The severity of the crash is higher when the bonnet length of the car is shorter. Of importance, the overhanging portion of the RUPD bends inwards, allowing the car structure to interact with the load platform of the HGV leading to deformation of the safety cage and intrusion. A detailed sequence of the event is explained in Appendix 1.

II. METHODS

The conventional configuration of an RUPD is explained in Appendix 2 to help in understanding the discussions below. Computer Aided Engineering (CAE) was used to develop an improved underrun protection system. LS Dyna was used for structural computations and MADYMO was used for injury predictions.

Simulation of offset underrun crash and test specifications development

The deformation seen in the field was reproduced using CAE simulations and a test specification was developed as follows:

- test speed = 40±1 kph;
- ground clearance of the RUPD = 550±10mm (this is in line with legal requirements;
- location of the car against the RUPD (i.e. distance between the outer side of the car and the chassis frame of the HGV) = 100mm. This results in about a 30-35% offset impact for the smaller vehicle.

A physical test was conducted to confirm the test condition as shown in Fig. 3.

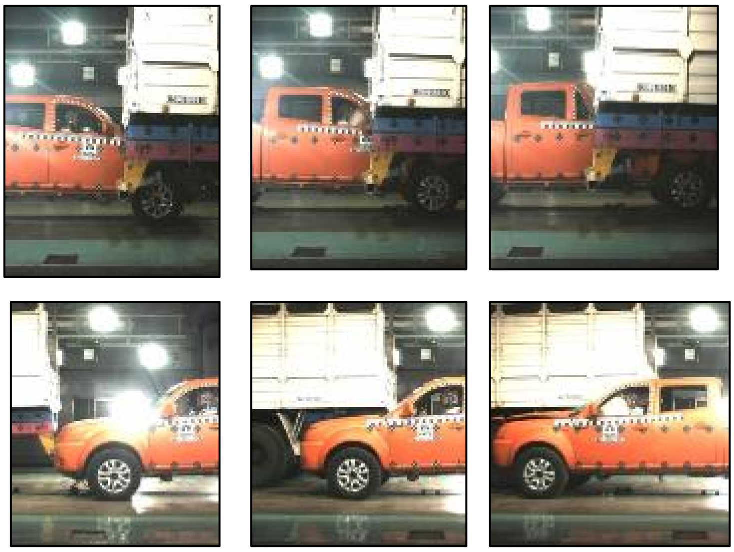


Fig 03

Development of CAE model for crash testing a small car vs. rear end of representative HGV

A CAE simulation was carried out based of the physical test results. As expected, it showed high A pillar and cowl panel intrusions.

Development of a stronger RUPD

An obvious way of improving RUPD strength was to increase the strength of P1 in line with P2 (i.e. increase P1 strength 4 fold – see Appendix 1 for P1 & P2 locations. Though this change was adequate to avoid the offset underrun impact, reinforcement members for a stronger RUPD structure were not possible for the following reasons: (1) There was no longitudinal support structure available along the line of the longitudinal force generated on P1 of the RUPD and (2) An oblique support from the chassis frame was not able to provide the required support in a longitudinal direction due to its inclination.

In the absence of an appropriate support structure, a standalone stronger RUPD structure proved to be much heavier. The weight of the RUPD increased from 35 kg to 61 kg when the strength at P1 was revised to P2.

As a new approach, instead of strengthening the RUPD, the team focused on avoiding interaction of the A pillar of the car with the load platform of the HGV. It was found that if, during impact, a smaller vehicle is in line with location P2, the chassis frame offers additional resistance at the bonnet level through the chassis frame cross member. Therefore, further development focused on extending the closing cross member of the chassis frame which would provide a wedging effect for stopping the small vehicle. As seen in Fig 4, the structure of the smaller vehicle locks against the rear end of the chassis frame of an HGV. (This is also termed as wedging effect.) This provides an additional means of stopping the small vehicle rather than an additional opposing member along the vehicle's longitudinal direction.

Fig 04

Development of closing cross member of the chassis frame

Mere extension of the closing cross member was not sufficient as it bends in an offset underrun impact. Therefore, a reinforcement was provided by a gusset member from the chassis long member. As can be seen in Fig. 05, the closing cross member (b) of the chassis frame (a) extended the cross member (shown as c) in line with the RUPD. It was additionally provided with gusset members (d) which connect the farthest ends of the extension with the chassis frame.

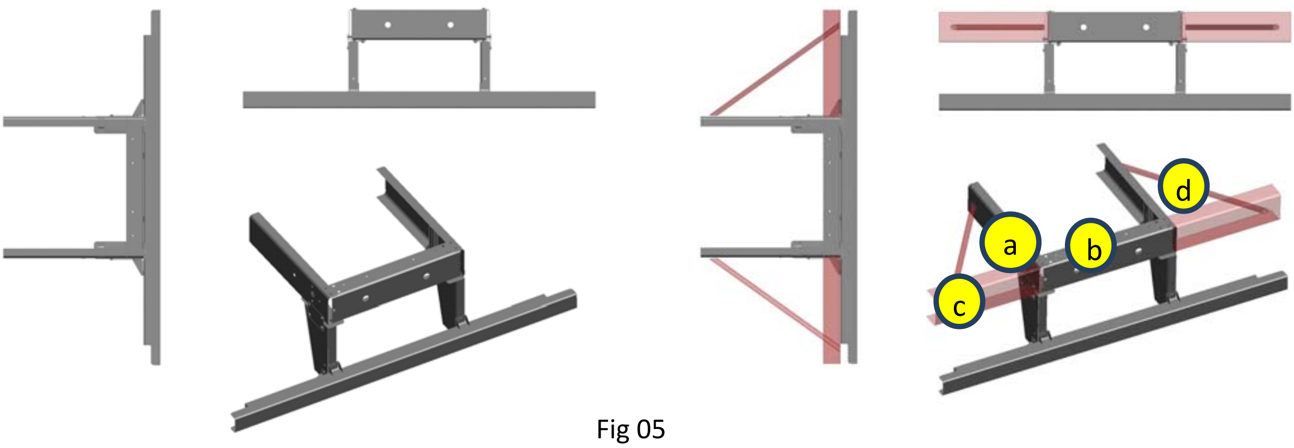


Fig 05

III. RESULTS

The proposed improved Rear Underrun Protection System (RUPS)[1] was validated through CAE for the following test conditions:

- Barrier impact according to the test specification described in the Methods;
- Car impact in order to study the worst case scenario.

The overall performance of the car was studied with a conventional RUPD and with the proposed RUPS in which the latter showed a marked improvement (Fig. 6). The proposed RUPD prevented A pillar contact with the load platform of the HGV. This means that there was no threat of a front seat occupant's head interacting with the load platform of the HGV directly. The comparative performance evaluation is shown in Figs. 7-10 in which the dark red line represents the existing situation and the green line represents the improved design.

[1] Subject system has been applied for Indian patent no IPA 610/Mum/2014.

With regard to ***crash pulse***, resistance picked up in the early stage of the crash which means improved energy absorption which is desirable to reduce the vehicle's penetration below the HGV. As a result the peak deceleration was reduced (Fig. 7). As a result of the change in crash pulse, the ***stopping distance*** was reduced by 37% which was desirable to avoid car A pillar contact with the HGV load platform (Fig. 8). ***Steering column intrusions*** were greater with the proposed design than with the present design of the RUPD (Fig. 9). However, there were much less intrusion than the regulatory limits of ECE R12 or ECE R94 which means the RUPD would not pose any harm to the car driver. The injury analysis also confirms that this is not a concern. With regard to ***energy balance***, Fig. 10 shows the energy transferred between the car and the HGV. There is no energy transfer to

Present design Improved design

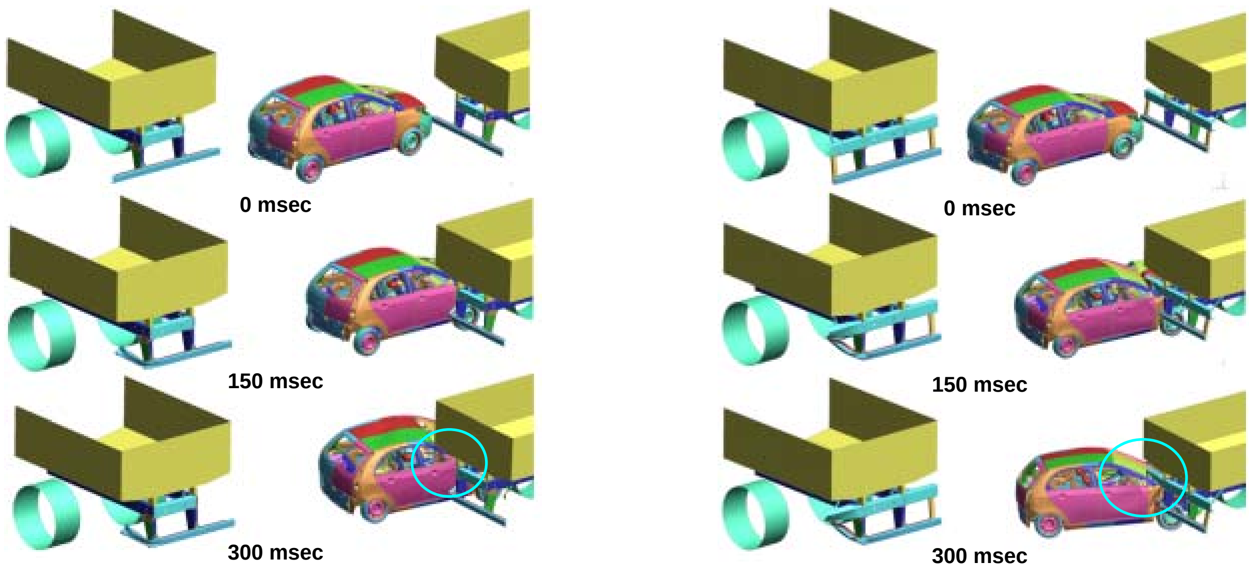


Fig 06

the HGV in the current design which suggests that the RUPD structure is not effective enough for energy absorption. Since the vehicle is retained with higher energy, when the A pillar and/or windshield contact the load platform, there is a considerable amount of energy available which leads to A pillar disintegration as well. On the contrary, there is gradual energy absorption between the HGV and the car with the proposed structure. Such performance is desirable.

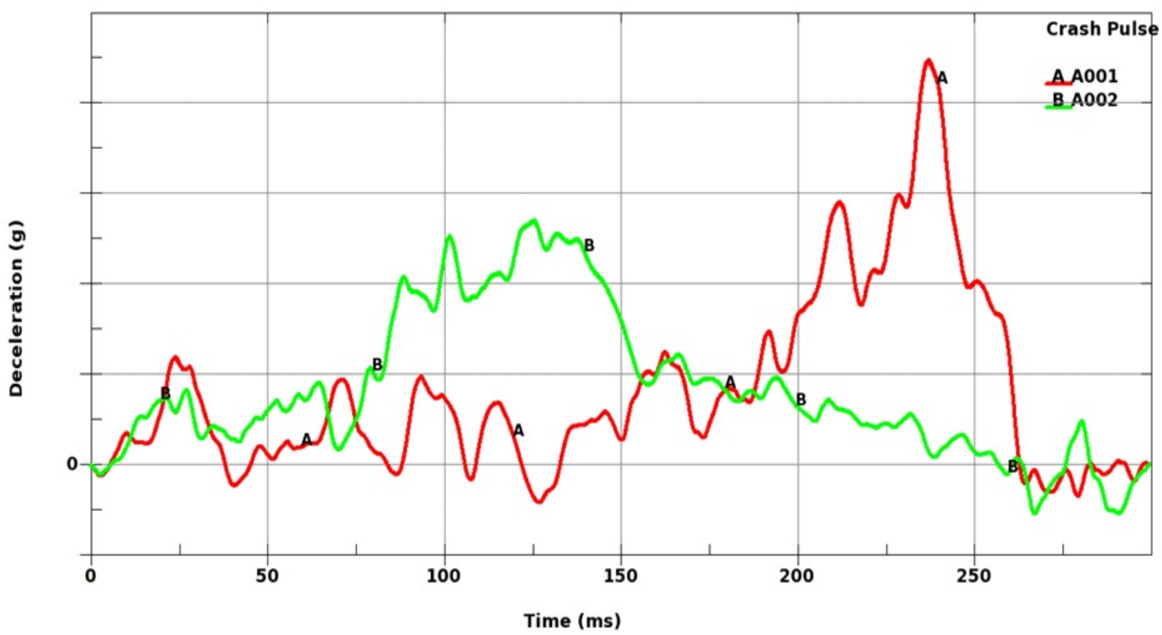


Fig 07 – comparison of crash pulses

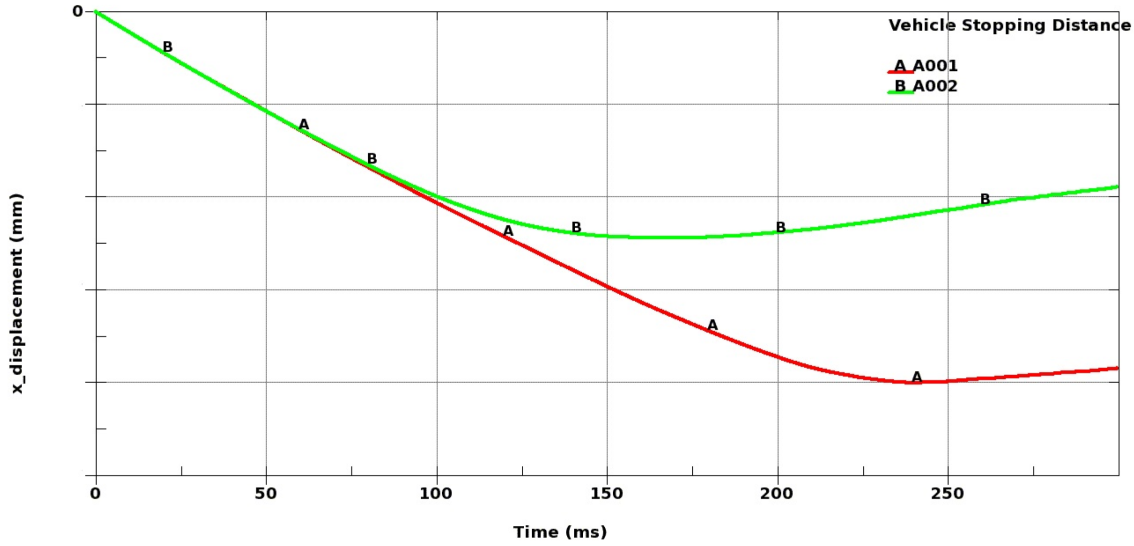


Fig 08 – Veh stopping distance

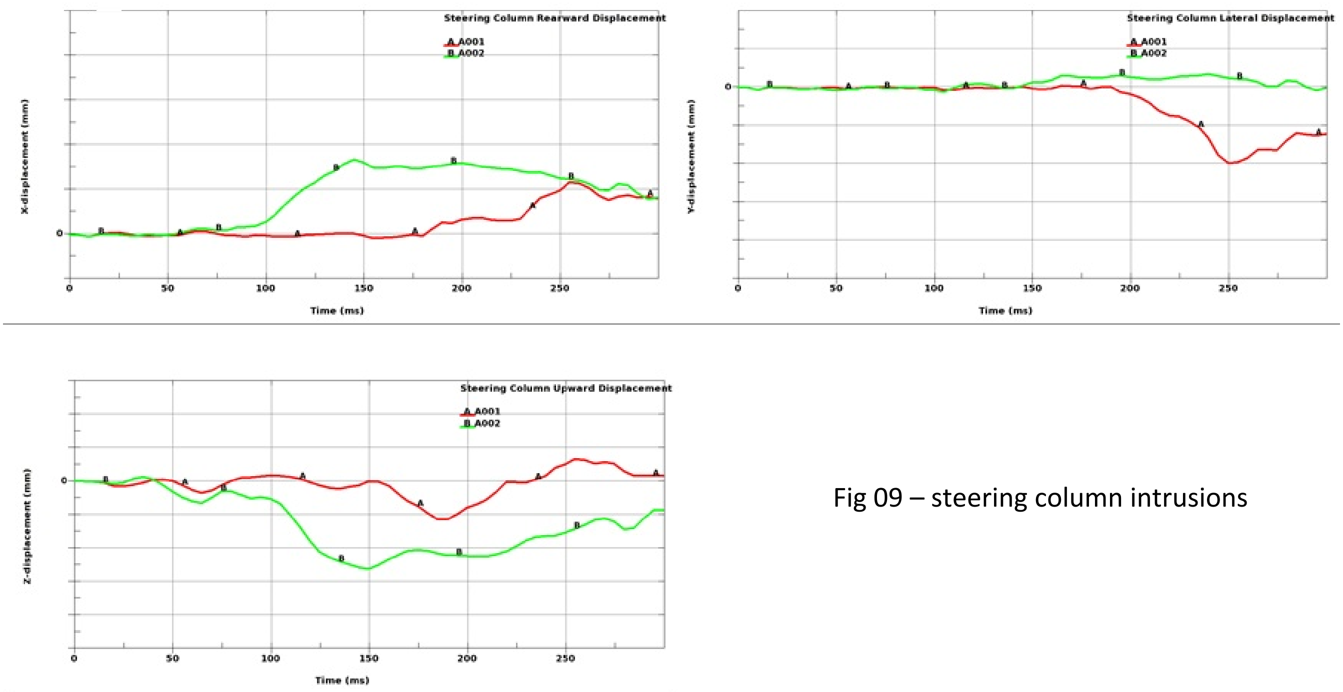


Fig 09 – steering column intrusions

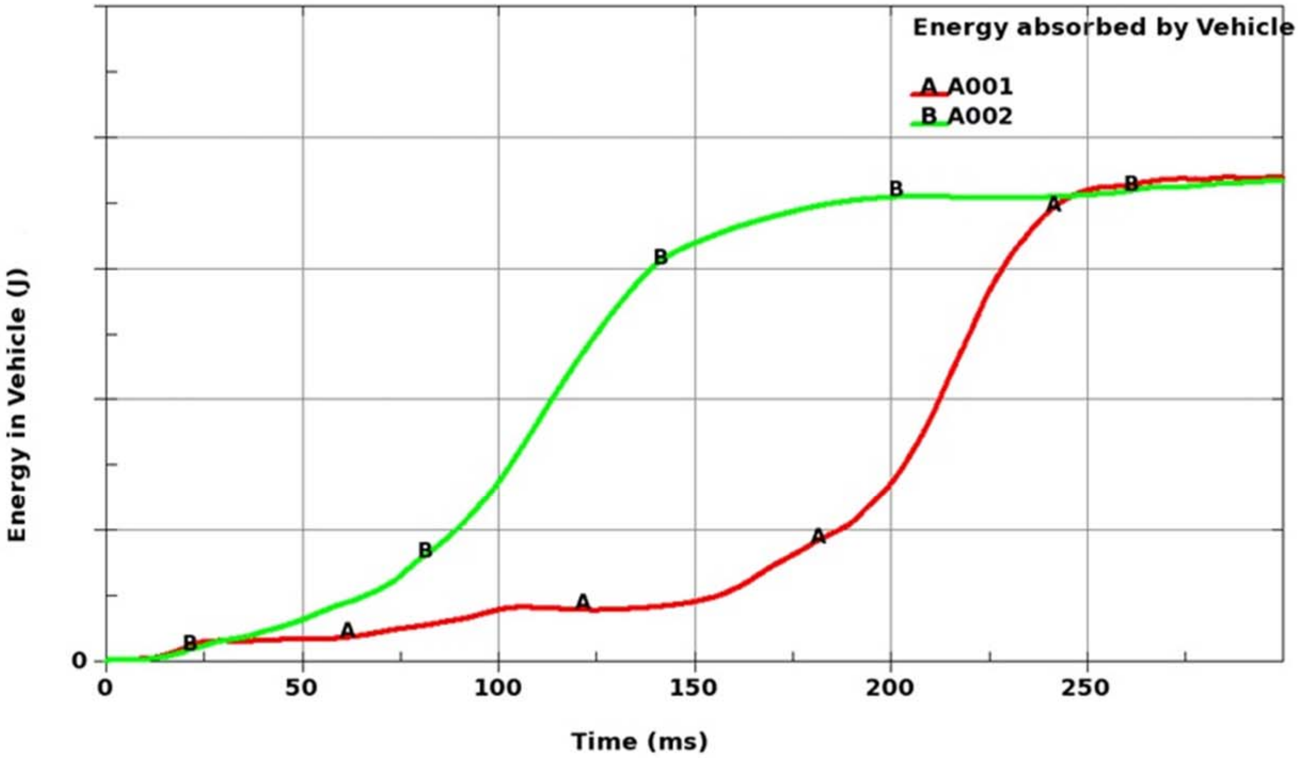
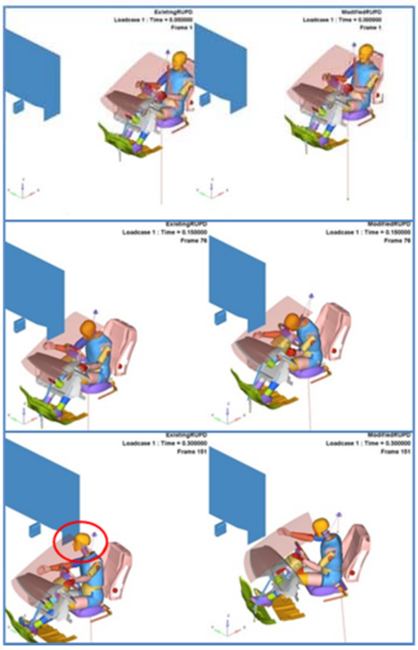


Fig 10 – energy absorber by the vehicle

Finally, with regard to ***injuries,*** the dummy kinematics in the current and modified design is shown in Fig. 11 which shows that there is a possibility of head interaction with the load platform of a truck leading to critical injuries.

IV. DISCUSSION & CONCLUSIONS

The accident analysis has shown that offset underrun crashes are one of the most serious types of



Injury criterion	*Current design*	*Modified design*
HIC36		
Peak head acceleration		
Head acceleration 3 mSec		
Neck shear force		
Neck tension force		
Neck extension bending moment		
chest deflection		
viscous criteria		
Femur force		
Tibia index		

Colour coding				
minor	moderate	severe	critical	maximum

accidents which lead to serious injuries due to excessive underrunning of a smaller vehicle due to absence of any barrier to vehicle intrusion. This leads to interaction between the A pillar and/or windshield aperture and the load platform of the HGV. Increasing the strength of the RUPD was not seen as an effective solution as it does not stop intrusions. Furthermore, the design demands a much heavier structure which is economically not feasible. Alternate protective systems for avoiding underrun as the one described in this paper need to be explored. The proposed system uses "wedging" of an inclined bonnet surface for stopping the smaller vehicle. This structure compliments the RUPD structure effectively and is a very efficient and cost effective approach. The amount of additional mass required for the proposed structure is much less than that required to upgrade RUPD strength.

V. ACKNOWLEDGEMENT

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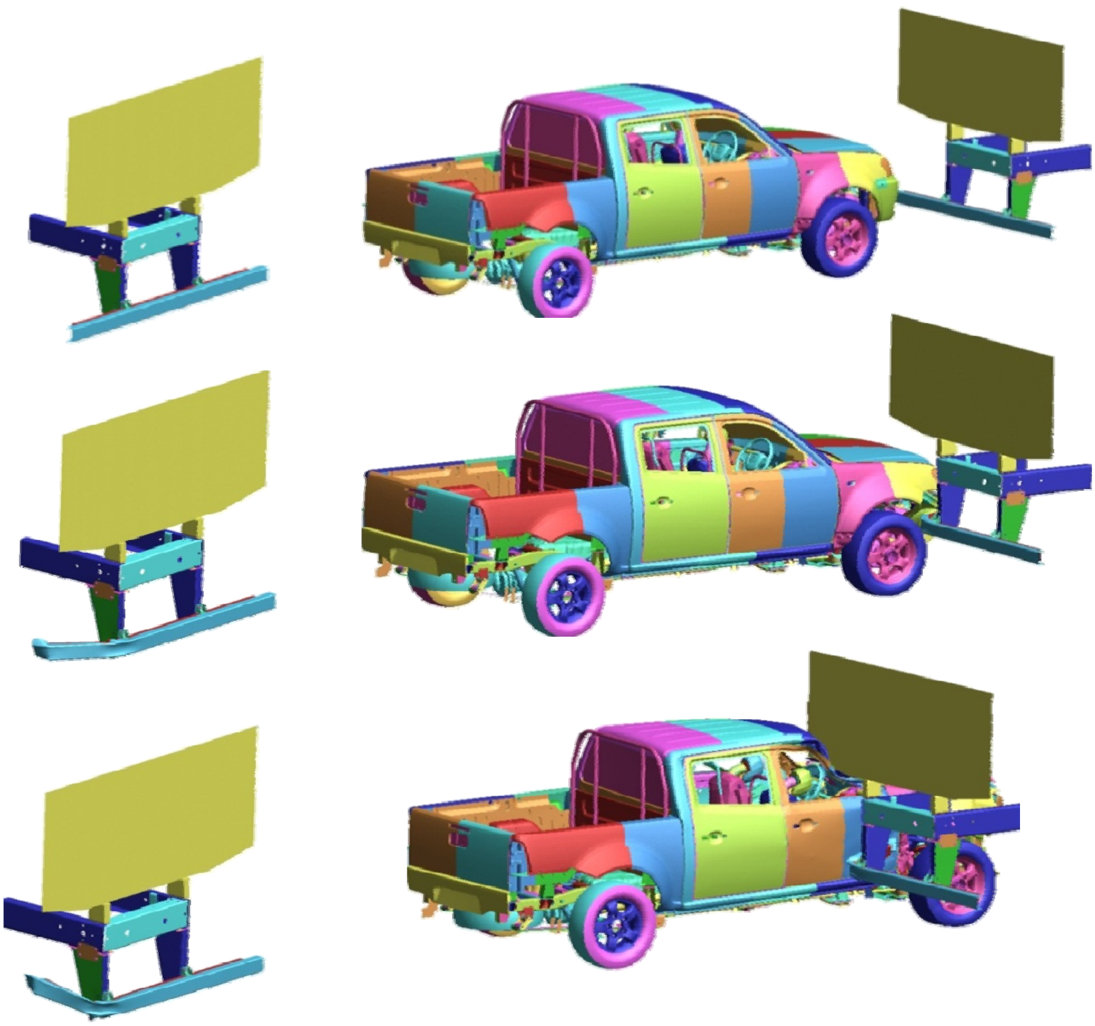
VI. REFERENCES

[1] Road Accidents in India 2012, Transport Research Wing of Ministry of Road Transport & Highways, Govt of India.
[2] Ravishankar R, et al. Accident Research – Pilot Study on an Indian Express Highway. *Proceedings of Expert Symposium on Accident Research (ESAR),* 2012, Hannover Medical School, Germany.
[3] IS 14812 (Indian standard), "Automotive vehicles - rear underrun protection device – general requirements".

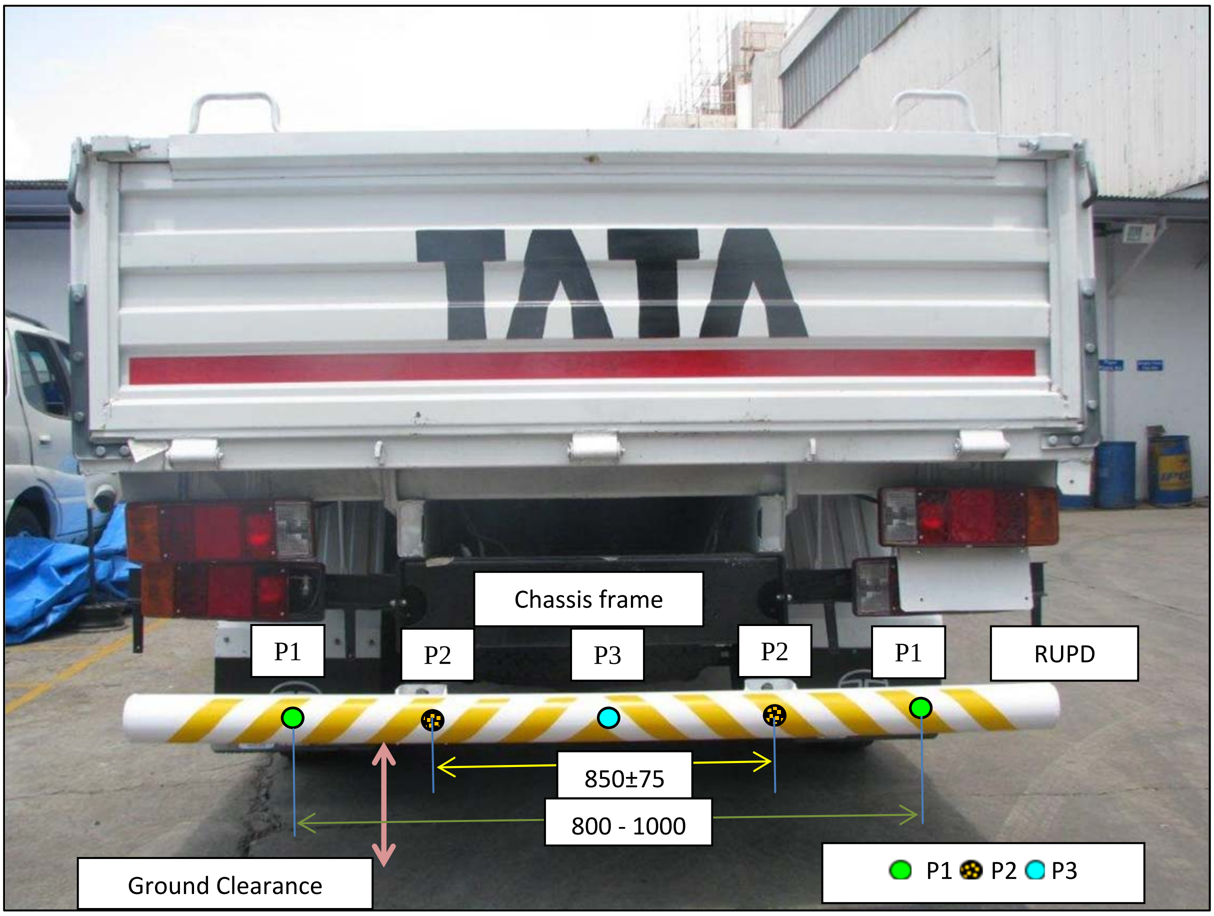
Appendix 1

The characteristic sequence of this type of loadcase is as follows :

- The car structure hits the overhanging end of the RUPD ,
- Bends it & continues to move ahead,
- The loadbody installed on HGV interacts with either of the A pillar and/or the windshield of the car. At times the loadbody interacts with the roof structure as well. This is particularly observed when the ground clearance of the bottom end of the chassis frame is ≥1000mm.
- The car comes to halt when its structure (A pillar, roof etc.) are adequately deformed & the kinetic energy is completely absorbed. Cutting of A pillar has also been recorded in rare cases. The detailed sequence is explained in appendix 2.
- The severity of the crash is higher when bonnet length of car is smaller.
- Critical Observations:
    - Overhanging portion of RUPD bends inwards
    - Car structures interacts with loadbody of the HGV leading to deformation of the safety cage and intrusions



Appendix 2



Ground Clearance ≤550 mm

P1 – located at ±300 inside the tyre outer edge. Generally about 800 to 1000 mm from vehicle centreline.

Strength ≥ 12.5% of GVW

P2 – located at 425±75 mm from vehicle centreline. Strength ≥ 50% of GVW

P3 – located along centreline of the vehicle. Strength ≥ 12.5% of GVW