ANALYSIS OF ROUNDED REAR UNDER RUN PROTECTION DEVICE OF HEAVY VEHICLE USING FINITE ELEMENT ANALYSIS FOR CRASHWORTHINESS

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Abstract
This paper proposes and analyses a new structure design of Rear Under Run Protection Device (RUPD) mounted on the rear of a heavy vehicle to protect under running of smaller vehicles like car. The RUPD is required to comply with the IS 14812 - 2005 regulation for its design and functional behavior under the practical conditions that a vehicle undergo during crash. The standard provides initial inputs and conditions as target and allows designers to generate effective design while maintaining the functionality as well as safety inspection norms. The paper analyses the new design of RUPD on heavy vehicles using finite element analysis tool viz. ANSYS and compares for the agreement with Indian safety regulations. The study comprises elastic simulation done on ANSYS and establishes relative merits from existing structure used.
Index Terms: under run protection devices, safety regulations, simulation, LS-Dyna, Crashworthiness

I. INTRODUCTION

India and many other developing countries are facing a serious problem of road accidents. The situation further worsens due to continuous increase in vehicles load on the roads. The Road Safety in India Status Report published under Transportation Research and Injury Prevention Programme (TRIPP) by IIT, Delhi (2015) compiles the growth in Vehicle population over the years (Figure 1)[1]. A Global Status reports on Road Safety (2009) by World Health Organization indicate that India has the highest number of traffic accident fatalities in the world [2]. The continuous increase in the road traffic load is creating an alarming situation in terms of road accidents, road injuries and fatalities.

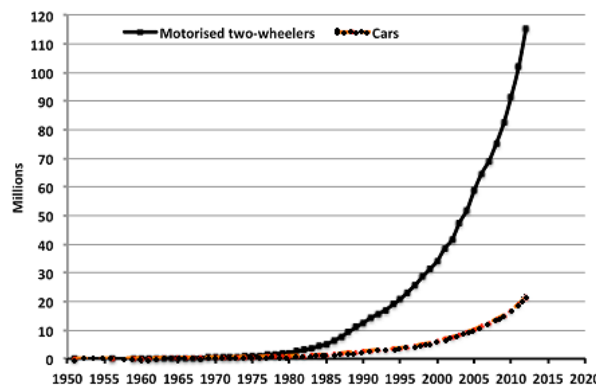

Figure 1: Cars and MTW registered in India over the years (Source: Transport Research Wing, 2014)

A study by Transport Research Wing, Ministry of Road Transport and Highways, Government of India, states that during year 2015 [3], there are 95.5% of accidents which involve motorized vehicles. Out of it, accident through cars and jeeps accounts for second largest accidents (23.6 %) after two wheelers (28.8%). These numbers of fatalities are alarming and establish a need to put efforts for crashworthiness of the smaller vehicles. Ulf Bjornstig et al. (2008) [4] emphasized the innovative, cost effective and improved configurations of protective devices on both and heavy vehicles. Such protective devices should be light in weight and good energy absorbing capacity in a crash situation.

The under run protection devices are the passive devices which are mounted on front (FUPD), side (SUPD) and rear (RUPD) of the heavy vehicles. These are used to prevent the pedestrians and smaller vehicles to under run the heavy vehicle and have direct impact. The other aspect of RUPD is to absorb maximum energy after the crash. This study is conducted for rear under run protection device (RUPDs). In 2006, National Highway Traffic Safety Administration (NHTSA) published a document on Large Truck Crash Causation Study (LTCCS) [5]. This study categorizes General accident into 13 types. The study states that 41% of vehicles are car or light trucks which get involved in accidents with heavy trucks. Out of these around 23% of vehicles undergo accidents at rear end of the truck which is second highest percentage out of 13 categories. The report from Insurance Institute for Highway safety, Highway loss data Institute (2015) states that 29% of passenger vehicle occupants killed in two-vehicle crashes with a large truck were in head-on crashes with the truck. 20% involved the front of the passenger vehicle striking the rear of the large truck [6].

A survey was conducted at Indian National highway 3 and National highway 59. It was found that the major truck manufacturers in India like TATA, Ashok Leyland, Eicher etc. are using straight bar under run with fixed / bolted mountings on chassis. Out of these, the section for bar is observed as square bar, round bar or channel section. The analysis of straight bar RUPD is attempted by many authors. Kaustubh Joshi et al. (2012) has analyzed the straight bar with circular cross section through explicit FE code LS-Dyna and verified the results in compliance to IS 14812:2005 [7]. Sumit Sharma et al. (2015) also analyzed straight bar RUPD using Hypermesh and Radioss using strain mapping method to optimize the design [8]. Alok Khore et al. explored the effect of thickness of straight bar RUPD for optimized energy absorption and crashworthiness [9].
An Indian regulation IS 14812:2005 [10] derived from ECE R58 standard is implemented for the design compliance. This standard regulates the design of RUPD which shall offer sufficient resistance to forces applied parallel to the longitudinal axis of the vehicle, and be connected; when in the service position with the chassis side members or whatever replaces them. As per this standard, consecutive static forces are applied at different locations P_1, P_2 and P_3 (Figure 2).

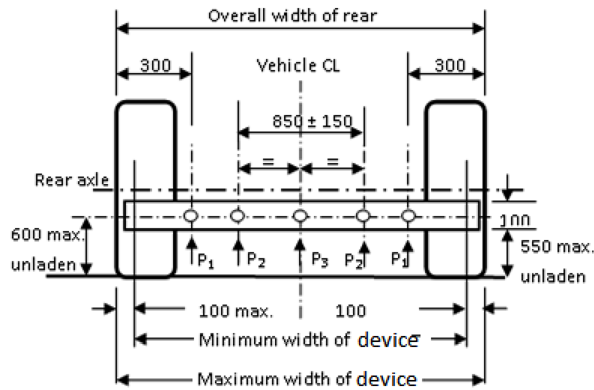

Figure 2: Legal requirement of RUPD (IS 14812:2005)[10]

1. Points P_1 are located 300 ± 25 mm from the longitudinal planes tangential to the outer edges of the wheels on the rear axle. The height above the ground of the point P_1 shall be defined by the vehicle manufacturer within the lines that bound the device horizontally. The height shall not, however, exceed 600 mm when the vehicle is un-laden. A horizontal force equal to 12.5 % of the maximum Simulate to Innovate 3 technically permissible weight of the vehicle, but not exceeding 25 kN shall be applied successively to both P_1 locations.
2. Points P_2, which are located on the line joining point P_1, is symmetrical to the median longitudinal plane of the vehicle at a distance from each other about 700 to 1000 mm inclusive the exact position has been specified by the manufacturer. A horizontal force equal to 50 percent of the maximum technically permissible weight of the vehicle, but not exceeding 100 kN shall be applied successively to both points P_2.
3. Point P_3, is located in line with the P_1 and P_2 at the center of the RUPD bar. The applied force at P_3 is similar to P_1. The forces specified above shall be applied separately, on the same guard. The order in which the forces are applied may be specified by the manufacturer. This

requirement shall be satisfied if it is shown that both during and after the application; the horizontal distance between the rear of the device and the rear extremity of the vehicle does not exceed 400 mm at any of the points P_1, P_2 and P_3.

II. METHODOLOGY

The design analysis for Rounded RUPD is carried out using numerical simulation. A Rounded RUPD assembly (Figure 3) consists of a vertical member box section. This vertical member is bolted to Chassis of the truck. This box section is welded to the rounded bar with a spacer. The spacer is welded with the box section and the RUPD bar.

2.1 Finite Element Modeling of RUPD

The parts of RUPD i.e. rounded bar, spacer and vertical member, are meshed with automatic mesh generation on Hypermesh. The surfaces are large as compared to the thickness and therefore they are meshed with shell elements and assigned with "SECTION_SHELL". The thickness of 3 mm, 3.5 mm and 4.5 mm is assigned to bar and spacer while vertical box section with 8 mm. The shell elements are used with the minimum thickness value among the components to represent welded joints. The vertical member, the spacer and rounded bar are welded together. This assembly is the bolted to the chassis member. The figure 3 shows the meshed model of Rounded rear under run protective device.

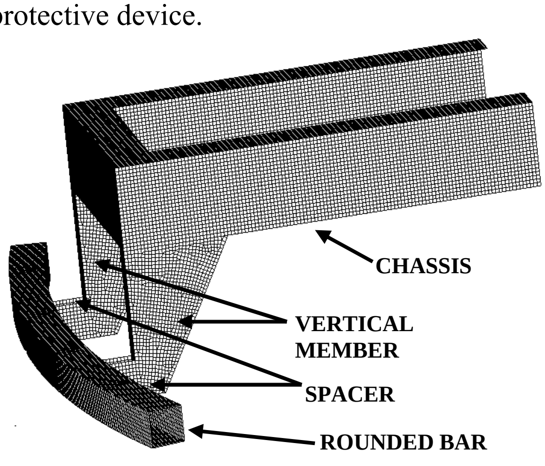

Figure 3: Rounded bar RUPD with meshing

2.2 Finite Element Modeling of Car

The Car model used in this work is taken from GrabCAD site. GrabCAD produce variety of Car models freely available for the purpose of analysis. The material of different parts and contacts are well defined in model. Although the car models have many parts, the car model used here is reduced to 206 parts. These parts are defined 186 shells, 8 discrete and 3 beam components.

The material card for the RUPD components is defined under MAT_PIECEWISE_LINEAR_PLASTICITY card. The card is used to define mass density (7.89E-009), Poison's ratio (0.3) and the Young modulus (2.1E+005) to describe material of all the three parts. The true strain-stress curve all the materials used is entered and assigned to respective materials. The interface between the RUPD bar and the Car is defined using CONTACT_AUTOMATIC_SINGLE_SURFACE card to establish contact between parts during simulation through LS-Dyna solver. The TERMINATION card defines

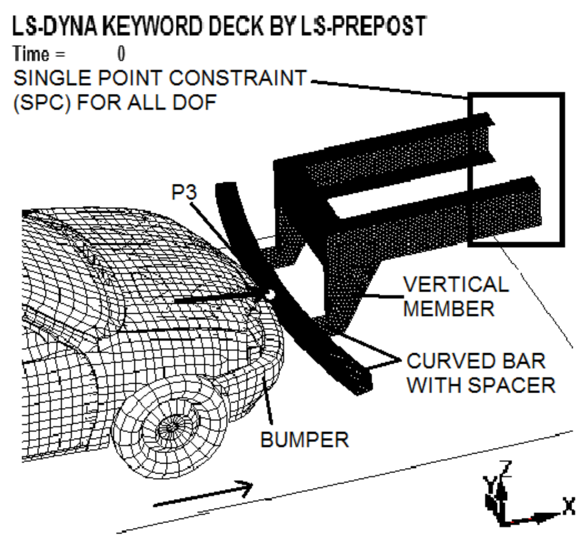

Figure 4: Boundary and loading conditions during crash

the termination time of simulation and is kept as 0.2 sec. The LS-Dyna keywords were referred from LS-DYNA Keyword User Manual [11].

2.3 Loading and Boundary conditions

The loading and boundary conditions are those which are set on the numerical model to simulate the actual physical conditions. These conditions applied in accordance to IS 14812:2005 are described below.

2.3.1 Boundary conditions

The nodes at end of the chassis cut section are constrained in all the directions to make it fixed. This simulates the heavy truck in stationary condition in lead vehicle stationary (LVS) type of crash. The end of the cut section of Chassis is considered as Single point constraint (SPC). The SPC is created using the nodes at the end of the chassis section (Figure 4). The chassis is also a critical component and may be difficult to change in case of deformation due to crash.

2.3.2 Loading condition

During a crash scenario, the car is simulated to strike the stationary truck from rear on rear under run protection device (RUPD) (Figure 4). The initial speed of the car is taken 80 kmph (highway limit) [3] which reduce to 36.26 kmph at the time of strike with a striking distance of 40 meters. The car strikes at the center of RUPD simulates for the Point P_3 as shown in figure 2.

The acceptance criteria of the simulation should be as under.

1. The maximum displacement of RUPD bar should be less than 400mm after the termination of the crash.
2. Maximum energy should be absorbed by the RUPD bar.

The RUPD should remain attached to chassis all the time during the simulation.

III. SIMULATION RESULT AND DISCUSSION

The simulation results were found out for three parameters which are useful in further discussion and conclusion for rounded structure of RUPD design. The correctness of numerical analysis is evaluated by balancing the energies before and after the crash. The kinetic energy of moving car gets transformed into friction and internal energies of various components of RUPD and car participating in crash.

a. Global Energies

The global energies of the system indicate typical energy balance between kinetic and internal energies through numerical method.

Figure 5 indicates the energy balance in the system during the crash condition. The Kinetic energy (KE) of the system gradually reduces as the crashing car comes to stationary after the crash. The internal energy (IE) of the system gradually increases. However, the increase in internal energy is different for different thicknesses of the RUPD bar and spacer. The maximum absorption is observed with 3.0 mm thickness.

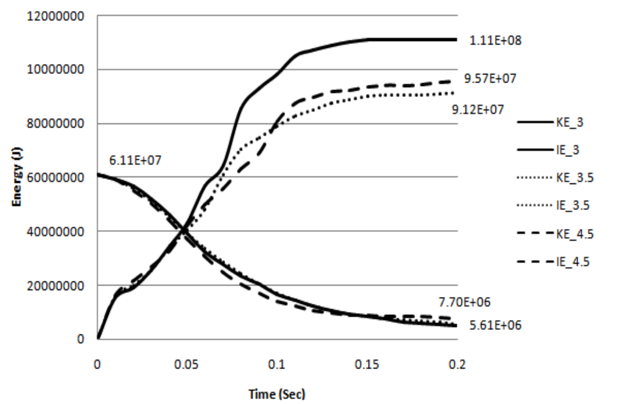

Figure 5: Global Energies for Rounded bar RUPD Simulation

b. Vehicle velocity and acceleration after crash

The acceleration of the car is an important consideration to be analyzed because it has direct effect on the occupants of the car. After crash, the stopping distance is very small, and hence a large force is generated at barrier. This force is `g-force' (g for gravitation) used to measure the type of acceleration which causes weight.

The velocity and acceleration curves (Figure 6) compares the three cases wherein the Rounded RUPD bar with 3.0 mm, 3.5 mm and 4.5 mm bar thickness. The velocity curve does not indicate much change in velocity curves for 3 mm and 3.5 mm RUPD bar cases. However there is steep reduction in velocity of car is observed for 4.5 mm RUPD bar. It justifies the increased rigidity of the RUPD system with higher thickness of the bar.

The comparison curve for acceleration also indicates that the curves for 3.0 m and 3.5 mm RUPD bar follows similar trend. Both of them reach to approximate maximum retardation of 8.44g at 0.1 second and declines to lowest value. But the acceleration curve for 4.5 mm RUPD bar structure reaches to maximum value of 7.86 g in a single slope pattern at 0.06 second. Here the RUPD offers greater resistance than the bumper system of the car and therefore it crushes the bumper system nullifying its required energy absorbing effect.

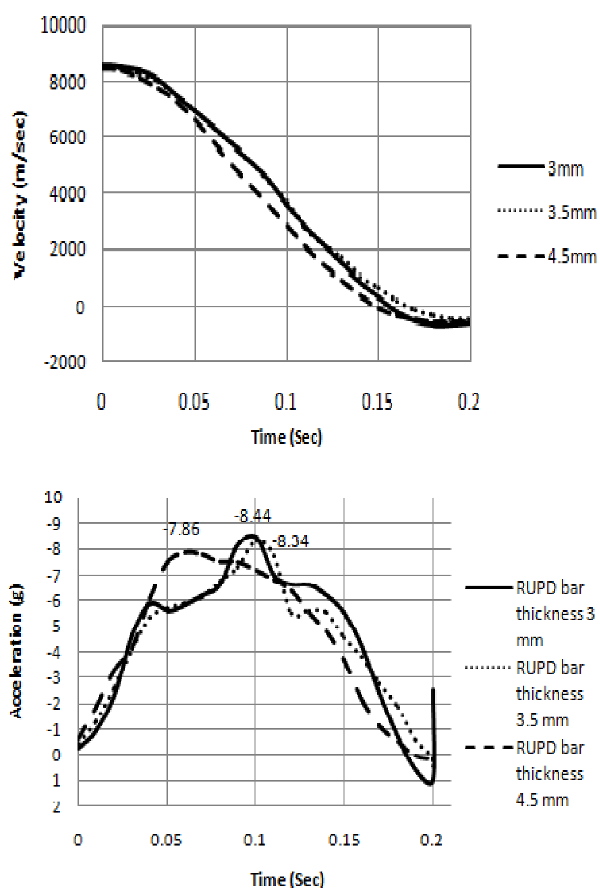

Figure 6: Change in (i) Car velocity and (ii) Acceleration of Round bar RUPD during crash simulation

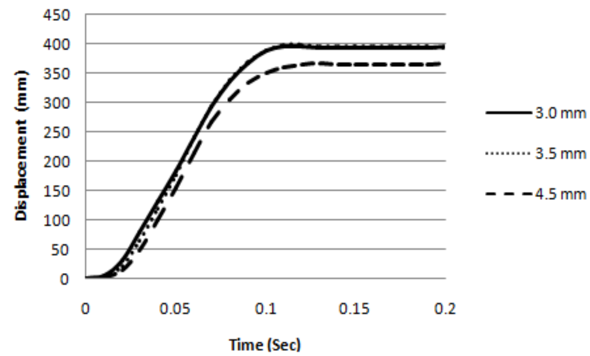

Figure 7: Displacement of Rounded RUPD for different thickness

c. Displacement of RUPD

Figure 7 indicates the effect on displacement of Rounded RUPD bar thickness. It is also observed that the displacement reduces with increase in bar thickness. The Rounded bar and spacer combination of RUPD bar absorbs more kinetic energy of the crashing vehicle. The displacement for 3.0 mm and 3.5 mm is 395 mm and that of 4.5 mm thickness is 366 mm. In all the thicknesses, the displacement does not exceed 400 mm. which is the required limit as per regulations of IS14812:2005.

IV. Conclusion

The following conclusions are drawn from above crash simulation with Rounded rear under run protection device (RUPD):

1. The termination time for the crash between 0.15 to 0.2 second is sufficient at initial car speed of 10.07 m/s i.e. 36.26 kmph. The car velocity becomes zero within this time after the crash.
2. The maximum deceleration of car after the crash is 8.44g which well within the acceptable limits. Hence the occupants will be in safe limits of force which will be exerted during sudden deceleration after crash.
3. The maximum displacement of RUPD bar is observed less than 400 mm. which meets the requirements of IS 14812:2005.
4. The virtual simulation can be used to eliminate physical testing of mechanical systems thereby reducing the time and cost of development.
5. The Rounded RUPD bar provides additional energy absorption, improved velocity and deceleration of vehicle after the crash than existing straight RUPD bar structure used.

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