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"SIMULATION OF MOUNTAIN BIKE FRAME USING FEM"

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ABSTRACT

Bikes keep on being the primary method of transport for the low and center salary families. This is on the grounds that the bike is both condition and individuals inviting. India is the biggest maker of bikes next just to China. It creates around 1.26 crore bikes each year. Considering the rising energizes cost and contamination, the bicycles are viewed as perfect. These can be kept up at low expenses. Since their commencement bikes have given society a wellspring of transportation, exercise, entertainment and game. New bike outlines are commonly persuaded by weight or potentially firmness contemplations and regularly fuse the utilization of superior designing materials. To be sure, aggressive bicycling has advanced the utilization of different progressed basic materials including non-ferrous amalgams (for example principally aluminum and titanium) and fortified polymers (for example carbon and graphite fortified epoxies). Both the edge structure and the material add to rider's vitality utilization. Vitality is exhausted for drive and versatile distortion of the casing. Along these lines a minimization of casing's all out mass and diversion are basic.

Most current bike outlines have basic structure for example jewel molded casing (Figure 2). It was in 1895 after a few remained essentially unaltered since that time. The requirement for low weight combined with high quality and solidness has prompted proceeding with trail and advancement of elite materials for dashing bikes The answer for the relating issue is to change to the most dependable and a demonstrated apparatus of basic building; the Finite Element Analysis Method (FEA).

Keyword: *Mountain bike frame, Finite element analysis, Frame building material tube geometry.*

I. INTRODUCTION

The demonstrating for the casing began with advancement of a few ideas for the exhibition of the edge. When an idea was chosen and sketch explicit structures that would use the idea settled on already. A precious stone casing was chosen to be structured as it was the most essential casing to be investigated. For that a jewel surrounded bike model from a standard bike size geometry diagram (Table 1) was chosen. From that a size for an individual with a tallness of 5 feet 10.75 inches an edge was developed. The chart variation of the frame size with height of the rider is as follows:
Here,
C-t = This refers to the length of the seat tube, from the base to the top.
C-c =This is similar to the c-t measurement except the top of the seat tube is defined by the in the intersection of the center of the top tube and center of the seat tube.

Table 1: Standard bicycle size geometry chart

Inseam (In.)	Height	Shoe size	Frame size cm (c-t)	Top tube cm (c-t)
36	6'4"	11.5	62	59
35.5	6'2.5"	11	61	58
34.75	6'1"	10.5	60	57.5
34.25	6'0"	10.5	59	57
33.75	5'10.75"	10	58	56.5
33	5'9.5"	9.5	57	56
32.5	5'8.75"	9	56	55.5
32	5'8"	9	55	55
31.25	5'7"	8.5	54	54.5
30.75	5'6"	8	53	54
30	5'5'	7.5	52	53
29.5	5'4.5"	7	51	52
29	5'4"	7	50	51
28.5	5'3"	6	49	51

Figure 1: Tubing diagram of the bike frame

II. REVIEW OF FRAME BUILDING MATERIAL

There are a wide variety of materials used in bicycle frames. Bike frames were originally made from wood, but modern frames are made primarily from aluminum, steel, titanium and carbon fiber. Some of the less common materials used in creating frames include bamboo, thermoplastics and magnesium. The materials used in analysis are namely:

1. Aluminum 6061-T6.
2. Aluminum 7005-T6.

The materials used for mountain bicycle frames have a wide range of mechanical properties. These properties can be seen in Table 2.

Table 2: Mechanical properties of common bicycle frame materials

Alloy	Density (g/cc)	Modulus of Elasticity (GPa)	Poisson's Ratio	Ultimate Tensile Strength (MPa)	Tensile Yield Strength (MPa)	Shear Modulus (GPa)
Aluminum 6061-T6	2.7	68.9	0.33	310	276	26
Aluminum 7005-T6	2.78	71	0.32	370	317	27

Table 3: Properties of frame materials

Alloys	Weldability and Machinability	Cost per kg (US $)
Aluminum 6061-T6	Excellent	2.42
Aluminum 7005-T6	Excellent	2.87

Tube Geometry

Frame geometry dimensions were taken from the standard mountain bike frame to characterize the overall tube layout geometry. The dimensions taken are standard dimensions used to characterize the geometry of the frame. These dimensions can be seen in Table 4.

Table 4: Geometry values for the solid model of the bicycle frame

PARAMETER	VALUE
Head tube angle	73.5^0
Seat tube angle	73.5^0
Seat tube length	580 mm
Top tube length	570 mm
Chain stay length	360 mm
Head tube length	120 mm

Theoretical analysis of bike frames

The modeled bicycle frame is made to apply with following load cases as a part of the investigation of the frame. The load cases are applied on all the 5 frames individually. The load cases are namely:

1) Static start up.
2) Steady state pedaling.
3) Vertical impact.
4) Horizontal impact.
5) Rear wheel braking.

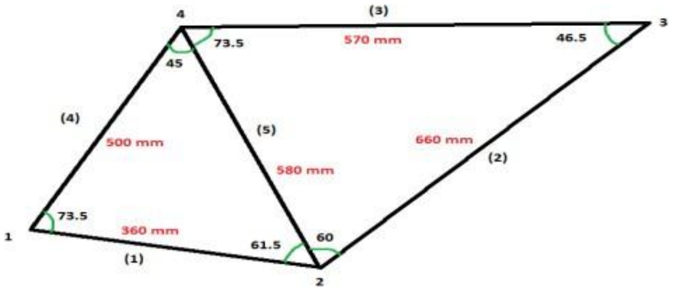

Figure 2: Bike frame truss

Finite element analysis of Mountain bike frame using ANSYS

To verify the analytical result of stresses for bicycle frame it is compared with FEA analysis. The problem to be modeled is a simple bicycle frame shown in the following figure 9. The frame is to be built of 2 different alloys (Table1).

Figure 3: Bike frame with meshing of 5mm

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III. RESULTS AND DISCUSSIONS

Theoretical stresses on members

As there are 2 different alloys, so we have to make 2 different tables in order to present the resultant stress in different loading cases for all alloys.

1. **Aluminum 6061-T6**

Table 5: Theoretical comparison of stresses on members

Load case	**Normal Stresses (x-axis) in members (MPa)**				
	Top tube (AB)	**Down tube (AD)**	**Seat tube (BD)**	**Seat stays (BC)**	**Chain stays (CD)**
Static start up	2.95	0.86	5.83	2.89	0.71
Steady state pedaling	3.29	0.99	7.2	1.51	0.81
Vertical impact	6.23	1.31	11.87	-0.48	1.53
Horizontal impact	7.88	7.01	0	0	0
Rear wheel braking	0	0	0	12.76	17.23

2. **Aluminum 7005-T6**

Table 6: Theoretical comparison of stresses on members

Load case	**Normal Stresses (x-axis) in members (MPa)**				
	Top tube (AB)	**Down tube (AD)**	**Seat tube (BD)**	**Seat stays (BC)**	**Chain stays (CD)**
Static start up	5.13	0.18	7.93	3.13	0.08
Steady state pedaling	6.43	0.53	9.01	4.53	2.56
Vertical impact	10.68	2.25	15.67	7.63	2.87
Horizontal impact	6.94	6.77	0	0	0
Rear wheel braking	0	0	0	12.13	16.71

Finite element analysis results by ANSYS

1. Aluminum 6061-T

Table 7: Comparison of stresses on members

Load case	**Normal Stresses (x-axis) in members (MPa)**				
	Top tube (AB)	**Down tube (AD)**	**Seat tube (BD)**	**Seat stays (BC)**	**Chain stays (CD)**
Static start up	**3.29**	**0.92**	**5.66**	**3.296**	**0.92**
Steadystate pedaling	**3.76**	**1.097**	**6.4**	**1.095**	**1.003**
Vertical impact	**6.6**	**1.86**	**11.32**	**-0.51**	**1.86**
Horizontal impact	**8.17**	**6.3**	**0**	**0**	**0**
Rear wheel braking	**0**	**0**	**0**	**13.11**	**17.5**

Figure 4: Static start up

Figure 5: Steady state pedaling

Figure 6: Vertical impact

Figure 7: Horizontal impact

Figure 8: Rear wheel braking

2. Aluminum 7005-T6

Table 8: Comparison of stresses on members

Load case	**Normal Stresses (x-axis) in members (MPa)**				
	Top tube (AB)	**Down tube (AD)**	**Seat tube (BD)**	**Seat stays (BC)**	**Chain stays (CD)**
Static start up	5.58	0.23	7.56	3.6	0.13
Steady state pedaling	6.57	0.56	8.77	4.37	3.9
Vertical impact	11.16	2.54	15.13	7.2	3.24
Horizontal impact	7.08	6.23	0	0	0
Rear wheel braking	0	0	0	12.64	16.87

Figure 9: Static start up

Figure 10: Steady state pedaling

Figure 11: Vertical impact

Figure 12: Horizontal impact

Figure 13: Rear wheel braking

IV. COMPARISON OF STRESS ON MEMBERS BY THEORETICAL AND F.E.A.

Aluminum 6061-T

a) **Static start up:**

Table9: Comparison of stresses on members, Static start up

	TOP TUBE	DOWN TUBE	SEAT TUBE	SEAT STAYS	CHAIN STAYS
STATIC START UP (ANALYTICAL)	2.95	0.85	5.83	2.89	0.712
STATIC START UP (FEA)	3.29	0.92	5.66	3.29	0.92
% DIFFERENCE	10.33	7.6	3	12.15	22.6

b) Steady state pedaling:

Table 10: Comparison of stresses on members, Steady state pedaling

	TOP TUBE	DOWN TUBE	SEAT TUBE	SEAT STAYS	CHAIN STAYS
STEADY STATE PEDALING (ANALYTICAL)	3.29	0.99	7.2	1.51	0.81
STEADY STATE PEDALING (FEA)	3.76	1.09	6.4	1.37	1
% DIFFERENCE	12.5	9.1	12.5	10.2	19

c) Vertical impact:

Table 11: Comparison of stresses on members, Vertical impact

	TOP TUBE	**DOWN TUBE**	**SEAT TUBE**	**SEAT STAYS**	**CHAIN STAYS**
VERTICAL IMPACT (ANALYTICAL)	6.23	1.31	11.87	-0.48	1.53
VERTICAL IMPACT (FEA)	6.6	1.86	11.32	-0.51	1.86
% DIFFERENCE	5.6	29.56	4.85	5.88	17.74

d) Horizontal Impact:

Table 12: Comparison of stresses on members, Horizontal impact

	TOP TUBE	**DOWN TUBE**	**SEAT TUBE**	**SEAT STAYS**	**CHAIN STAYS**
HORIZONTAL IMPACT (ANALYTICAL)	7.88	7.01	0	0	0
HORIZONTAL IMPACT (FEA)	8.17	6.3	0	0	0
% DIFFERENCE	3.54	11.26	0	0	0

e) Rear wheel braking:

Table 13: Comparison of stresses on members, Rear wheel braking

	TOP TUBE	**DOWN TUBE**	**SEAT TUBE**	**SEAT STAYS**	**CHAIN STAYS**
REAR WHEEL BRAKING (ANALYTICAL)	0	0	0	12.76	17.23
REAR WHEEL BRAKING (FEA)	0	0	0	13.11	17.5
% DIFFERENCE	0	0	0	2.66	1.54

Aluminum 7005-T

a) Static start up:

Table 14: Comparison of stresses on members, Static start up

	TOP TUBE	**DOWN TUBE**	**SEAT TUBE**	**SEAT STAYS**	**CHAIN STAYS**
STATIC START UP (ANALYTICAL)	5.13	0.18	7.93	3.13	0.11
STATIC START UP (FEA)	5.58	0.23	7.56	3.6	0.13
% DIFFERENCE	8.06	21.73	4.89	13.05	15.38

b) Steady state pedaling:

Table 15: Comparison of stresses on members, Steady state pedaling

	TOP TUBE	DOWN TUBE	SEAT TUBE	SEAT STAYS	CHAIN STAYS
STEADY STATE PEDALING (ANALYTICAL)	6.43	0.53	9.01	4.53	3.56
STEADY STATE PEDALING (FEA)	6.57	0.56	8.77	4.37	3.9
% DIFFERENCE	2.13	5.35	2.73	3.66	8.71

c) Vertical impact:

Table 16: Comparison of stresses on members, Vertical impact

	TOP TUBE	DOWN TUBE	SEAT TUBE	SEAT STAYS	CHAIN STAYS
VERTICAL IMPACT (ANALYTICAL)	10.68	2.25	15.67	7.63	2.87
VERTICAL IMPACT (FEA)	11.16	2.54	15.13	7.2	3.24
% DIFFERENCE	4.31	11.41	3.56	5.97	11.41

d) Horizontal impact:

Table 17: Comparison of stresses on members, Horizontal impact

	TOP TUBE	DOWN TUBE	SEAT TUBE	SEAT STAYS	CHAIN STAYS
HORIZONTAL IMPACT (ANALYTICAL)	6.94	6.77	0	0	0
HORIZONTAL IMPACT (FEA)	7.08	6.23	0	0	0
% DIFFERENCE	1.97	8.66	0	0	0

e) Rear wheel braking:

Table 18: Comparison of stresses on members, Rear wheel braking

	TOP TUBE	DOWN TUBE	SEAT TUBE	SEAT STAYS	CHAIN STAYS
REAR WHEEL BRAKING (ANALYTICAL)	0	0	0	12.13	16.71
REAR WHEEL BRAKING (FEA)	0	0	0	12.64	16.87
% DIFFERENCE	0	0	0	4.03	0.94

Equivalent (von–mises) stress analysis for bike frames
Aluminum 6061-T

Figure 14: Equivalent stress, Static start up

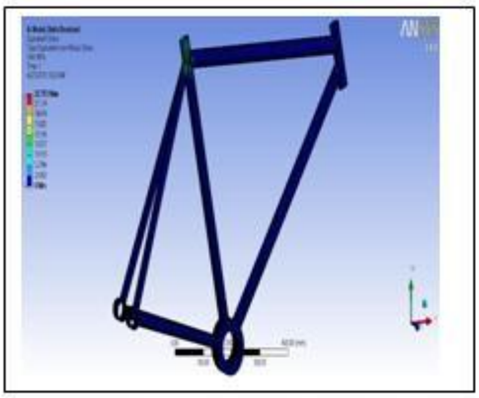


Figure 15: Equivalent stress, Steady state pedaling

Figure 16: Equivalent stress, Vertical impact

Figure 17: Equivalent stress, Horizontal impact

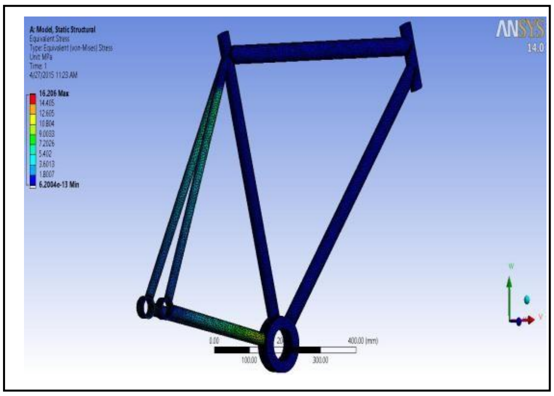


Figure 18: Equivalent stress, Rear wheel braking

Table 19: Comparison of equivalent stresses on members

Load case	Equivalent (von-Mises) Stress in members (MPa)				
	Top tube (AB)	Down tube (AD)	Seat tube (BD)	Seat stays (BC)	Chain stays (CD)
Static start up	20.66	0	23.25	18.08	0
Steady state pedaling	21.11	0	23.75	18.47	0
Vertical impact	41.33	0	46.5	36.16	0
Horizontal impact	28.96	25.75	0	0	0
Rear wheel braking	0	0	0	14.4	16.2

Figure 19: Equivalent stress, Static start up

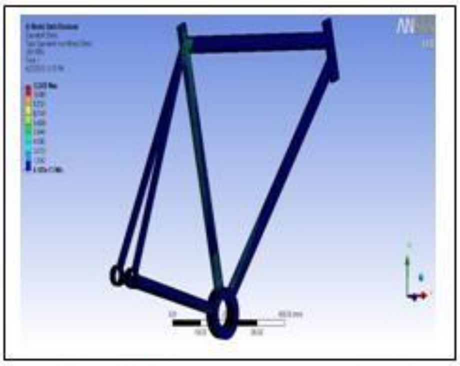


Figure 20: Equivalent stress, Steady state pedaling

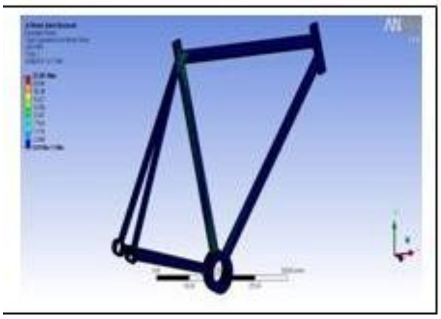


Figure 21: Equivalent stress, Vertical impact

Figure 22: Equivalent stress, Horizontal impact

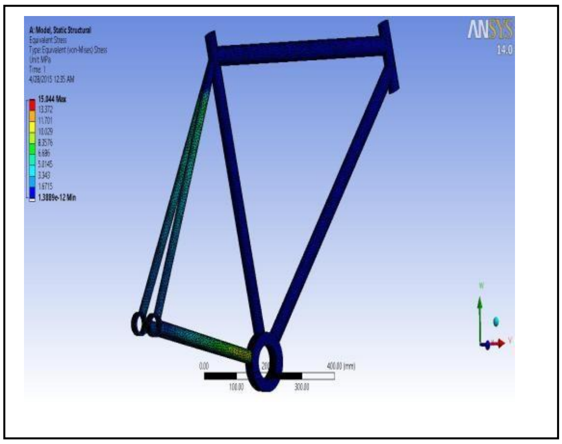


Figure 23: Equivalent stress, Rear wheel braking

Table 20: Comparison of equivalent stresses on members

Load case	Equivalent (von-Mises) Stress in members (MPa)				
	Top tube (AB)	**Down tube (AD)**	**Seat tube (BD)**	**Seat stays (BC)**	**Chain stays (CD)**
Static start up	10.34	0	11.64	9.05	0
Steady state pedaling	10.68	5.34	12.02	9.35	4.01
Vertical impact	20.69	12.93	23.28	18.1	2.58
Horizontal impact	32.42	28.81	0	0	0
Rear wheel braking	0	0	0	13.37	15.04

Comparison Of Maximum Stress Obtained For Different Cases

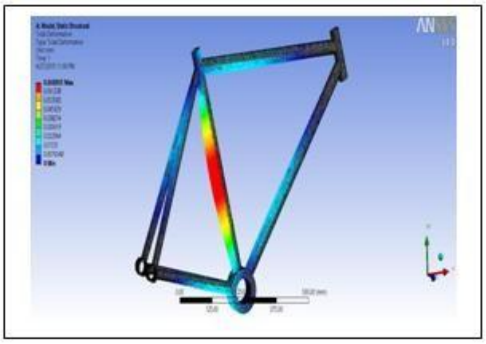
The maximum values of stresses obtained for the different loading cases for different alloys are compared in order to ascertain the properties of material alloy to take the impact of the loading (Table 20).

Table 21: Comparison of maximum stress (MPa) obtained for different cases

ALLOYS	Maximum stress obtained for different cases (Mpa)				
	Static start up	**Steady state pedaling**	**Vertical impact**	**Horizontal impact**	**Rear wheel braking**
Aluminum 6061-T	23.25	23.75	46.5	28.96	16.2
Aluminum 7005-T	11.64	12.02	23.28	32.42	15.04

Comparison Of Maximum Deformation Obtained For Different Cases

The maximum values of deformation obtained for the different loading cases for different alloys are compared in order to ascertain the properties of material alloy to take the impact of the loading. (Table 21).



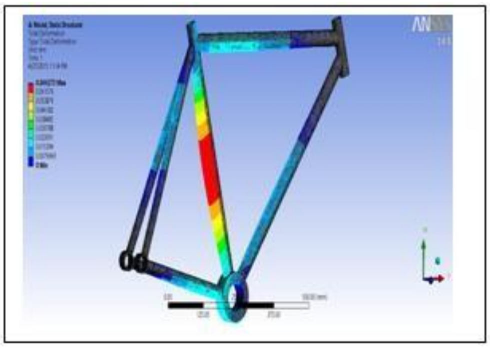


Figure 24: Static start up (maximum deformation) **Figure 25:** Steady state pedaling (maximum deformation)

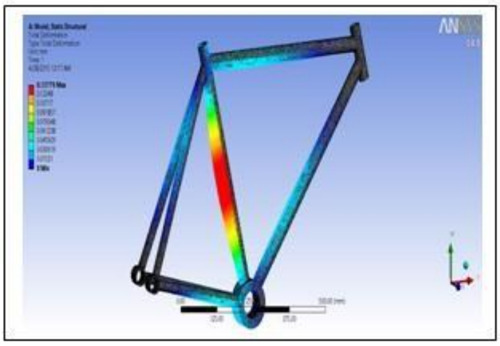


Figure 26: Vertical impact (maximum deformation) **Figure 27:** Horizontal impact (maximum deformation)

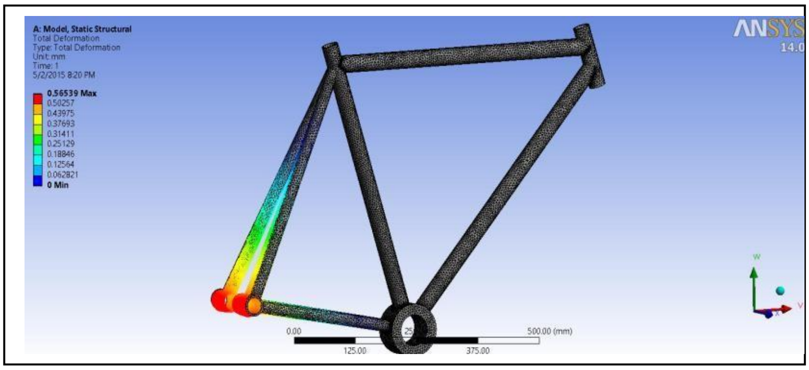


Figure 28: Rear wheel braking (maximum deformation), Aluminum 6061-T

Table 22: Comparison of maximum deformation (mm) obtained for different cases

	Maximum deformation obtained for different cases (mm)				
ALLOYS	**Static start up**	**Steady state pedaling**	**Vertical impact**	**Horizontal impact**	**Rear wheel braking**
Aluminum 6061-T	0.023	0.024	0.047	0.049	0.56
Aluminum 7005-T	0.068	0.069	0.137	0.05	0.54

- Aluminum 7005-T happens to be the most deformed alloy with a deformation of 0.068, 0.069, 0.137 and 0.05 mm for static start up, steady state pedaling, vertical impact and horizontal impact loading cases respectively.
- Aluminum 6061-T is the most deformed alloy for rear wheel braking loading case with a deformation of 0.56 mm.

Factor Of Safety

Factor of safety decides the structural capacity of a system beyond the expected loads or actual loads. Factor of safety is decided by the minimum value for any case of a particular alloy. The more the factor of safety the more is the chance of material alloy to bear the loading case.

Factor of Safety = Material Strength / Design Load

Table 23: Factor of safety for different loading cases

ALLOYS	Factor of safety obtained for different cases				
	Static start up	**Steady state pedaling**	**Vertical impact**	**Horizontal impact**	**Rear wheel braking**
Aluminum 6061-T	11.87	11.62	5.93	9.52	15
Aluminum 7005-T	15	15	14.5	9.77	15

The least factor of safety of 5.93 is for Aluminum 6061-T frame on the vertical impact loading case. The highest factor of safety happens to be for Titanium-6Al-4V frame where for each case it is 15. Here for all alloys the factor of safety happens to be above 2 which is a safe case for any designed model. It means that all the alloys can withstand the applied loads without any failure. Besides from Table 77 the increasing order of safety factor for alloys can be as follows: ***Aluminum 6061-T < Aluminum 7005-T***

IV. V. MODAL ANALYSIS

Vibration analysis is made to be performed on all the 5 material alloy frames. No boundary condition is applied on the bike frames. Seat tube is supported so as to make the bike frames stable for the vibration test. When the simulation has finished the mode shapes are made visible

Aluminum 6061-T

Figure 29: Mode 1, 235.78 Hz

Figure 30: Mode 2, 255.27 Hz

Figure 31: Mode 3, 301.66 Hz

Figure 32: Mode 4, 324.36 Hz

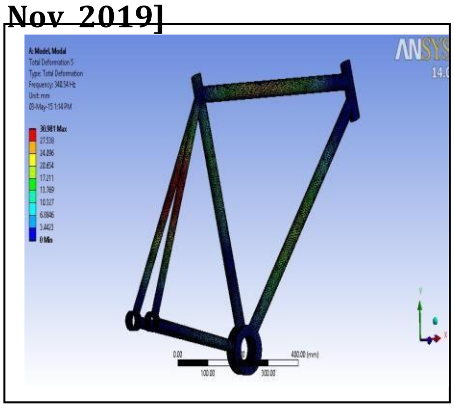


Figure 33: Mode 5, 340.54 Hz

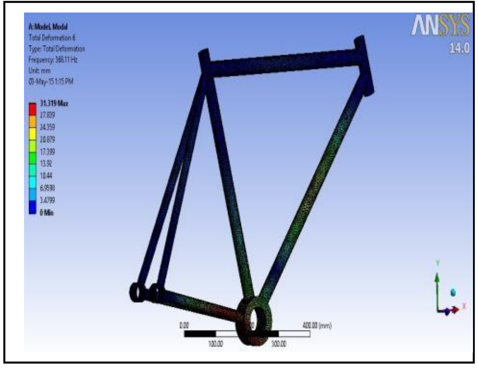


Figure 34: Mode 6, 368.11 Hz

Figure 35: Mode 1, 235.86 Hz

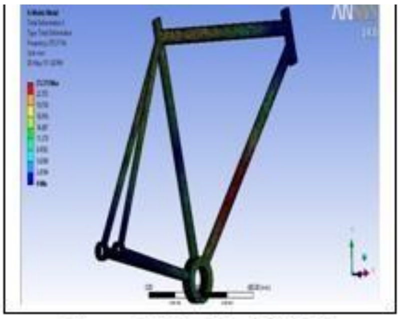


Figure 36: Mode 2, 255.37 Hz

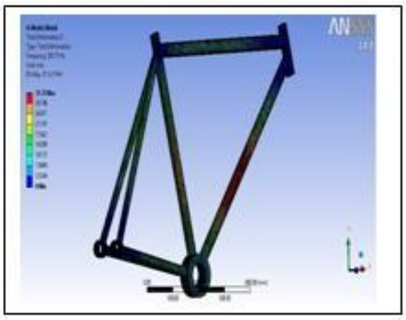


Figure 37: Mode 3, 301.71 Hz

Figure 38: Mode 4, 324.53 Hz

Figure 39: Mode 5, 340.61 Hz

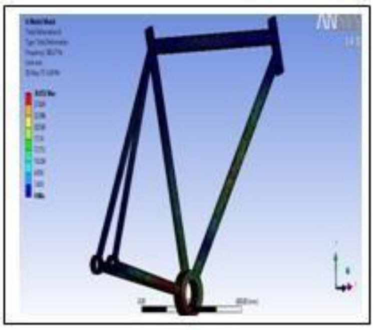


Figure 40: Mode 6, 368.27 Hz

Table 24: Comparison of natural frequencies of the bike frames (Hz)

	NATURAL FREQUENCY OF THE BIKE FRAMES (Hz)					
ALLOYS	**MODE 1**	**MODE 2**	**MODE 3**	**MODE 4**	**MODE 5**	**MODE 6**
Aluminum 6061-T	235.78	255.27	301.66	324.36	340.54	368.11
Aluminum 7005-T	235.86	255.37	301.71	324.53	340.61	368.27

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The modal analysis clearly suggests the dynamic behavior of the bike frames on free vibration conditions. The mode shapes quantify the vibration pattern of the material alloy. The 1st mode shape obtained defines the 1st vibration obtained for the bike frame on free vibration. From Table 78 we can deduce the mode shape obtained for different alloys. The increasing order of frequency is as follows:

Aluminum 6061-T < Aluminum 7005-T

The increasing order of deformation can be made out from the figure (124-154) which is as follows:
Aluminum 7005-T<Aluminum 6061-T

Frame Weight

Table 25: Comparison of frame weight (kg)

ALLOYS	FRAME WEIGHT (Kg)
ALUMINUM 6061-T	2.28
ALUMINUM 7005-T	2.52

VI. CONCLUSION

A mountain bike frame is designed with standard dimensions for a person with a height of 5 feet 10.75 inches. It has been designed for off road cycling. The dimensions of the frame are in accordance to the industry standards.

The design methodology was such chosen that the designer should have more control over outcome of Results. The inner and outer diameter of top tube, seat tube and down tube is 33 mm and 29 mm with a Thickness of 2mm. The inner and outer diameter of seat stays and chain stays are 23 mm and 21 mm with a thickness of 1mm. The lengths of the tubes are taken in accordance to the rider’s height. The lengths are close to industry standard. Modeling of the designed bike frame is done in NX Unigraphics 7.5 software. The bike frame is designed in 2 different material alloys so as to analyze and compare the frame material according to one’s need. For these 2 frames, 5 different load cases are defined in order to make out the stress and deformation in each frame. Normal stress analysis along x-axis is also performed in ANSYS software with the same loading cases. The stresses obtained from both the theoretical (analytical) and ANSYS are compared and a difference of 0% to 42.6% is seen in the results but the average difference is around 5% which can validate the ANSYS results as there is difference in meshing standard in both the analysis. Equivalent (von-Mises) stress analysis for all material alloys for all load cases is performed in ANSYS to make a comparative study. Results of all cases reveal that the maximum stress in the member of the bike frames is less than the yield strength in tension for the material selected. A comparative study is also made for the total deformation in the members of alloys for all load cases. Aluminum alloys are light weight but are easily deformed.

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