



# FMVSS208 Simulation using Finite Element Methods

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**Abstract** - A number of people die every year due to car accidents every year. The main goal of this study is to improve the crash attenuation capabilities of the vehicle using Finite Element Methods (FEM). AS FEM is a very advance tool to analyze the strength behavior of the vehicle and its occupants. Front impact is common and responsible for thousands of deaths every year. Vehicle hits to any other object and attend stable condition in very short period of time in case of frontal impact. The severity of crash can be measured by crash impulse or deceleration pulse during crash. Front part of vehicle always plays an imperative role in case of frontal accident. It absorbs maximum part of the crash energy therefore, it is also called Crush Zone. With the help of Hypermesh (Altair's Product) frontal crash simulations were carried out. Modifications were performed in the Crush Canes of the vehicle to improve the vehicle crash resistance power at the time of accidents. Significant reduction in the vehicle deceleration was found in the final design that would be very useful to save many lives during accidents.

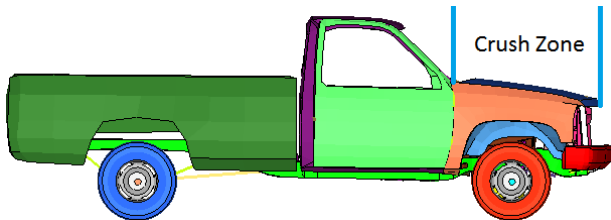


Figure-1. Finite element Model of Vehicle and Crush Zone

## I. INTRODUCTION

The main objective of this study is to prepare and study the finite element simulation of frontal impact test as per

FMVSS208. The data presented in this study should be used just to understand the FE simulation process.

Even now a days the use of seatbelts and airbags is common, frontal crash related injuries are frequently occurred. It was observed that airbags and seatbelts could reduce the chances of fatalities by more than 60%. Still we need to care about remaining 40% cases.

FARS (Fatality Analysis Reporting System) claimed that there were about four thousands fatalities observed in 2007.

<http://www.nhtsa.gov/FARS>

Point out the trends of fatalities of occupant during 2000-2007 in frontal impacts to drivers and right-front passengers of cars and LTVs, the years when a uniform definition enabled by FARS of “frontal” impact based on the variables IMPACT-2 (principal impact point), IMPACT1 (initial impact point), ROLLOVER, HARM\_EV (first harmful event) and M\_HARM (most harmful event).

To analyzing this, we define “frontal” impacts by including any vehicle whose IMPACT-2 (or IMPACT1 if IMPACT-2 is unknown) is 11, 12, or 1 o’clock, even including some cases with subsequent rollover – but we exclude any vehicles of which first harmful event was due to immersion, was a rollover and/or of which most harmful event was a rollover.

To account for the percentages of small missing data on these variables, the estimates have been adjusted.

CY	2003	2004	2005	2006	2007
Frontal Fatalities	12,894	12,521	12,300	12,163	11,659
All drivers and RF Fatalities	28,557	28,136	27,873	27,218	25,663
Present that are frontal	45	45	44	45	44
Car and ATV VMT10 <sup>6</sup> miles	2656173	2727054	2749555	2771684	2755131
Frontal fatalities per 10 <sup>9</sup> miles	4.85	4.59	4.47	4.39	4.23
Belted frontal fatalities at seats with air bags	N	3,775	4,083	4,443	4,630
	%	29.3	32.6	36.1	38.1
Observed on road belt use %	79	80	82	81	82
% of on road fleet with air bag	64.2	67.9	71.4	74.7	77.6

FMVSS 208

The National Highway Traffic Safety Administration (NHTSA) tries to set up the test procedures in regulatory necessity lead to advancement in real world safety repeatedly in connection with performance standards. In Federal Motor Vehicle Safety Standard (FMVSS) No. 208 "Occupant Crash Protection," a rigid barrier crash test was applied. Historically, this test has applied to both belted and unbelted 50th percentile male anthropomorphic dummies for impact conditions from 0 to 48 kmph and impact angles from 0 to 30 degrees.

WILLIAM T. HOLLOWELL et al. FMVSS NO. 208 OFFICE OF VEHICLE SAFETY RESEARCH (ref.1)

Frontal Impact tests (FMVSS208) is categorized into following types:

1. Car-to-Car Crash Test
2. Full Frontal Fixed Barrier
3. Oblique Frontal Fixed Barrier
4. Frontal Offset Deformable Barrier
5. Oblique Moving Deformable Barrier (MDB) Test
6. Full Frontal Fixed Deformable-face Barrier (FFFDB)

Figure-2 shows an example of an oblique offset car-to-car test. These car-to-car crashes generate a wide range of crash responses. In car-to-car tests, the vehicles differ in their change in velocity, with the lighter vehicle experiencing a greater velocity change than the heavier vehicle.

In rigid barrier tests, there is a lesser vehicle-to-vehicle variation in the velocity change.

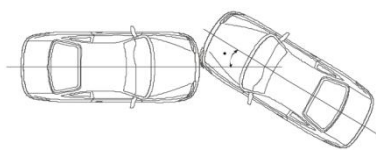


Figure-2<sup>1</sup>. Car-to-Car Crash Test

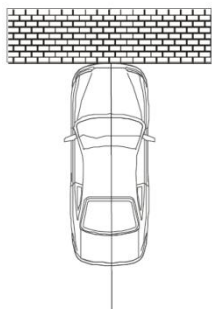


Figure-3<sup>1</sup>. Full Frontal Fixed Barrier

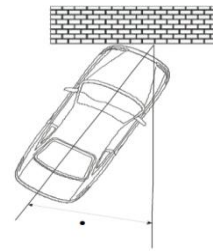


Figure-4<sup>1</sup>. Oblique Frontal Fixed Barrier (shown at 30<sup>0</sup> Impact Angle)

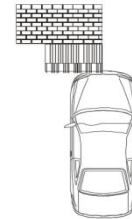


Figure-5<sup>1</sup>. Frontal Offset Deformable Barrier

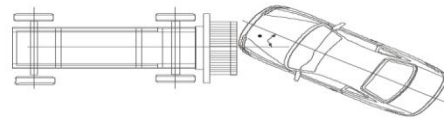


Figure- 6<sup>1</sup>. Oblique Moving Deformable Barrier (MDB) Test

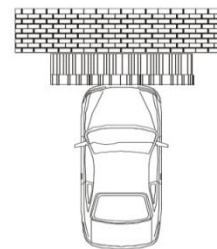


Figure- 7<sup>1</sup>. Full Frontal Fixed Deformable-face Barrier (FFFDB)

CRUSH-ZONE OR FRONT IMPACT ENERGY ATTENUATION

The crumple zone (known as crush space also), mainly used in automobiles, is a structural feature recently incorporated into railcars. To absorb the energy from the impact during a traffic collision by controlled deformation, these crumple zones are designed. This is much more energy than commonly realized. Though crumple zones may be found on other parts of the vehicle also but typically, in order to absorb the impact of a head-on collision, crumple zones are located in the front part of the vehicle.

The damage impact occurs on vehicle: 65% were front impacts, 25% rear impacts, 5% left side, and 5% right side, according to a British Motor Insurance Repair Research Centre study. To form an impact attenuator that dissipates crash energy using a much smaller volume and lower weight than road car crumple zones, some racing cars use aluminum or composite/carbon fiber honeycomb.

In the last few decades, the auto safety has come a long way and crumple zone is one of the most effective innovations. The areas of a vehicle that are designed to deform and crumple in a collision are known as crumple zone or crush zone. These prevent the energy, being transferred to the occupants, by absorbing some of the energy of the impact.

Surely, the safety of people in auto accidents of a completely crumple vehicle is not easy therefore factors like designing safer cars, including vehicle size and weight, frame stiffness and the stresses the car is likely to be subjected to in a crash have to be considered by the Engineers. For instance, in comparison to the street cars, the racing cars undergo more severe impacts, and SUVs often crash with more force than small cars.

Let's find out that how the forces involved in a crash are redistributed by the crumple zones, what crumple zones are made out of and learn about a few other advanced safety systems that are being tested right now. We'll also discover that how crumple zones have been incorporated into, and how in the earlier time, the racing fatalities could have been prevented by adopting these safety features.

We will also consider the design of crumple zones to absorb the massive impact of a train collision. Thanks to inertia, when you and your passengers will continue to move forward inside the car, If your car is moving at speed and then collides with another car or object. You will hit the steering wheel or dashboard with a force greater than your normal weight, because of gravity. The force will increase depending on the speed you are travelling at. A crumple zone is intended to absorb energy to reduce the difference between the speed of the car occupants (still travelling at speed due to momentum) and the car (abruptly halted) and also to slow down the crash.

#### Finite Element Analysis (FEA)

The widely used simulation technique in Automobile industries to analyze the overall design of the vehicle is Finite Element Analysis (FEA). As discussed earlier that sufficient durability of vehicle must be analyzed against crash because frontal impact of the vehicle can lead to severe casualty of the occupants and sometimes death. In this study a full frontal fixed barrier FMVSS208 regulation of Chevrolet Pickup truck has included. To improve the crash safety capabilities of the vehicle, modifications on the Crush zone of the vehicle are made.

The simulation is the mock operation of real process. A model should be developed before act of simulate something to represent the key characteristics or behaviors/functions of the selected physical or abstract system or process. The simulation represents the operation of the system over time whereas the model represents the system itself.

The basic finite element procedures used ensures the large success of FEM. Problem formulation in variational form: the formulation of the problem in variational form, the finite element discretization of this formulation and the effective solution of the resulting finite element equations. For considering any problem, basic steps are the same and together with the use of the digital computer present a quite natural approach to engineering analysis.

#### Full Frontal Fixed Barrier

A vehicle-to-vehicle full frontal engagement crash with each vehicle moving at the same impact velocity is represented by the Full Frontal Fixed Barrier Crash Test (of Rigid Barrier Test). The Figure-8 depicts a schematic of the test configuration.

The most real world crashes (both vehicle-to-vehicle and vehicle-to-fixed object) with significant frontal engagement in a perpendicular impact direction are intended to represent. The barrier rebound velocity and the impact velocity is 0 to 48 kmph (0 to 30 mph) For FMVSS No. 208, and, while varying somewhat from car to car, typically ranges up to 10 percent of the impact velocity for a change in velocity of up to 53 kmph. Note that although from vehicle to vehicle, the rebound velocity varies somewhat, it is small compared to the impact speed. This test evaluates the protection provided by both the energy-absorbing vehicle structure and the occupant restraint system since this is a full systems test. Together with performance requirements, it ensures that the vehicle provides the same minimum level of protection in single vehicle crashes also regardless of the vehicles mass or size. The vehicle changes velocity very quickly upon hitting the barrier in the rigid barrier test.

The crash produces a high deceleration crash pulse frequently referred to as a "stiff" pulse of short time duration.

## II. METHODS:

In this study Chevrolet C2500 Pick truck FE model was used to simulate the FMVSS208 test and propose finest optimized vehicle design against the same test. In order to simulate FMVSS208 in FEA our understanding about this test must be clear. The setup of FMVSS208 is shown in figure 9.

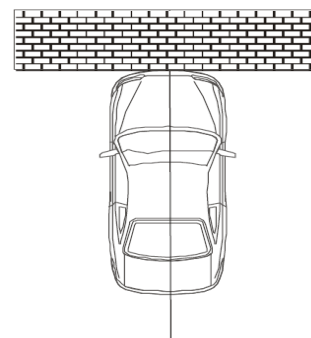


Figure - 8. Full Frontal Fixed Deformable-face Barrier (FFFDDB)

A vehicle-to-vehicle full frontal engagement crash with test vehicle moving at the same impact velocity is represented by the Full Frontal Fixed Barrier Crash Test (of Rigid Barrier Test). The Figure-8 depicts a schematic of the test configuration.

The most real world crashes (both vehicle-to-vehicle and vehicle-to-fixed object) with significant frontal engagement in a perpendicular impact direction are intended to represent. The barrier rebound velocity and the impact velocity is 0 to 48 kmph (0 to 30 mph) For FMVSS No. 208, and, while varying somewhat from car to car. This test evaluates the protection provided by both the energy-absorbing vehicle structure and the occupant restraint system since this is a full systems test. Together with performance requirements, it ensures that the vehicle provides the same minimum level of protection in single vehicle crashes also regardless of the vehicles mass or size. The vehicle changes velocity very quickly upon hitting the barrier in the rigid barrier test.

The crash produces a high deceleration crash pulse frequently referred to as a “stiff” pulse of short time duration.

Figure below shows the FE model of Chevrolet C2500 Pick truck and the real vehicle model.



Figure- 9. Chevrolet C2500

[http://cimg.carsforsale.com/385875/434C2206-B1F3-425A-8665-D13CC3CE3924\\_1.jpg](http://cimg.carsforsale.com/385875/434C2206-B1F3-425A-8665-D13CC3CE3924_1.jpg)

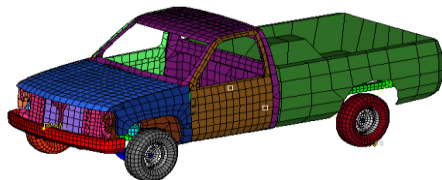


Figure 10. FE model of the vehicle Chevrolet C2500 Pick

As shown in figure rigid wall was create to depict the rigid barrier as given in test. vehicle initial velocity was defined as 30mph similar to FMVSS208 test setup.

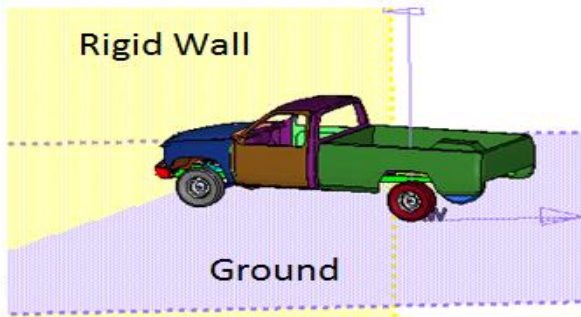


Figure- 11

FMVSS208 fully fixed frontal impact test setup of FE Model

As mentioned earlier in frontal impact two types of safety assurance can be obtained in any vehicle:

1. Crash absorption i.e. Crush attenuate parts
2. Safety restrained systems such as airbags, seatbelts etc.

This study focuses upon the crush zone of vehicle to improve the crash absorbing strength of the vehicle using finite element approach. It should be noted that this study was performed to understand clearly the FMVSS208 FE simulations and due to limited test facility, it was not possible to validate the simulation process with test setup.

Figure below shows the vehicle from ground. The crush zone can be seen in the figure below. These crush cans cat as a crash attenuator during frontal crash and the stiffness of these plays an imperative role to reduce the frontal crash severity. Two cases were simulated with base and low stiffness of crush canes and compared in terms of energy absorption characteristics of the design modifications.

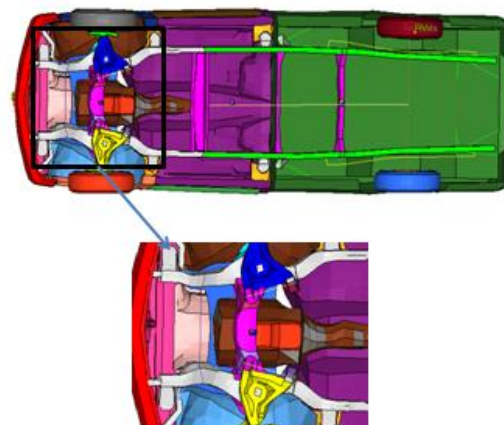


Figure 12

### III. RESULTS

Figure below shows the vehicle conditions at initial (Pre-crash) and final (Post crash) conditions.

It can be seen clearly that crush zone was deformed severely as compare to the other part of the vehicles.

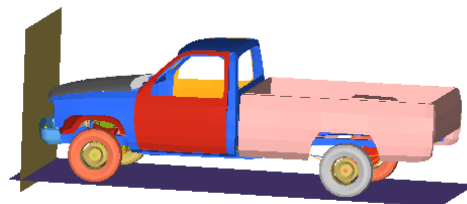


Figure 13 Vehicle condition at initial stage

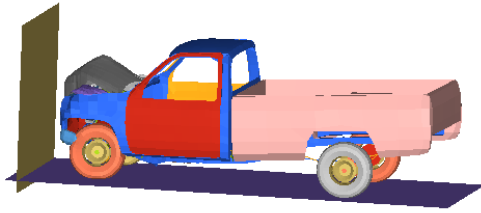


Figure 14: Vehicle condition after the crash test

Figure below shows the strain observed in the frontal region of the vehicle during crash. Peak strain was found to be around 35%.

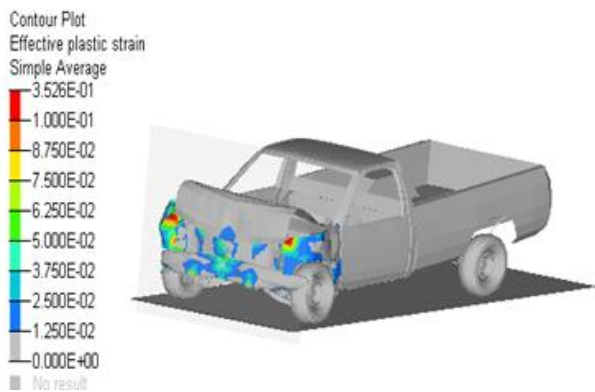


Figure 15: Strain contour at crush zone

As mentioned before the resultant velocity stiff pulse is the main parameter to observe crash attenuator properties of the vehicle. Figure below shows the comparison in two cases in terms of velocity time history. As per FMVSS208 initial velocity of the vehicle was around 30mph (14mm/ms).

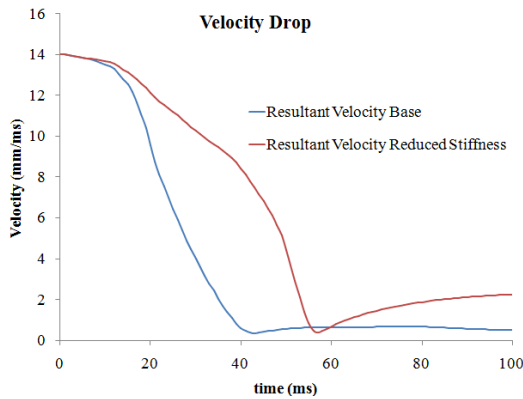


Figure 16: Velocity time history of vehicle

The overall performance of crash attenuator can also be assessed by the internal energy of the vehicle. Figure below shows the comparison in internal energy of both the cases.

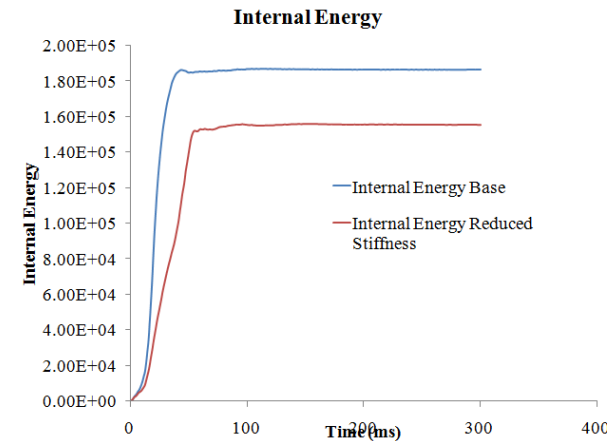


Figure 17: Internal energy time history

#### IV. CONCLUSIONS AND DISCUSSIONS

FMVSS208 fully fixed frontal barrier FE simulation was carried out successfully. The severity of the frontal impact is measured in terms of acceleration as shown in equation below.

Suppose a vehicle is travelling with initial velocity of  $V_1$  and hitting to an immovable object at  $t_1$ .  $t_2$  is the time when vehicle will be stopped i.e. final velocity of vehicle  $v_2$  will become zero.

$$\text{Acceleration} = \text{Change in Velocity} / \text{Change in time}$$

$$\text{acceleration} = \delta V / \delta T$$

$$\text{Where } \delta V = V_2 - V_1$$

$$\delta T = t_2 - t_1$$

In the real crash scenario, initial velocity of vehicle was constant and final velocity was zero, hence

$$\text{Acceleration } \propto 1 / \delta T$$

Again  $\delta T$  only depends upon  $t_2$ . Hence, by increasing  $t_2$  acceleration can be reduced.

Crumple part of vehicle mainly plays a role to reduce the acceleration of vehicle at the time of impact by increasing  $t_2$ . when we compared the velocity drop time in both the cases it was found that time taken by vehicle to have zero velocity was higher in less stiffened crush cane vehicle as compare to the baseline design. Hence, the modified stiffness of vehicle crush canes can provide better safety as compare to the baseline vehicle. Peak internal energy again validates this point. The baseline design experienced higher crash induced internal energy as compare to the modified vehicle design.

Finally, it can be concluded that with the help of finite element modelling, complex engineering problems can be solved and analyzed very clearly.

#### REFERENCES

[1] William T. Hollowell, Updated Review of Potential Test Procedures for FMVSS No. 208, NHTSA, 1999.

- [2] U.S. department of transportation , Fatalities in Frontal Crashes Despite Seat Belts and Air Bags Review of All CDS Cases Model and Calendar Years 2000-2007 ,122 Fatalities,(NHTSA).
- [3] Qian Wang, Review of Correlation Methods for Evaluating Finite Element Simulations of Impact Injury Risk, Virginia Tech-Wake Forest, Center for Injury Biomechanics Blacksburg, VA 24061.
- [4] Kennerly H. Digges, The Use of Computer Finite Element Models of Humans and Crash Test Dummies for High Acceleration and Impact Biomechanics Studies, The National Crash Analysis Center The George Washington University 20101 Academic Way Ashbum, VA 22011, USA.
- [5] Marcin Lisiecki, Finite Element Method in Car Compatibility Phenomena, Technical University of Warsaw Faculty of Power and Aeronautical Engineering Nowowiejska Street 24, 00-665 Warsaw.
- [6] Ruan JS et al, Impact response and biomechanical analysis of the knee-thigh-hip complex in frontal impacts with a full human body finite element model.
- [7] Jaroslav Mackerle, Finite Element Crash Simulations, and Impact-Induced Injuries: An Addendum. A Bibliography, <http://svd.sagepub.com/cgi/content/abstract/35/4/273>.
- [8] S. Roth et al, Crash FE Simulation in the Design Process - Theory and Application, ILaboratoire M3M: Mécatronique, Méthodes, Modèles, Métiers, Université de Technologie de Belfort-Montbéliard, Cedex, 2DPS - Digital Product Simulation, Croissy sur Seine,France.

