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# Shape And Material Optimization Of A Two Wheeler Front Suspension Frame For Pipe Type And Rectangular Cross Sections

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## ABSTRACT

The front suspension frame of a motor vehicle supports all the drive assemblies, i.e. the engine, gearbox and axles. In addition the suspension and steering systems and the shock absorbers are attached to it. The appropriate body is fixed to the chassis. It is essential that the frame should not buckle on uneven road surfaces and that any distortions which may occur should not be transmitted to the body. The frame must therefore be torsion‒resistant. The frame of a motor vehicle is the load bearing part of the chassis which supports all forces (wheel forces) and weights. It should be as rigid as possible.

The main aim of the project is to model a frame of a two wheeler using 3D modeling software Pro/Engineer. Two models of suspension frames are designed for pipe type and rectangular cross sections. Calculations are done to determine the displacement and stress by applying pressure.

To validate the strength of two models, Structural analysis is done by applying the wheels pressure. Analysis is done for frame using two materials steel and carbon epoxy to verify the best material for frame. Modal analysis is also done to determine natural frequencies of suspension frame. Comparison is done by two FEA analysis, and also we can validate the better cross section and material for suspension frame.

**Key words :** Analysis, ANSYS, Meshing, Modeling

## 1. INTRODUCTION

Whenever to build a motorcycle, the frame determines the basic look of the bike. Of course motorcycle frames affect not only the appearance of the bike but the handling and safety of the finished machine.Frames are the basic skeleton to which other components are attached. They hold the motorcycle tanks and engine and provide support to the whole bike.

Motorcycle frames are usually made from welded aluminium, steel or alloy, carbon-fibre is used in some expensive or custom frames. The purpose of a motorcycles frame is to act as
a base on which all the various components can be bolted . The engine generally sits inside the frame, the rear swingarm is attached by a pivot bolt (allowing the suspension to move) and the front forks are attached to the front of the frame. The frame can also help to protect the more sensitive parts of a motorcycle in a crash. A motorcycle frame includes the head tube that holds the front fork and allows it to pivot. Some motorcycles include the engine as a load-bearing, stressed member. The rear suspension is an integral component in the design. Traditionally frames have been steel, but titanium, aluminium, magnesium, and carbon-fibre, along with composites of these materials, have been used. Because of different motorcycles' varying needs of cost, complexity, weight distribution, stiffness, power output and speed, there is no single ideal frame design

### 1.1 Types of Suspension Frames

**Single cradle frame –** It is simples type of frame and looks like first ever motor cycle frame. It consists of smaller diameter tubes made firm steel tubes that surrounded the engine with a main tube above and other. It becomes double cradle frame at the exhaust, it is referred to as a split single cradle frame. These are usually found in off-road motor cycles.

**Double cradle frame** – These are descended from single cradle frames. In this the engine can support with two cradles on either side. Double cradle frames are commonly used in simpler road bikes and custom motor cycles. They are offer good strength, rigidity & lightness. Now, they have been technically similar by perimeter frames.

**Backbone frame –** It is most desirable frame, the engine is suspended by single, wide main beam. This frame allows great flexibility in design, because it hidden inside the finished motor cycle. The engine simply seem to long in mid air. It is simple & cheap to make, and usually found on naked and off-road motor cycle.

**Figure 1:** Backbone Frame

**Perimeter frame –** Motorcycle racing research shows that to main advantage is to gain rigidity by joining steering head to swing arm in a shortest distance as possible. Flexure and torsion are abnormally reduced, this is the main concept behind the perimeter frame. In previous days perimeter frame is made of steel, but need to improve rigidity to weight rations adopt aluminum instead. For modern super sports motor cycles are made of aluminum perimeter frame is most popular frame.

**Figure 2:** Perimeter Frame

**Monocoque frame –** These are mainly used exclusively on completion bikes and is very rarely on road bikes. It acts as a single piece unit and its functions as seat mounting, tank and tail section. Though monocque frames offerer. Good rigidity, heavy and generally not worth the effort.

**Trellis frame -** The trellis frame rivals the aluminium perimeter frame for weight & rigidity. An European & Italian manufacturers are proved that a great success in racing and competition. The principle behind the Trellis frame & perimeter frame is same, the main difference in Trellis frame is connects steering head and swing arm as directly as possible, but in case of perimeter frame connects a shortest distance as possible. This frame is made up of large no. of short steel or aluminium tubes welded together to form a trellis. The manufacturing of Trellis frame not only easy but extremely strong as well. The pictures of frame is from the Suzuki SV65OS.

**Figure 3**: Trellis Frame

## 2. LITERATURE SURVEY

The following reviews mainly focuses on replacement of steel pipe type suspension frame of two wheeler with composite suspension frame made up of carbon epoxy material and majority of the published work applies to them.

C. H. Neeraja a C. R. Sireesha and D. Jawaharlal [1] have modelled a suspension frame used in two-wheeler. Modelling is done in Pro/Engineer. They have done structural and modal analysis on suspension frame using four materials Steel, Aluminium Alloy A360, Magnesium and carbon fiber reinforced polymer to validate our design. By observing the results, for all the materials the stress values are less than their respective permissible yield stress values. So the design was safe, by conclusion.By comparing the results for four materials, stress obtained is same and displacement is less for carbon fiber reinforced polymer than other three materials. So for design considered, CFRP is better material for suspension frame. Karaoglu and Kuralay [2] investigated of truck chassis of stress analysis with riveted joints by using FEM. By observing the results, by increasing the side member thickness locally, then stresses on the side member can be reduced.

Ferreira et al Filho Et. al.[3] have investigated that dynamic and structural behavior of optimized chassis design for an off road vehicle. In December 2007 Teo Han Fui, Roslan Abd. Rahman,[4] works on the static and dynamics, structural analysis of 4.5ton truck chasis. Under static loading conditions of truck chasis determined the dynamic characteristics and local bending vibrations occurs at top crown mention where the gear box is mounted on it.O Kurdi, R Abd- Rahman, M N Tamin, [5] works on the, Stress Analysis by using FEM of heavy duty truck chasis, mainly focus on the important steps of new truck chasis is prediction of fatigue life span and durability loading of the chasis frame. Cicek Karaoglu and N. Sefa Kuralay [6] works on FEA of truck chasis. In this analysis reduce the stresses on joint areas by increasing the side member thickness, but overall weight of chasis increase. Increases the side member thickness by using local plates only in joint areas. So, the excessive weight of the chassis frame is prevented. Kutay Yilmazçoban, Yaşar Kahraman, [7] did FEA o optimization of chasis, mainly focused on reducing the weight of the chasis for using three different thickness (4mm, 5mm and 6mm), finally concluded that less thickness i.e., 4mm thickness is better because the stress and displacement are better than remaining two thickness. In June 2012 Haval Kamal Asker1, Thaker Salih Dawood1 and Arkan Fawzi, [8] stress analysis by FEA of standard truck chasis during ramping on block. Mainly focused on strength and intensity of frame play vital role of truck design. Conle and Chu [9] did research fatigue analysis of Volvo S80 Bi-fuel and local stress strain approach in complex vehicle structure.

### 2.1 Material Properties of Steel

The material properties plays a vital role the design of the product. The suspension frame steels have different nomenclatures based on different systems and is has been shown in table. The chemical composition of various elements in the existing conventional suspension frame steel (AISI 1086 / SAE 1086) has been shown in table. The mechanical properties of the existing conventional steel suspension frame material are shown in table.

**Table 1:** Composition of various elements in AISI 1086 / SAE 1086

| Grade | C % | Si% | Mn% | P% | S% |
|---|---|---|---|---|---|
| AISI 1086 / SAE 1086 | 0.86 | 0.07 | 0.45 | 0.04 | 0.05 |

**Table 2:** Material Properties of Carbon Steel AISI 1086 / SAE 1086

| Parameters | Value |
|---|---|
| Young's Modulus (E) | 205GPa |
| Poisson's Ratio | 0.29 |
| Tensile Strength( Ultimate) | 1962 MPa |
| Tensile Strength (Yield) | 1500 MPa |
| Density | 7850 kg/m$^3$ |
| Thermal Expansion | 11x10$^{-6}$ /$^0$C |

### 2.2 Material Properties of Carbon Epoxy Resin

The Mechanical Properties of Composite (Carbon Epoxy Resin) material can be taken as per Ansys Standard material library. The below mentioned composite materials are used to perform the finite element analysis and compared with the conventional steel material for better improved mass and low stress and low total deformation

**Table 3 :** Material Properties of Carbon Epoxy Resin

| Parameters | Value |
|---|---|
| Young's Modulus (E) | 134GPa |
| Poisson's Ratio | 0.33 |
| Density | 1600 kg/m$^3$ |
| Thermal Expansion | 0.1x10$^{-6}$ /$^0$C |

### 2.3 About PRO/Engineer

Customer requirements may change and time pressures may continue to mount, but your product design needs remain the same - regardless of your project's scope, you need the powerful, easy-to-use, affordable solution that Pro/ENGINEER provides. Pro ENGINEER can be packaged in different versions to suit your needs, from Pro/ENGINEER Foundation XE, to Advanced XE Package and Enterprise XE Package, Pro/ENGINEER Foundation XE Package brings together a broad base of functionality.

### 2.3 About ANSYS

ANSYS is general purpose FEA software package. FEA is a numerical method of dividing complex system in to very small pieces called elements. These elements behavior are governed by software implementation of equations and solves them all. The results of this software is in the form of tabulated or graphical forms. The problems which are too complicated i.e., they are not possible to solve by hand, those problems are designed and optimized by this analysis. Systems that may fit into this category are more complex because their geometry, scale or governing equations.

## 3. METHODOLOGY & MODELING OF SUSPENSION FRAME

In order to achieve objective of the present project, a flow chart is prepared which shows various steps involved in the analysis. The flow chart is shown in figure.

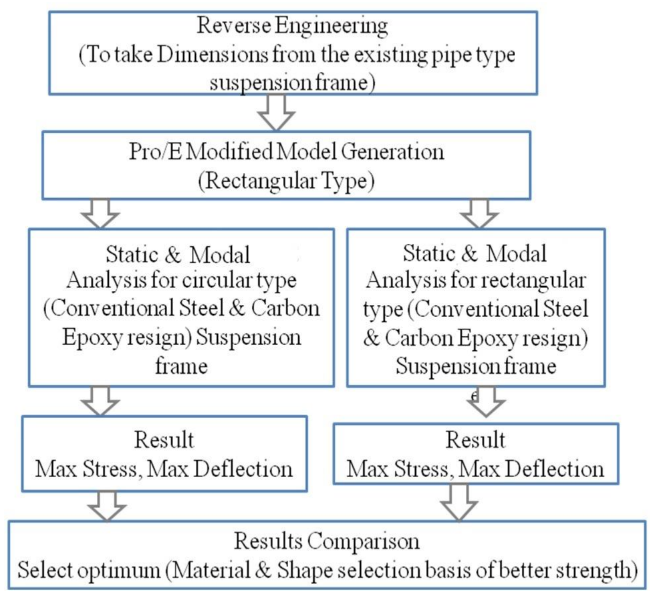


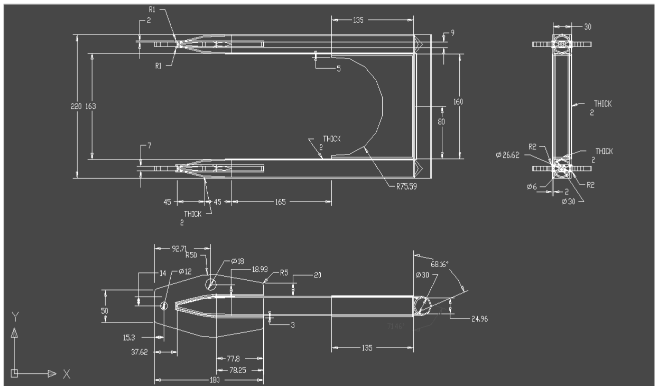

**Figure 4 :** Flow chart to achieve the object

### 3.1 Pro/E Modeling of Circular Suspension Frame

Pro/ENGINEER Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards. Integrated Pro/ENGINEER CAD/CAM/CAE solutions allow you to design faster than ever, while maximizing innovation and quality to ultimately create exceptional products.

### 3.2 2D Model of Circular Suspension Frame

open>pro/engineer>file>set working directory.
File>new file>sketch>toggle off>ok set units>mmns>ok>sketch>ok



All Dimensions are in mm

**Figure 5** : 2D Diagram of Circular Suspension Frame

### 3.1.2 3D Model of Circular Suspension Frame

open>pro/engineer>file>set working directory.
File>new file>sketch>toggle off> units>mmns>ok

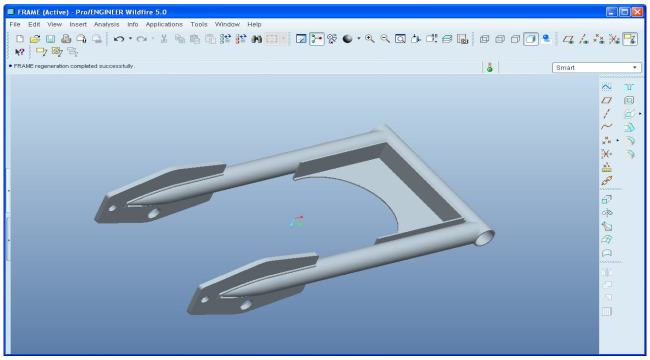
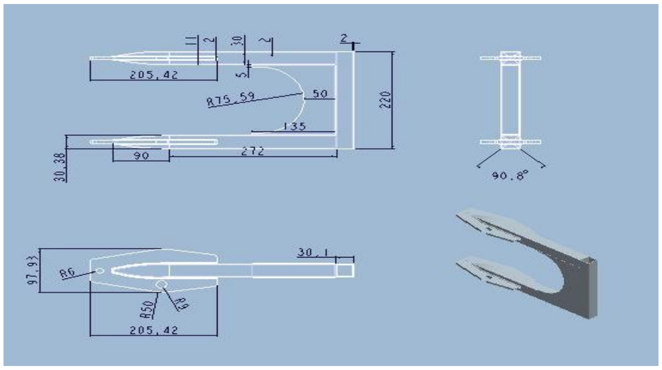


**Figure 6** : 3D Diagram of Circular Suspension Frame

### 3.2 PRO/E Modeling of Rectangular Suspension Frame

### 3.2.1 2D Model of Rectangular Suspension Frame

open>pro/engineer>file>set working directory.
File>new file>sketch>toggle off>ok set units>mmns>ok>sketch>ok




All Dimensions are in mm

**Figure 7:** 2D Diagram of Rectangular Suspension Frame

### 3.2.2 3D Model of Rectangular Suspension Frame

open>pro/engineer>file>set working directory.
File>new file>sketch>toggle off>ok set units>mmns>ok>sketch>ok

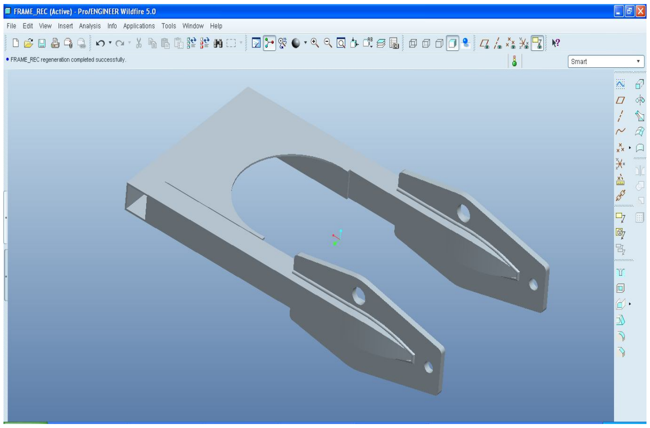


**Figure 8 :** 3D Diagram of Rectangular Suspension Frame

## 4. ANSYS ANALYSIS OF SUSPENSION FRAMES

### 4.1 Structural Analysis of Circular Suspension Frame Using Steel

This Analysis used to determine displacements, stresses, etc., under static loading conditions. ANSYS can compute both linear and non-linear static analyses. Non-Linearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces and creep.

### 4.1.1 Import Model from PRO/Engineer

The model of suspension frame is imported into ANSYS software using importing tool. The model was created in PRO/E.

file>import>iges>ok>select from iges option>select required file>ok

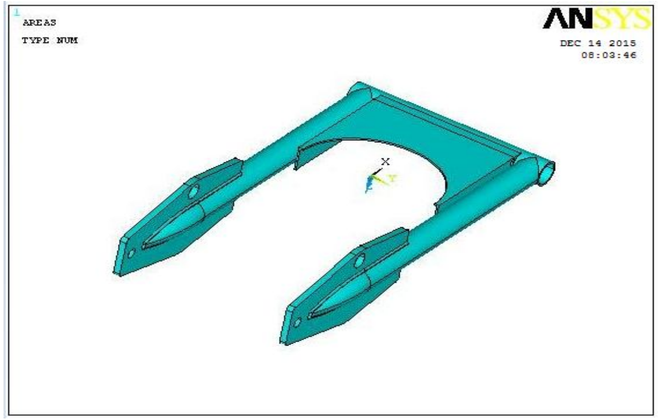



**Figure 9:** Import of Circular Suspension Frame from PRO/E

### 4.1.2 Meshed Model of Circular Suspension Frame

The below figure 10 shows the meshed PRO/E model of suspension frame. A very high mesh quality is being used in order to get more precise values.

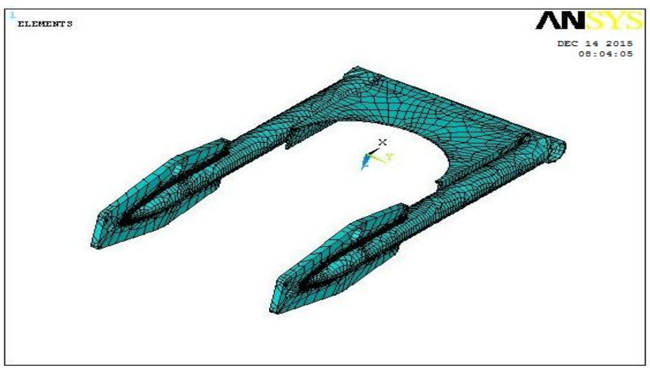



**Figure 10 :** Meshed Model of Circular Suspension Frame

### 4.1.3 Loads applied on Circular Suspension Frame

The right side end of frame fixed and the constant pressure applied of magnitude 0.32 N/mm$^2$ in the downward direction on the two legs of suspension frame.

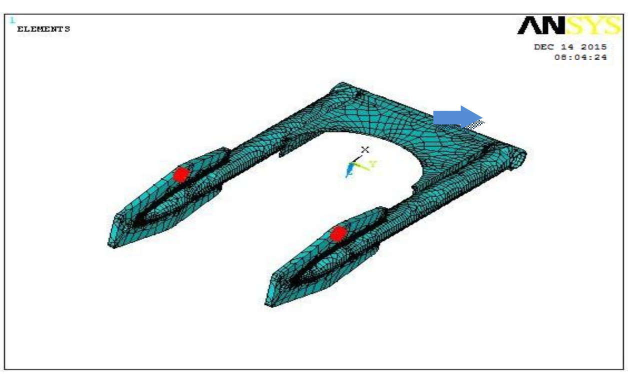



**Figure 11 :** Loads applied on Circular Suspension Frame

### 4.1.4 Total Deformation of Circular Suspension Frame

Element Type : Solid 20 node 95
Material Properties :
Young's Modulus (EX) : 205000 N/mm2
Poisson's Ratio (PRXY) : 0.29
Density : 0.00000785 kg/mm3

The figure 4.4 shows the deflection of suspension frame under the application of the pressure 0.32 N/mm$^2$ . The maximum deflection is obtained is 0.297 E-03 mm.

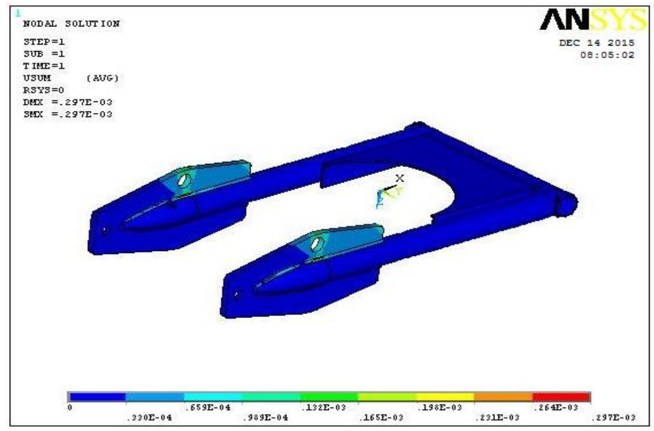



**Figure 12 :** Nodal Solution (Deflection) of Circular Frame

### 4.1.5 Normal Stress for Circular Steel Suspension Frame

General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress

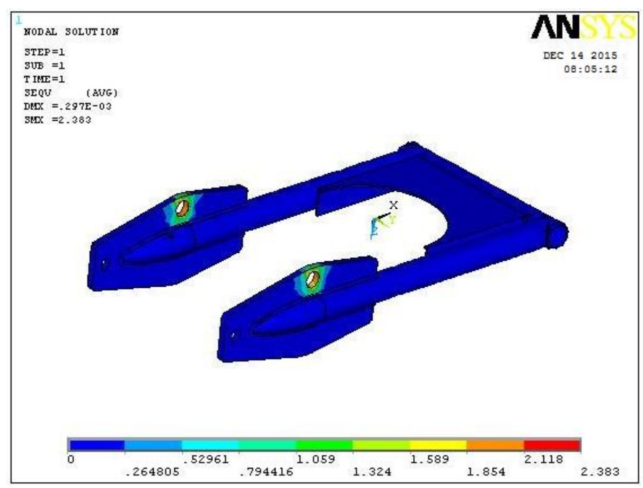



**Figure 13 :** Nodal Solution (Stress) of Circular Frame

### 4.2 Modal analysis of Circular Frame using Steel Material

Any physical system can vibrate. The frequencies at which vibration naturally occurs, and the modal shapes which the vibrating system assumes are properties of the system, and can be determined analytically using Modal Analysis.

Main menu>Preprocessor>Loads>Analysis Type>
New Analysis> Select Modal> Click> OK
Main menu>Preprocessor>Loads>Analysis Type>
Analysis Options> No. Of Modes to Extract: 5 Click> OK

Main menu>Solution>Solve>Current Ls>Ok
Main menu>General Postproc>Read Results> First Set
Plot result>Deformed Shape> Def+ Undeform > Click> OK

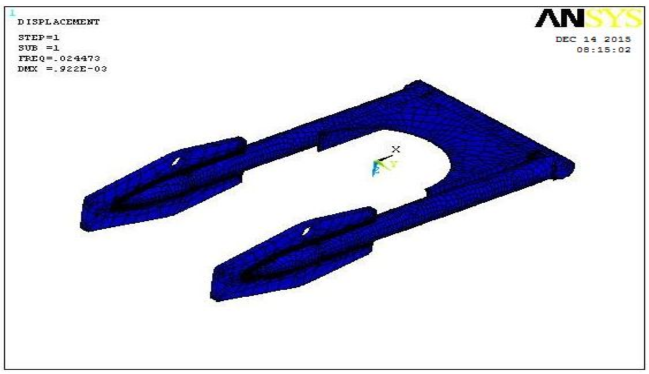



**Figure 14:** Modal analysis of Circular Suspension Frame

### 4.3 Structural Analysis of Circular Suspension Frame using Carbon Epoxy Resin

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum

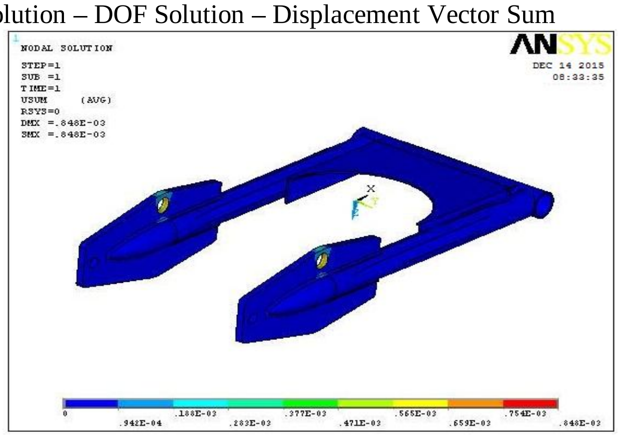



**Figure 15:** Nodal Solution (Displacement) of Circular Frame

General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress

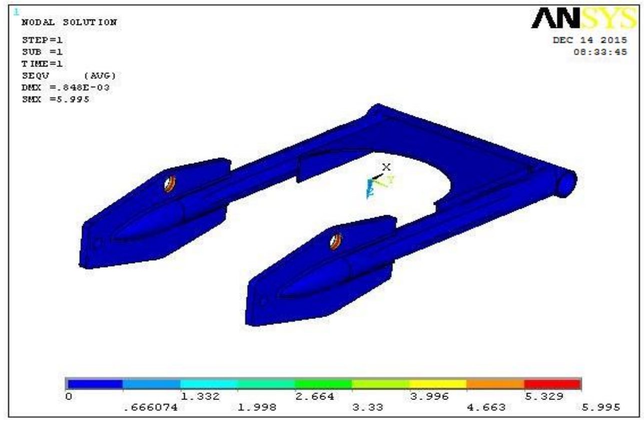



**Figure 16:** Nodal Solution (Normal Stress) of Circular

### 4.4 Modal Analysis of Circular Suspension Frame using Carbon Epoxy Resin

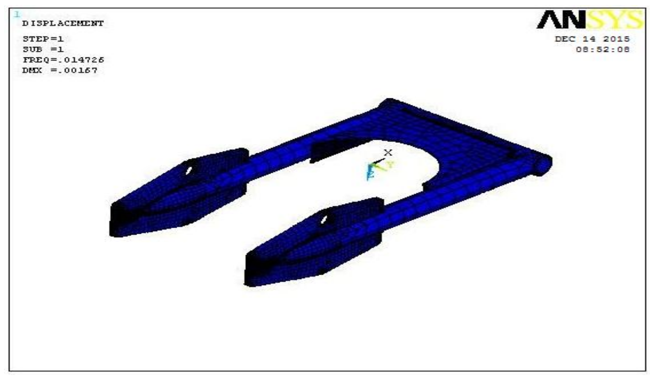



**Figure 17:** Modal analysis of Circular Suspension Frame

### 4.5 Structural Analysis of Rectangular Frame using Steel

This Analysis used to determine displacements, stresses, etc., under static loading conditions. ANSYS can compute both linear and non-linear static analyses. Non-Linearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces and creep.

#### 4.5.1 Imported Model from PRO/Engineer

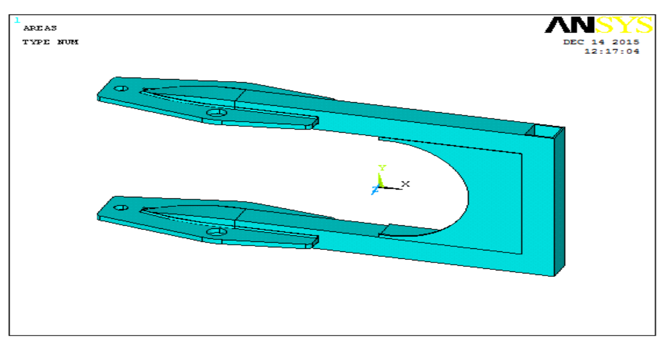



**Figure 18:** Import Model of Rectangular Frame from PRO/E

### 4.5.2 Meshed Model of Rectangular Suspension Frame

The below figure 10 shows the meshed PRO/E model of suspension frame. A very high mesh quality is being used in order to get more precise values.

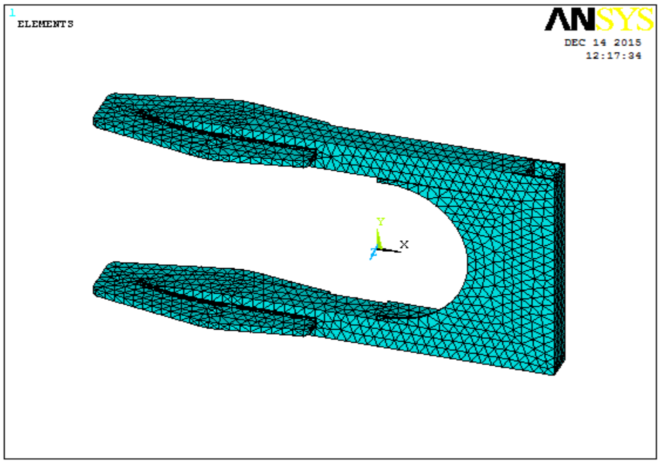



**Figure 19:** Meshed Model of Rectangular Suspension Frame

### 4.5.3 Loads applied on Rectangular Suspension Frame

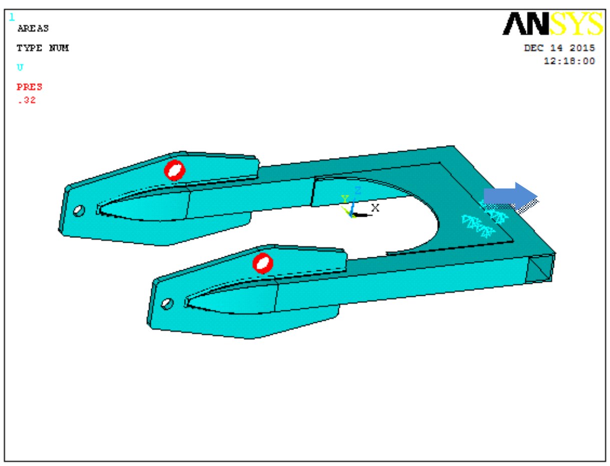



**Figure 20:** Loads applied on Rectangular Frame

### 4.5.4 Delfection and Normal Stress of Rectangular Suspension Frame for Steel:

Element Type : Solid 20 node 186
Material Properties:
Youngs Modulus (EX) : 205000N/mm$^2$
Poissons Ratio (PRXY) : 0.29
Density :0.00000785 kg/mm$^3$

**Solution**

Solution – Solve – Current LS – ok

**Post Processor**

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum

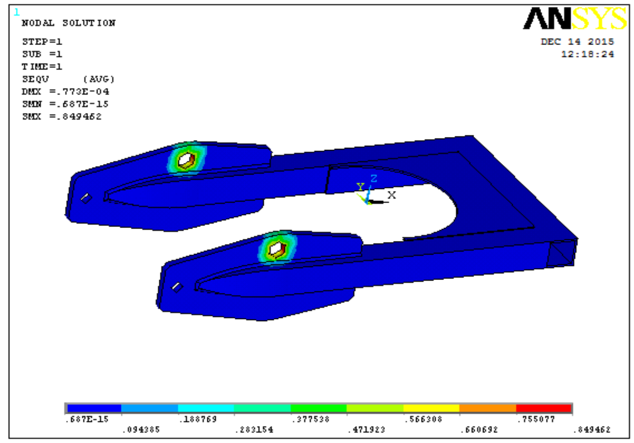



**Figure 21:** Nodal Solution (Deflection & Normal stress) of Rectangular Suspension Frame

### 4.6 Modal analysis of Rectangular Suspension Frame using Steel

Any physical system can vibrate. The frequencies at which vibration naturally occurs, and the modal shapes which the vibrating system assumes are properties of the system, and can be determined analytically using Modal Analysis.

Main menu>Preprocessor>Loads>Analysis Type>
New Analysis> Select Modal> Click> OK
Main menu>Preprocessor>Loads>Analysis Type>
Analysis Options> No. Of Modes to Extract: 5 Click> OK

Main menu>Solution>Solve>Current Ls>Ok
Main menu>General Postproc>Read Results> First Set
Plot result>Deformed Shape> Def+ Undeform > Click> OK

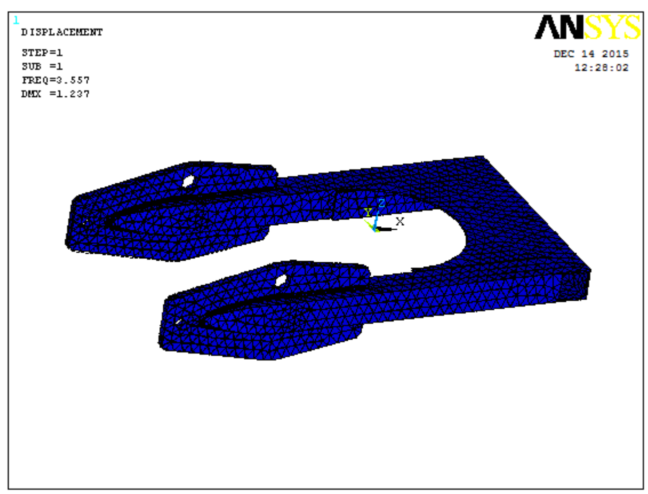



**Figure 22:** Modal analysis of Rectangular Frame

### 4.7 Structural Analysis of Rectangular Suspension Frame using Carbon Epoxy Resin

Element Type : Solid 20 node 95
Material Properties:
Youngs Modulus (EX) : 134000N/mm$^2$
Poissons Ratio (PRXY) : 0.33
Density :0.0000016 kg/mm$^3$

**Solution**

Solution – Solve – Current LS – ok

**Post Processor**

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum

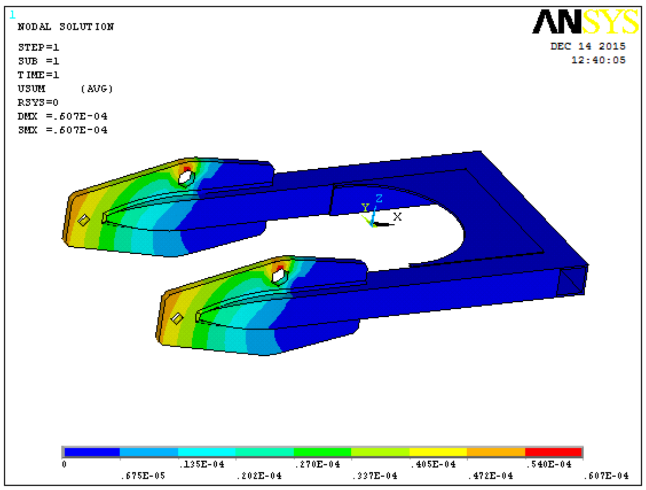



**Figure 23:** Nodal Solution (Displacement) of Rectangular Suspension frame

### 4.8 Modal Analysis of Rectangular Suspension Frame using Carbon Epoxy Resin

Main menu>Preprocessor>Loads>Analysis Type> New Analysis> Select Modal> Click> OK
Main menu>Preprocessor>Loads>Analysis Type> Analysis Options> No. Of Modes to Extract: 5
Click> OK

Main menu>Solution>Solve>Current Ls>Ok
Main menu>General Postproc>Read Results> First Set
Plot result>Deformed Shape> Def+ Undeform > Click> OK

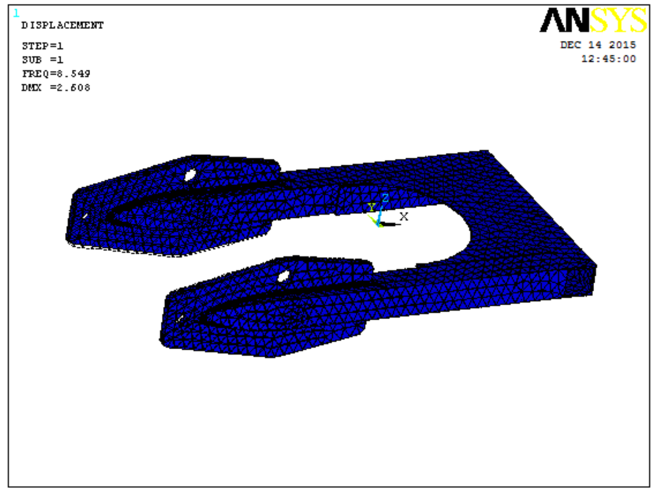



**Figure 24 : Modal Analysis of Rectangular Frame**

## 5. RESULTS TABLE

### 5.1 CIRCULAR MODEL:

**Table 4:** Structural & modal analysis results of Circular Suspension Frame using Steel

| | RESULTS | |
|---|---|---|
| DISPLACEMENT (mm) | 0.297e$^{-3}$ | |
| VONMISES STRESS (N/mm$^2$) | 2.383 | |
| | Frequency (Hz) | Displacement (mm) |
| MODE 01 | 0.024473 | 0.922 e$^{-3}$ |
| MODE 02 | 0.025756 | 0.001876 |
| MODE 03 | 0.026079 | 0.001991 |
| MODE 04 | 0.02613 | 0.925 e$^{-3}$ |
| MODE 05 | 0.032796 | 0.004175 |

**Table 5:** Structural & modal analysis results of Circular Suspension Frame using Carbon Epoxy resin

| | RESULTS | |
|---|---|---|
| DISPLACEMENT (mm) | 0.848 e$^{-3}$ | |
| VONMISES STRESS (N/mm$^2$) | 5.995 | |
| | Frequency (Hz) | Displacement (mm) |
| MODE 01 | 0.04726 | 0.00167 |
| MODE 02 | 0.014729 | 0.00167 |
| MODE 03 | 0.021785 | 0.001547 |
| MODE 04 | 0.021795 | 0.001547 |
| MODE 05 | 0.023324 | 0.002075 |

### 5.2 RECTANGULAR MODEL:

**Table 6:** Structural & modal analysis results of Rectangular Suspension Frame using Steel

| | RESULTS | |
|---|---|---|
| DISPLACEMENT (mm) | 0.723e-4 | |
| VONMISES STRESS ($N/mm^2$) | 2.383 | |
| | Frequency (Hz) | Displacement (mm) |
| MODE 01 | 3.557 | 1.237 |
| MODE 02 | 3.562 | 1.237 |
| MODE 03 | 4.583 | 1.28 |
| MODE 04 | 4.588 | 1.281 |
| MODE 05 | 20.964 | 2.206 |

**Table 7:**Structural & modal analysis results of Rectangular Suspension Frame using Carbon Epoxy resin

| | RESULTS | |
|---|---|---|
| DISPLACEMENT (mm) | 0.607 $e^{-4}$ | |
| VONMISES STRESS ($N/mm^2$) | 0.842676 | |
| | Frequency (Hz) | Displacement (mm) |
| MODE 01 | 8.549 | 2.603 |
| MODE 02 | 8.56 | 2.609 |
| MODE 03 | 11.008 | 2.709 |
| MODE 04 | 11.03 | 2.713 |
| MODE 05 | 48.927 | 4.861 |

## 6. CONCLUSION

*From the above investigation the following conclusion were made:*

In our project we have modeled a suspension frame used in two wheeler. The original cross section is circular we are changing the model to rectangular cross section. Modeling is done in Pro/Engineer.We have done Structural & Modal analysis on both models of suspension frame using materials Steel and Carbon Epoxy. After static analysis we have done modal analysis. Modal analysis is mainly used to determine the frequency of suspension frame model. Present used material for suspension frame is steel. We are replacing with Carbon Epoxy. The density of Carbon Epoxy is less than that of Steel, so the weight of the frame reduces when Carbon Epoxy is used.

By observing the results, for both the materials the stress values are less than their respective permissible yield stress values. So our design is safe. Using rectangular cross section is also safe. By comparing the results for both the cross sections, the displacement and stress values are less for rectangular cross section than circular cross section.By comparing the results for steel and carbon epoxy, the stress values are less for carbon epoxy than steel.

So we can conclude that using rectangular cross section and material Carbon Epoxy is better for suspension frame.

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