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Research Paper

IMPACT CRASHWORTHINESS OF REAR UNDER RUN PROTECTION DEVICE IN HEAVY VEHICLE USING FINITE ELEMENT ANALYSIS

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The paper focuses on simulation and analysis of a Rear Under Run Protection (RUPD) system under crash scenario. The basic objective is to improve the safety of the car and the occupants by designing the RUPD and car bumper. The choice of material and the structural design are the two major factors for impact energy absorption during a crash. It is important to know the material and mechanical properties and failure mechanism during the impact. This study concentrates on component functions, geometry, behavior of material and other parameters that influence the compatibility of the car bumper and rear under run protection device. The analysis was carrying out using Finite Elements software (LS-Dyna), Meshing tools by Altair Hyper mesh and Modeling on Pro-E. This analysis is a partial work of a major project wherein the RUPD will be subjected to static testing with variable load distributions at different locations on RUPD. The analysis establishes the method and parameters of the simulation on modeling and analysis software used by demonstrating the energy absorption pattern in bumper and RUPD during frontal crash of a car with different design parameters of RUPD.

Keywords: CAD (Modeling and Simulation-Pro-E), Meshing (Hypermesh), Preprocessing (LS-Dyna), ANSYS solver

INTRODUCTION

Truck accidents represent a significant factor in the overall road accident scene. Analysing the Indian problem (1997), trucks with a gross vehicle weight of more than 3.5 tonnes are involved in around 20% of the fatal road accidents; and approximately 60% of these are car to truck accidents. The injury risk in accidents involving heavy vehicles appears to be far greater for occupants of opponent vehicles, specially for cars. And this risk increases in the case of car to truck frontal collisions.

The collisions can be classified in many ways such as crashes oncoming vehicle's

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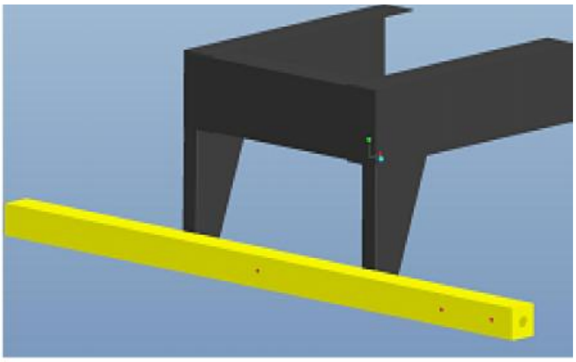
lane, under icy, snowy, or wet conditions; crashes into heavy vehicles generally occurred in daylight, on workdays, in winter etc. Primary evaluation is according to head and chest injuries. The injuries are categorized based on critical, death head injuries and multiple fatal injuries. Investigators 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.

EEVC WG14 started in 1994 a research programme for defining the requirements of energy absorbing front under run protection systems for truck, and for the development of a test procedure for these devices. The overall objective of the project, consists of developing a test procedure and performance standard for energy-absorbing rear under run protection systems for trucks in order to reduce the injuries to passenger car occupants in frontal collisions. The Spanish partner in this working group is INSIA (University Institute for Automobile Research). The strategy in selecting a test procedure is to identify tests that have the potential to improve the crash protection provided across a broad range of real-world impact conditions. The crash test conditions, e.g., impact speed, impact angle, test devices and configurations, must be carefully selected to be representative, as much as possible, of the real car to truck crashes.

The most important condition is the RUPD resistance to loading forces acting along or parallel to the vehicle longitudinal axis. The regulation also calls for a practical RUPD testing on the testing machine, where the RUPD is subjected to prescribed loads at some particular loading points. If the measured deformations fall into the allowable range, the RUPD can be declared to comply with the regulation. The practical testing is required for all standard mounted RUPD.

Figure 1: RUPD Design 1



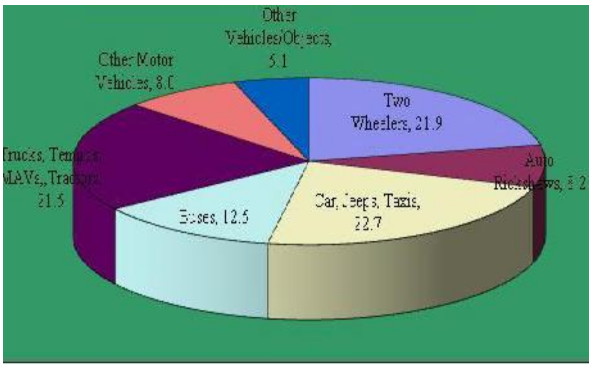
Heavy commercial vehicle Under Run Protection (URP) has a long history of investigation. European research organizations as well as heavy commercial vehicle manufacturers have been studying the subject since the 80s, initially commencing with rear and side URP and followed by front URP. Research in Australia, Canada, and the United States commenced in the late 90s and focused mainly on rear under runs, which in Australia contributes to only about 10% of under run trauma. In recent years, the member countries of the European Union have been instrumental in financing and managing research efforts directed at generating solutions for addressing front under run trauma, which in Australia accounts for 75% of under run trauma. Protection for vulnerable road users and passenger car occupants from heavy commercial vehicle under run is now mandatory in Europe for commercial vehicles exceeding a GVM of 3.5 tones. Some member countries of ASEAN and the three most populous and fast growing economies of China, India and Brazil also have some form of URP requirements for heavy commercial vehicles.

SURVEY

Road accidents are human tragedy. They involve high human suffering and monetary loss in terms of fatality, injuries and loss of potential income. During the calendar year 2010, there were close to 5 lakh road accidents in India, which resulted in more than 1.3 lakh deaths and injuries on 5.2 lakh persons. These numbers translate into one road accident every minute, and one road accident death every 4 minutes.

In 2010-2011 an accidental (Figure 2) shows maximum Percent of Trucks and car, jeep approx 21.5 to 22.7 its huge injuries cause of front and rear crash. Trucks accident results in major deaths because high impact and low safety equipments. It was observed in a survey at National highway 3 and National highway 59 that maximum accidents takes place on rear of truck because of rear view and improper mountings of RUPD.

Figure 2: Survey

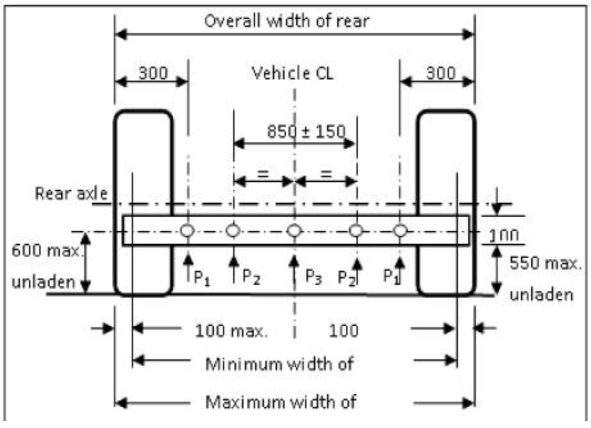


LEGAL REQUIREMENTS OF RUPD

RUPDs to be implemented are regulated by ECE's R58. An Indian regulation IS 14812-2005 is derived from ECE R58 standard,

- 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 (Figure 3). 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 800 to 1100 mm inclusive, the exact position being specified by the manufacturer. The height above the ground of points P1, and P2 (see Figure 3) 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.
- A horizontal force equal to 12.5% of the maximum technically permissible weight of the vehicle but not exceeding 25 KN shall

Figure 3: RUPD Requirement



be applied successively to both points P, and to point P3.

- A horizontal force equal to 50% of the maximum technically permissible weight of the vehicle but not exceeding 100 KN shall be applied successively to both points P2.
- 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.
- Whenever a practical test is performed to verify compliance with the above mentioned requirements, the following conditions shall be fulfilled.

METHODOLOGY

The finite element method is comprised of three major phases: (1) pre-processing, in which the analyst develops a finite element mesh to divide the subject geometry into sub-domains for mathematical analysis, and applies material properties and boundary conditions, (2) solution, during which the program derives the governing matrix equations from the model and solvesfor the primary quantities, and (3) post-processing, in which the analyst checks the validity of the solution, examines the values of primary quantities (such as displacements and stresses), and derives and examines additional quantities (such as specialized stresses and error indicators).

Crash-testing requires a number of the test vehicle to be destroyed during the course of the tests and is also time consuming and uneconomical. One new recent trend that is gaining vast popularity is computer simulated crash-testing. Here instead of a real vehicle, a Finite Element (FE) model of the vehicle is generated and is used to carry out the different tests that were carried out before using actual vehicles. There are several software packages that are equipped to handle the crash-testing of vehicles, but one of the most popular in dynamic analysis software is LS-DYNA.

In this analysis the rear impact crash is conducted using a modeled (car), and truck chassis (half segment) as the test Finite element model. The car and the RUPD were modeled on Pro-E and integrated on Hypermesh for critical meshing. After meshing the system, the model was imported in LS-Dyna environment (LS-Prepost) for setting various simulation parameters. The output of Prepost (.k file) was solved in ANSYS LS-Dyna solver.

The truck chassis has a fixed and the initial velocity of car model is assumed 50 kmph before impact the RUPD bar. The simulation is given a termination time 0.5 sec. The reason for termination time is that for rigid RUPD bar.

The Model generated is in 5 steps:

1. Modeling (Pro-E)
2. Meshing (Altair Hyper mesh)

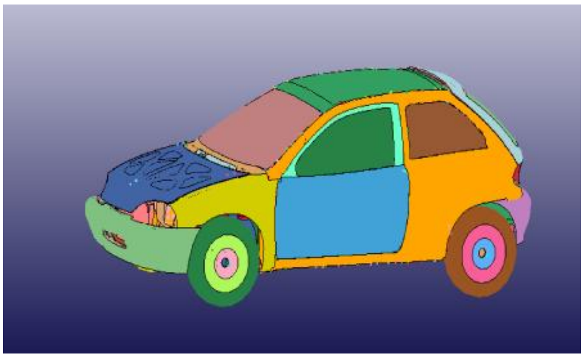
3. Pre-Processing
4. Solver
5. Post Processing

Pro/ENGINEER is a feature-based product development tool. The models are constructed using a series of easy to understand features rather than confusing mathematical shapes and entities. The geometric dentition of a model is defined by the type of features used and by the order in which each feature is placed. Each feature builds upon the previous feature and can reference any of the preceding features; this enables design intent to be built into the model. Individually, each feature is typically simple but as they are added together they form complex parts and assemblies. After selecting features, geometry, or components in a model, assembly, or drawing, you are able to make medications to the selected items. Direct selection is one of the three basic methods of selection.

Hypermesh (Meshing)

Universal finite element pre- and post-processor. Hyper mesh is a high-performance finite element pre- and post-processor for major finite element solvers, which allows engineers to analyze design conditions in a highly interactive and visual environment. Hyper mesh's user-interface is easy to learn and sup-ports the direct use of CAD geometry and existing finite element models, providing robust interoperability and efficiency. Advanced automation tools within Hyper mesh allow users to optimize meshes from a set of quality criteria, change existing meshes through morphing, and generate mid-surfaces from models of varying thickness. Reduce time and engineering analysis cost through high-performance finite element modeling and post-processing and reduce redundancy and model development costs through the direct use of CAD geometry and existing finite element models and Support numerous commercial solvers by providing direct interfaces to a wide array of analysis codes ensuring the best code can be used for specific situations and also Cost-effective pricing to deliver maximum functionality for your software investment.

Figure 4: Car Design



ELEMENTS AND BOUNDARY CONDITIONS

The completed model contains approximately 208 parts, 61 materials and 42191 elements and 45547 nodes. Structural components and specific element types used in the model include.

1. Beam
2. Discrete
3. Mass
4. Seatbelt accelerometer
5. Shell
6. Solid

The function of the boundary conditions is to create and define constraints and loads on finite element models. To simulate a full vehicle car crash all loads and boundary conditions that occur in the actual crash event need to be modeled. Just as a car is subjected to gravitational loads in real life, the simulated model should have a representative gravity force applied. Friction forces between the tires and the road surface play an important role in how the vehicle behaves on impact, so these have to be accounted for in the simulation.

Today's automobile manufacturers are increasingly using lightweight materials to reduce weight; these include plastics, composites, aluminium, magnesium and new types of high strength steels. Many of these materials have limited strength or ductility, in each case rupture is a serious possibility during the crash event. Furthermore, the joining of these materials presents another source of potential failure. Both material and joining failure will have serious consequences on vehicle crashworthiness and must be predicted.

During an automobile crash, some parts in the front of the automobile body may have plastic deformation and absorb a lot of energy. Structural members of a vehicle are designed to increase this energy absorption efficiency and thus to enhance the safety and reliability of the vehicle. The crashworthiness of each member needs to be evaluated at the initial stage of vehicle design for good performance of an assembled vehicle. As the dynamic behaviour of structural members is different from the static one, the crashworthiness of the vehicle structures has to be assessed by impact analysis.

Hence it becomes necessary to check the car structure for its crash ability so that safety is achieved together with the fuel economy. There are two ways by which this safety feature can be assessed.

1. Performing an actual crash test.
2. Simulating the crash in some FE code like ANSYS LS DYNA.

Though the first option is more accurate and reliable, it demands time and high cost. A more practical solution which results in a compromise between the factors of accuracy, cost and time is simulation. With appropriate initial conditions, loads and element formulations, engineers can develop a precise enough FE model to judge the crash response in an actual accident. This technique has superseded the testing using an actual model. Thus computer simulations are used to find the automobile model's crash ability.

The model to be simulated is usually developed using data obtained from the disassembly and digitization of an actual automobile using a reverse engineering technique. This approach is necessary because the models developed by the manufacturers are proprietary, and not available either to the public or to the government.

There are various test configurations. We have limited our analysis to frontal impact with a rigid wall at a speed of 35 mph, corresponding to a NHTSA (National Highway Traffic Safety Administration) full frontal impact.

The H.S steel simplified FE model was investigated using ANSYS LS-DYNA. Since, the main aim of the project was to develop expertise in the field of crash analysis; the analysis was kept simple using assumptions. It was noted during the course of the project that H.S steel could be used effectively for light weight mass without affecting the necessary impact energy absorbing capacity of the car body.

The subject of computational analysis based on the finite element method is the real protection device that consists of two vertical pillars made of welded steel profiles, of which median vertical planes are 1180 mm apart, and a transversal cantilever made of standard deep drawn aluminium profile of width 2365 mm. The basic dimensions of the profiles are shown in The transversal profile is fastened onto vertical pillars with four screws M 14 x 30 of quality 10.9. The protection device is mounted on the vehicle symmetrically in respect to the median vertical plane of the vehicle, with horizontal distance between the rear part of the protection device and the rear end of the vehicle being equal to 150 mm, and the height of the lover edge of the device for unladen vehicle equalling 475 mm. The largest width of the rear end of the vehicle is 2500 mm and a maximum mass of the vehicle is 38250 kg.

Figure 5: Simulation and Energy Absorption in Car Bumper and RUPD with Thickness 3.00 mm

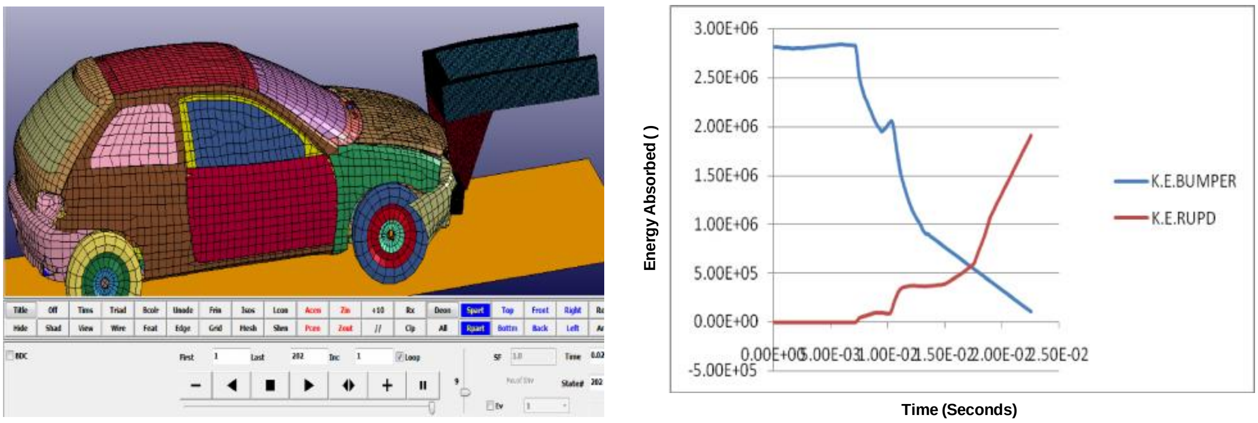


Figure 6: Simulation and Energy Absorption in Car Bumper and RUPD with Thickness 3.50 mm

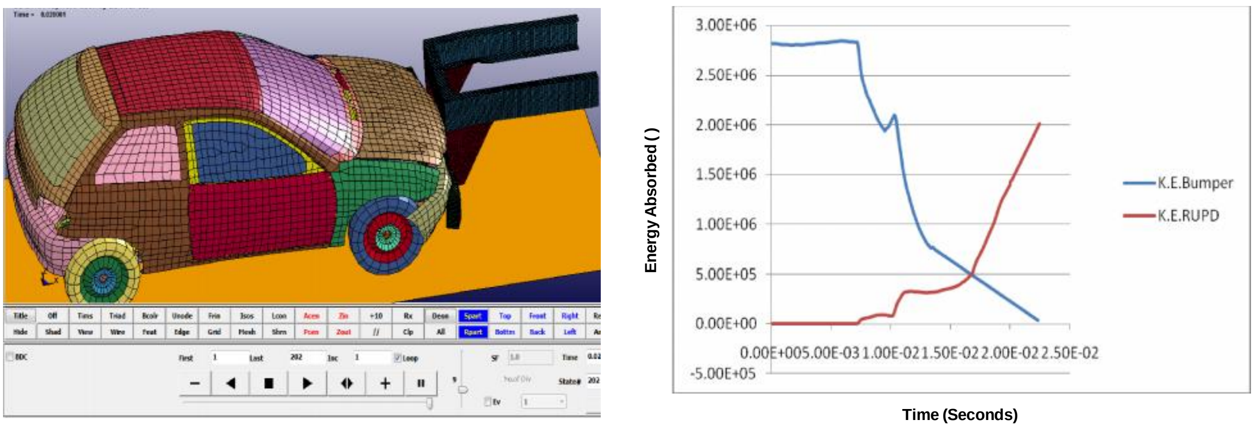


Figure 7: Simulation and Energy Absorption in Car Bumper and RUPD with Thickness 4.00 mm

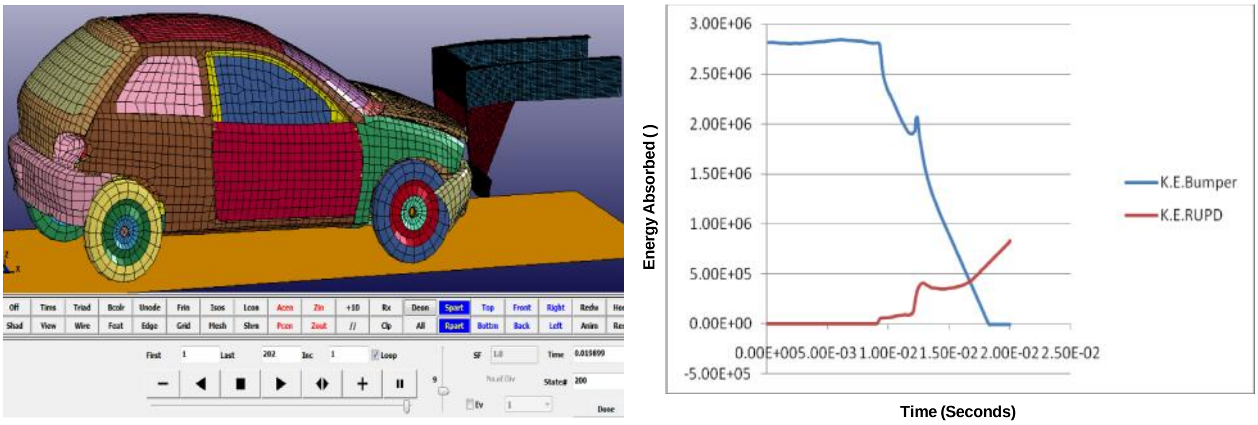


Figure 8: Simulation and Energy Absorption in Car Bumper and RUPD with Thickness 4.50 mm

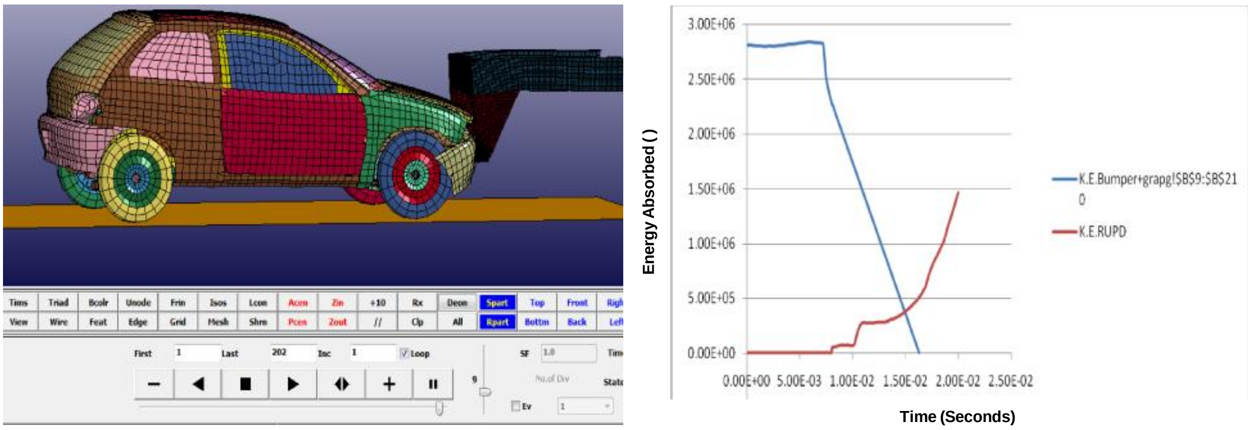
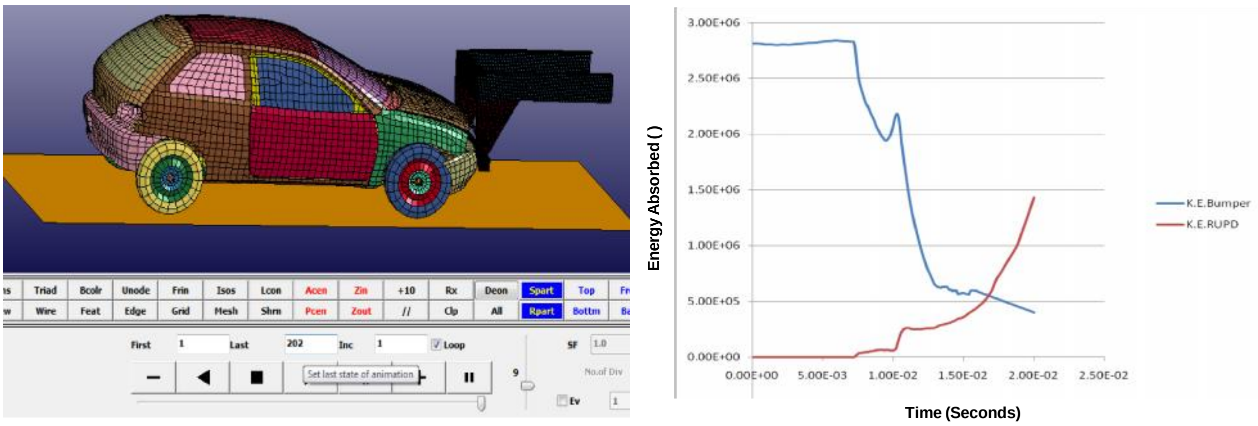


Figure 9: Simulation and Energy Absorption in Car Bumper and RUPD with Thickness 5.00 mm



RESULTS AND DISCUSSION

Five Simulation tests were carried out for the rear impact. The model 1 is having 3 mm thickness of RUPD bar, model 2 is a 3.5 mm thickness of RUPD, model 3 is a 4 mm thickness of RUPD, model 4 is a 4.5 mm thickness of RUPD and model 5 is a 5 mm thickness of RUPD. As observed, the most of the energy of the impact is absorbed by the RUPD bar, bumper and the rails. These components absorb most of the energy of the crash before the tires impacts the rigid bar. The maximum values of kinetic energy of the Test model as shown in graph. For the Test model 2.5 and 2.6, whose main purpose was the maximum energy absorption of the RUPD bar of the vehicle, the lower values of the results is not unexpected. The Test model experience lower forces as a result of its weight.

SCOPE OF FUTURE WORK

The FE model can be used for further simulation of in the simulations of the offset rear impact test, where one side of the rear of the vehicle is impacted against a barrier or another vehicle. Other tests include the side impact test, where a vehicle is impacted from the side by and oncoming vehicle and oblique car-to-truck or car-to-car impacts the two or more vehicle take part in a collision. Rollover simulation can also be carried out wherein the vehicle rolls on its sides due to the cause of an impact or other factors.

Further crash-testing involving the effects of the crash forces on the occupants of the vehicle can also be carried by using FE models of test dummies. Human- surrogate dummies called Anthropomorphic Test Devices (ATDs) could be placed inside the FE vehicle models and an entire crash test event could be simulated. The FE dummies are used to simulate the behavior of a vehicle occupant in the event of a crash. These FE dummies can then be placed inside the vehicle and the crash-simulation performed, they can provide various insights into the dynamic behavior of the human body in the event of a crash. This, however, requires detailed occupant compartment geometry as well as a detailed dummy model. This could easily double the FE models complexity and greatly increase the needed computer resources.

CONCLUSION

The overall objective of the work was to simulate a Rear crash-test and validate the results of the simulations obtained from the crash-test. Simulation was performed using the LS-DYNA software package.

The analysis has well established the method and parameters of the simulation on modeling and analysis software. It demonstrates the energy absorption pattern in bumper, rail and RUPD during frontal crash of a car with different design parameters of RUPD. It can be seen from the plots that the RUPD bar absorbs most of the energy during impact of the car bumper. Almost half of the energy of the crash is absorbed by these components after about 0.5 ms of the crash initiation.

It will be possible to recommend some relevant characteristics for an energy absorbing rear under run protection device. Head on collision contribute significant amount of serious accidents which causes driver fatalities. The car safety performances can work effectively by providing RUPD to the heavy trucks. 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. 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. The virtual simulation is a tool which can be used to avoid or reduce the physical testing of mechanical systems and components. Overall effect of this is reduction in development cost as compared to real time physical testing.

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