

PAPER • OPEN ACCESS

Design and Development of Truck Rear Underrun Protection Device

To cite this article: S. Pooudom *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **501** 012017

View the [article online](#) for updates and enhancements.

Design and Development of Truck Rear Underrun Protection Device

S. Pooudom¹, S. Chanthanumataporn^{1,2*}, S. Koetnuyom^{1,2}, and J. Carmai^{1,2}

¹ The Sirindhorn International Thai-German Graduate school of Engineering (TGGS)

² Automotive Safety and Assessment Engineering Research Centre
King Mongkut's University of Technology north Bangkok, 1518 Pracharat 1 Rd.,
Bangkok, 10800, Thailand

* Corresponding Author: saharat.c@tggs.kmutnb.ac.th

Abstract. Underride truck crashes occur when a passenger car rides under the rear of a large truck. These kinds of accidents are especially dangerous because of the size difference between trucks and passenger cars. Therefore, it is necessary to install the Rear Underrun Protection Device (RUPD) at the rear of trucks for safety enhancement. The aim of this research is to design an effective RUPD which is strong enough to prevent a passenger car falling under the rear of the truck and able to absorb large amount of crash energy to minimize accident severity. The novel RUPD design, equipped with energy absorption guard and proper support structure is proposed in this paper. The study on the angle and separation distance of support structures is performed to find the proper design for the support structure of RUPD. The internal energy and displacement of various design of support structures are investigated by performing Finite element crash simulation in LS-Dyna. The FMVSS 223 standard is utilized as reference for the standard design of RUPD. The result shows that the support structure angle of 20 degree yields optimal displacement and energy absorption. Moreover, the new proposed RUPD is able to avoid the A-pillar deformation and eliminates underride altogether.

1. Introduction

The difference in size and height between passenger cars and trucks can allow the underride of the car in rear end collision, in which the entire vehicle will go underneath the truck. The passenger compartment is crumpled and completely absorbs impact energy. This kind of accident results in severe passenger injury and death. It has been estimated that the energy-absorbing front, rear and side under-ride protection could reduce deaths in car to truck impacts by about 12% [1].

The UNECE R58 and FMVSS 223 standards were used as the reference for evaluating the capability of the RUPD to protect underride collisions between cars and trucks rear-end. Based on the UNECE R58 and FMVSS 223 standards the static test is performed on each point of the Rear Underrun Protection surfaces. The UNECE R58 [2] standard focuses on the deflection distance on the Rear Underrun Protection surfaces. Nevertheless, the FMVSS 223 standard concerns at both the deflection distance and the energy absorption on the Rear Underrun Protection surfaces. The UNECE R58 and FMVSS 223 standards have the same goal, in which the Rear Underrun Protection have to be strong enough to prevent the automobile sliding under the truck and enable the automobile's crumple zone to absorb collapse energy.



The main requirements of rear underrun protective systems are essentially two: avoiding the underride of the car and absorbing the greatest amount of energy so as to reduce the deceleration peaks and, consequently, the injuries suffered by the passengers.

In any designing or redesigning process of a new device, it is also necessary to follow the regulations governing its use. In FMVSS 223 [3], the regulation imposes that (as shown by figure 1.):

- The ground clearance of the horizontal member shall not exceed 560 mm when measured at each support to which the horizontal member is attached.
- Distance between RUPD and tail end must not exceed 305 mm.
- Length of RUPD must not exceed more than 100 mm on each side of truck.
- Cross-sectional guard must not less than 100 mm.

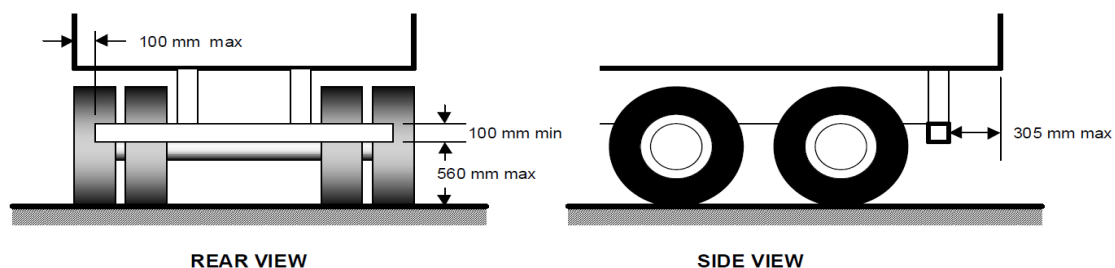


Figure 1. Dimensional limit of a RUPD [3].

The Underrun Protection device is not only a high-strength structure but also able to absorb collision energy in order to secure the car occupants. The Department of Transportation and the National Highway Traffic Safety Administration (NHTSA) has previously stated that the more rigid the Underrun Protection devices, the more likely they are to injure passengers. On the other hand, the more collapse of Underrun Protection, the more harmful it will be to passengers.

The objective of the study is to design and develop the safer RUPD, which is able to absorb collapse energy while at the same time it must be strong enough to protect rear underride truck crashes. In this paper, the effect of RUPD support structures is focused by investigating the angle and separation distance of support structures in order to define the proper design for the support structures of the safer RUPD.

2. Development of safer RUPD

The common standard rear underrun protection device [4] is consisted of two support structures and a crossbar as shown in figure 2. The support structures are used to rigidly connect the RUPD cross bar with the truck frame. In this paper, the support structures has been focused in designing for improve the strength and energy absorption ability by varying the support structures angle and the separation distance between support structures. The RUPD crossbar is generally designed to be rigid structure for underride protection. However, in this study, with the objective to enhance crashworthiness, the crossbar structure is designed with a six-stage compression of steel beams, so as to allow good energy absorption during crushing [5].

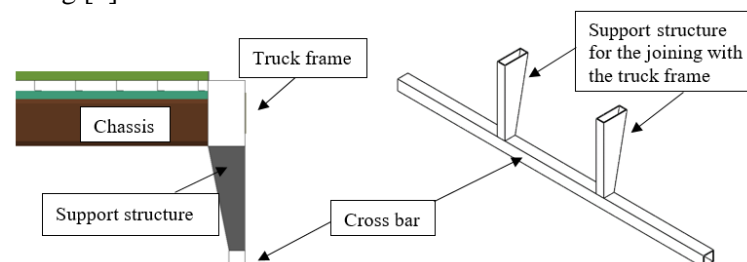


Figure 2. Scheme of the standard RUPD.

2.1. Support structure angle

In the process of support structure development, the variation of the support structure has been designed to study the effect of support structure angle and define the proper angle used for design the safer RUPD. The angle of support structure (θ) as shown in figure 3(a) were design to be 15, 20, 25, 30, 45, and 60 degree respectively. However the separation distance between support structures is 748 mm. corresponding to the width between chassis rails as shown in figure 3(b). Based on the standard RUPD, each support structure is attached under the chassis rail since the installation is quite convenient and secure.

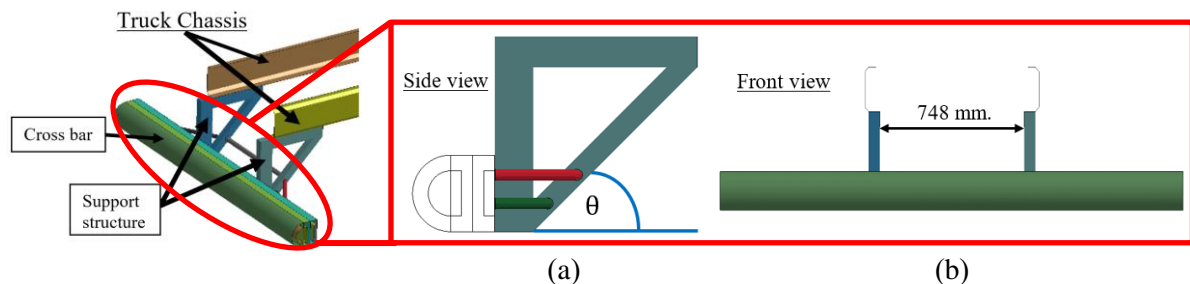


Figure 3. (a) Support structure angle, (b) separation distance between support structures.

2.2. Separation distance between support structures

The effect of separation distance between support structures is investigated with the hope to enhance the crashworthiness from the offset collisions. The distance between support structures has been increased from the standard distance of 748 mm. (30% of crossbar length) to the wide one of 1232 mm (50% of crossbar length). Moreover the support structures are installed under the truck's bed instead of the chassis rail. The upper part of the support structures has been redesigned to install the support structure under the truck's bed as shown in figure 4.

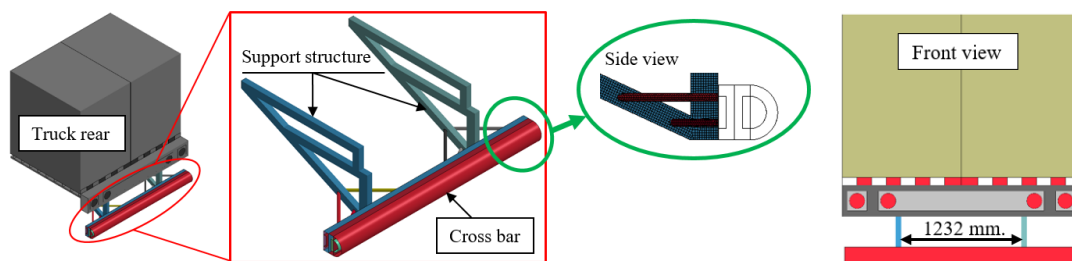


Figure 4. Scheme of proposed RUPD.

3. Finite Element model of car

Vehicle Finite element model of 2010 Toyota Yaris passenger sedan adopted from the National Crash Analysis Center (NCAC) [6] was utilized in this research as the car model. The detail model of this vehicle can be seen in the figure 5. The utilized vehicle model has been validated against the full scale crash test performed by NCAP [6]. As shown in the figure 6, the validation focuses on the comparison of the NCAP test high speed camera picture and simulation picture, in which the crush depth in the front of the car and the acceleration at different locations of the car are compared. The simulation results are found to be consistent and in good agreement with the NCAP crash test data.



Figure 5. The detail FE model of Toyota Yaris passenger sedan 2010.

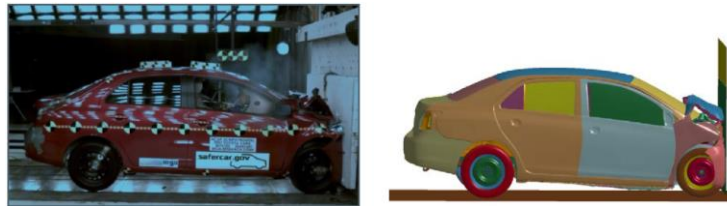


Figure 6. Comparison between NCAP test and simulation results [6].

4. Result and discussion

4.1. Effect of support structure angle

The effect of support structure angle was investigated in the condition of 50% offset crash as shown in figure 7(a). The car travels forward with speed of 56 km/hr. and the ground clearance of the RUPD is 37 cm. as shown in figure 7(b).

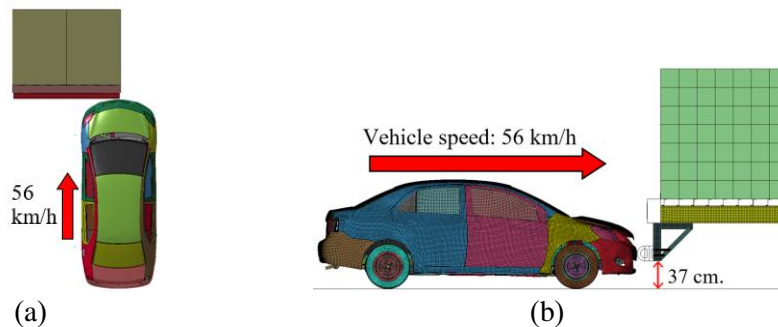


Figure 7. (a) 50% offset, (b) test speed and ground clearance.

Table 1. Material property for proposed RUPD model.

Material	Young modulus	Density	Yield stress	Poisson's ratio
Mild steel	210 GPa	7.85 g/cm ³	200 MPa	0.3

The internal energy and displacement of the proposed RUPD with various support angles are presented in figure 8 and 9 respectively. In the first stage of investigation, the support structure angle is defined to be 15, 30, 45, and 60 degrees as shown in figure 8(a) and figure 9(a) to approximately observe how much energy was absorbed by the device and how much bending displacement in each support structure occur during car crashes. The results in figure 8(a) and figure 9(a) shows that the support structure at an angle of 15 degrees has the highest capability of energy absorption with the least bending displacement.

In the second stage, the support structure angle of 15, 20, 25, and 30 degrees has been defined for deeper investigation. The obtained results as presented in figure 8(b) and figure 9(b) reveals that the

energy absorbed by the support structure of angle 20 degrees is almost identical to that of 15 degrees. Also, the displacement of the support structure of 20 degrees is quite identical to that of 15 degrees as well as lesser than that of 25 and 30 degree. Therefore, the 20 degree support structure has been defined for the safer RUPD.

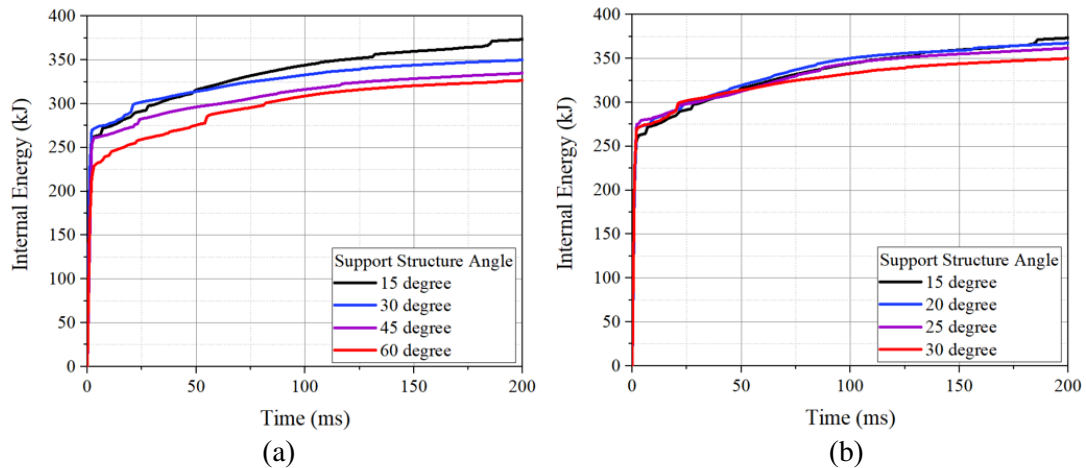


Figure 8. (a) Internal energy for 15, 30, 45, 60 degree, (b) Internal energy for 15, 20, 25, 30 degree.

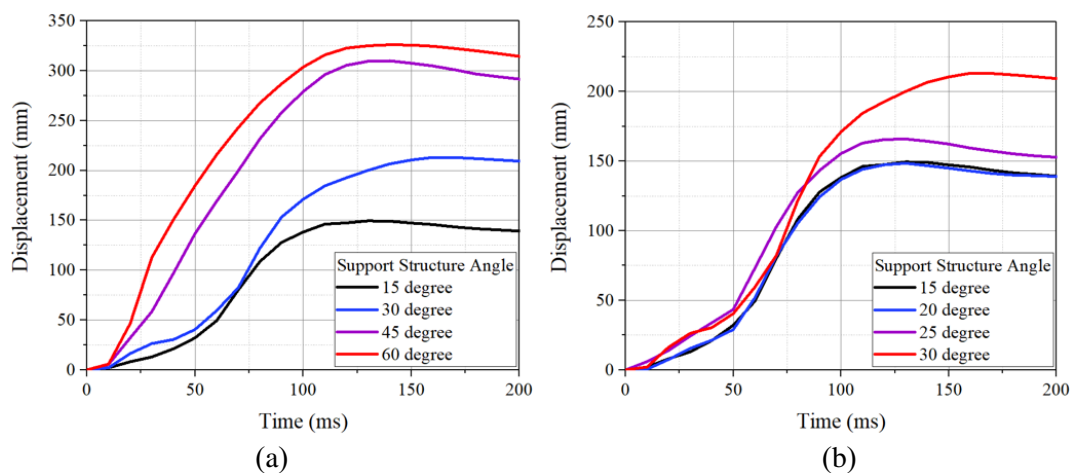


Figure 9. (a) Displacement for 15, 30, 45, 60 degree, (b) Displacement for 15, 20, 25, 30 degree.

4.2. Effect of separation distance between support structures

The effect of separation distance between support structures has been investigated by comparing two condition of separation distances, the standard distance of 748 mm. (30% of crossbar length) and the wide distance of 1232 mm (50% of crossbar length) as shown in figure 10.

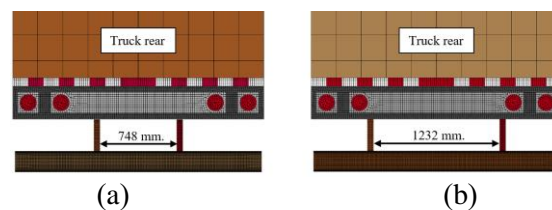


Figure 10. Separation distance between support structures of (a) standard separation, (b) wide separation.

The crash simulation is set up for three conditions, full width, 50% overlap, and 30% overlap as shown in figure 11. The vehicle speed was set equal to 56 km/h and the ground clearance for all conditions is 37 cm. as shown in figure 12.

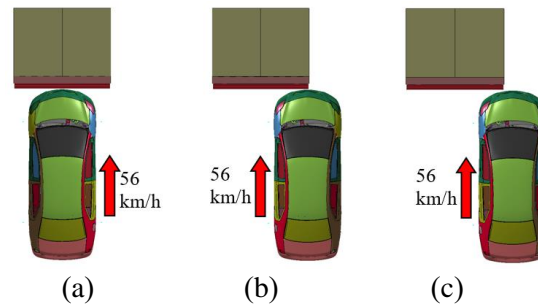


Figure 11. (a) Full width, (b) 50% overlap, (c) 30% overlap.

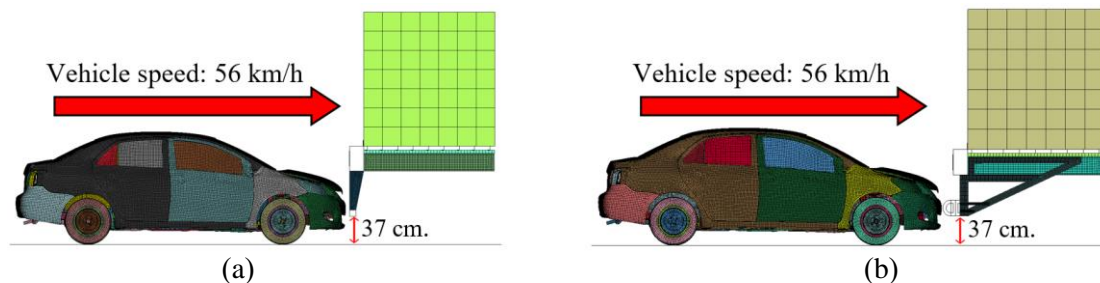


Figure 12. The crash simulation set up in side view of (a) standard RUPD and (b) proposed RUPD.

The results of six crash tests are concluded in table 2 and the maximum crash intrusion scenario of the test vehicle were shown in figure 13-15. The results indicate that there is no underride which occurs in the condition of full width crash. Moreover, the longitudinal A-pillar deformation is equal to zero for both standard and wide separation RUPD.

For the condition of 50% overlap crash, zero longitudinal A-pillar deformation is measured. None of the underride happens for both standard and wide separation RUPD. As shown in figure 14, although the deformation of the standard separation RUPD is greater than that of wide separation RUPD, the longitudinal A-pillar deformation is equal to zero for both cases.

Table 2. Toyota Yaris sedan front into the standard separation and wide separation RUPD crash simulation results.

Conditions	RUPD	Guard performance	Underride	Max. longitudinal A-pillar deformation (cm)
Full width	Standard separation	Good	None	0
	Wide separation	Good	None	0
50% overlap	Standard separation	End bent forward	None	0
	Wide separation	End bent forward	None	0
30% overlap	Standard separation	End bent forward	Severe	24
	Wide separation	End bent forward	None	0

For the condition of 30% overlap crash, the underride present in the standard separation RUPD of which the longitudinal A-pillar deformation is equal to 24 cm. On the other hand, none of underride happens for wide separation RUPD and there is no longitudinal A-pillar deformation. As shown in

figure 15, the standard separation RUPD unfortunately allows the car underride the truck because the car does not crush the support structure but crush only the cross bar which is not strong enough to save the car from underriding. The wide separation RUPD can absorb more energy than the standard separation RUPD which leads to no deformation in passenger cell and no underride happens after crash. Nevertheless, the crossbar of both RUPD still bends forward due to offset crash.

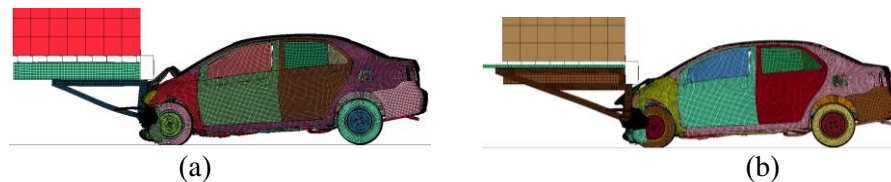


Figure 13. Full width tests with (a) standard separation RUPD and (b) wide separation RUPD.

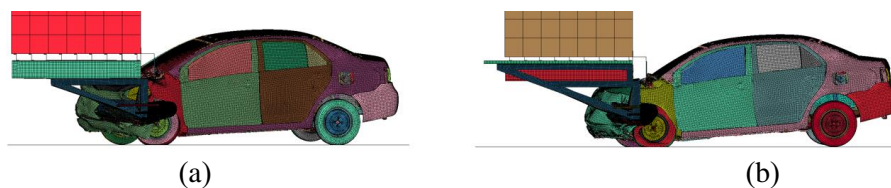


Figure 14. 50 percent overlap tests with (a) standard separation RUPD and (b) wide separation RUPD.

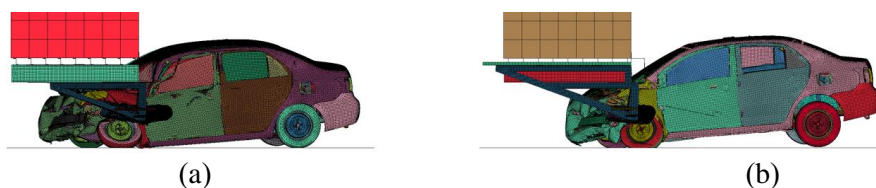


Figure 15. 30 percent overlap tests with (a) standard separation RUPD and (b) wide separation RUPD.

After the investigation of the separation distance between support structures, the proposed RUPD with the wide separation design was further investigated by comparing the crash result with those of standard RUPD. The results of six crash tests were shown in table 2 and the maximum crash intrusion scenario of the 2010 Toyota Yaris passenger sedan was shown in figure 16-18. The results indicate that there is no underride which occurs in the condition of full width crash. Moreover, the longitudinal A-pillar deformation is equal to zero for both standard and proposed RUPD.

For the condition of 50% overlap crash, severe underride is observed for the standard RUPD while the longitudinal A-pillar deformation is equal to 57 cm. No underride happens for proposed RUPD and no longitudinal A-pillar deformation is measured as shown in figure 17.

Table 3. Toyota Yaris sedan front into the standard and proposed RUPD crash simulation results.

Conditions	RUPD	Guard performance	Underride	Max. longitudinal A-pillar deformation (cm)
Full width	Standard RUPD	End bent forward	None	0
	Proposed RUPD	Good	None	0
50% overlap	Standard RUPD	End bent forward	Severe	57
	Proposed RUPD	End bent forward	None	0
30% overlap	Standard RUPD	End bent forward	Catastrophic	101
	Proposed RUPD	End bent forward	None	0

For the condition of 30% overlap crash, the catastrophic underride can be seen for the standard RUPD while the longitudinal A-pillar deformation is equal to 101 cm. as shown in figure 18(a). On the other hand, no underride happens for the proposed RUPD and the longitudinal A-pillar has no deformation as shown in figure 18(b). Nevertheless, the cross bar of both guards still bends forward due to offset crash.

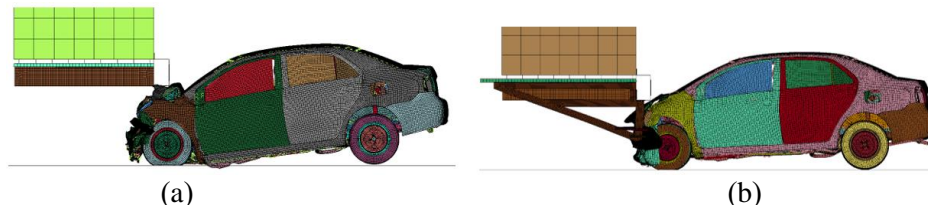


Figure 16. Full-width tests with (a) standard RUPD and (b) the proposed RUPD.

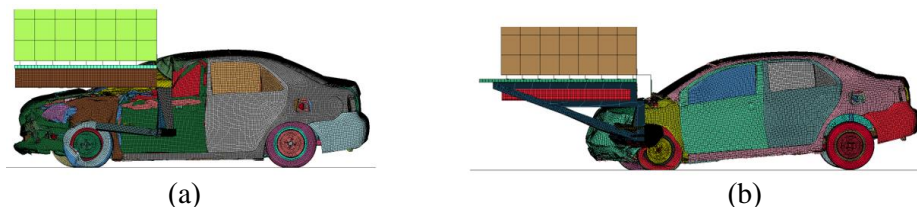


Figure 17. 50 percent overlap tests with (a) standard RUPD and (b) the proposed RUPD.

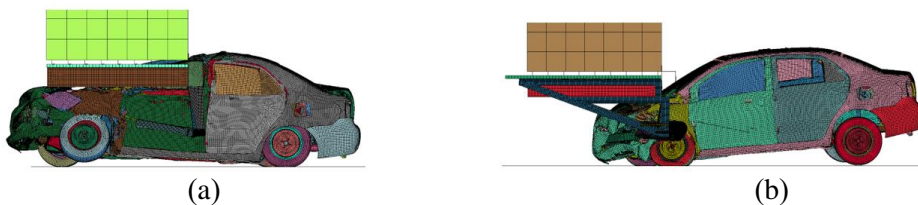


Figure 18. 30 percent overlap tests with (a) standard RUPD and (b) the proposed RUPD.

5. Conclusion

The proposed RUPD model were set up with different support structure angle using LS-DYNA. The crash simulations for studying the effect of support structure angle and separation distance were conducted. The results indicated that the support structure angle of 20 degrees is the optimal one for the proposed RUPD and the wide separation support structure (50% of cross bar length) can protect the car from underride for full width, 50%, and 30% overlap crash. Thus the optimal condition was employed for designing the proposed RUPD. In addition, the crash test results of the standard RUPD were compared with those of proposed RUPD. It is observed that the proposed RUPD shows better performance than the standard one. Based on these results, RUPD designers can consider these factors for designing the support structure of RUPD to improve crashworthiness in car to truck rear end collisions.

References

- [1] Z. F. Albahash, M.N.M. Ansari 2016 A review on rear under-ride protection devices for trucks *International Journal of Crashworthiness*
- [2] United Nations Economic Commission for Europe, ECE Regulation No. 58: "Uniform provisions concerning the approval of rear underrun protective devices (RUPD)", unece.org/trans/main/wp29/wp29regs41-60.html
- [3] National Highway Traffic Safety Administration 2009 Title 49 Code of Federal Regulations (CFR) Part 571, rear impact protection Washington, DC: Office of the Federal Register

- [4] M. L. Brumbelow, Insurance Institute for Highway Safety, United States 2011 Crash test performance of large truck rear underride guards *NHTSA DOT HS*. 11-0074
- [5] A. Chege, Kshitij, A Kale, M. R. B. Agrewale, K. C. Vora. 2017 Design and development of impact energy absorbing bumper *J.Sci. & Eng.research* **8** 2229-5518
- [6] D. Marzougui, R. R. Samaha, C Cui, S. Kan, The National Crash Analysis Center, The George Washington University 2012 Extended Validation of the Finite Element Model for the 2010 Toyota Yaris Passenger Sedan