International Journal of Engineering Research and Development
ISSN: 2278-067X, Volume 1, Issue 7 (June 2012), PP.19-26
www.ijerd.com

Finite Element Analysis of Rear Under-Run Protection Device (RUPD) for Impact Loading

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Abstract—*Under-running of passenger vehicles is one of the important parameters to be considered during design and development of truck chassis. Rear Under-run Protection Device (RUPD) plays an important role in avoiding under-running of vehicles from rear side of a truck. In India, the legal requirements of a RUPD are fixed in regulation IS 14812-2005.*

To reduce number of iterations during the development process, the computational simulation method is used in RUPD analysis for impact loading. An explicit finite element code like Ls-Dyna is used for the simulation. The deformation of RUPD bar and plastic strains in RUPD components can be determined before the physical test for predicting failure of the system to meet the compliance requirements as per IS 14812-2005. Additionally, failure of the RUPD attachment points with chassis can be determined. Physical testing can be reduced significantly with this approach which ultimately reduces the total cycle time as well as the cost involved in product development.

This paper explains the FE analysis of RUPD for impact loading. All the results obtained from the CAE analysis are evaluated against the requirements of IS 14812-2005 which could reduce the process development time and cost involved in the same.

Keywords*—Rear Under-run Protection Device (RUPD), IS 14812 -2005, Chassis design, ECE R58, Heavy Vehicle Systems*

I. INTRODUCTION

It is very common incident that during the accident a passenger vehicle going under the heavy commercial vehicle either from rear, front or side. During collision, there is a risk that the passenger vehicle will penetrate under (run under) the front or rear part of the truck and thus there are great chances of fatal injuries to the occupants of the passenger car. The study of such statistical data is done by Bjorsting Ulf et.al [1, 5]. The Under-run Protection Device (UPD) is an attachment fixed to the heavy commercial vehicle which will avoid the under running of the passenger vehicles and further reduce the chances of severe fatal injuries to the passenger vehicle occupant.

The design and the strength of the Rear Under-run Protection Device (RUPD) should be such that it should take the impact load and avoid the under running of the passenger vehicle from the rear of the heavy commercial vehicle. The Indian Standard IS 14812-2005 specifies the requirements of the RUPD. Physical testing is done with 5 impactors with specific load and sequence; hit the RUPD to evaluate its strength.

This scenario is replicated using Finite Element (FE) solvers like Ls-Dyna. The load taken by the RUPD is evaluated using reaction forces. This virtual validation is important for cost saving in the tooling, repetitive testing of the vehicle and cost involved in the same.

II. LITURATURE SURVEY

Bjorsting Ulf and others [1] have studied the data of accidents occurred in northern Sweden between 1995 and 2004. They have found that 293 passenger car occupants died out of which half involved heavy vehicles. It is also seen from the data that annual number of passenger car occupant death per 100000 car-truck collision remains same as they were in 1980. The collisions are classified in various ways such as crashes oncoming vehicle's lane, under icy, snowy, or wet conditions; crashes into heavy vehicles generally occurred in daylight, on workdays, in winter etc. Primary evaluation is according to head and chest injuries. The injuries are categorized based on critical, death head injuries and multiple fatal injuries. Investigators also looked at data concerning suicide and driving with alcohol for a proper statistical representation. They also observed that the risk of frontal collisions may be reduced by a mid barrier, front energy absorbing structure for trucks and buses and driving conditions etc.

A study in Japan is done by Hirase T, Kubota H and Sukhegawa [5] presents Japan's approach for car-to-truck compatibility in head-on collisions. Front Under-run Protection Devices (FUPD) should be designed in such way that it should meet Economic Commission of Europe (ECE) R 93 so that it should prevent the under-running of the car in head on collision with trucks. Japan Automobile Research Institute (JARI) has studied and analysed the various accidents in Japan. This study is done on various aspects such as vehicles with and without seat belts, types of collisions, types of vehicles involved in crash. The study predicted that car driver fatalities could be reduced by 45 percent by equipping truck with

FUPD. The study also suggested that off-road vehicles like tipper trucks and cement trucks should also be equipped with FUPD since it is beneficial in head on collision for car occupants.

Ian Johnson [6] has explained the benefit of energy absorbing structure for front of the heavy trucks. He has shown there is significant weight difference between passenger car and heavy trucks. Due to this there is great risk of injuries to passenger car occupants in case of car collision with heavy trucks. It is not possible to eliminate the weight difference between the car and heavy trucks, but is possible to modify the truck in such a way that effects of impact between the heavy trucks and car could be lessened. This paper estimates the effects of modifying the front of the heavy truck to incorporate the energy absorbing structure with stiffness characteristics similar to front of cars. Equation of motion are used to show that the truck with front energy absorbing device could increase deceleration distance by 40 percent and reduce average deceleration by factor 1.4. This paper also explains that the passenger car injuries could be reduced by 33 percent with an illustrated example.

III. LEGAL REQUIREMENTS OF IS 14812 – 2005:

RUPDs to be implemented are regulated by ECE's R58. An Indian regulation IS 14812 – 2005 is derived from ECE R58 standard, and its requirements are follows [8]

1. The device shall offer adequate 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.
   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 P1,P2 and P3 (See Figure 1). In measuring this distance, any part of the vehicle which is more than 3 m above the ground when the vehicle is un-laden shall be excluded.
   Point P, are located 300 + 25 mm from the longitudinal planes tangential to the outer edges of the wheels on the rear axle; point P2 which are located on the line joining point P1, are symmetrical to the median longitudinal plane of the vehicle at a distance from each other of 700 to 1000 mm inclusive, the exact position being specified by the manufacturer. The height above the ground of points P1, and P2 (see Figure 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. P3 is the centre point of the straight line joining point P2.
2. A horizontal force equal to 12.5 percent of the maximum technically permissible weight of the vehicle but not exceeding 25 kN shall be applied successively to both points P, and to point P3.
3. 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 P2.
4. 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.
5. Whenever a practical test is performed to verify compliance with the above mentioned requirements, the following conditions shall be fulfilled.

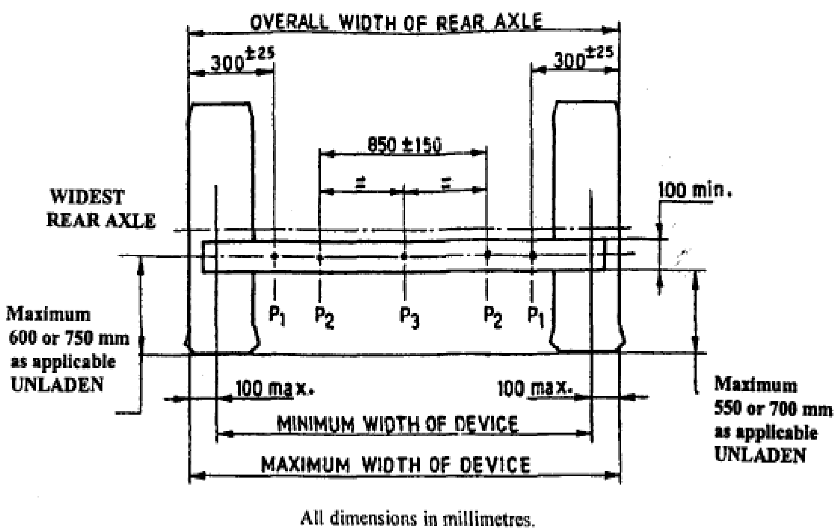

Fig. 1: Position of Rear Under-run Protection Device and the Resistance Points P1, P2 and P3 [8]

IV. FINITE ELEMENT ANALYSIS OF RUPD

A RUPD assembly shown in Figure 2, which mainly consists of a main plate and a cross plate are welded together to form a box section. Then this box section is welded to the bar and bar support member. The support member is also welded with the box structure and the RUPD bar. The other end of this structure is connected with a mounting plate which is bolted to the chassis member.

4.1 FE Modelling of RUPD

All the parts of RUPD are with large surface are as compared to the thickness hence they are meshed with shell elements and assigned with "SECTION_SHELL" and the respective thickness is assigned to them.. The components which are expected to have large deformation are made as fully integrated elements with element formulation 16 while the rest of the components are with element formulation 2, reducing computation time. To represent the welding the shell elements are used with the minimum thickness value among two components. The main plate and cross plate are welded together to form box structure which is connected to other parts like bar and support member. For all the properties are with integration points along the thickness are more than 3 so that stress and strain can be verified across the thickness. This assembly is the bolted to the chassis member as shown in Figure 2. The bolting is done with the one spider on the both the end and the beam is connected in between them. The respective diameter is assigned to the beam and "SECTION_BEAM" is used as property card.

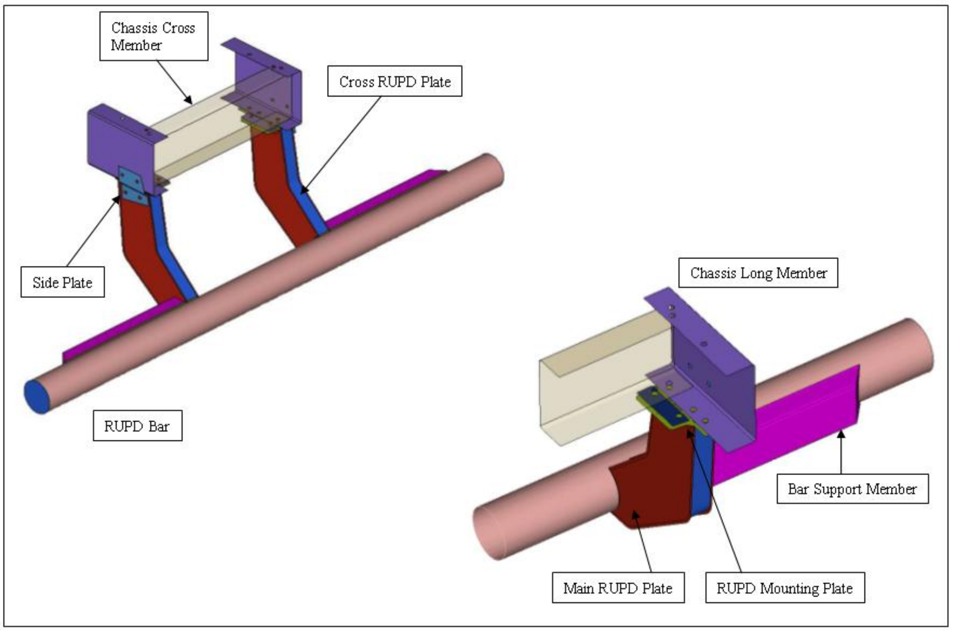

Fig 2: FE modelling of RUPD Structure

Material modelling of all the bolts and welding is done with elastic material *MAT_ELASTIC. This material requires only the poison's ratio, mass density and young's modulus. For rest of the components the material is used as *MAT_PIECEWISE_LINEAR_PLASTICITY. This material provides the user to enter the true stress-strain curve for the material. All these types of materials are assigned with respective true stress strain curve. This material also facilitates the user to enter failure plastic strain limit which is defined as per data.

After the material assignment, the interface between the parts is defined through the contact. There are various types of contact available in Ls-Dyna but *CONTACT_AUTOMATIC_GENRAL is preferred.

4.2 FE Modeling of Impactor

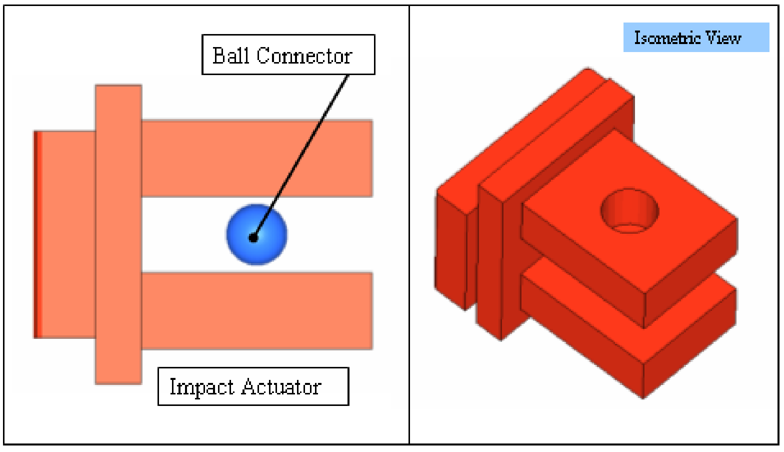

Fig 3: Impactor used in the FE Simulation

The impactor shown in the Figure 3 is used for the analysis. This Impactor geometry is same that would be used for the physical testing. It has a spherical joint at the centre which permits the rotation of the impactor or in other language it should follow the RUPD bar after the impact. The actuator is modelled using the *MAT_RIGID. The spherical joint is defined at the centre of the ball. The ball is also modelled with *MAT_RIGID material. The actuator and the ball are connected to each other using *CONSTRAINED_EXTRA_NODE and spherical joint.

The interface between the RUPD bar and the actuator is defined using *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE. This contact is activated for certain time because only one impactor needed to be in contact with bar.

4.3 Boundary and Loading Conditions

The boundary conditions are applied such that it will be same as the physical test and it will not add any numerical error in the analysis. The loads are applied as per standard IS14812 – 2005.

4.3.1Boundary Conditions

The nodes at chassis are constrained in all the direction (see Figure 4). The chassis member is very critical and its deformation may lead to severe structural damage as well. It would be also impossible to change the chassis member as it is major component in the heavy commercial vehicles.

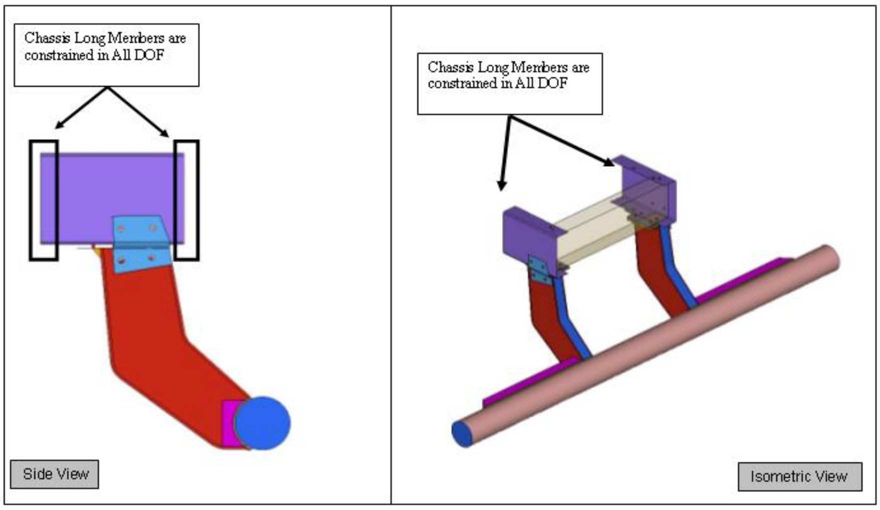

Fig 4: Boundary Conditions used for RUPD Analysis.

4.3.2 Loading Conditions

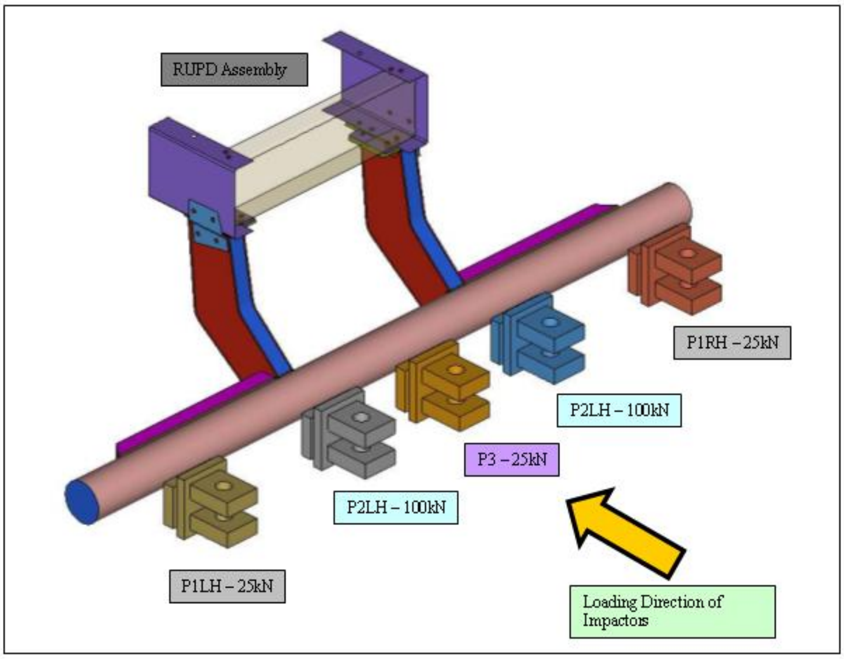

Fig 5: Loading of the RUPD with all the 5 Impactors

The Figure 5 shows the loading of the RUPD. The loading is done in sequential manner. First the impactor with load 25kN at location P1 on left hand side pushes the RUPD bar as soon as it gets unloaded the second impactor P1 on other end came and pushed the deformed bar with 25kN. Third one is central impactor with the same load.

Most severe loads are P2 which 100kN. After completion of loading of P3 the P2 on left hand side hit the bar and there after it is P2 on right hand side.

It is also ensured that all the loading is quasi-static as mentioned in the regulation. A figure 6 below shows the loading curve and loading sequence of all the 5 impactors. Also the positions of all the impactor are as per regulation.

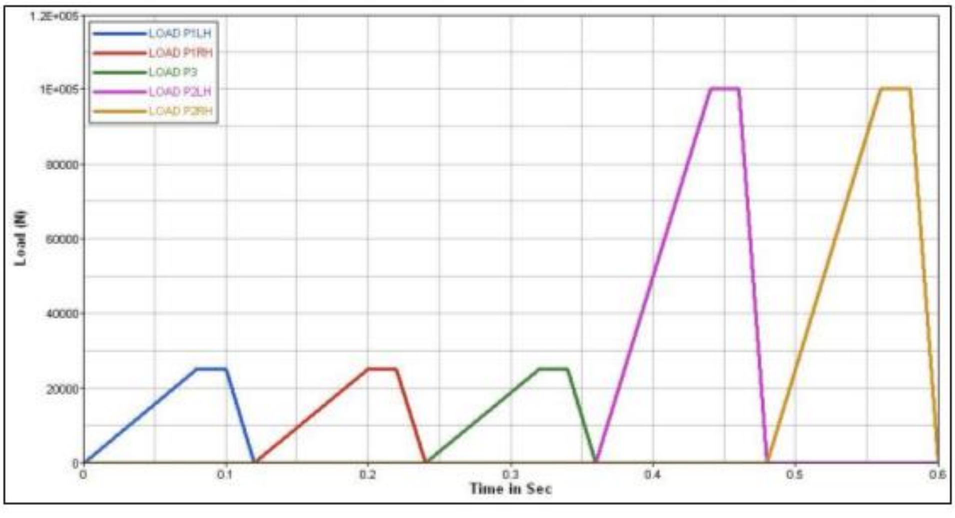

Fig 6: Loading Curves of the Impactor

4.4 Acceptance Criterion for FE Analysis

1. The maximum displacement of RUPD bar should be less than 400mm after the application of all the 5 Impactors.
2. The RUPD should remain attached to chassis all the time during the simulation.

V. RESULT AND DISCUSSION

The energy balance is method to evaluate the correctness of the numerical analysis. The typical energy balance of RUPD system is shown in Figure 7. All the energies are shown in the plot. The internal energy has started from the zero magnitude and increased to maximum. This increase in the internal energy is due to deformations in the system. The energy in terms of the applied force is stored in the RUPD in terms of plastic deformation. The kinetic energy in the system is very negligible which shows that there are no real velocities in the system. It also ensured that the FE analysis is quasi-static. The peaks shown at some locations are due to sudden interaction of the impactor with the RUPD bar. The interface energy is positive which shows that there is no penetration in the system. The hourglass energy is very negligible. The total energy is the summation of all the other energies like kinetic energy, internal energy, interface and hourglass energy etc.

Overall the energy balance is reasonable hence it the FE analysis results are acceptable.

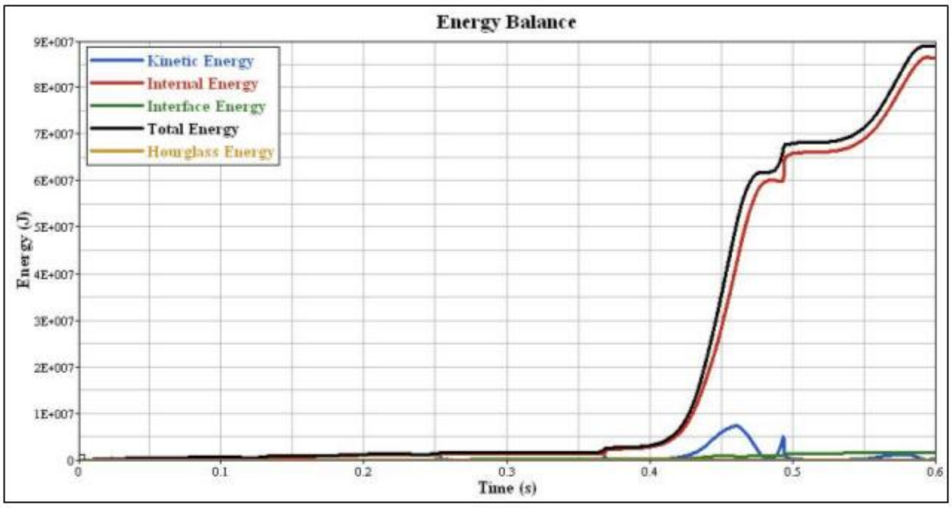

Fig 7: Energy Balance in FE Analysis of Baseline Design.

Another aspect for result evaluation is reaction force for each of the impactor. For all the impactors reaction force is increased gradually and then stabilized. This also confirmed that RUPD is loaded as per regulation (see Figure 8).

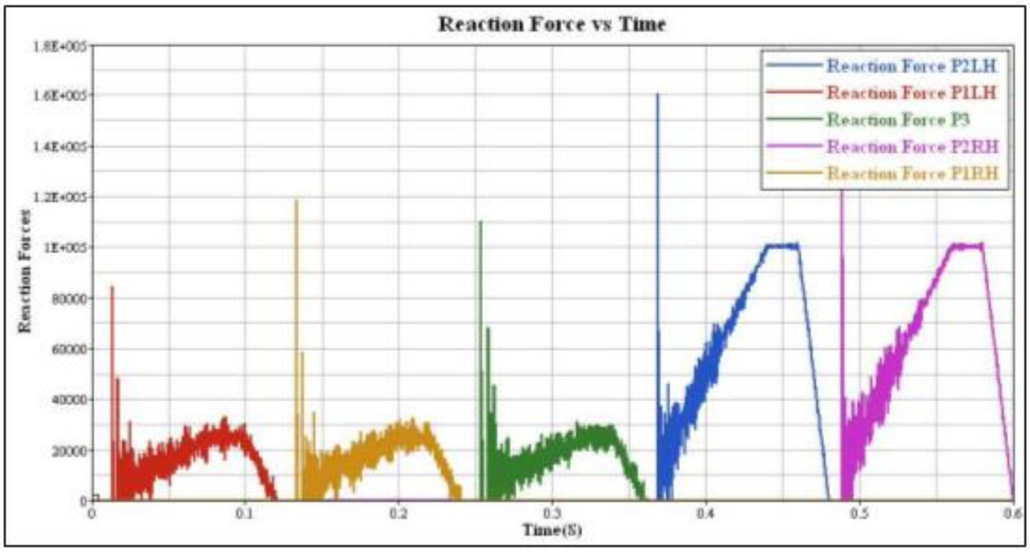

Fig 8: Reaction Force on Impactor.

The displacement and plastic strain is observed for all the loads P1, P2 and P3 but load P1 and P3 are small so the deformation in structure is negligible. The chances of maximum displacement and plastic strain are for P2 load which is having magnitude of 100 kN. Since all the loads are applied sequentially on deformed structure as P1LH – P1RH – P3 – P2LH – P2RH, it is clear that if the deformation after P2RH loading meets the requirement rest would definitely meet.

The displacement is one of the major parameter on the basis of which RUPD could be evaluated. The maximum displacement in the RUPD is less than 50mm (see Figure 9) which is very much less than limiting value.

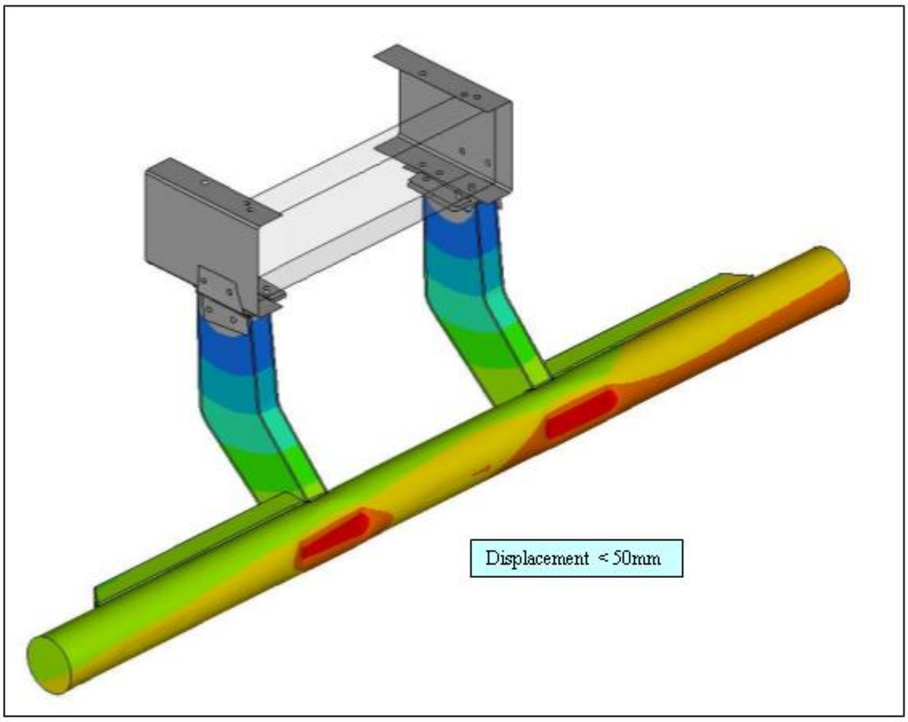

Fig 9: Displacement of RUPD bar after P2RH Loading

The plastic strain is another criterion on the basis of which the failure of RUPD could be determined. The plastic strains are observed in all the parts and they are compared against the limiting plastic strain for respective material. The failure plastic strain for RUPD parts is 20 percent hence it is required that the plastic strain in the RUPD parts should be less than this value to avoid the tearing of the parts. But, again it is also required to observe the nature (compressive or tensile) and location of strain. The chassis members had shown very negligible plastic strain almost less than 5 percent. Hence there are no chances of failure or tearing in the chassis long and cross members.

The plastic strain in the box structure is less than 15 percent which is shown in Figure 10. This plastic strain is less than the failure plastic strain of the material.

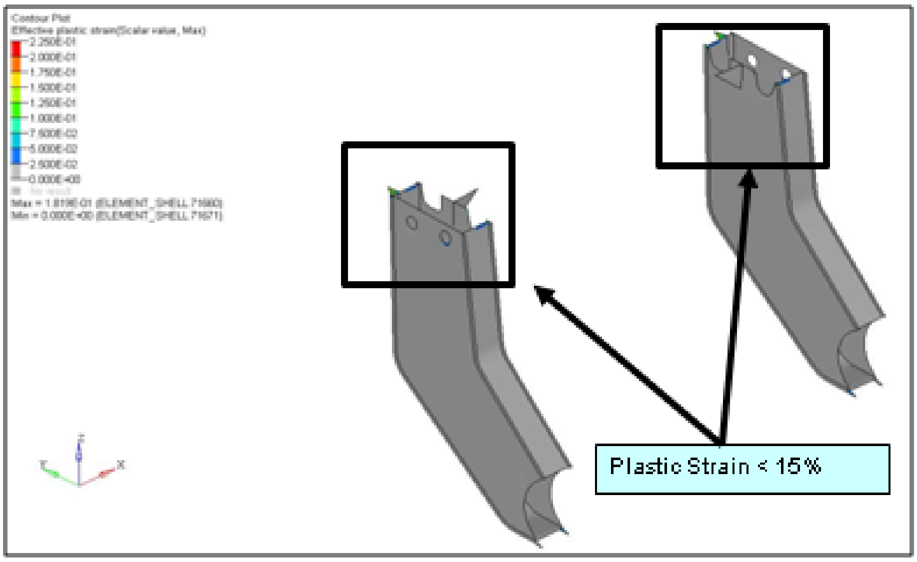

Fig 10: Plastic Strain in Main Plate and Cross Plate after P2RH Loading

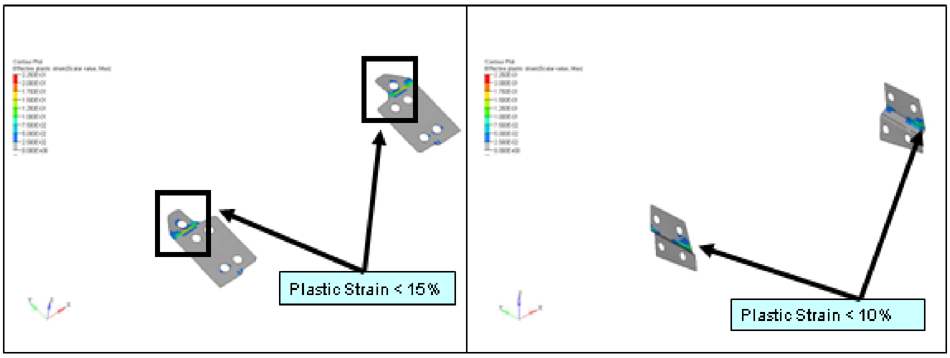

Fig 11: Plastic Strain in Mounting Plate and Side plates after P2RH Loading

The plastic strain in the mounting plate is less than 15 percent which is less than the failure plastic strain of the mounting plate material. The plastic strain in the vertical mounting plate is small. The maximum plastic strain in the side plate is limited to 10 percent as shown in figure 11. It is also necessary to monitor bolt forces at various locations in the mounting plate. The maximum force in bolt is around 90kN.

This design meets all the requirements of IS 14812 – 2005. But for meeting the same mounting of RUPD the bolts of M16 with class 10.9 should be used. But this needs to be confirmed with physical testing and correlation in future.

The above design meets the requirements as per IS 14812 – 2005, but it is also possible to improve the design in the FE model and analyse it till meets the requirements. This way FE Analysis could be a very efficient tool to for design improvements. It could also save a cost and time required in repetitive manufacturing and physical testing.

VI. CONCLUSION

1. Head on collision contribute significant amount of serious accidents which causes driver fatalities. The car safety performances can work effectively by providing UPD to the heavy trucks. The trucks with UPD can reduce the car driver fatalities by 40 %
2. In India, for Rear Under-run Protection Device, IS 14812:2005 regulation is required in for the trucks to meet the safety requirement to protect under running of the passenger car.
3. In above said design, the maximum displacement of RUPD bar is limited to 50mm and the plastic strain is limited to 15% hence it meet the requirements as per IS 14812:2005. But this needs to be confirmed with physical testing in future.
4. The virtual simulation is tool which can be used to avoid or reduce the physical testing of mechanical systems and components. Overall effect of this is cost saving and same is done with RUPD analysis.

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