ISSN 2229-5518

Analysis of Vehicle Compatibility With Respect to Bumper Design of M1 Vehicles under Crash

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Abstract— Vehicle safety is one of the vital factors governing the automobile design. According to the road accidents data, the total number of road accidents in India decreased by 4.1 per cent in 2016 as compared to 2015,but the number of persons killed in accidents has increased by 3.2%. In order to improve the vehicle safety the position of bumper is one of the important parameter. Bumper is a structure attached to the front of vehicle mounted with an intention of absorbing some energy in case of impact. The objective of this project is to optimise the height of bumper for M1 category vehicles which reduces the transfer of impact energy to the passenger cabin. This is achieved mainly by optimising the bumper height to reduce the overlapping of vehicles under impact. The modelling of the bumper beam is done in CREO tool and the impact analysis is carried out by using LS Dyna tool. The result shows significant changes with respect to different positions of bumper for M1 category vehicles. The optimized height of bumper with vehicle compatibility shows increase in overlapping of the bumper beam which leads to reduction of impact energy to passenger compartment. This will help in improving the safety of the passengers.

Keywords: Bumper Beam, M1 category vehicles, Optimization, LS Dyna.Compatibility, Override, Underride, Overlap.

1 Introduction

According to the road accidents data the total number of road accidents decreased by 4.1 per cent in 2016 (i.e. 4,80,652) as compared to 2015.But the total number of persons killed in accidents (i.e. 1,50,785) is around 3.2% more as compared to that in 2015 [1].While the total number of persons injured were 4,94,624. Vehicle Safety plays a very important role in improving the safety of passengers during collissions. In order to improve the vehicle safety the position of bumper is one of the important parameter. Bumper beam is the part of bumper which absorbs maximum amount of energy in cases of crashes.

Compatibility in case of bumpers mainly means the ability of the bumper to absorb maximum amount of energy without transferring it to the passenger cabin. Hence in order to improve the compatibility of the bumper, it is very important that during crashes the bumper beams of the two vehicles should overlap with each other. If they do not overlap the condition of Override/Underride [1] may occur and it would result to a greater damage to the vehicle and occupants.

In frontal impacts the structure above the bumper is deformed more than the bumper itself. This condition is mainly termed as override or underride. This mainly arises due to variation in the vertical height of the bumper and often proves to be more dangerous for the passenger as major amount of the crash energy generated in the form of kinetic energy is transferred to the passenger cabin.

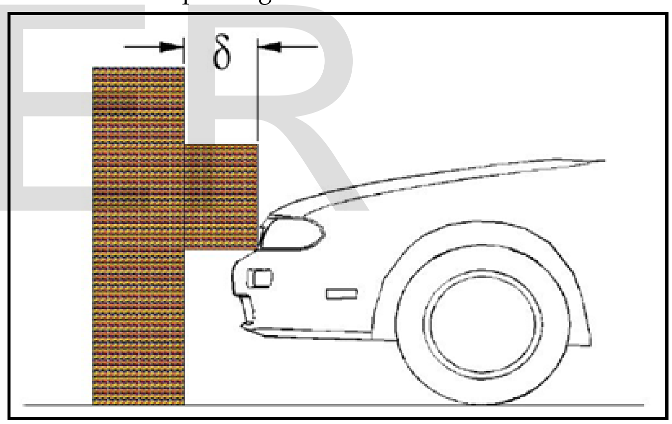

Figure 1: Experiments to Simulate Override [1]

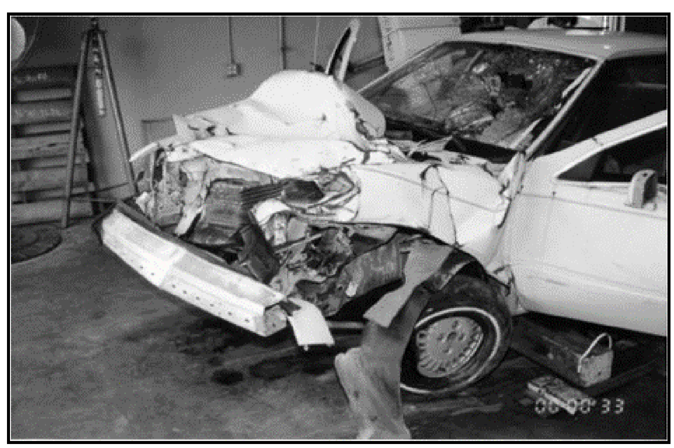

Figure 2: Example of fatality of Override [1]

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ISSN 2229-5518

LITERATURE REVIEW:

The conventional bumper assembly mainly consist of facia, energy absorber and bumper beam as shown in figure 3 [2]. Fascia is meant to be aesthetically appealing and provide a superior look to the vehicle. It is generally light weight andusually made up of polypropylene, polyurethane or polycarbonate. Energy absorber is usually designed to absorb maximum amount of kinetic energy in case of collision. It is generally made up of foam or homeycomb structures. The bumper beam is the most important part of the bumper assembly and designed to absorb around 85-90% of the energy absorbed by the bumper in case of collision.

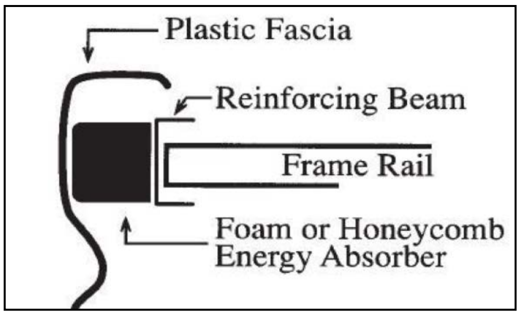


Figure 3: Conventional bumper beam assembly [2]

Andrew J. Happer et.al mainly focuses on the methodology to obtain the severity of the low speed impacts involving little or no vehicle damage [3]. It states that vehicle collision force and acceleration play a very vital role in determining the severity of the damage caused due to the low speed impact. As the velocity increases there is gradual increase in the severity of the impact and as a result more damage is caused to the vehicle and injury to ccupants. Based on the various experiments it is concluded that coefficient of restitution can predict the severity of collision. Cipriani's restitution relationship predicts the collision yielded a better vehicle to vehicle prediction. Also vehicle type, bumper impact orientation and closing speed are some of the factors that affect the selection of collision restitution. Osamu Takatori et.al [4] discussed various tests performed on bumpers with consideration of changes in offset ratio, barrier face form, barrier face rigidity, crash velocity, the degree of changes of the velocity behaviour, vehicle deformation, dummy behaviour and injury with 50% and 40% overlapping. The results estimated 40% overlapping is much better in reproducibility of actual crash scenario. Abhishek Sinha et.al [5] mainly focussed on the various combinations of bumper beam structures such as pipes and sheet metal structures to prevent investment in costly process technologies such as hot forming or usage of advanced high strength steels. It concludes that closed box cross-section based bumper beam structures are more effective in meeting low speed impact conditions than open section based structures. Also it is shows that increase in rigidity of bumper beam may contribute to improvement in pedestrian lower leg performance. Darin Evans [6] discussed differences in impact testing with consideration of test method and set-up. He performed tests such as flat barrier, angled barrier, longitudinal pendulum, angled pendulum, IIHS pole impacts in three different labs each using a different test cart and impact set-ups.This results used to compare with traditional Finite Element Modelling techniques to predict bumper system performance. This helped to reduce development cycle time and cost of bumper design. RCAR (Research Council for Automotive Repair) discussed the test procedures for bumper testing which can replicate the actual conditions arising in case of frontal collissions in the real world [7]. They have introduced following three factors for checking the bumper performance:

- Geometry: The bumper must be placed at common height and must extend laterally so that it is able to match the height of the vehicle to be engaged in the frontal impact as shown in figure 4.
- Stability: The bumper must remain stable inspite of the motion of the vehicle in the opposite direction.
- Energy absorption: The bumper must absorb energy without passing it to the other parts of the vehicles in case of frontal low speed impact.

Figure 4: Condition for Bumper Testing [7]

METHODOLOGY:

The optimized height of bumper with vehicle compatibility shows increase in overlapping of the bumper beam which leads to reduction of impact energy to passenger compartment. This will help in improving the safety of the passengers. Therefore in order to optimize the bumper height and for compatibility analysis, four M1 category vehicles (passenger cars) are selected on the basis of the variation of their ground clearance, weight, height and width as shown in Table 1. The modelling of the bumper is done in CREO and simulation is carried out by using LS Dyna tool.

Table 1: Vehicles Selection

Factors	Vehicle A	Vehicle B	Vehicle C	Vehicle D
Ground clearance (mm)	165	190	205	225
Weight (Kg)	1022	1180	1740	2610
Height (mm)	1535	1630	1625	1835
Width (mm)	1647	1780	1822	1855
Bumper Beam Thickness(mm)	2	1.4	1.4	1.8

In order to optimize the bumper height, the vehicle having lowest ground clearance and highest ground clearance are taken

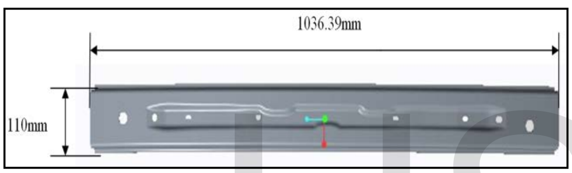
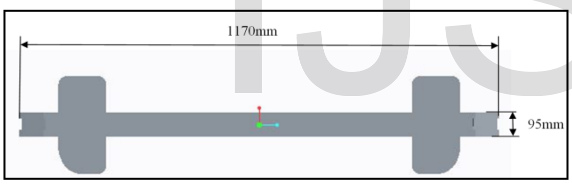
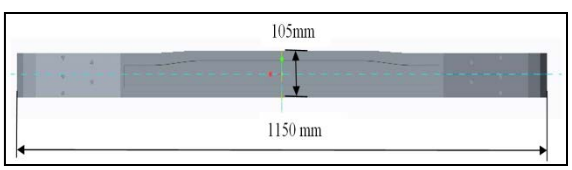
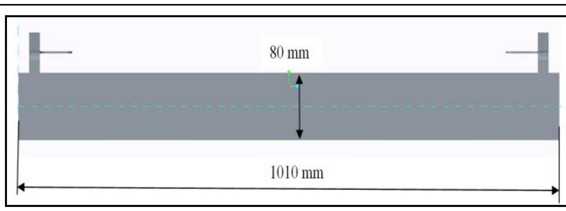
ISSN 2229-5518

into consideration. For analysis, the actual weight and dimensions of the vehicles are considered. During optimization the height of the bumper with lowest ground clearance is increased by 25 mm whereas in vehicle with highest ground clearance is decreased by 25mm.This procedure is repeated to set minimum 30% overlap of the bumper of the vehicles. Based on the optimized height, the further analysis is carried out for combinations of these vehicles in order to determine the effect on various parameters like energy absorbed, maximum displacement of bumper beam, etc.

Modelling of Bumper

Based on benchmarking, the modelling of the bumpers are done and triangular & quad elemnets are used for meshing. The mild steel is the material selected for bumpers which is having density of 7850 Kg/m^3, young's modulus of 2.1 * 10^5 MPa, and Poisson's ratio of 0.3. The models of bumpers along with their dimensions are as shown figure 3:

Table 2: Vehicles Bumper Models

Vehicle	Bumper Model
A	
B	
C	
D	

The simulation analysis tool usually makes use of Finite element analysis in order to observe large deformations and energy absorbed in cases such as collisions [8].It mainly makes use of explicit time methodology in order to carry out the analysis.

Analysis of Bumpers

For optimization first, the vehicles having lowest and highest ground clearance are selected with consideration of vehicle weight, bumper beam and Fascia. The analysis is carried out to increase the overlapping of the bumper beam of the two vehicles. The height of the vehicle A having lowest groud clearance is incresed by 25mm where as in vehicle D having highest groud clearance is reduced by 25mm. This process is continued till an overlapping of minimum of 30% is achieved. For simulation, MAT20 (Rigid) and MAT 24 (Piecewise linear isotropic plasticity) materials are selected for vehicle and bumper beam respectively. The velocity of 8kmph is selected for both vehicles relative to each other. The table 3 shows selection of various iterations and overlapping in each case.

Table 3: The overlapping of bumper beam with bumper heights of vehicle A and vehicle D

Iterations	Vehicle A	Vehicle D	Overlap %
1	475	755	0
2	500	730	0
3	525	705	0
4	550	680	0
5	575	655	11.46
5.1	585	645	30.27
5.2	595	635	48.16
6	600	630	57.33

From simulation, it is observed that the overlapping of the bumper beam started from 5th iteration onwards. To achieve the closest possible overlap the 5.1 & 5.2 iterations have been taken into consideration. In these cases, the upper and lower bumper heights are moved by 10mm each instead of 25mm. In case of 5.1 iteration, the overlap is 30.27% with optimzed bumper height in the range of 585 to 645 mm. based on optimized compalitibility bumper height for overlapping, further analysis is carried out for remaining vehicle combinations with respect to each other. The percentage overlap and amount of energy absorbed by the bumper are determined in each cases.

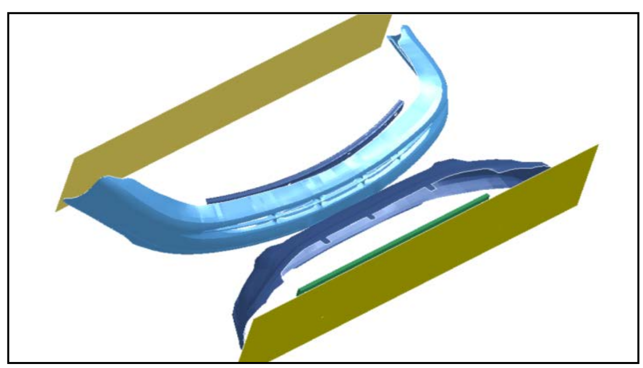


Figure 5: Initial State of Bumper

ISSN 2229-5518

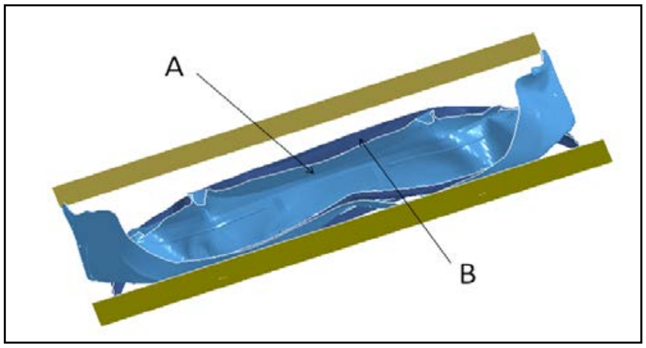


Figure 6: Final State of Bumper

The result shows that Bumper of vehicle D deformed due to impact energy in case of frontal collision whereas bumper of vehicle A shows an overlapping of 30.27% and it is able to successfully absorb energy in case of collision to avoid the override situation.

RESULTS:

The simulation results for diffrrent combination of vehicle under various considerations are discussed as follow.

1) **Maximum Stresses**:

Table 4: Maximum Stresses induced for different combination of vehicles.

Sr.No.	Combination	Maximum Stress (MPa)
1	Vehicle A – Vehicle D	488.85
2	Vehicle A- Vehicle C	523.909
3	Vehicle A –Vehicle B	541.47
4	Vehicle D – Vehicle C	505.16
5	Vehicle D – Vehicle B	493.645

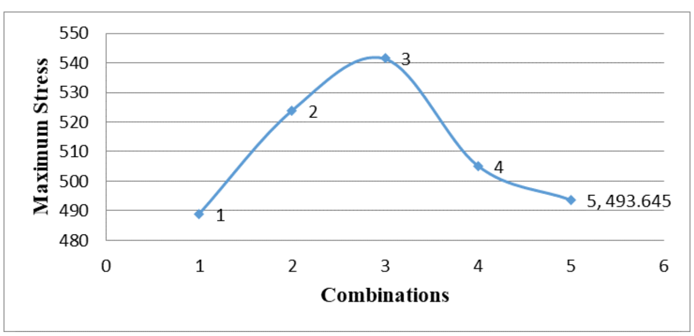


Figure 6: Variation of maximum stress for different combinations of vehicles.

The result shows that the maximum stress occurs at point 3 (541.57 MPa) which mainly consists of combinations of vehicle A and vehicle B. Also it shows that this combination of vehicles gives the maximum (%) overlap. Hence it shows that increases in overlapping, increases the stresses acting on the bumper beams.

2. Kinetic Energy Absorbed:

Table 5: Kinetic Energy Absorbed for different combination of vehicles

Sr.No.	Combination	Kinetic Energy Absorbed (*10^6 mJ)
1	Vehicle A – Vehicle D	5.2
2	Vehicle A- Vehicle C	6
3	Vehicle A –Vehicle B	5.4
4	Vehicle D – Vehicle C	5.7
5	Vehicle D – Vehicle B	6.3

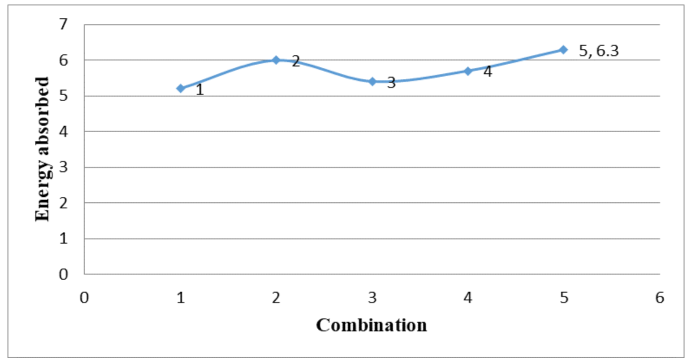


Figure 7: Variation of Kinetic Energy Absorbed for different combinations of vehicles.

The result shows that maximum kinetic energy (6.3*10^6 mJ) is absorbed in case of combination of Vehicle D and Vehicle B. This indicates that this combination of vehicles transfers minimum amount of impact energy to the passenger cabin by getting plastically deformed and as a result improving the safety of passengers.

3. Displacement:

Table 6: Displacement for different combination of vehicles.

Sr.No.	Combination	Displacement(mm)
1	Vehicle A – Vehicle D	311.54
2	Vehicle A- Vehicle C	316.19
3	Vehicle A –Vehicle B	313.95
4	Vehicle D – Vehicle C	442.13
5	Vehicle D – Vehicle B	378.15

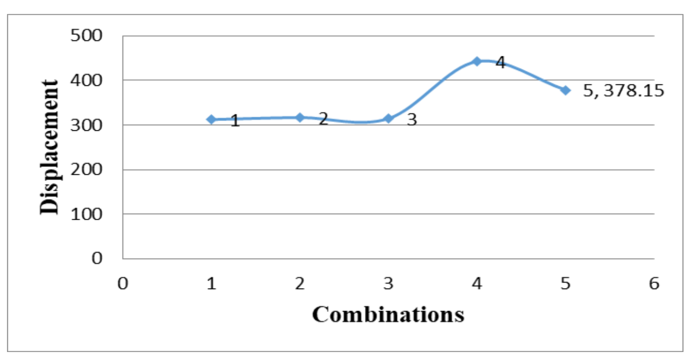


Figure 8: Variation of displacement for different combinations of vehicles.

The result shows that the resultant displacement is more in case of fourth case, i.e. combination of vehicle C and vehicle D. this is due to increase in the overlap percentage (71.05%).

4. **Percentage Overlap of Bumper Beams:**

Table 7: Simulation results of % overlap for different combination of vehicles.

Sr.No.	Combination	Overlap
1	Vehicle A – Vehicle D	30.27
2	Vehicle A- Vehicle C	56.42
3	Vehicle A –Vehicle B	83.94
4	Vehicle D – Vehicle C	71.05
5	Vehicle D – Vehicle B	45.23

From the above table it is observed that the achieved overlap is 30.27% in case of vehicles having lowest and highest ground clearance.Also the percentage of overlap varies for different combination of vehicles with a maximum overlap of 83.94% between vehicleA and vehicleB.

CONCLUSION:

The bumper overlapping is one of the important parameters to reduce override/underride situation in case of vehicle crash. As bumper beams absorbs maximum energy acting on bumper assembly in case of frontal crashes. Hence the optimization of bumper height is important consideration. The analysis result shows significant overlapping of bumper with selected combination of M1 category vehicles. It shows that the minimum bumper overlapping of around 30% in combination of vehicles with lowest and highest ground clearance and range of 45 to 83 percentage overlapping in case of different combination of vehicles. This can mainly help in reducing the override situation. Also with optimized bumper height, around 50% to 75% of the impact energy is absorbed by bumper assembly in combinations of different M1 category vehicles. This will reduce damage to the vehicle and occupants which improves the safety.

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