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Design and development of Effective Low weight racing bicycle frame using FEA, alternate material

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ABSTRACT

A Bi-cycle frame is prominent part in whole racing cycle system which is subjected to static and dynamic loads. The dependency of the performance is directly proportionate to weight of the cycle and frame structural design, Optimization of weight and structure of the frame is the best scope of optimizing the overall performance of the racing cycle, A monocoque design is advisable in racing utility hence we are targeting towards composite design and how its frame can be optimizes by using static and dynamic FEA Analysis. The paper deals with the performance improvement of the existing racing bicycle frame with certain design changes (trying different materials & changing structure).The parts are developed with Computer Aided Design software (CATIA) & analysis is done using Hyper mesh & ANSYS software. Aluminum alloy 6061 is used to replace the existing Mild Steel material and study the results. Analysis is done under static and dynamic load conditions. The loads studied are static start-up, static peddling, and vertical impact.

Keywords— **Racing bicycle frame, Alternate material, Static & dynamic Load conditions, Weight reduction, ANSYS.**

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I. INTRODUCTION

Most modern bicycle frames have the simple form. This shape emerged in about 1895 following several decades of vigorous development and evolution and has remained basically unchanged since that time. The need for low weight coupled with high strength and stiffness has lead to continuing trail and development of high performance material for racing bicycles. Thus in trial and error method is costly and slow, and intuition does not always yield reliable result. A promising solution is to turn a proven tool of structural engineering; the Finite Element Analysis method. The method used for modeling will be described and theoretical predictions of frame stresses will be compared with F.E.A result for some simple loading cases. This design has been the industry standard for bicycle frame design for over one hundred years. The frame consists of a top tube, down tube, head tube, seat tube, seat stays, and chain stays .The head tube of the frame holds the sheerer tube of the fork, which in turn holds the front wheel. The top tube and down tube connect the head tube to the seat tube and bottom bracket. The seat tube holds the seat post, which holds the saddle. The bottom bracket holds the cranks, which hold the pedals. The seat stays and chain stays hold the rear dropouts, which connect the rear wheel to the frame. With the abusive conditions of mountain biking, bicycle riders require frames that can withstand significant forces, and have high fatigue lives. Aluminum is the material of choice for most bicycle companies when it comes to mountain bicycle frames, with other common materials being steel, titanium and carbon fiber. Aluminum has a favorable strength to weight

Ratio and a lower cost compared to other materials used for bicycles.

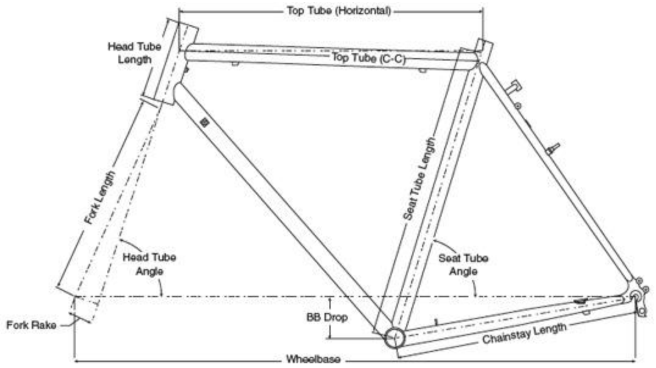

Fig.1 Components of racing bicycle frame

Head Tube:

The head tube is the part of a tubular cycle's frame that the front fork steer tube is mounted within. On a motorcycle, the "head tube" is normally called the steering head. On bicycles the manufacturer's brand located on the head tube is known as a head badge. Head tubes can use one of several size standards.

Top Tube:

The top tube, or cross-bar, connects the top of the head tube to the top of the seat tube. In a traditional-geometry diamond frame, the top tube is horizontal (parallel to the ground). In a compact-geometry frame, the top tube is normally sloped downward toward the seat tube for additional stand over clearance.

Down tube:

The down tube connects the head tube to the bottom bracket shell. On racing bicycles and some mountain and hybrid bikes, the derailleur cables run along the down tube, or inside the down tube. On older racing bicycles, the shift levers were mounted on the down tube. On newer ones, they are mounted with the brake levers on the handlebars.

Seat tube:

The seat tube contains the seat post of the bike, which connects to the saddle. The saddle height is adjustable by changing how far the seat post is inserted into the seat tube. On some bikes, this is achieved using a quick release lever. The seat post must be inserted at least a certain length; this is marked with a minimum insertion mark.

The seat tube also may have braze-on mounts for a bottle cage or front derailleur.

Chain stays:

The chain stays run parallel to the chain, connecting the bottom bracket shell to the rear fork ends or dropouts. When the rear derailleur cable is routed partially along the down tube, it is also routed along the chain stay. Chain stays may be designed using tapered or un tapered tubing. They may be relieved, oval zed, crimped, S-shaped, or elevated to allow additional clearance for the rear wheel, chain, crank arms, or the heel of the foot.

Seat stays:

The seat stays connect the top of the seat tube (often at or near the same point as the top tube) to the rear fork dropouts. A traditional frame uses a simple set of paralleled tubes connected by a bridge above the rear wheel. When the rear derailleur cable is routed partially along the top tube, it is also usually routed along the seat stay.

There are different opinions of literature review about weight reduction of frame. By referring this work include static analysis racing bicycles for weight reduction. This can be done by replacing current material (which is Mild steel) by aluminum alloy Al 6061 as well as study of different loading conditions of bicycle. The material properties of both materials are as follows:

TABLE I
COMPARISON OF MATERIAL PROPERTIES

Material	**Density**	**Modulus of Elasticity**	**Poisson's ratio**	**Yield strength**
	Tons/mm^3	**Mpa**		**Mpa**
M.S.	7.85×10^{-9}	21000	0.3	390
Al 6061	2.7×10^{-9}	69000	0.33	325

II. LITERATURE RIVEIW

Nathaniel A. Jannettiet al. [1] the tubes are then welded together to create the desired fork or frame geometry. This welding operation is done at high temperatures, which creates areas of degraded material properties called Heat Affected Zones (HAZ). The analysis and testing of these HAZs are performed in this study. Understanding of the heat affected region in welded bicycle forks and proper analysis of the dynamic loading allow for more rapid and effective part design. In addition, the increased demand for lighter bicycle components while maintaining a high level of safety requires an integrated mechanical-metallurgical analysis and validation of a given design and materials-process optimization. This paper presents a methodology for developing the necessary data to enable rapid design iteration of welded bicycle forks that meet current ASTM and CEN standards

Brent Proctor[2]The purpose of this project was to mod ify the design of the PDC DH-One bike frame, specific ally the rear end component. The original PDC was or iginally designed and tested in 2003. In the spring of 2008 the rear end of the PDC DH- One was modified without an structural analysis. This report investigates this desi gn using a finite element analysis.

M.V.Pazare [3] This paper deals with the stress analysis of bicycle frame by using Finite Element Method. The analysis is carried out in Ansys, The F.E.A. results are compared with theoretical results. In theoretical analysis the frame is treated as truss like structure and the stresses in various members of frame like top tube, down tube, seat tube, chain stay and seat stay are determined, considering various condition like, static start up, steady state paddling, vertical impact, horizontal impact, rear wheel braking. Also Finite Element Analysis is done considering the above conditions. From the analysis it is found that there is a good agreement between analytical and F.E.A. results. Result of all the cases reveals that maximum stress is found in top tube of the bicycle frame as compared to other frame members and is equal to 24.84 MPa which is less than yield strength in tension (i.e.Syt = 290 MPa)for the material (aluminum T 6061) selected.

Maestrelli and Falsini, (2008) developed a parametric model to optimize a composite frame geometry using varied frame shapes to reduce vertical stiffness and increase lateral stiffness. These authors used six load cases based on experimental loads measured in the field (Soden and Adeyefa, 1979) and the model was bounded by constraints on frame geometry imposed by professional bodies, with potential limitations to such design solutions including difficultly in manufacturing and potentially unappealing aesthetic outcomes. Other optimization algorithms have been applied to bicycle frame geometries, bearing in mind simple load cases and evolutionary optimization (Xie,1994) and as part of a process to fit the frame and key components to rider biomechanics (Xiang et al, 2011). Liu and Wu (2010) investigated the influence of fiber stacking sequence and orientation on the stress distributions on a carbon-epoxy composite frame using shell elements to simulate torsion, frontal and vertical load cases. While this study focuses on the details of the layup with the intent of identification and elimination of highly stressed regions, like all the above papers no consideration was given to the influence of key frame geometry, i.e. tube lengths and angles.

III. ANALYSIS OF EXISTING FRAME

A. Modeling:

A general-purpose commercial finite element code, Hyper Mesh and Ansys is applied to conduct the static simulations. The FEA model of bike chassis in this study is constructed based on the geometry. A full 3-D solid model is constructed for the static test simulation. The schematic of an FEA model used in static test simulations is shown in figure.

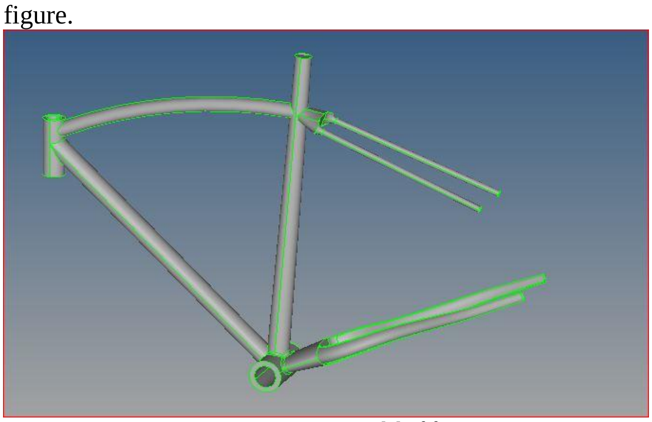

Fig.2 existing CAD model of frame

B. Loading:

Static start up: A 700N rider is applying maximum effort to accelerate from a standing stop. Aerodynamic, rolling, and gyroscopic forces are assumed negligible. The bicycle is in vertical equilibrium with the front wheel pointed straight.

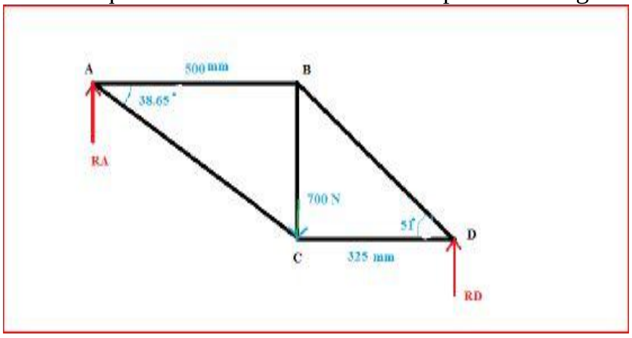

Fig.3 Static start up

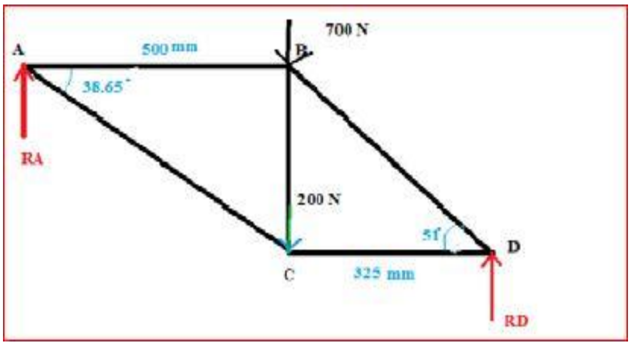

Fig.4 Static paddling

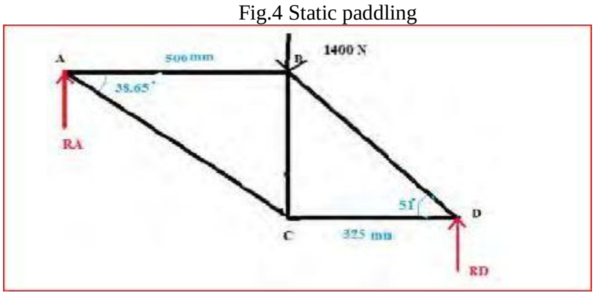

Fig.5 Vertical Impact

C. Meshing and results:

The cad model in IGES format is imported in Hyper Mesh for the preparation of FE model. Then geometry cleanup was done by using options like 'geometry cleanup' and 'defeater' to modify the geometry data and prepare it for meshing operation. This process involves deletion of curvature of very small radius (less than 2mm) which has less structural significance. Mixed type of elements which contains quadrilateral as well as triangular elements, have been used in analysis. These 2D elements are converted into 3D tetra elements. The sensitive regions have been re-meshed by manually considering the shape and size of the parts. Quality check of all the elements has been performed and mesh is accordingly optimized.

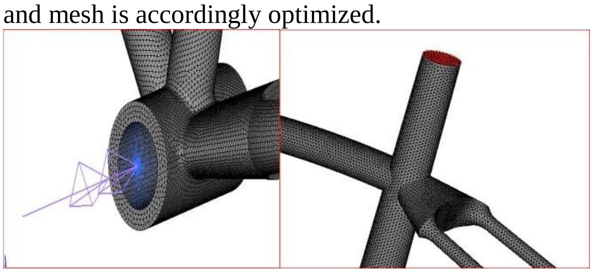

Fig.6 Meshing of model

Some default quality criteria are available in Hyper Mesh, including following:

1. Min. Side Length: Length of the smallest side of an element.
2. Max. Side Length: Length of the largest side of the element.
3. Aspect Ratio: Ratio of longest side to the shortest side of element.
4. Warpage: Deviation of an element or element face from being planar.
5. Min/Max Quad Internal Angle: The minimum/maximum angle of a quad element.
6. Min/Max Tria Internal Angle: The minimum/maximum angle of triangle element.
7. Percentage of Triangular Elements: The ratio of the number of triangular element to the total number of elements.

For quality criterion was prepared as listed in the below and it is maintained throughout the meshing process.

Quality Parameter Allowable

1. Maximum Aspect Ratio 5
2. Maximum Warpage Angle 15
3. Minimum Quads Internal Angle 45
4. Maximum Quads Internal Angle 135
5. Minimum Tria Internal Angle 15
6. Maximum Tria Internal Angle 120

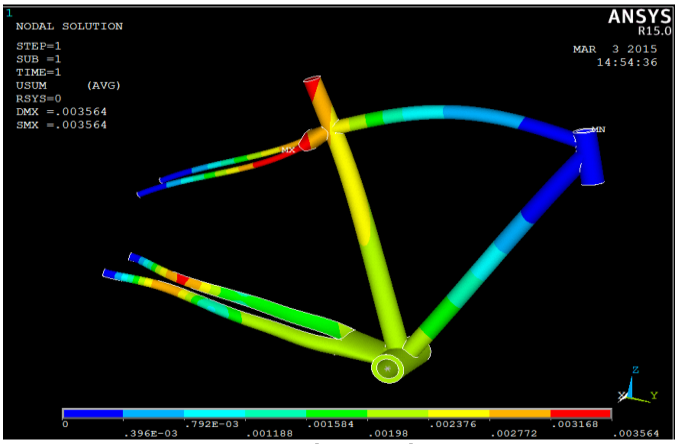

Fig.7 Displacement Plot

From figure the maximum displacement value for bicycle frame is 0.03 mm which is very less hence the design for bicycle frame is safe.

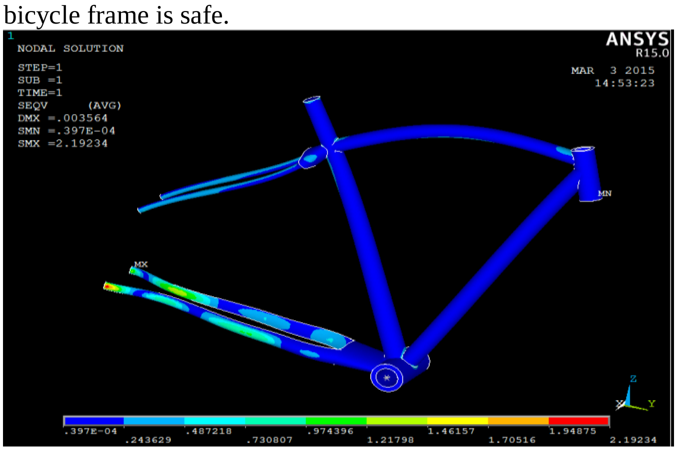

Fig.8 Stress Contour

From figure the maximum stress value for bicycle frame is 2.2 MPa which is very less hence the design for bicycle frame is safe.

IV. OPTIMIZED FRAME

Shape- and size-optimization

Shape- and size-optimizations are mainly concerned with increasing strength and _nding the best compromise between many different design parameters for a previously prescribed layout. For small, continuum structures, the main concern is reducing stress concentrations and increasing fatigue life.

Shape Optimization with regard to shape takes into consideration the specified design parameters of a model and varies these until the desired design responses and constraints are filled. This included changing fillets, chamfers, radius, material thickness, etc. The optimization algorithms will not include or remove holes, rather adjust the ones specified in the analysis.

Size Size optimization, on the other hand, will often handle issues concerning truss-like structures; bridges, support bars, space frames, etc. If having no lower limit of a member cross section area, the optimization can fully remove a nonsupporting member if its radius or height is included in the parameters available for variation. If all possible combinations of connections between specified connection nodes have been modeled and parameterized, size optimization can be seen as a simplified approach to topology optimization.

Sizing optimization is also concerned with changing the thickness of plates in sheet metal constructions, in order to find the optimum solution with regard to weight, stress, displacements, etc. Used solely to change the thickness of distinct plates or members, size optimization can be seen as a somewhat simplified type of topometry optimization.

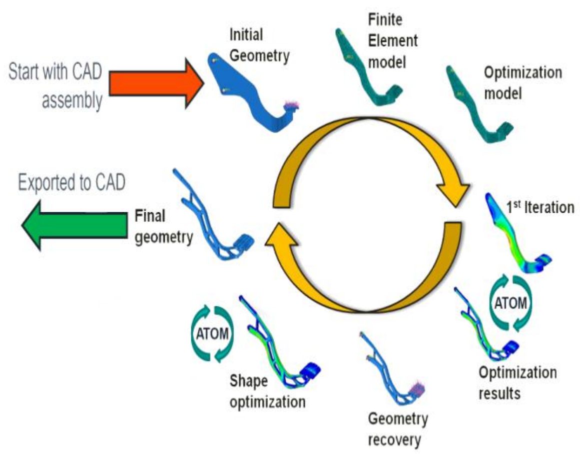

Fig.9 Topology Optimization Results-

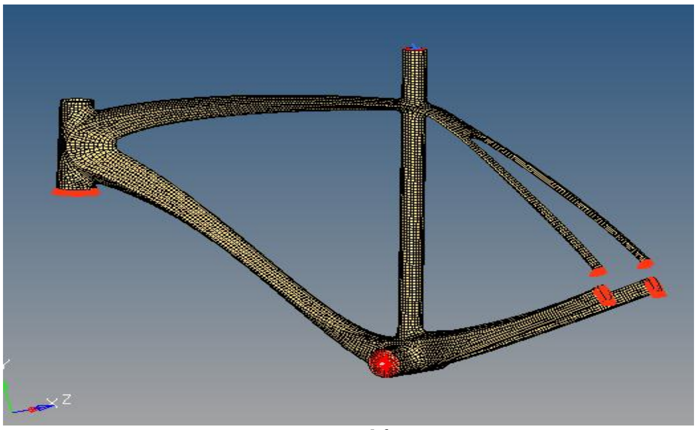

Fig.10 Optimized frame

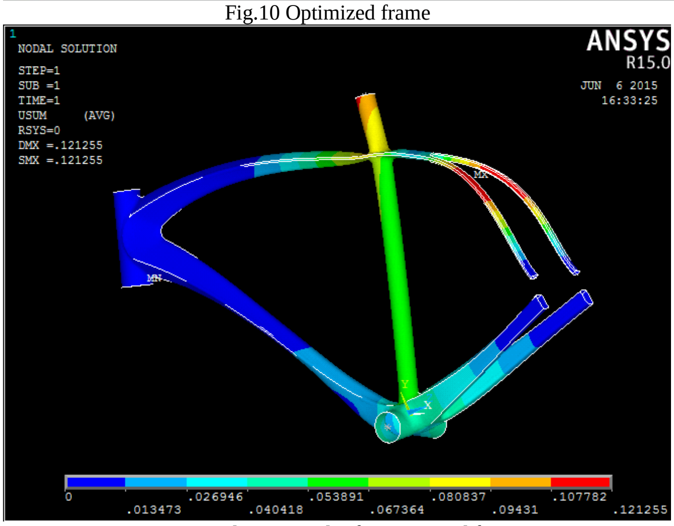

Fig.11 Displacement plot for optimized frame

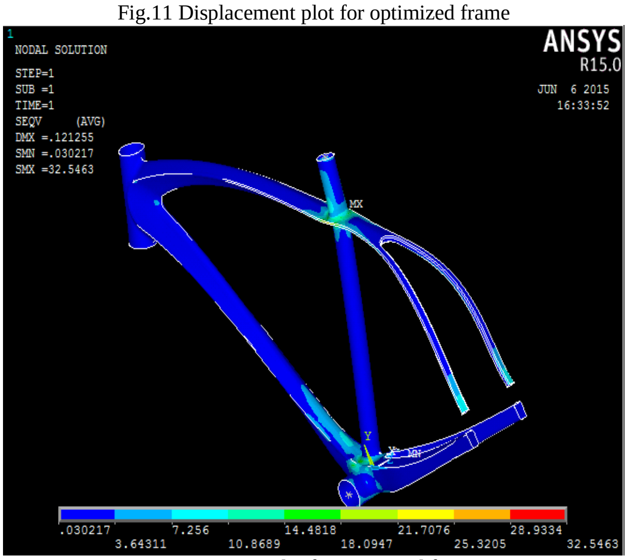

Fig.12: Stress plot for optimized frame

from above figures, the maximum deformation and the stress values are 0.12mm and 32.5 MPa respectively which is within safety limit hence the optimized bicycle frame is safe.

V. EXPERIMENTATION RESULTS

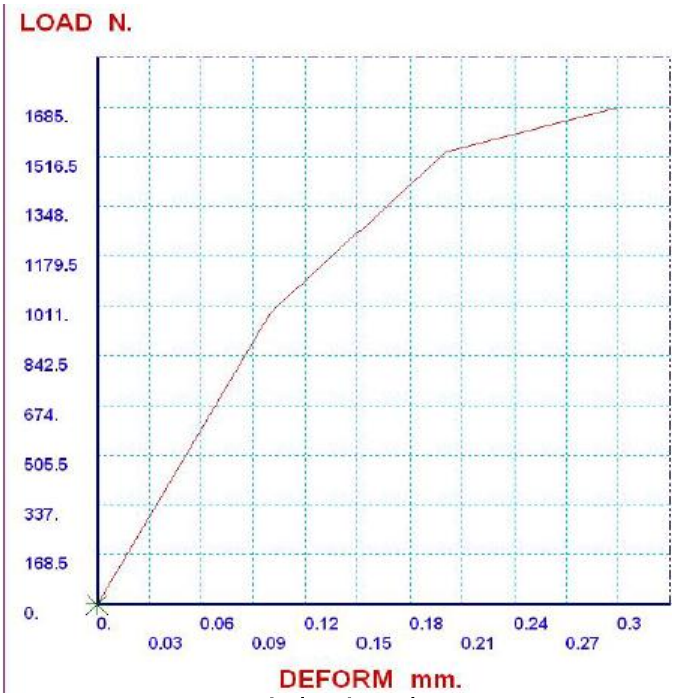

Fig.13: Graph of Load vs Deformation

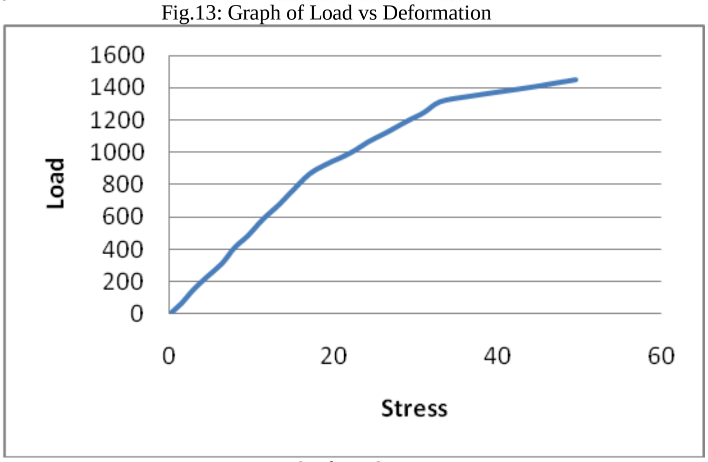

Fig.14: Graph of Load vs Stress

VI. CONCLUSION

Looking at the FEA results, it is observed that the stress distribution is not truly uniform across the cross section of the tube. This invalidates our truss analysis since two-force members can only have uniform stress across the cross section of the component.

The good agreement is found with FEA results. Results of all case reveals that the maximum stresses in the member of bicycle frame in top tube is 23.94 MPa which is less than yield strength in tension i.e.(Syt = 450 MPa) for the material selected.

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