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CRASH ANALYSIS OF CAR CHASSIS FRAME USING FINITE ELEMENT METHOD

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ABSTRACT

Vehicle crash is a highly nonlinear transient dynamics phenomenon. The purpose of a crash analysis is to see how the car will behave in a frontal or sideways collision. Crashworthiness simulation is one typical area of application of Finite-Element Analysis (FEA). This is an area in which non-linear Finite Element simulations are particularly effective. In this project impacts and collisions involving a car frame model are simulated and analyzed using ANSYS software. The chassis frame forms the backbone of a heavy vehicle; its principle function is to safely carry the maximum load for all the designed operating conditions. The frame should support the chassis components and the body. It must also withstand static and dynamic loads without undue deflection or distortion. The given model is tested under frontal collision conditions and the resultant deformation and stresses are determined with respect to a time of 80 Mille sec for ramp loading using ANSYS software. The crash analysis simulation and results can be used to assess both the crashworthiness of current frame and to investigate ways to improve the design. This type of simulation is an integral part of the design cycle and can reduce the need for costly destructive testing program.

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INTRODUCTION

In automobile design, crash and structural analysis are the two most important engineering processes in developing a high quality vehicle. Computer simulation technologies have greatly enhanced the safety, reliability, and comfort, environmental and manufacturing efficiency of today's automobiles. This significant achievement was realized with the advanced software and powerful computers that have been available in the last twenty years. The primary concern for drivers and passengers is safety. Governments have responded to this key concern and expectation with an increasing number of regulations. Although the details may vary slightly from country to country, the fundamental requirements are almost similar. A vehicle is expected to provide adequate protection to drivers and passengers in a not so serious accident. To protect the occupants of a car, there are many new tangible safety features such as airbags; ABS control brakes, traction control. A less tangible feature that cannot easily be seen by drivers and passengers is the crash response behavior. In a well designed automobile, the car body and various components are the protective layer for the occupants of the vehicle. They serve as the crumpling zone to absorb the energy of impact. The traditional approach involves multiple iterations of design, prototype and crash tests. The process is time consuming and expensive. The availability of high performance computers and crash simulation software has revolutionized the process. Instead of relying on experimental validations, the safety design process is supplemented with computer simulation to evaluate the design. Since the inception of crash simulation, the product cycle of a new automobile has been reduced by half and the resultant vehicle is safer, better and more comfortable..

Lonny L.Thompson e.t. al , determined that a high sensitivity value indicates a strong influence on the torsional stiffness of the overall chassis. Results from the sensitivity analysis are used as a guide to modify the base line chassis with the goal of increased torsional stiffness with minimum increase in weight and low center-of-gravity placement.[1].

A method for vehicle analysis based on finite element technique has been proposed by **Johansson, I.** and **Gustavsson, M**. **e.t.al,** Vehicle dynamics and durability have been taken into account in their work and in house developed pre and post processor is used to achieve effective[2]**. Oijier**, F e.t.al,. has provided a method for force and stress calculation using complete vehicle models in**.nastran**, where variables such as road profile and curve radii are used as input[3].

1.1.Crash Simulation Evolution

Year	Regulatory Requirements	FE Model Size (elem)	Prototypes Reqd (cars)
1985	1	10000	150
1990		20000	120
1995	5	80000	100
2000		0.5M	50
2005	20	1M	20
	Reduce Injuries & Fatalities ↓	Made possible by supercomputers ↓	Significant cost savings ↑

In the present thesis an attempt has been made to

(i) To investigate the deflection and stresses in a chassis using static analysis

(ii) To see the transient response of a car frame under crash simulation

2. FRAME STRUCTURE

2.1 The Automobile Structure

Safety engineers design and manufacture vehicle body structures to withstand static and dynamic service loads encountered during the vehicle life cycle. The vehicle body provides most of the vehicle rigidity in bending and in torsion. In addition, it provides a specifically designed occupant cell to minimize injury in the event of crash. The vehicle body together with the suspension is designed to minimize road vibrations and aerodynamic noise transfer to the occupants. In addition, the vehicle structure is designed to maintain its integrity and provide adequate protection in survivable crashes.

Figure 2.1 Body-In-White image of a typical unibody construction (passenger cars)

The automobile structure has evolved over the last ten decades to satisfy consumer needs and demands subject to many constraints. Among these constraints are materials and energy availability, safety regulations, economics, competition, engineering technology and manufacturing capabilities. Current car body structures and light trucks include two categories: body-over-frame structure or unit-body structure**.** The latter designation includes space-frame structures.

2.1.1.Unibody Construction: Most vehicles today are manufactured with a Unitized Body/Frame (Unibody) construction. This is a manufacturing process where sheet metal is bent and formed then spot welded together to create a box which makes up the structural frame and functional body of the car. These vehicles have "crumple Zones" to protect the passengers in case of a collision.

2.1.2.Body-on-Frame Construction: Most heavy duty trucks and a few premium full-size cars are still manufactured with a body-on-frame construction. This is a manufacturing process which a weight-bearing frame is welded together and then the, engine, driveline, suspension, and body is bolted to the frame.

In an accident, the Unibody frame is designed to "crumple" and absorb the energy of an impact better than a Body-on-Frame construction.

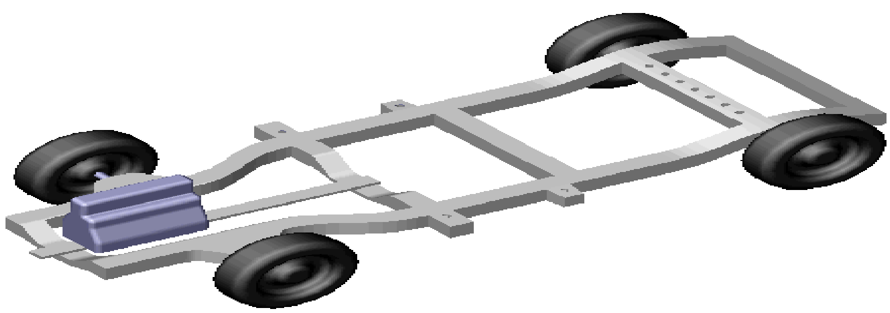

Figure 2.2: Body-on-frame construction, Ladder frame (trucks/ SUV's)

2.2 Materials Used :

Most auto bodies today use stamped sheet as structural members that are spot welded together to form a unitized body. This unitized structure is called the body-in white (BIW). BIW structural members support most of the loads designed for strength, fatigue resistance, stiffness, as well crush loads for crashworthiness.

Body materials should also possess sufficient strength and controlled deformations under load to absorb crash energy, yet maintain sufficient survivable space for adequate occupant protection should a crash occur. Further, the structure should be lightweight to reduce fuel consumption. The majority of mass-produced vehicle bodies over the last six decades were manufactured from stamped steel components. Manufacturers build only a few limited production and specialty vehicle bodies from composite materials or aluminum.

property	**Nomenclature**	**Value**
Young's modulus	EX	200000 N/mm^2
Density	DENS	7800 kg/mm^3
Poisson's ratio	NUXY	0.3
Ultimate strength	UT	340-2100 MPa

CHAPTER – 3

CRASH WORTHNESS TESTS CRITERIA AND MODEL REQUIREMENTS:

In the automotive industry, crashworthiness connotes a measure of the vehicle's structural ability to plastically deform and yet maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration loads. Restraint systems and occupant packaging can provide additional protection to reduce severe injuries and fatalities. Crashworthiness evaluation is ascertained by a combination of tests and analytical methods. Currently vehicle crashworthiness is evaluated in four distinct modes:

- Frontal
- Side
- Rear
- Rollover crashes

Types of crash tests: All cars undergo front- and sideimpact testing, which includes

- 64kph (40mph) Front impact test: to assess
- car's performance in severe accident 50kph (30mph) Side impact test
- 29kph (18 mph) optional Pole impact test: to
- driver's head 40kph (25mph) child and adult pedestrian
- impact tests

Crash Tests - Regulatory Rules:

The following are the requirements for the consumer rash tests conducted by

- Federal Motor Vehicle Safety Standard (FMVSS)
- Insurance Institute for Highway Safety (IIHS)

FMVSS Frontal impact requirements:

- 30 mph (48kph) into a fixed barrier
- Hybrid III in front driver and passenger seats
- Uses dummy injury measures for regulation
- o chest G's <= 60 o HIC <=1000 o Femur loads <= 10KN Protection must be automatic
- Purpose of this test is to examine the performance of the occupant restraint systems (seatbelts, airbags, etc.)

IIHS Frontal impact requirements:

- 40% offset 40 mph (64kph) into a deformable barrier
- Male Hybrid III dummy in front driver seat Good, Acceptable, Marginal and poor ratings to assess vehicle's overall crashworthiness
- Rating based on:

o dummy injury measures

o structural performance

o restraint/dummy kinematics Evaluates the structural performance of the vehicle.

FMVSS Side impact requirements:

- 33.5 mph (54kph) crabbed impact
- Impact or mass 1367.6 kg (3015lb)
- uses SID dummy in front and rear seats
- uses dummy injury measures for regulation
- TTI(d) <= 85g for 4 door passenger cars
- TTI(d) <= 90g for 2 door passenger cars pelvic acceleration <= 130g
- Where TTI(d) = 0.5 x (Gr + Gs)

o Gr = Max. Rib acceleration

o Gs = Lower spine acceleration

IIHS Side impact requirements:

- impactor mass = 1500 Kg
- impactor shape derived from Ford F150 front profile
- 30 mph perpendicular impact
- driver and rear passenger dummies purpose is to represent crash type that poses greatest risk to occupants (pickups/SUV as striking vehicle)promote head protection

Modelling and meshing of chassis

3.1 Modeling

The model of the chassis frame has been created using the primitives approach using CATIA software.

1. Model is a unibody structure
2. The figures shown in the literature review were the basis of our model
3. A work plane is established(xy plane)
4. By using different geometrical primitives basic geometry is obtained
5. By using different modeling options of CATIA for several times model is created according to dimensions as shown in figure 3.1

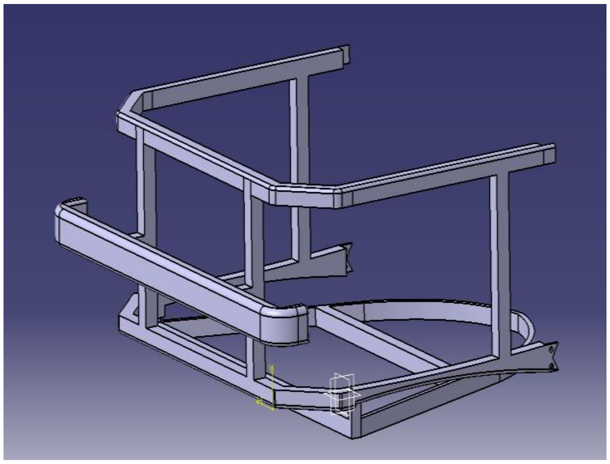

Figure 3.1 CATIA model of car front part

3.2 Element Description:

(i) Solid45 (ANSYS library) Element Description (Figure 6.5):

Solid45 is used for the 3-D modelling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. A reduced integration option with hourglass control is available

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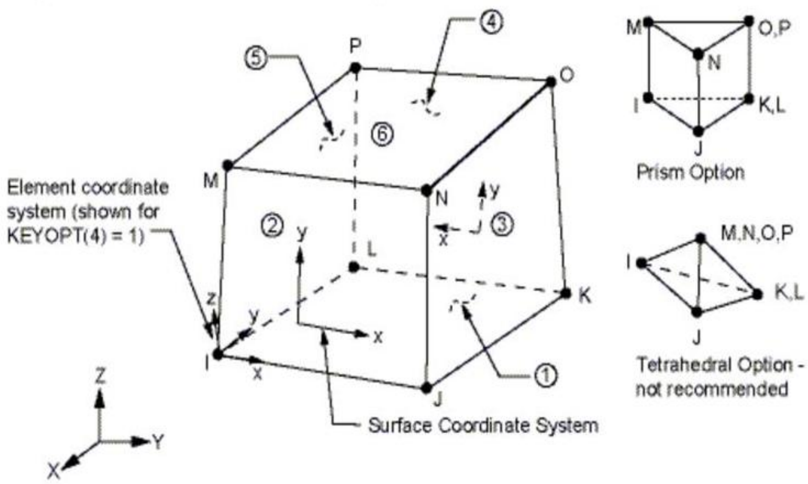


Figure 3.2 Solid45Geometry

3.3 Mesh Generation of Model

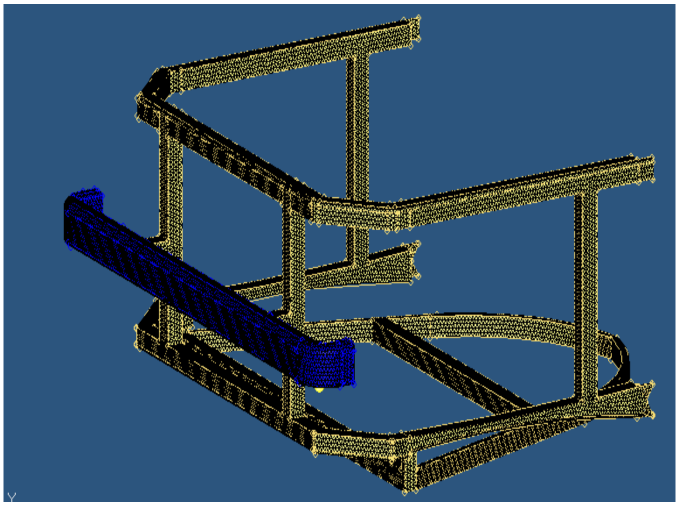


Figure 3.3 Final Mesh of Car Frame

4. ANALYSIS OF AUTOMOBILE MODEL

4.1 Types of Analysis Used

The following analysis has been carried out

- STATIC
- MODAL
- TRANSIENT

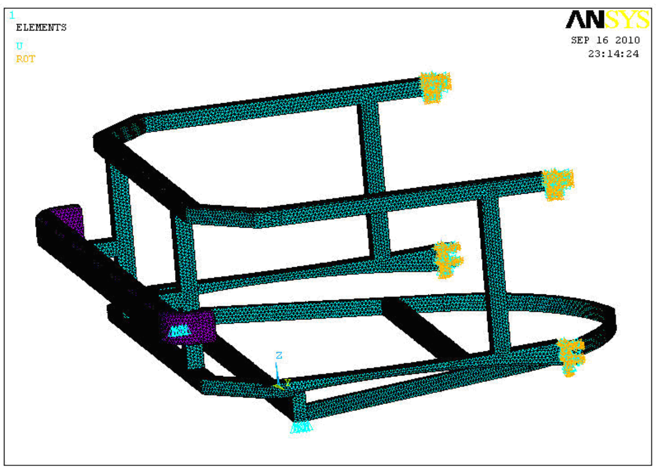


Figure 4.1 Car Frame with Imposed Boundary Conditions

4.2 STATIC ANALYSIS:

Definition: A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads (such as the static equivalent wind and seismic loads commonly defined in many building codes).

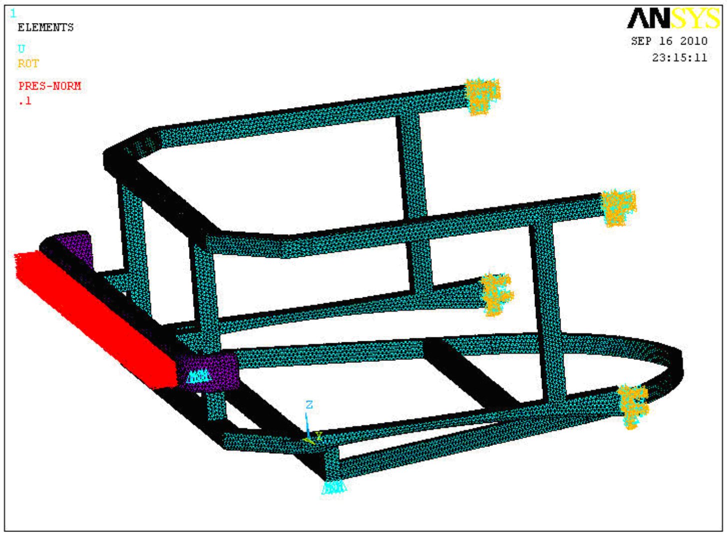


Figure 4.2 Car Frame with Load and Boundary Conditions

The below figure shows the plot of pressure vs time where pressure is taken on y axis and time on x axis before impact at time t=0 the pressure is 0 after impact the pressure increases from 0 to 0.1 and then decreases gradually with increase in time

- Figure [4.3] is the reference for the loads applied in transient analysis
- For static analysis a constant pressure of 0.1MPa is taken.

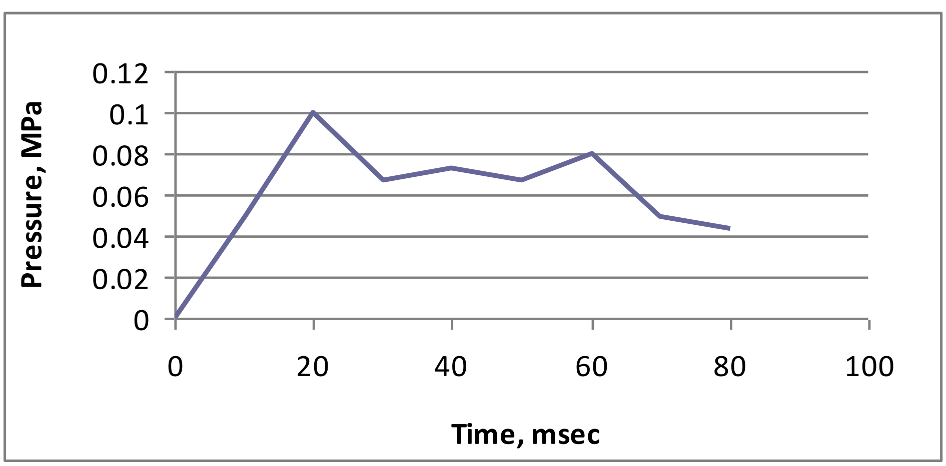


Figure 4.3 variation of Pressure against Time

5. RESULTS AND DISCUSSION

5.1 Results for Static Analysis:

From the static analysis the deflections and stresses are obtained in the bumper under a load of 0.1MPa.

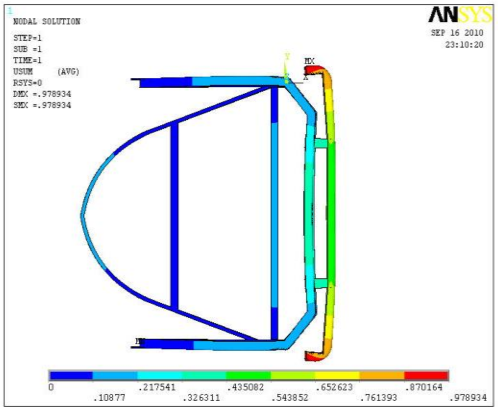


Figure 5.1 Vector plot of deformation for shell thickness 3mm under static load

From the figure 5.1 it is observed that that the maximum deflection is 0.978934mm for the bumper made of thickness 3mm at the point which is indicated as MX which is at node 63982. The minimum deflection is obtained at the constrained points which are indicated as MN.

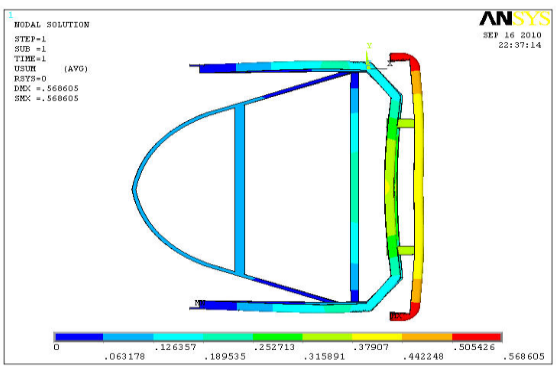


Figure 5.2 Vector plot of deformation for shell thickness 5mm under static load

From the figure 5.2 it is observed that that the maximum deflection is 0.568605mm for the bumper made of thickness 5mm at the point which is indicated as MX which is at node 61483. The minimum deflection is obtained at the constrained points which are indicated as MN.

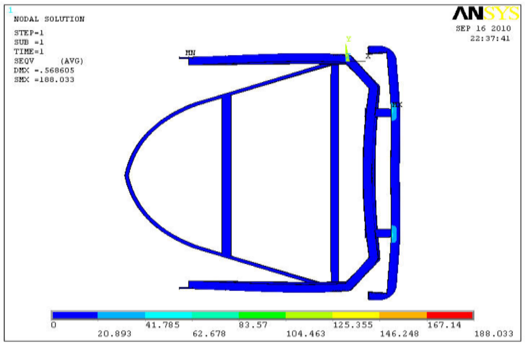


Figure 5.3 Vector plot of Von-mises stress for shell thickness 5mm under static load

From the figure 5.3 it is observed that that maximum stress for the bumper having thickness 5mm is found out to be 188.033MPa at the node 1030 which is indicated as MX in the figure.

From the figures 5.1 to 8.3 it is observed that that as the bumper made of thickness increases from 3mm to 6mm the maximum deformation and maximum Von-mises stress are decreasing which indicates the rigidness of the modal for the loads. But heavy bumper made of thickness elements leads to increase in weight which consumes more fuel and even for high loads instead of bumper chassis may be deformed. Thus optimum thickness of bumper should be selected while manufacturing. Generally 2.5mm to 3.5mm of bumper thickness are used. But in practical they may vary from 3mm to 5mm thickness.

5.2 Results for Modal Analysis:

The modal analysis of the car frame is carried out to estimate the natural frequencies and corresponding mode shapes for the structure of car frame. The table 8.1 gives the first ten natural frequencies of the model with different thickness of the shell of the bumper of an automobile, which varied from 3mm to 6mm.

Table 5.1: Natural Frequencies of Car Frame by Varying Thickness of the Bumper

Mode No	Natural Frequencies, Hz			
	Bumper Thickness, mm			
	3	4	5	6
1	0.531657	0.526162	0.520871	0.51576

2	0.587794	0.587785	0.587776	0.587768
3	1.236	1.232	1.228	1.224
4	1.729	1.695	1.663	1.633
5	2.144	2.141	2.137	2.132

Different mode shapes of the structure of car frame with bumper thickness **3mm** are shown in fig 5.4

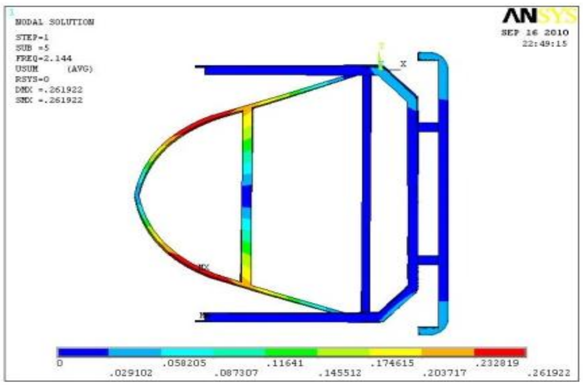
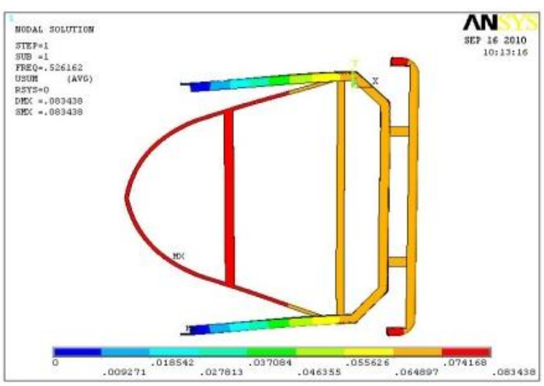


Figure 5.4 Mode shapes of car frame having bumper thickness 3mm

Different mode shapes of the structure of car frame with bumper thickness **4mm** are shown in fig 5.5



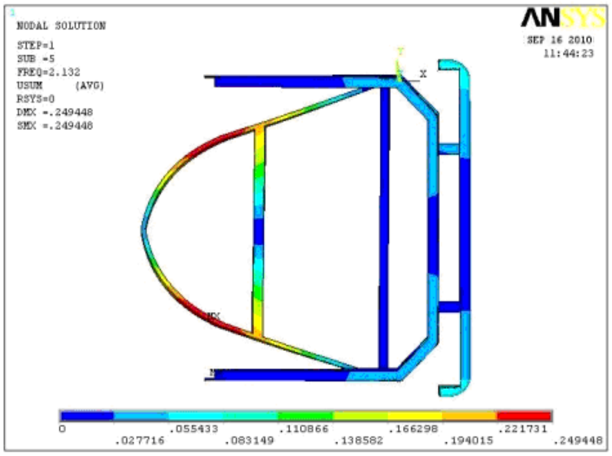


Figure 5.6 Mode shapes of car frame having bumper thickness 6mm

Different mode shapes of the structure of car frame with bumper thickness **6mm** are shown in fig 5.6

5.3 Results for Transient Analysis:

Transient analysis yields results about deformation, velocity of deformation, acceleration of deformation, stress induced in the car frame with respect to time. The following graphs shows the variations of deformation, velocity, acceleration and stress with respect to time in x, y, z directions for varying thicknesses of bumper as shown in figures 5.7 to 5.13

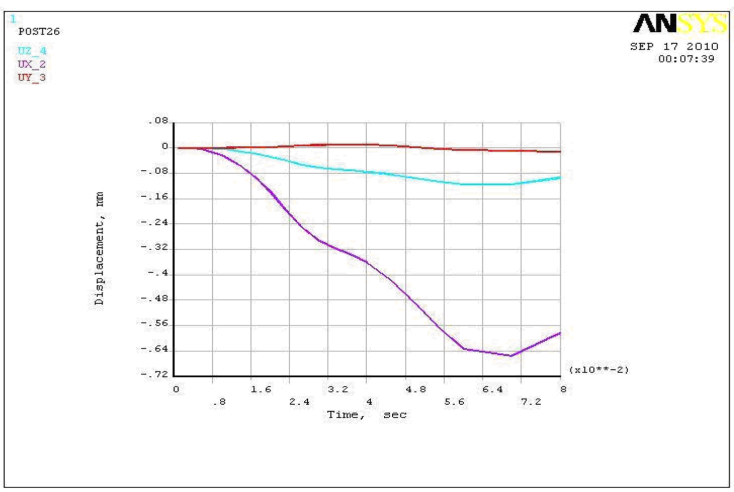


Figure 5.7 Displacement Vs Time graph for shell thickness 3mm

From the figure 5.7 the above graph is a plot of displacement vs time of 3 mm shell where displacement is taken on y axis. in the graph violet red and blue colours indicates that x,y,z directions it is observed that the deflections in x,direction varies from 0 to 0.6mm and deflection in y direction varies from 0 to 0.1mm and deflection in z directions vary from 0 to 0.9mm respectively. For the shell of thickness 3 mm

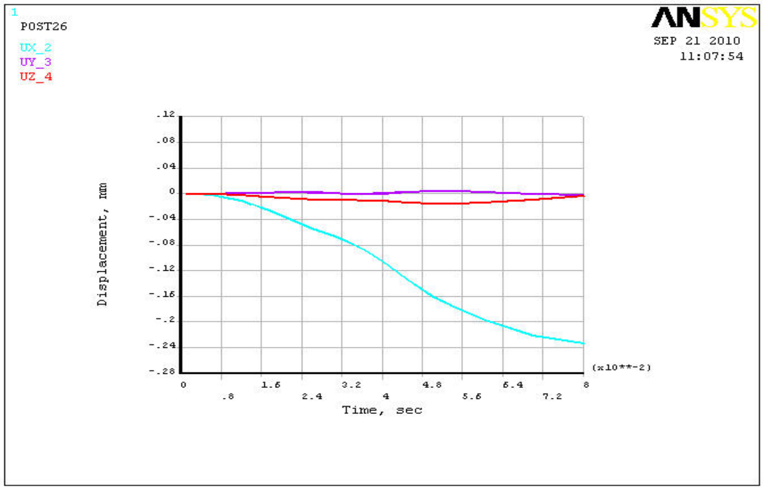


Figure 5.8 Displacement Vs Time graph for shell thickness 6mm

From the figure 5.8 the above graph is a plot of displacement vs time of shell thickness 6 mm where displacement is taken on x axis and time is taken on y axis in this graph the blue,violet an the red colour indicates the deflections in x,y,z directions it is observed that the deflection in x direction varies from 0 to 0.23mm, and the deflection in y direction varies from 0 to 0.1mm ,in the z direction the deflection varies from 0 to 0.1mm respectively for the bumper thickness 6mm.

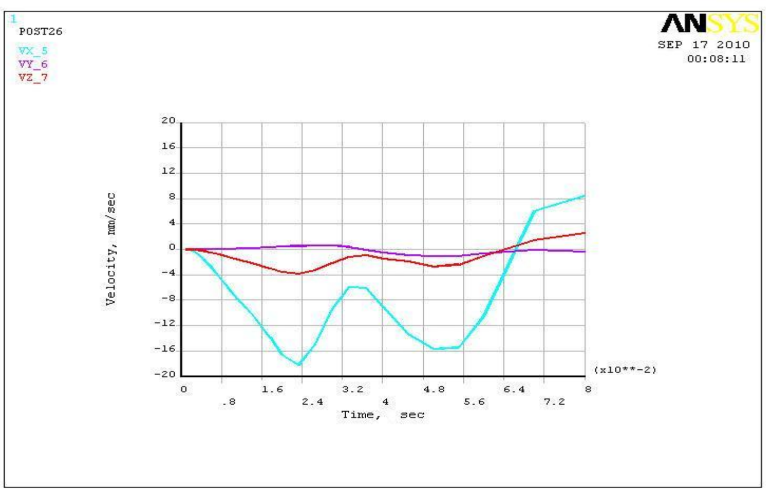


Figure 5.9 Velocity Vs Time graph for shell thickness 3mm

From the figure 5.9 the above graph is the plot of velocity vs time where velocity is taken on y axis and time is taken on x axis in which the blue violet and red colours in the graph indicates that the change in velocity in x,y,z directions the velocity in x, directions varies from -18mm/sec to 8mm/sec, and the velocity in y direction varies from 0mm/sec to 0.2mm/sec and in z direction the velocity varies from -4mm/sec to 4mm/sec for bumper thickness 3mm.

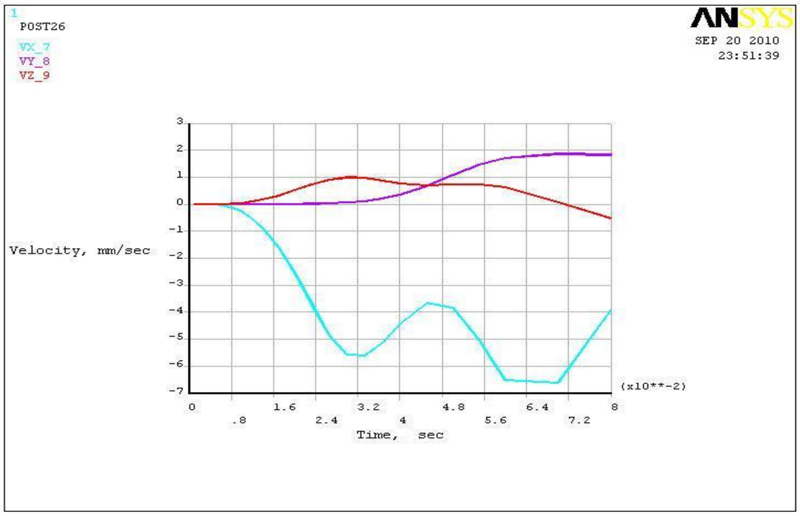


Figure 5.10 Velocity Vs Time graph for shell thickness 6mm

From the figure 5.10 the above graph is the plot of velocity vs time for 6 mm thickness where velocity is taken on y axis and time is taken on x axis in which the blue violet and red colours in the graph indicates that the change in velocity in x,y,z directions the velocity in x, directions varies from 0mm/sec to -6mm/sec,and in y direction it varies from 0mm/sec to 0.4mm/sec and in z direction the velocity varies from -0.4mm/sec to 0.7mm/sec for bumper thickness 6mm.

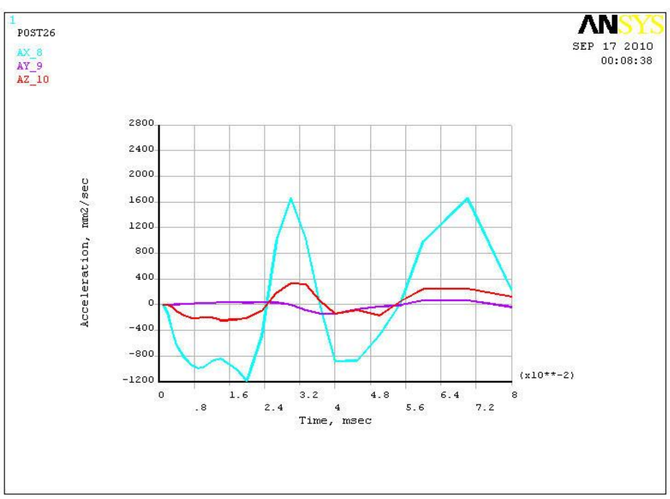


Figure 5.11 Acceleration Vs Time graph for shell thickness 3mm

From the figure 5.11 the above figure shows the plot of acceleration vs time of shell thickness 3 mm where acceleration is taken on y axis and time is taken on x axis the blue violet and red colours lines in the graph indicates that the change of acceleration with respect to time in x,y,z, directions it is observed that that acceleration of deformation of bumper in x direction varies from -1200mm/sec^2 to 1700mm/sec^2, the acceleration of deformation of bumper in y direction varies from 10mm/sec^2 to -10mm/sec^2 and in z direction it varies from -300mm/sec^2 to 300mm/sec^2 for the bumper thickness 3mm

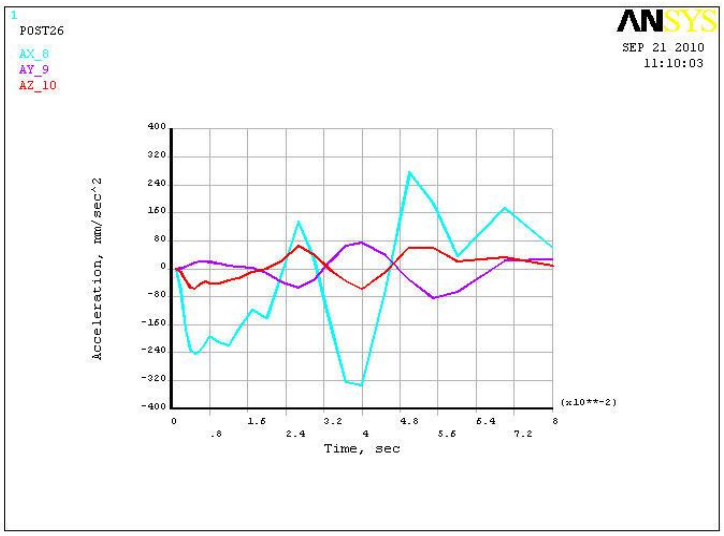


Figure 5.12 Acceleration Vs Time graph for shell thickness 6mm

From the figure 5.12 the above graph shows the plot of acceleration vs time of shell thickness 6 mm where acceleration is taken on y axis and time is taken on x axis the blue violet and red colours lines in the graph indicates that the change of acceleration with respect to time in x,y,z, directions it is observed that that acceleration of deformation of bumper in x ,y,z varies from -330mm/sec^2 to 260mm/sec^2, 80mm/sec^2 to -80mm/sec^2 and -70mm/sec^2 to 70mm/sec^2 for the bumper thickness 6mm

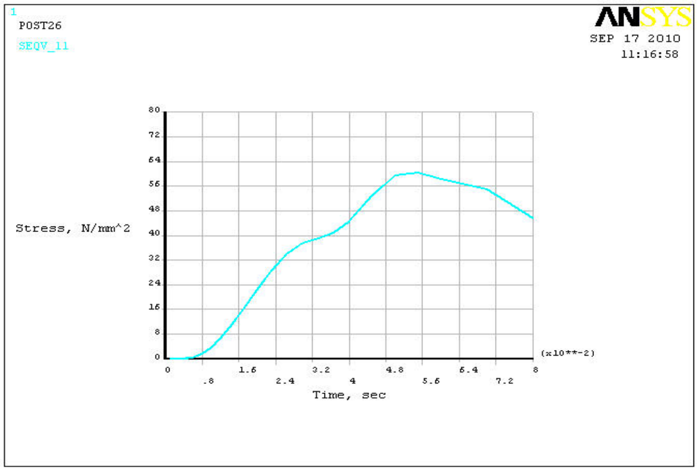


Figure 5.13 Von-mises stress Vs Time graph for shell thickness 3mm

From the figure 5.13 the above graph shows the plot of stress vs time where stress are taken on y axis and time is taken on x axis it is observed that that Von-misses stress for the model is maximum at 5msec with a value of 60N/mm^2 for the bumper thickness 3mm.

6. CONCLUSIONS AND FUTURE SCOPE OF WORK

6.1 Conclusions:

The following conclusions are drawn from the present work:

- By increasing thickness the deflections are reduced for various thickness of bumper under applied load condition, which is rigid. Hence based on the rigidity the design is safe.
- The stresses are reduced when the thickness of the bumper increases.
- The natural frequencies estimated for various thicknesses are very low as the structure is stationary.and there is no chance for the phenomena of the resonance to occur.
- When the impact takes place on the bumper, the maximum amplitude is very less as per the **Ford Motor Vehicle Design Test (FMVDT)**. Hence the bumper design is safe based on dynamic conditions.

6.2 Future Work:

The bumper of a car can be made as sandwich model or springs can be placed in the bumper in order to reduce the impact that is transferred to the passenger compartment. Analysis of these designs can be done which may yield to better safety. These designs may also reduce the weight of the bumper leading to increase fuel efficiency.

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