Roof Crush Resistance of Passenger Vehicle

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Abstract:- Vehicle rollover accidents are most damaging types. These crashes include the deformation of the vehicle roof and its supporting members. The neck and head injuries are more, and these are associated with the roof deformation. The main objective of this paper is to identify the different vehicle body structure design and assigning the suitable material, FMVSS 216 (Federal motor vehicle safety standard) is the only standard regulation for rollover crashworthiness for passenger vehicles and is to establish a minimum level of vehicle roof strength. This standard gives strength requirements for the vehicle roof, supporting members and is intended to decrease the injuries and deaths resulting from the damaging of the roof into the passenger compartment in rollover crashes. Therefore, this study is according to the standard way of doing analysis by numerical approach i.e FEA. The software packages used to simulate this are hyper mesh, LS-Dyna. Finally evaluated the displacements and reaction forces of the vehicle roof and validated with the FMVSS standards.

***Keywords**:- Roof crush resistance,FMVSS 216, Hypermesh, LS-Dyna.*

I. INTRODUCTION

The purpose of the FMVSS 216(Federal motor vehicle safety standard) is to reduce the head injuries, neck injuries and deaths by the roof crush of the car in to the passenger compartment in rollover crashes. The resistance of the vehicle roof to deformation is dictated by a static test, in which the force of 1.5 times the unloaded vehicle weight or 5000 pounds, which is less, is progressively applied to the roof of the vehicle in the region of the “A” pillar. Force is applied to the plate at a roll angle of 25 degree and a pitch angle of 5 degree to the direction of the forces simulation can be experienced in rollover crashes. At the t time of the test, displacement of vehicle roof should not more than 5 inches of intrusion, as estimated by the movement of the test device[6]. The quarter of Australian light vehicle occupant fatalities come out in crashes involving rollover crashes. These crashes strive to be more crucial than closely other types of crashes One factor associated mutually the risk of injury in a rollover crash is roof strength. Although there is no Australian Design Rule for roof strength, it is maybe that all cars marketed in Australia would Australia would equal the necessities of US Federal Motor Vehicle Safety Standard 216 (FMVSS 216). Henderson found that there was little answer introducing an ADR based on FMVSS 216 - mainly because practically cars already complied with the FMVSS 216 [3].

A. Roof crush resistance test

The vehicle roof front corner to holds a quasi-static force more than 1.5 times of the unloaded vehicle weight, up to 127mm of displacement. This 1.5 is known as the SWR (strength to weight ratio)of the vehicle. The fig 1 shown below is FMVSS216 test rig. An improved vehicle roof crush test is first introduced by NHTSA (National Highway Traffic Safety Administration) in USA[6]. This current test set up is followed by a same loads applied to the vehicle roof on the already untested pillar of the roof in the opposite side of the the vehicle. the base SWR requirement in the FMVSS216 will increased from 1.5 to 3.5 for the light weight vehicle(net weight under 2700 kg)[4].

Fig 1:- FMVSS no 216 Test setup

B. Vehicle safety standard

Prior, in February 2009, the IIHS (Insurance Institute of Highway Safety) reported another rating framework based around roof crush testing. The rating is must to guarantee the security of the travelers amid rollover mischance of auto. In spite of the fact that their strategy is like that of FMVSS 216 (Federal Motor Vehicle Safety Standards), which is the American wellbeing principles utilized for roof crush test. The prerequisite of this test setup is to procure the most noteworthy rating of 4.0 times the unloaded vehicle weight. The rating is 4, determined by both IIHS and FMVSS to build the security of the travelers. This paper reviews the IIHS test methodology and present information from both the FMVSS 216 and IIHS test conventions. Perusers of this paper will pick up a significantly more extensive comprehension of rooftop pulverize testing and the effect it will have on future vehicle outlines [4].

C. New Car assessment program(NCAP) rating system based on FMVSS216

Insurance institute of highway safety (IIHS) from last 2 years included the estimation of the strength to weight ratio (SWR) for the different models of the vehicle. The main Performance of the vehicle in comparative categories identified in wide range. In the year 2009 march the safety institute IIHS announced the first-results of its new type of vehicle roof strength framework. This will give a good rating of SWR more than 4.0, more than 3.5 and up to 4 is the acceptable, 2.5 is marginal that is from 2.5-3.25 or less than 2.5 SWR is poor, contingent upon the SWR, as shown in Figure 2[5].

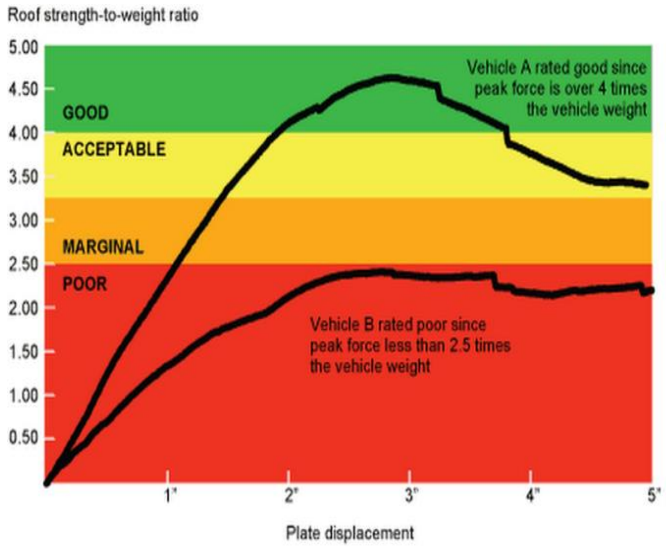

Fig 2:- IIHS strength to weight ratio rating system [5]

D. Objective

- In order to avoid the deformation of roof and its supporting members up to the residual space, different approaches viz. Geometrical and Material approaches are used.
- In geometrical approach the geometry of roof and its supporting members i.e. A pillar, B pillar etc. has to be changed. But it is not applicable to all cases hence material approach was used. In this approach shock absorbing materials were inserted in roof body and pillars to improve their strength. The main objective of this work is to study both these approaches, different materials and testing methods and determine the best method for improving roof and pillars of a vehicle.

E. Methodology

- Modeling of the CAD model using CATIA V5
- Build the finite element model in Hyper mesh for meshing
- Apply Loads and Boundary Conditions in LS-DYNA
- Assign Material Properties
- Control Parameters
- Run the Analysis
- Review and Interpret Results

II. MODELING

Car roof and outer body model are first created using CATIA V5. All the geometric dimensions are directly taken from the research papers and the model is assembled and the system includes roof and outer body of the car. The CAD models are shown below figure 3.

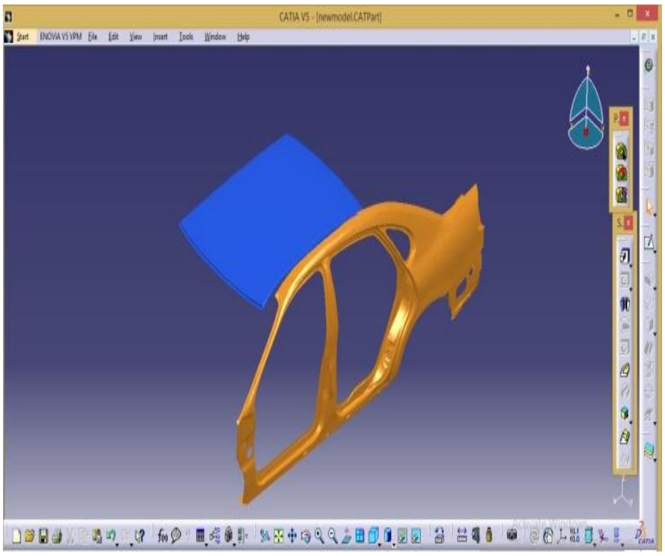

Fig 3: Full model of the car

III. MESHING IN HYPER MESH

Fully assembled CATIA V5 model is exported into Hyper mesh .IGS format. The meshing of CAD model is carried out. Full model of the car is meshed using shell element quad4 with an average element size of 10mm. Triangular elements tria3 are also allowed in the finite element mesh in order to allow good mesh quality. The meshed models are as shown below.

A. Meshing details

Element size =10
Warpage>15, skew >60, Jacobean> .6
Min length=2, max length=12 ,
Max angle quad= 140, min angle quad = 40
Max angle tri=120, min angle quad=20

B. Meshed Details

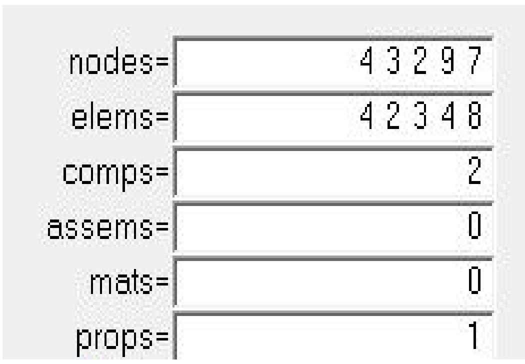

Fig 4:- Outer body meshed part

Fig 5:- Roof meshed part

IV. BOUNDARY CONDITIONS

Finite Element Analysis (FEA) gives the visualization of where those structures crash or bend, indicating the displacements and resulting forces. By this designs are created, optimized and evaluated in 3-D before the manufacture of the car. FEA is a very useful tool in designing the new cars; here we can analyze the destructive testing of the car before the actual prototype manufacturing. Finite element model is shown in below figure 6.

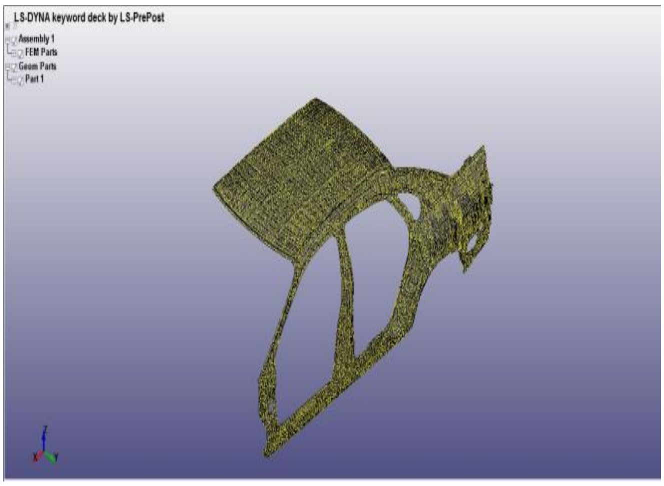

Fig 6:- Finite element model

As per standard test conditions vehicle is clamped at chassis hence for FEA analysis fixed constraints are given to the vehicle chassis. Also only half vehicle is considered for analysis to reduce simulation time. Hence at other half side of the vehicle is given with fixed constraint .The constraints are given to the vehicle roof and the outer body of the car as shown in the below figure 7.

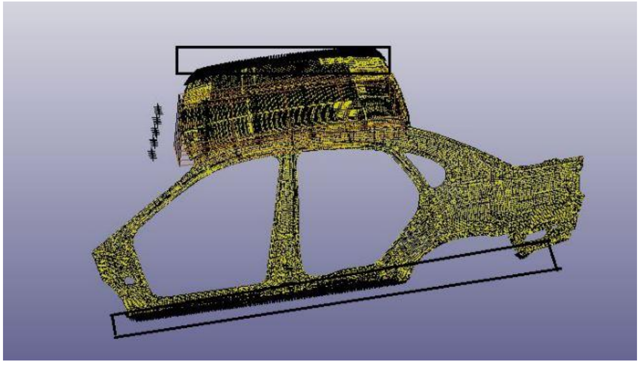

Fig 7:- Boundary conditions for simulation

V. ROOF MODEL MATERIALS PROPERTIES

The material selected for the roof and the supporting pillars is Dual phase steel. These offer an exceptional mix of drawability and strength because of their microstructure. These are high strain hardenability steels. This gives them great strain redistribution limit and in this manner drawability and additionally got done by including yield, quality, that are far better than those of the underlying color. The yield, quality of Dual Phase steels is additionally expanded by the paint preparing BH process. There are some different properties are used for the analysis are given below [1].

Material	Dual Phase 780 LCE
Yield stress:	450-550 MPa
Youngs modulus	210 Gpa
Poisson’s ratio:	0.3
Thickness:	1.5mm
Density	780kg/m3

Table 1. Material properties

VI. CALCULATIONS

A. *load calculations*

We should apply a force of 1.5 times the emptied vehicle weight (UVW) or 5000 lbs (22224N),whichever is less , to either side or forward edge of the vehicle. This test can be led on either side of the rooftop structure, the front left or the front right side yet not on the two sides in a single test and still meet the standards of the test.

Curb weight of the car: 1447 kg
F=Curb weight×9.81×1.5
F=1447×9.81×1.5
F=21270.9N

According to the standards the force applied is 21270.9 N which is less than 22240N and the plate should not move 0.5mm/second.

B. Strength to weight ratio

The vehicle roof should withstand a force 4 times the unloaded vehicle weight prior to roof crush by 5 inch according to the FMVSS 216.

SWR=F/(m×g)
F=1447×9.81
F=1447×9.81×4
F=56780.28N
m =mass of the vehicle in kg
g=9.81 m/s2
SWR=56780.28N/(1447×9.81)
SWR=4

VII. ANALYSIS RESULTS

According to the Standard of FMVSS 216: In the actual care test, the plate is loading with the same loading velocity should not be more than 13m/s and loading should complete within 0.12s. and according to the standard displacement should not higher than 127mm.

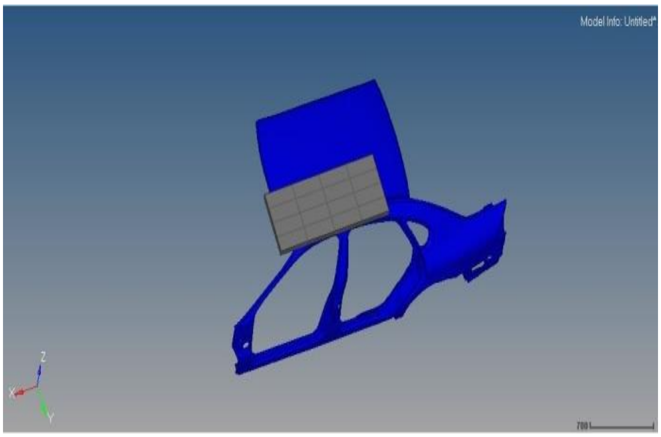

Fig 8:- After the application of the load

The above figure 8 shows the after the application of load which is multiplied by 4 to the unloaded vehicle weight, constantly the load is applied by 0.5inch/sec and the Time vs Displacement graph is shown in below table 2. In the below shown figure 9 Displacement vs time graph after the application of the constant load of 56780.28 N by 0.5inch/sec the roof is displaced within 121mm and with time step of 9.77sec.

X	Y
0.0	0.0
1.0	13.0
2.0	26.0
3.0	39.0
4.0	52.0
5.0	65.0
6.0	78.0
7.0	91.0
8.0	104.0
9.0	117.0
9.77	127.0
100	127.0

Table 2. Displacement Vs Time

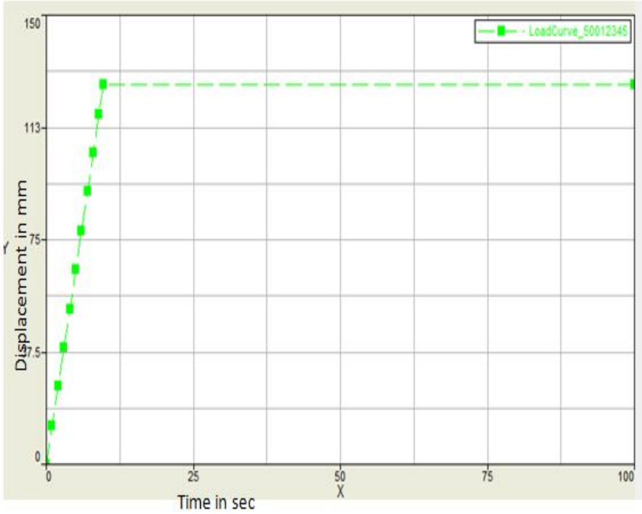

Fig 9:- Displacement vs Time

A. Displacements of A-Pillar, B-Pillar and Roof

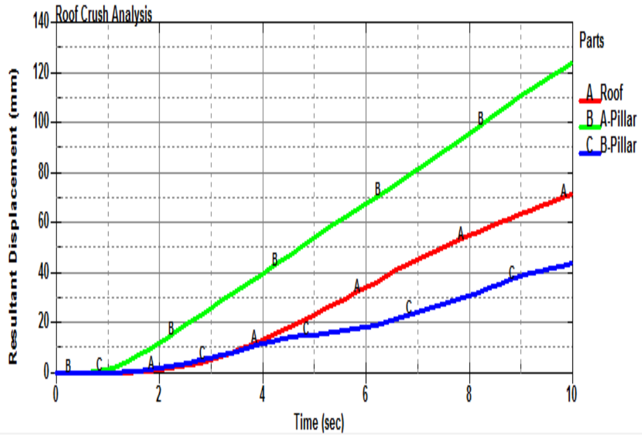

Figure 10: Resultant displacement vs Time

The above shown figure 10 is the resultant displacement vs Time graph. When the constant load is applied in the limiting time of 9.77 sec. When rollover accidents happens the A-pillar of the vehicle will affect more. Roof of the car is displaced 70mm, A-pillar of the outer body is displaced 121mm and B-pillar is crushed with the displacement of 42mm and here according to the FMVSS 216 displacement should below 127mm.

B. Reaction Forces from Complete Body Structure

All the components such as A-pillar, B-pillar and the vehicle roof are having the capability to resist higher loads according to the mandate in the new FMVSS 216. But in the real time test these structural displaced 121mm and B-pillar is crushed with the displacement of 42mm and here according to the FMVSS 216 displacement should below 127mm. Roof members only capable of resisting half of applied loads, making the roof in real world rollover crashes to collapse at far much earlier time.

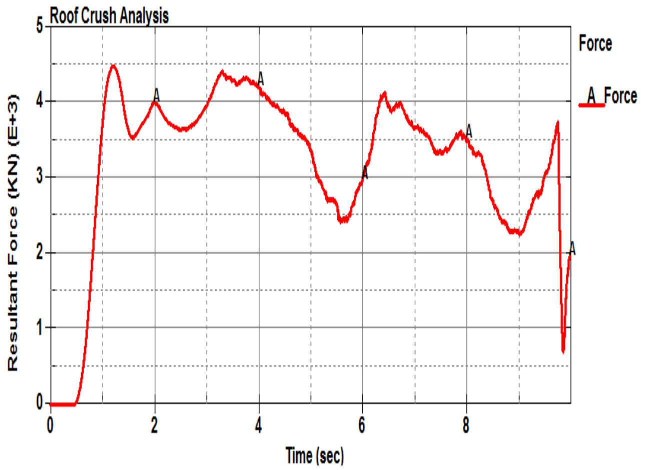

Fig 11:- Resultant force vs Time

The resisting force developed by the body structure 45KN as shown in the above figure 11 Resultant force vs tome graph. As per the Standard of FMVSS 216 (Roof crush resistance, Passenger vehicle) , the reaction forces higher than 42.6 KN said to be a good car body.

VIII. VALIDATION

- The maximum load carrying capacity of structural components given by the finite element model with the load of 56780.28N at roof displacement 70mm, A-pillar displacement is 121mm and B-pillar displacement is 42mm.
- But As per the Federal motor vehicle safety standard (FMVSS 216) Roof crush Resistance, Passenger car test regulation the vehicle roof members should have the capacity to sustain the maximum 56800N at 127mm displacement which is 4 times the unloaded vehicle weight (14195N). Hence from calculations this FE model full filled the requirements of the Standards of FMVSS 216.
- As from the resultant force vs time graph shown in figure 11 the resisting forces developed by the body structure are 45KN. As per the Standard of FMVSS 216 (Roof crush resistance, Passenger vehicle), the reaction forces higher than 42.6 KN said to be a good car body.
- The strength to weight ratio is 4 which is acceptable vehicle with the multiplication of the unloaded vehicle weight (14195N) with 4. According to standard the vehicle should have at least 2.5 strength to weight ratio as shown in the below graph.

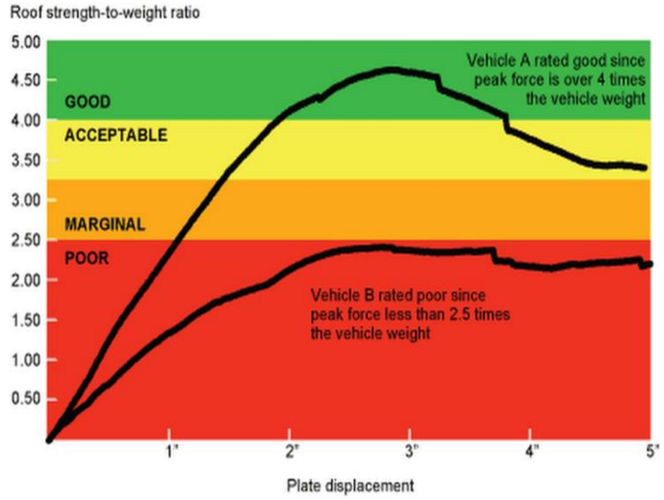

Fig 12:- IIHS rating system for strength to weight ratio

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