Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Strength and Stiffness Analysis of Motorcycle Frame

Master's Final Degree Project

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Kaunas, 2018

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Declaration of Academic Integrity

I confirm that the final project of mine, Hadi Slaiman, on the topic ‘’ Strength and stiffness analysis of motorcycle frame “is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

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Hadi Slaiman, Strength and Stiffness Analysis of Motorcycle Frame Master's Final Degree Project / supervisor Dr. Paulius Griskevicius; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.
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Summary

A new layout of Honda CBR250R motorcycle chassis is redesigned in order to achieve high strength ,factor of safety, advanced materials and stiffness for a very low overall weight, in addition to this, frame must be easily able to be manufactured and maintained , thus keeping the production cost low.

So we design both of frames: Honda CBR250R (tubular chassis) and the new one (perimeter chassis) using the SOLIDWORKS software, analyzing all the test (lateral, longitudinal, vertical, rig, natural frequency, mechanical fatigue)using ANSYS 18.0 software and calculates external and internal forces at maximum acceleration and braking and all other parameters, using MATLAB Software

Hadi Slaiman, Motociklo rėmo stiprumo ir standumo analizė Magistro baigiamasis projektas / Dr. Paulius Griskevicius; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.
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Kaunas, 2018. 75 p.

Santrauka

Honda CBR250R motociklo rėmas yra naujai suprojektuotas panaudojant pažangias medžiagas, projektuojant siekta užtikrinti stiprumą, saugą ir sumažinti bendrą svorį. Be to, rėmas turi būti lengvai pagaminamas ir prižiūrimas, išlaikant mažą gamybos kainą.
Darbe, naudojant "SOLIDWORKS" programinę įrangą, projektuoti du Honda CBR250R motociklo rėmai turintys įprastus cilindrinius vamzdinius elementus ir naują perimetrinį rėmą. Naudojant ANSYS 18.0 ir MATLAB programines įrangas tirtas projektuoto rėmo atsparumas šoninėms, išilginėms ir vertikalioms apkrovoms, analizuotas mechaninis nuovargis, apskaičiuotos išorinės ir vidines jėgos įsibėgėjimo ir stabdymo metu.

Acknowledgements

The following Thesis is a substantial scholarly achievement that should be presented with pride, which has been prepared by SLAIMAN HADI as part of the completion of the Master's education in Vehicle Engineering, Kaunas University of Technology (KTU). This report is a product of all the knowledge gained during my study in this honorable institute and the past Bachelors education.

I would like to heartily thank Dr. Paulius Griskevicius (Pedagogical work: Strength of materials, Mechanics of materials; Strength of Structural Elements, Numerical Engineering of Vehicles Structures) for the support and availability during the consultation of this thesis.

Finally, we would like to thank my family and friends for being helpful and supportive throughout my studies in Master's (Hon) degree in Vehicle Engineering at Kaunas University of Technology (KTU).

Motivation

The motivation for this thesis comes because of the love I have for motorcycles. I chose to do vehicle engineering because I have always been crazy about flying machines and high speed sorties from my very childhood. Mathematics and physics have always been my favorite subjects. After researching about various ideas, I decided to do a thesis on this as it is one of the most important aspects of our day to day life. Transportation has always played a key role in reducing human efforts and saving time while travelling.

Though Technology has advanced a lot during past couple of decades, there are millions of people out there who have not had the opportunity or has not been able to afford them yet. That was the reason why i decided to come up with this thesis on motorcycles so that I can help to find a way to reduce the cost and increase the efficiency of motorcycles and further make it available for everyone who have not been able to afford an expensive mode of transportation. I have always believed that a person’s success is not measured by the money or degrees that he earns but by the work that he does for the upliftment of common people and the society as a whole. I have always loved studying here. I had the best time here when I was studying at KTU.

This is the most crucial point of my life and if I could get scholarships in KTU It would mean a lot of help and inspiration towards my further studies, that I know that I could pursue my dream career. I believe I have the potential and drive much needed for this course. Ever since I had discovered my passion in vehicle engineering, I wanted to extend my skills into helping poor and underprivileged creating assisting devices and transportation devices to people. My final year project is based on developing such an assist device. Of the years spent in studying the course and researching on them, I believe this project can improve the present condition of our transportation mode and make it more reliable and less expensive to the common people. With a burning desire to learn more and venture ahead in my favorite field, I have spent all my time and thoughts to this final project and I thank everyone especially all my Professors for this opportunity.

Aim and Tasks of the Project

Tubular or trellis chassis consist of multiple short straight steel tubes welded together into a series of triangles to get high stiffness, but on the other hand ,these series of triangles can be heavy for the motorcycle (more weight more fuel combustion) , More expensive to manufacture than any others motorcycle frame (because of welding, it takes time for the manufacturing process) and also the problem consisting of using material such as steel (corrosion, fatigue and fracture).

So,the aim of this thesis is to ensure that the strength of dynamic structure of the motorcycles chassis by making the frame lighter (changing material, modifying the shape of chassis from tubular to perimeter), less costly (advantages of using perimeter frame such as less welding, less time for manufacturing, low drag coefficient for aerodynamics, use of simpler shapes and structures and also keeping the factor of safety high (more than 1.5)).

In this paper a new motorcycle frame is re-designed in order to compare the pros and cons of tubular frame to that of perimeter frame (rig test, fatigue test and static test such as lateral, vertical and longitudinal) and all other parameters that are mentioned in the above paragraph. The dynamic structure analysis is needed to improve the motorcycle frame design structure which had been already designed using the MATLAB Program to calculate all of the possible forces that can act on the chassis, furthermore the SOLIDWORKS Software is used to provide the chassis its shape and finally ANSYS Software is used to examine all the simulations and compare the results.

Introduction

A motorbike has as defining characteristics which are its high stiffness, high power-to-weight ratio, flexural resistance, inertia, low fuel consumption and its nimbleness (mainly provided by its thin body shape), that's why the lightness of motorcycle plays an important role and this is the main reason to make this thesis. Chassis is one of the major body components of the vehicle; the motorcycles consisting of chassis must be strong and must support itself including the other components. It should be able to support static load such as holder engine and so on. In this paper, a motorcycle chassis is re-designed in order to make it stronger, safer, lighter and also while being easy to manufacture and maintain further by keeping the production cost reliable and low for the customers.

In the beginning of thesis, general information regarding the history of motorcycles (1861-2018) is provided. Then a brief introduction about the types of chassis used is considered by describing the main important points that define the geometry of motorbike, overview of the company (Honda Company) and finally selecting the superior material that will be used for its manufacturing process.

In the second part, a motorcycle frame is chosen (CBR 250 Honda frame) and the three-dimensional structure of the chassis is drawn using SOLIDWORKS Software and then further analyzed by ANSYS (static, fatigue simulation).
In the third part ,a new chassis is produced by modifying and designing the shape of the frame (tubular chassis to perimeter one) and further also changing the material (from steel to cast aluminum) by keeping the cost of production approximately the same or less, in front to get a stronger, lighter and more reliable chassis.
In the final step, a comparison of the static and dynamic comparison between original CBR 250 motorcycle and the new frame design is made in-order to analyze and further showcase the advantages of the produced design (static, dynamic, fatigue, stiffness).

Chapter 1

1 Literature Review

- History of motorcycle
- Type of chassis

1.2 History of motorcycles

A brief history of motorcycles is described down below and how it figure has been improved throughout the years.

Mr. Michaux and Mr. Guillaume Perreaux (1867-1868)

MICHAUX-PERRAUX STEAM VELOCIPEDE:

Figure 1. 1 Iron framed pedal bicycle

It is one among the three motorcycles, claimed to be the first motorcycle. It is an iron framed pedal bicycle. It has a single cylinder steam engine with twin leather belts. It had no brakes and the frame is diamond shape iron tube.[1]

Mr. Sylvesster H. Ropper (1867-1868): ROPER STEAM: It is one of the steam powered motorcycles that is doubted to be first motorcycle. It is based on STATE OF ART safety bicycle frame type. It is now restored in the Smithsonian Institute. It also had an iron frame with spoon brakes. The engine is twin cylinder steam. It is a comfort model with rigid suspension.

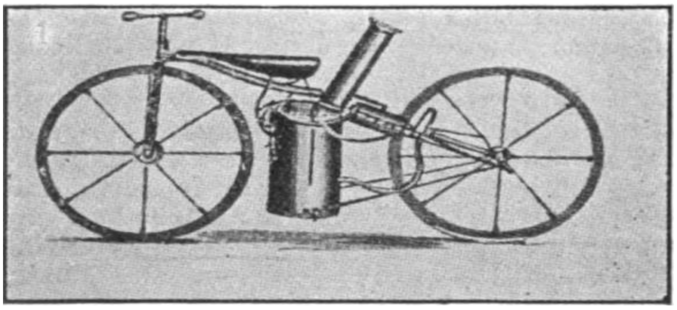


Figure 1. 2 Steam bike that is doubted to be first motorcycle

Mr. Gotlieb Daimller and Mr. Wilhilm Maybash (1885): DAILMER PETROLEUM REITWAGEN: Mr. Daimler is often called as the “father of motorcycles” for his invention. It is an air cooled four stroke single with hot tube ignition. The frame is made of wood and it is built with no suspension. It had a rear shoe brake which is still used in this era. It is also called as “the vehicle with gas or petrol engine”. It is one of the overwhelmingly popular engine types.

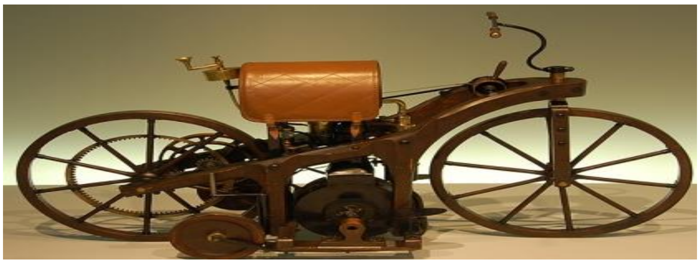


Figure 1. 3 The air cooled four stroke single with hot tube ignition.

Mr. Eddward Buttler (1887): BUTTLER PETROL CYCLE: English inventor and butler motor cycle is called as the first British car. It has a three wheeled petrol internal combustion engine. It is equipped with carburetor Ackermann steering and radiator.

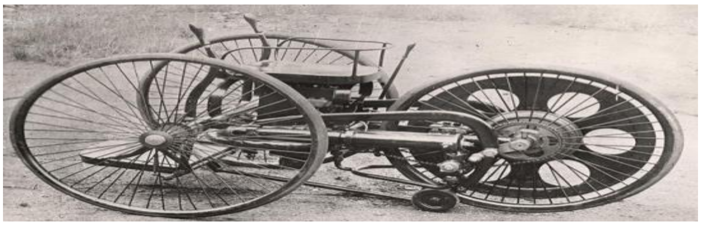


Figure 1. 4 Three wheeled petrol internal combustion engine

Mr. Heinrish Mr. Wilhelm Hidbrand and Mr. Alois Wolfmuler (1894): HILDEBRAND AND WOLFMULER: It is the world’s first production motorcycle. It had a hot tube ignition with steel frames. It also had two cylinders with water cooler and had a carburetor. The transmission is made through connecting rods which are connected to the rear wheels. It had spoon brake and was one of the well-developed designs at that time.

Figure 1. 5 World’s first production motorcycle

HARLEY-DAVIDSON AND TRIUMPH: During WW1 Harley Davidson was devoting over 50% of its factory output towards military. The First World War played a vital role in development and production of motorcycles .The Triumph almost sold 30,000 of its motor cycles during the world war. It had good suspension and speed and users nicknamed it as"trusty triumph".

Figure 1. 6 First World War played a vital role in development and production of motorcycles

1960's through 1990's: Small two stroke engine motorcycles were popular worldwide as they are light weighted and more powerful. During these periods, the grand prix races got popular and it increased a heavy growth in the production of motorcycle sports. During this time, the Germans took over the largest manufactures in the world.

Mr. Antonio Cobbass (1990): Antonio Cobbass (Spain 1952 – April 14, 2004) was a Spanish Grand Prix motorbike designer, mechanic and constructor who designed world championship winning motorcycles. Cobbass was credited with being the originator of the modern, aluminum layout chassis which is now used in production of a lot of modern racing motorcycle.

Figure 1. 7125cc JJ Cobbass which Àlex Crivillé rode to win the 1990 world championship

1.3 Type of chassis

The chassis or frame is the important part in the vehicle. It holds the components of the motorcycle. The design and strength of the motorcycle relays on the frame. Basically the material used to make chassis should be good or else the life of the motorcycles dramatically decreases. The frame protects the most sensitive part of the motorcycles during a crash. The chassis acts as a base to motorcycles.

The frame should be stronger than all components of motorcycle and it should be light in weight. The engine nearly sits inside the frame and other components are attached using bolts. The efficiency of motorcycle should be good. A well designed frame can add to the joy of riding a motorcycle as the bike would feel more stable, effortless, and confident around corners, in straight lines and while braking. Each motorcycle has its own design and type of frame. The various kinds of frames or chassis are described below:

SINGLE CRADLE FRAME: Resembles as that of old first ever motorcycle frames. It is mainly used as an off-road motorcycle. The engine is not a stressed part in this type of frame. It has a large tube for spine and small ones for other parts. It is one of the simplest types of frame.

DOUBLE CRADLE FRAME: It is the next generation of the single cradle frame. It is used in simple motorcycles and it is not used widely. It's been overcome by the perimeter chassis. It has two parts connecting to the tank[2]

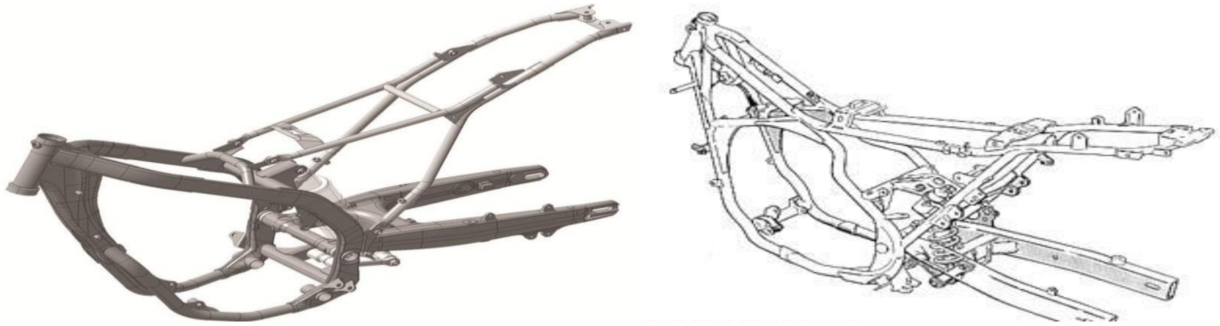


Figure 1. 8 Single vs Double cradle frame

TUBULAR BACKBONE FRAMES: It is one of the rarely used frames. It is known for good structural efficiency. It is simple in design and not too expensive but other chassis are better than the backbone chassis. It is more flexible and not that strong and rigid. The engine and tank is mounted to the chassis. It cannot be used for sport motorcycles and only in off road bike

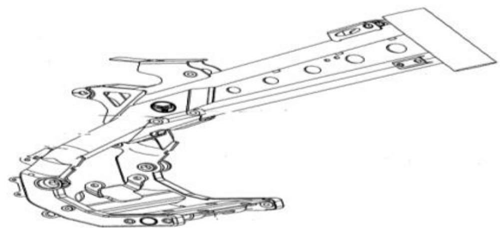


Figure 1. 9 Tubular backbone frame

MONOCOQUE FRAMES: These are rarer than the backbone chassis. These are rigid and are used in few motorcycles only. All the components of motorcycles such as tank, Engine and seat are attached to a single piece of metal. These cannot be used in street bikes. It has poor accessibility for maintenance, making it too difficult and slow. This type of frame is used nearly exclusively on specialized motorcycle competition so they are not comfortable for street bike.

Figure 1. 10 Monocoque frames

TRELLIS FRAMES: Trellis is the name of the small tube which makes up the frame. Trellis frames are similar to perimeter frames in rigidity and weight. It requires a lot of effort to make this frame but it results in a stronger frame than the perimeter frame. It can manage and withstand heavy weight compared to other types of chassis.

TWIN SPAR FRAMES: Basically this frame is made of aluminum and iron of which is light and heavy in weight respectively. It is the common type of frame that is used in sport and racing motorcycles. It has two beams running around connecting engine and towards the tail. The structural efficiency is good and the chassis is rigid.

Figure 1. 11 Honda CBR650 made of aluminum (Twin spar frame)

OMEGA FRAMES: It is used in racing motorcycles only. It has many connecting rods. The rims of both the wheels are attached to the connecting rod of chassis. This frame is also made out of aluminum and cast iron and also used in racing because of perfect steering and balancing.

DIAMOND FRAME: It is used is many kinds of light vehicles. It is connected with steering head to one part and engine to other side (the engine is laterally hanging.).Diamond chassis consists of multiple short straight steel tubes welded together into a series of triangles to get high stiffness, but in other hand, these series of triangles can be heavy for the motorcycle (more weight more fuel combustion), More expensive to manufacture than others motorcycle frames (welding takes time in manufacturing) and also the problems caused by using steel (corrosion...)

PERIMETER FRAMES: The perimeter frame saves a lot of weight and is used in many motorcycles. Due to its rigidity and light weight, it is used in all racing motorcycles. It is manufactured using iron in older times but it has changed to aluminum due to its lightweight efficiency. It is also called as twin beam frames. The cost of manufacturing is quietly high but it is one of the best advanced frames that one can put on a motorcycle. It has the best handling of brakes and suspension. It has more advance features due to which all the manufactures started using it. It is currently the favorite among moto group teams. For these reasons, my thesis is going to focus on redesigning a new chassis that has a perimeter shape and compared to older chassis is well enhanced to optimize its stiffness, safety, and also to be reasonably light weight, further keeping the price of production very low.

Figure 1. 12 Perimeter frame (CBR600R)

Chapter 2

2. Honda CBR250R:

2.1 Styling

DESIGN: Honda has its own specific designs compared to other sports bike. The Honda has the universally appreciated and recognized styles of bike. The customer can easily recognize the styling of bikes from Honda, it has a comfortable riding positions for bike racers and it has an excellent handling performance with 250cc engine building on a dynamic and sporty form based on the "mass centralization form," the cutting-edge design concept for Honda's full-cowl sport bikes from the VFR1200F and CBR1000RR on down, a simple and clean advanced styling was refined further from the functional viewpoint, producing a distinctive presence.

Figure 2. 1 CBR250R Honda (side view)

COMFORT: A separated seat that enables the rider to enjoy a wide variety of situations from touring to sports riding and easy-to-grasp separate left/right rear grips that provide the passenger a sense of comfort come as standard equipment. The comfort of this bike enables the rider to feel the convenience and highly. The bike has the split seat design which adds more comfort to the riders. It has a good riding space and it adds the feeling of riding into pleasant wind which only sport bikes can provide.[3]

FRONT FACE AND UPPERCOWL: The Honda adds an excellent feature in this bike on front face. It has wide spread high visibility than other sports bikes. In addition, the left/right side air outlets provided on the upper cowl boost the turning ability of the vehicle body while directing a proper amount of the wind from riding toward the rider

Figure 2. 2 CBR 250R Honda (front view)

MIDDLE AND UNDERCOWL: The middle and under cowl exhibits good aerodynamic design and beautiful surface design. It has high-efficiency air management function that aims to achieve both high cooling performances. The cowl under leads the wind to blow through the engine and helps in cooling performance. Its design looks beautiful as it encloses the engine in its under cowl and highlighting the functional beauty

METER DESIGN: The meter and indicator designs are analog tachometer placed in the center of instrumental panel. The needle dials back down; the speed displayed on the LCD also counts down, making it possible to check if there is anything wrong with each meter. In this way, sporty and functional features are provided together. In this way, the meters are designed to stimulate the rider's sports-oriented spirit by producing an effect that is fitting to the cockpit of a sport bike while accurately providing the rider with the information to be checked. The design makes the rider to feel the spirit of motor racing.

ENGINE DESIGN: It has a new-generation liquid-cooled 250cc DOHC single-cylinder engine with high performance. It has compact and powerful head area which is coated in black.

MUFFLER: It has a special pentagonal designed silencer for reveling the cutting edge design of Honda motorcycles. It has well comforted muffler coated in matte silver that adds the extra feature to the rear end of the bike.

2.2 Engine

POWER UNIT: It has a powerful 250cc single cylinder engine that runs in low rpm as well as high rpm range. It is a sporty engine with easy handling and making advantages of fuel economy. The CBR250R engine was developed by aiming at a global single-cylinder engine that transcends regions, while being sporty and eco-friendly at the same time, with a look ahead at the next generation. It has conventional single cylinder engines that are light and compact.

Figure 2. 3 250cc single cylinder engine

ENVIROINMENTAL PREFORMANCE: It has double overhead cam to set high performance for environmental factors. The double overhead cam helps to improve combustion efficiency by reducing the weight of reciprocating valves. The choice of a shim design for valve tappet adjustment reduced the rocker arm weight, while friction was reduced by setting the valve spring load to a low level ,for better maintainability, the shim can be replaced without removing the camshaft.
To decrease the blow-by gas and oil consumption, a spiny sleeve was adopted for the cylinder sleeve. Small spines have been added to the outer surface to increase the cooling performance and help decrease in distortion of the inner cylinder's shape. In addition, centrifugal casting allowed a thin, uniform wall thickness, which helps in weight reduction. For emission measures, the oxygen sensor is combines with the built-in air induction system and a catalyzer is fitted inside the exhaust pipe to comply with Euro3 emission regulation.

2.3 Chassis

FRAME/CHASIS: The frame is designed with mass centralization and sporty feel as the rider can really feel the riding of sports bike. The rider can use bike casually, take for a long ride and enjoy sporty rides on other times. Not only for bike racers, can the beginners also use this motorcycle. Development is mainly in the case of size, dimensions, riding positions and stability than other bikes. The people can feel the fundamental feeling of riding a sports vehicle. A sporty riding position that takes into account a level of comfort and ease of handling that will satisfy customers around the world. It has the first of its ABS so the people can feel more secure.

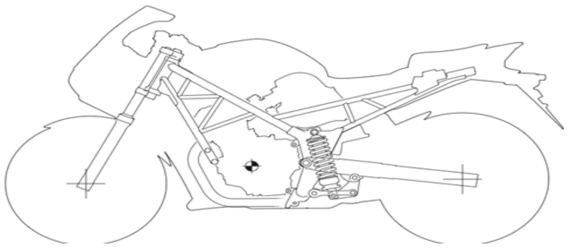


Figure 2. 4 The white design of CBR 250R Honda

RIDING POSITION: This has the best riding for both the small and big stature so that they can enjoy the riding without any discomfort. A sporty riding position that is stress-free and makes it easier to handle the bike was realized by considering how people use bikes in various countries, including touring from a congested urban area over highways to suburban areas and taking a sports ride on a winding road. The seat comfort is better in this bike and the riders can enjoy the long ride without any disguise.

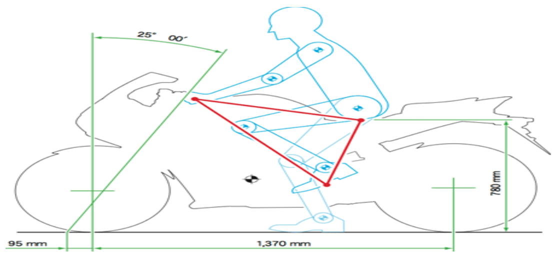


Figure 2. 5 Dimension with the rider

FRAME DIMENSIONS AND PARTS PLACEMENT: It has a straight forward handing which feels more secure for riding. At the same time, weight reduction, straightforward handling with a sense of security, and reduced vehicle vibration were achieved by optimizing the position of the engine mount and the frame rigidity balance. The components are made in a way to be center weighted as there will be easy handling for the riders.

REAR SUSPENSION: The suspension features damping force characteristics that change progressively, and having a compact suspension layout near the center of gravity contributes greatly to improved driving stability. The suspension is a pro link suspension which helps to ride the bike in all kinds of environment. It has high road tractability through ratio optimization. In addition, the five-position preload adjusting can be adjusted to respond to the rider's preferences. Proper toughness along with high rigidity has been achieved through a 574mm rear swing arm and 60 × 30mm pipes with square sections. Because the plastic inner protector (fender) also serves as the chain case, high design quality and weight reduction were achieved while reducing splashes of mud and chipping on the vehicle body, rear cushion and ABS modulator.

2.4 Technical specification

Table 2. 1 The technical specification of CBR250R Honda (Chassis /Frame)

Sales name	CBR250R
Model type	Honda MC41
Overall length × Overall width × Overall height (m)	2.035 × 0.720 × 1.125
Wheelbase (m)	1.370
Ground clearance (m)	0.145
Seat height (m)	0.780
Curb weight (kg)	161 (STD) 165 (ABS)
Riding capacity (No. of people)	2
Minimum turning radius (m)	2.5
Engine type	CS250RE, liquid-cooled 4-stroke DOHC single cylinder
Displacement (cm^3)	249
Bore × Stroke (mm)	76.0 × 55.0
Compression ratio	10.7
Fuel supply system	Programmed fuel injection system (PGM-FI)
Starter type	Self-starter
Ignition type	Full-transistor battery ignition
Lubricating type	Wet sump
Fuel tank capacity (L)	13
Clutch type	Wet multiplate with coil springs
Transmission type	Constant mesh 6-speed return

Transmission gear ratio	**1-speed**	3.333
	2-speed	2.118
	3-speed	1.571
	4-speed	1.304
	5-speed	1.115
	6-speed	0.963
Reduction gear ratio (primary, secondary)	2.808 / 2.714	
Caster angle/Trail (mm)	25°00´/ 95	
Tire size	**Front**	110/70-17M/C
	Rear	140/70-17M/C
Brake type	**Front**	Hydraulic disk
	Rear	Hydraulic disk
Suspension type	**Front**	Telescopic
	Rear	Swing arm (Pro-link suspension system)
Frame type	Diamond	

The following table shows the technical specification of CBR250R Honda motorcycle (Honda MC41 model type) including the transmission gear ratio in all speed (this type of motorcycle have 6 gears), the reduction gear ratio (primary, secondary 2.808/2.714), caster angle/ trail (25.00 degree/95 mm).

In the next page, the caster and trail will be described deeply including the use of this particular dimension for the caster angle ,about the trail and tire and the material used on it , showing the suspension type and the brakes used as well (in the next chapter, the maximum brake will be calculated in order to know all the loads that affect the chassis geometry of CBR250R model (diamond type) and how to optimize it in order to make it more stronger and more safer (perimeter type), along with the mass, dimension of (the chassis(overall length, width, height),wheel ,bore ,stroke and seat height.

About the engine and its container, this engine has 4-stroke liquid-cooled DOHC single cylinder, the compression ratio equals to 10.7 with self-starter type and wet sump type, with 13 liters fuel tank capacity and wet multi-plate with coil spring.

Chapter 3

3. Geometry of motorcycle frame

The most important part of the motorcycle is motorcycle frame. It is designed in a specific way that it enhances comfortability and the whole riding experience of the customer. The geometry should mainly concentrate on aerodynamics, comfort and good design so that it should be attractive. Generally, motorcycles frames are designed to make power transfer from rider to wheels as efficient as possible so that it should be pleasant driving through the wet and dry roads also.

Geometry means it should contain all the angle of bike and it supports the whole body perfectly. Every angle and tube length is a part of a bike's overall geometry. Geometry plays most vital role in any bike design. The geometry defines the bike style and its capacity. The geometry varies for each country depending on its styling. These parameters provide the base for designing the frame and the stability of the bike completely depends on the joints. Further there is a big interaction between them so it is not useful to examine the effects produced by only one geometric parameter.

Trail and caster angle are mainly used in the design of the steering head. The definition of the properties of steering and directional stability of motorcycles entirely depends on them.

Seat angles should not slope and it should be perfectly stable for the rider. It should provide comfort and must be enjoyable to take it out for a stretch.

Bottom bracket drop determines how high your cranks sit from the ground when you pedal. A lower bottom bracket helps in lower saddle height.

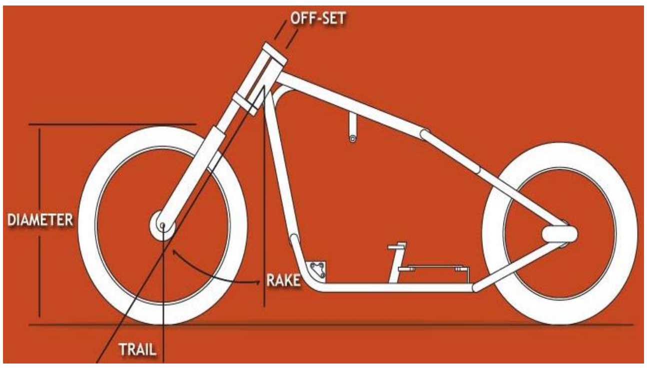


Figure 3. 1 Simple geometry of motorcycle (Trail, Rake, Off-set…)

3.1 Wheelbase geometry

It is the distance between the contact points of the tires on the road. The value of the wheelbase depends entirely on the type of motorbike. It ranges from 1150 mm in small scooters to 1250 mm for light motorcycles like 125cc to 1350 mm for medium displacement motorcycles (250cc) up to 1550 mm and more for touring motorcycles. Most of motorcycle can vary wheelbase from 18 to 45 mm depending on the preferences of an individual, further also on the crown and chain stress of the bike. The wheelbase can also be referred as the distance from axle to axle. Head angle also influences wheelbase and front center, which in turn affects the weight distribution. Ideally, a rider should have 46% of their body weight on the front wheel and 54% on the rear wheel. Long wheelbase is preferred in most of the bicycle, but it should not happen to reduce the mileage of the bikes. The bikes should have good wheelbase as it should move in wet and damp roads without slipping or sliding. Most of the motorcycles can have a failed design due to its bad wheelbase angle. So the designers and engineers working on them must keep those designs as their top priority for providing a perfect and all weather motorbike. Wheelbase is the horizontal distance between the front and rear wheels of the bike. Wheelbase is a function of rear frame length, steering axis angle, and fork offset. The center of the gravity play an important rule on the wheelbase, it's considered as main factor for the wheelbase

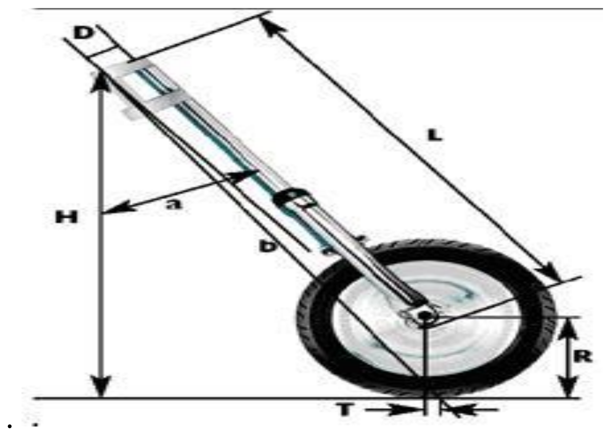


Figure 3. 2 Front wheelbase geometry for a motorcycle

3.2 Caster angle or Rake angle

Caster angle is the displacement in the angle of the steering axis from the vertical axis of a steered wheel in a motorcycle, or any other modes of vehicles. The caster angle is measured in the longitudinal direction. Bike racers sometimes adjust caster angle to optimize their bike's handling characteristics. It controls where the tire touches the road in relation to an imaginary center line drawn through the spindle support.

Caster angle can give the stability for the rider during traveling in high speed, also caster angle play an important role on the tilt of the wheel which occurs during steering. So the caster angle varies according to the type of motorcycle: from 19º . So each type of motorcycle(racing, off-road, touring motorcycles….) have its own caster angle, and can varies from 18º to 30º.

Rake angle has a major part in a motorcycle's handling characteristics. When the rake angles are small then the stability of the bike is maximum. Trail's dimension has a proportional relation with caster angle's value.

3.3 Trail

It's the distance on the ground between a straight line drawn through the center of the front wheel spindle and a line drawn through the center of the headstock axis. When the trail is larger than the straight line of vehicle stability is larger. It makes turning harder.

Trail is measured in distance. Too much trail makes a motorcycle difficult to turn and too little makes it unstable.

Comparing the rake and trail numbers for different motorcycles, it may give you some idea of how much easier it would be to handle and how much the related between them is deep.

To maintain good stability and proper handling with the fork angle being in the normal range, a certain amount of trail is designed in. Generally, there are exceptions such as the more trail a motorcycle has, the more stable it can be. However, increase the trail by too much and it gets back to chopper-like handling. So too little trail and the motorcycle's stability begins to be dramatically affected.

3.4 Center of gravity

The center of gravity is a point in a body or system around where it's mass or weight is evenly distributed or balanced and through which the force of gravity acts. The center of gravity of a body is the point where the mass is equal throughout the entire body.

The statement about lowering the center of gravity has caused a lot of argument among riders and those schooled in the laws of physics. Riders claim the point of contact with the bike is lowered from the seat to the footers, therefore lowering the center of gravity. The center of gravity of the rider is so much higher than the bike. The height of the center of gravity has importance on the dynamics behavior of a motorcycle, especially during the acceleration and braking. As higher the center of gravity is, as larger load transfer from the front to the rear wheel so it increases the power allowed at rear axle, but wheeling is more probable.[1]

So, the center of gravity should lie at the center of the bike. The riders would fall off and get hurt if there was any problem regarding center of gravity. Most of the riders complain about the center of gravity while doing stunts and especially during braking, so there must be perfect geometry based on the center of gravity

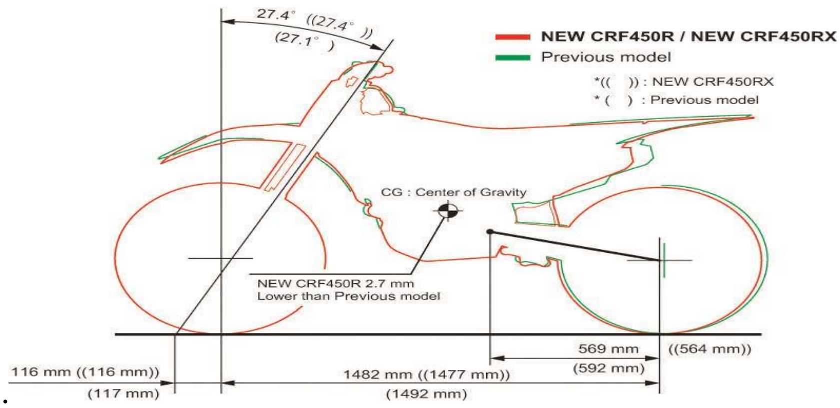


Figure 3. 3 Center of gravity, trail and caster angle for a motorbike

Chapter 4

4. Frame materials:

4.1 Materials used for motorcycles frame

A motorcycle frame is the part that combines the seat, suspension and engine. The frame should be ideal, weigh a little and should have perfect geometry. But more than these, the material used in the motorcycle frame should be better, large and should give fine handling. So the automobile engineer should focus more about the selection of motorcycle. The selection process should consider things like light weight, safety, economically effective and perfect comfort.

Among these factors the engineers have been using many materials through the years to provide the effective frame. The frame quality and character will vary with respect to the material used in the frame. The most frequent used materials are described. The material should have good rigidity and easy to work like welding. The material should have fine quality like light weight, strong, cheap in cost so that it fits the motorcycle perfectly.

TITANIUM

Titanium is frequently used in expensive vehicles. It is stronger than steel and two times less than its weight. In titanium used motorcycles, the spine is made into a solid structure. The titanium is easy to weld and has good flexibility but the main disadvantage is it is too expensive. **MAGNESIUM**

It is another light weight metal that is becoming increasingly common in automotive engineering. It is 32% lighter than Al. And 74% lighter than steel/ cast iron components. Although the tensile strength of magnesium is same as Al, it has a lower ultimate tensile strength, fatigue strength when compared to Al. And the thermal expansion co-efficient is higher for Magnesium. It has better machinability, manufacturability, longer die life and faster solidification other than that, the titanium has good resistance against corrosion and can be designed easily.

CARBON FIBER

Comparing to steel and aluminum, the carbon fiber gives good rigidity and more light weight but the standard of the motorcycles is reduced. Like titanium, the carbon fiber is also too expensive. The motorcycle frames produced by carbon fiber and good on papers but the material doesn’t last like other. So only few bike frames are produced with carbon fiber. The carbon is combined with epoxy to get good results but it is never been used in motorcycle frames.

STEAL

Steal is a cheap material which can be used easily. It is popularly used as the frame in 70s and 80s. It is fine and heavy material to work. Even though they are cheap, the material gets eroded easily. The steel is stronger but harder to form. In light weight motorcycles the steel cannot be used as frame. It can get oxidized easily and cannot be used for a long time. It has good impact during crush situation, but the increased weight reduces the economy of motorcycle. Many improvements have been done in steel to make it light weight and not affected by corrosion as it lasts longer. Meanwhile it is used in cheap motorcycles and not mostly in sports motorcycles.

ALUMINIUM

Aluminum is used is modernized bikes as its most common character of light weight. It is also strong enough and light weight which made it to use these in most of the sports bikes. The material can be made more stiffness than steel which makes it better than other materials. The aluminum has good resistance against corrosion and in heat transmission. In recent times the using of aluminum material for frame is increased to large scale in both cars and motorcycle manufacturing. Many standard racing motorcycles are fitted with aluminum materials.

4.2 Material used in Master Thesis

CBR250R motorcycle use steel material to make its chassis, but the main characteristics sought in this frame is good handling and the low weight. To achieve this, aluminum was employed as a material, while keeping the use of steel to decrease the price of the bike

4.2.1 Diamond chassis made of steel material (S355J2G3)

S355J2G3 structural grade steel with a minimum yield strength of 355 N/mm² which widely used in the engineering and construction industries) this type of steel has a good weldability as a result of equivalent carbon; all mechanical and chemical properties are mentioned on the table.[4]

Table 4. 1 S355J2G3 Mechanical Properties:

C	**Si**	**Mn**	**P**	**S**	**C.E.**
max	max	max	max	max	max
0.22	0.55	1.60	0.035	0.035	0.047

Table 4. 2 S355J2G3 Chemical Composition (max %):

Thickness (mm)	**Yield Strength Reh Min (N/mm²)**	**Tensile Strength Rm min (N/mm²)**	**Elongation A5 min (%)**	**Impact Values Charpy-V-Notch Longitudinal Average from 3 Specimens Thk. >10 ≤ 150mm**
≥ 3 - ≤ 100	315 - 355	490-630	max 22	27 Joules at -20°C

Table 4. 3 Properties from ANSYS R Workbench 18.0

Density	7.85e-009 tonne mm^-3
Isotropic Secant Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	4.34e+008 mJ tonne^-1 C^-1
Isotropic Thermal Conductivity	6.05e-002 W mm^-1 C^-1
Isotropic Resistivity	1.7e-004 ohm mm

4.2.2 Perimeter chassis made from aluminum (A380)

Aluminum is used is modernized bikes as its most common character of light weight. It is also strong enough and light weight which made it to use these in most of the sports bikes. The material can be made more stiffness than steel which makes it better than other materials On perimeter chassis, we use cast aluminum (A380) material, Aluminum is used is modernized bikes as its most common character of light weight. The aluminum is also strong enough and light weight which made it to use these in most of the sports motorcycles

Table 4. 4 Cast aluminum (A380) Chemical Composition (max %)

Copper	Magnesium	Iron	Tin	Nickel	Manganese	Silicon	Others
Max	Max	Max	Max	Max	Max	Max	Max
3.0	0.1	13.0	0.35	0.5	3.0	7.5	0.5

Table 4. 5 Mechanical Properties cast aluminum (A380)Chemical

[^]Thickness (mm)	**Yield Strength Reh Min**	**Tensile Strength Rm min**	**Elongation A5 min (%)**	**Impact Values Charpy-V-Notch Longitudinal Average from 3 Specimens**

	(N/mm^2)	**(N/mm^2)**		**Thk. >10 ≤ 150mm**
`≥ 3 - ≤ 100	160	318-335	max 35	23 Joules at -20°C

Table 4. 6 Properties from ANSYS R Workbench 18.0

Density	2.77e-009 tonne mm^-3
Isotropic Secant Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	8.75e+008 mJ tonne^-1 C^-1

Chapter 5

5. Methodology

5.1Chosen methodology for this project

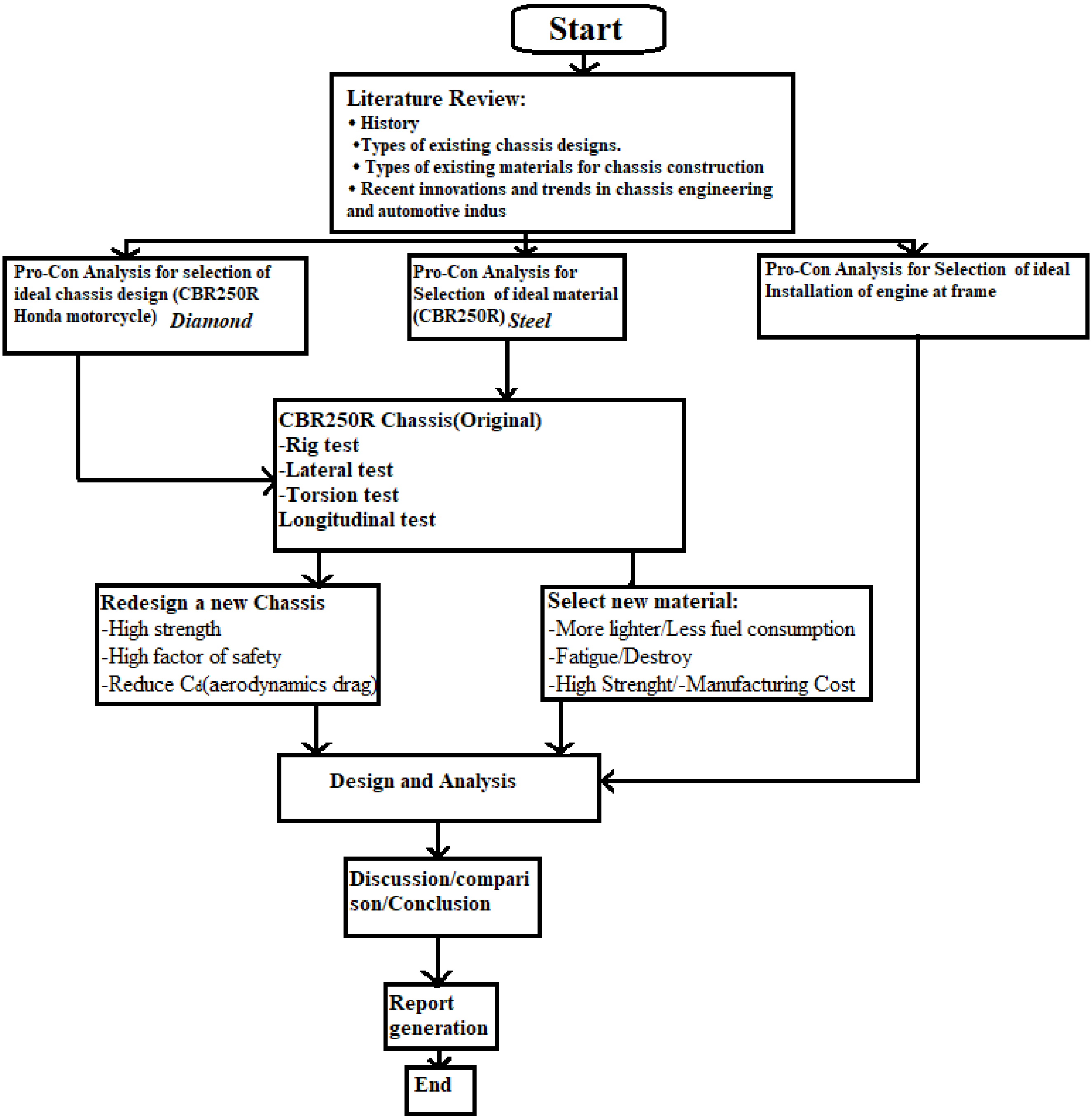


Figure 5. 1 Flowchart for the Master thesis

The project is to design and develop a chassis for CBR250R Honda motorcycle, for which the methodology is applied in flow chart below

Chassis is the primary structural component of a vehicle. It is the main supporting structure of an automobile to which all other frameworks, such as differential, suspension and braking and are linked, so main frame of a motorcycle plays an important role in vehicle dynamics. In order to understand the main influences of this component ,a static simulation was applied on this type of chassis by knowing and calculating all external force then apply the maximum load when the motorcycle will be in high acceleration , in maximum braking to the front axle ,in maximum braking to the rear axle and final conclude where are the week point or join in this chassis to redesign a new one in order to achieve high strength ,factor of safety, advanced materials and stiff ness for a very low overall weight and also reaped the same procedure to verify our work .

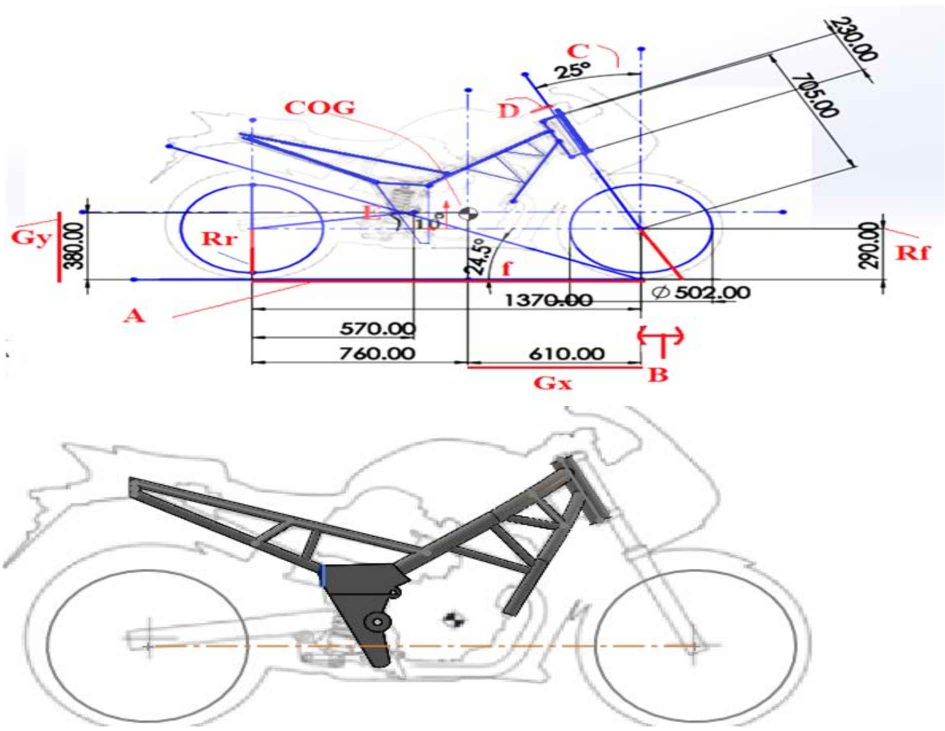


Figure 5. 2 Dimension for a diamond chassis with the center of gravity

Table 5. 1 Dimension for a diamond chassis shown in the previous figure (figure 5.2)

Symbol	Gx	Gy	A	B	C	D	E	f	Rf	Rr	COG
Parameter	COG to rear	Height of COG	Wheelbase	Trail	Caster angle	Radius of pipe	Load angle	Load transfer angle	Radius front	Radius rear	Center of gravity
dimension	610mm	380mm	1370mm	130mm	25º	30mm	10º	24.5º	290mm	290mm	(760;380)

On this chapter, a static simulation was applied on our model in:

- Maximum acceleration.
- Maximum braking to the front axle
- Maximum braking to the rear axle

First of all, we need to calculate all unknowns (external forces) during this 3 conditions then a static simulation will be applied to test the stiffness of our model.[5]

While testing our model we need to take into account the following factors (hypothesis):

1. The road will be straight (without inclination, no water ,no snow, smooth and clean) and in normal condition
2. In calculation the weight of rider will be neglected because it affect and change the center of gravity of overall system and by this way we cannot get a specific result.
3. The weight of fuel and cooling system (water, oil) is added to the mass of overall bike and approximately equals to 13 kilograms.
4. Transfer load while braking and acceleration are considered constant without any loss (energy losses). In this way we can get higher load and the factor of safety will be more.
5. The gravity center never stay in the same position because the rider moves constantly while driving, When the acceleration goes to the rear part and braking goes to front part, the center of gravity will change its place and will be towards the front part, when the bike goes left or right also the COG will change even when the fuel level goes down so center of gravity changes its position too. In our thesis, the COG will be the same (when the motorcycle is not moving and also neglecting the weight of the rider).
6. The load that will act on rear wheel acts directly to the frame (Transfer load during braking and acceleration are considered constant)
7. In reality, all loads suspended on the wheels (rear or front) will affect directly to the chassis of motorcycle. For sure the value of this parameter will be much higher than normal because suspensions aren't working (in our model but in reality it will work normally and also absorb some energy) so security coefficient will be less than the normal stat but on other hand the motorcycle will be checked in tougher conditions and will be stronger than the real model (because in our model the loss energy will not be considered and by this way more load will act on the frame).

Situations studied:

- Maximum acceleration.
- Maximum braking to the front axle

5.2 Calculation of external forces with:

5.2.1Maximum acceleration

Maximum acceleration (Diamond frame)

In this section we reflect on the studies of all forces that can affect the frame of motorcycle when the motorcycle travels at maximum acceleration (maximum speed equal to 135 km/hr) so first of all we need to find all known parameters (forces) then we need to calculate all other parameter using some static equation (Newton second low, Equilibrium low and dynamic equation) then input all this parameters in computer program (using SOLIDWORKS like a design software and ANSYS to find all stress and displacement)of finite elements correctly, and getting the results as accurate as possible . The figure below (figure 5.3) will be useful to calculate all the unknown forces remaining, further using ANSYS Software to get all the results and comparing the 2 models(diamond frame, perimeter frame) .

First part, a diamond frame with all the dimensions such as figure 5.2shown in the figure below is taken.

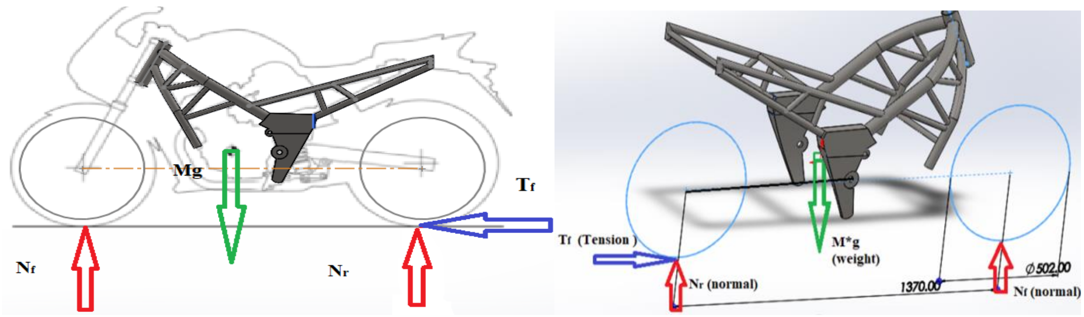


Figure 5. 3 Forces act on the motorcycle (diamond chassis) 2D vs 3D

- Normal forces Nf and Nr exchanged between the road and the tires (ascending force) (mentioned in red color)
- The weight of motorcycle (mg) that acts at its center of gravity (descending force) (mentioned in green color)
- The driving force of the engine T, which the floor applies to the bike at the contact point of the rear wheel (opposite direction of the wheel).(mentioned in blue color).[6]

Need to take into account:

- The resistance of the air will be neglected which means the system will be in a steady state (The aerodynamic lift force equals to zero)
- Chemical reaction will not affect the movement of the bike and also will be considered a steady state system (while fuel combustion happen the mass of motorcycle stay the same ,no need to decrease the weight of motorcycle)

- Consider that the rider is not moving (the rider and the motorcycle will be one system)
- The rolling resistance force between the floor and the wheel will be neglected.
- No inclination on the road and the road should be in good condition.

Table 5. 2 Mass properties (mass of chassis /center of gravity/moment of inertia)

Density	0.01 grams per cubic millimeter
Mass	29243.08 grams
Volume	4793948.02 cubic millimeters
Center of mass	(95.23 , 264.96 , 0.07)
Principle axes of inertia	Ix(1 ,0.09 ,0) Iy(0 , 0 , -1) Iz(0.09 , 1 , 0)
Principle moment of inertia	Px(15.91) Py(23.21) Pz(28.42)

The mass of the motorcycle (diamond chassis) = 161 kg.

Using SOLIDWORKS Software, Mass of the chassis equal approximately 30 kg so the mass of the all the motorcycle equal =to overall the body –the mass of the chassis =131 kg.

Using Newton second law of motion (For the diamond chassis)

$$\sum fx = M * a \quad \text{(Eq 1)}$$

$$T_{dr} = \text{T}*\frac{G_Y}{A} \quad \text{(Eq 2)}$$

$$\sum fy = M * a \;\; ; \quad \text{(Eq 3)}$$

$$N_{dr} - m_d \text{g}*\frac{(A-Gx)}{A} = 0; \quad \text{(Eq 4)}$$

$$N_{df} - m_d \text{g}*\frac{G_x}{A} = 0 \quad \text{(Eq 5)}$$

On the rear wheel for diamond chassis $N_r = N_{dr} - T_{dr} = m_d \text{g} * \frac{(A-Gx)}{A} - \text{T} * \frac{Gy}{A}$ (Eq 6)

On the front wheel for diamond chassis $N_f = N_{df} - T_{dr} = m_d \text{g}*\frac{G_x}{A} - \text{T}*\frac{G_Y}{A}$ (Eq 7)

Knowing that during the maximum acceleration the front wheel or the normal on the front wheel will be approximately neglected.

N_f=$N_{df}$$_-$$T_{dr}$=$m_d$g*$\frac{G_X}{A}$ –T*$\frac{G_Y}{A}$=0 (Eq 8)

N_r= N_{dr}-T_{dr}=m_dg=161*9.81=1579.41 N (Eq 9)

$$T_{dr} = N_{dr} = m_d g * \frac{(A-Gx)}{Gy} = 161 * 9.81 * \frac{(1370-610)}{380} = 3158.82 \text{ N} \quad \text{(Eq 10)}$$

Maximum acceleration (Perimeter frame)

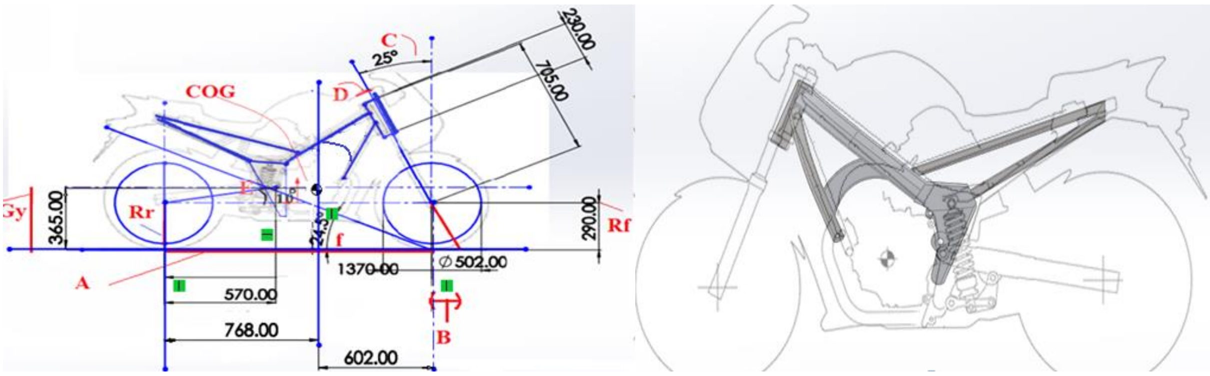


Figure 5. 4 Dimension for a perimeter chassis with the center of gravity

Table 5. 3 Dimension for a diamond chassis shown in the previous figure (figure 25)

Symbol	Gx	Gy	A	B	C	D	E	f	Rf	Rr	COG
Parameter	COG to rear	Height of COG	Wheelbase	Trail	Caster angle	Radius of pipe	Load angle	Load transfer angle	Radius front	Radius rear	Center of gravity
dimension	602mm	365mm	1370mm	130mm	25º	30mm	10º	24.5º	290mm	290mm	(768;365)

We conclude that in perimeter chassis the center of gravity is changed and becomes closer to the ground and Gx and Gy also changes.

On the rear wheel for perimeter chassis N_r=N_{pr}-T_{pr}=m_pg*$\frac{(A-Gx)}{A}$ –T*$\frac{Gy}{A}$ (Eq 11)

On the front wheel for perimeter chassis $N_f = N_{pf}$$_-$$T_{pr}$=$m_p$g*$\frac{G_X}{A}$ –T*$\frac{G_Y}{A}$ (Eq 12)

$$N_f = N_{pf} - T_{pr} = m_p g * \frac{G_x}{A} - T * \frac{G_Y}{A} = 0 . N_r = m_p * g = 150 * 9.81 = 1471.5 \text{ N} \quad \text{(Eq 13)}$$

$$T_{pr} = m_p g * \frac{(A - Gx)}{A} = 150 * 9.81 * \frac{(1370 - 602)}{365} = 3096.2 \text{ N} = 3.0962 \text{ KN} \quad \text{(Eq 14)}$$

5.2.2 Maximum braking to the front axle

Diamond frame

On this part, all the forces needs to be found and calculated when the maximum braking of the front axle will occur and also compare between the two models (diamond, perimeter chassis).

In this case, it will be similar to the last case(maximum acceleration) but in this one, the rear normal will be neglected and this way we can calculate all unknowns forces on this system.

Forces act on the motorcycle (diamond chassis) (Figure 5.5):

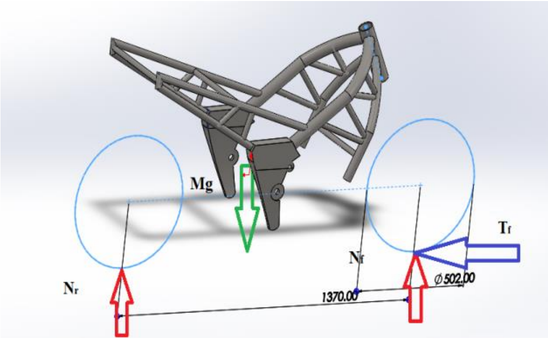


Figure 5. 5 Forces act on the motorcycle (diamond chassis)

- Normal forces Nf and Nr exchanged between the road and the tires (ascending force) (mentioned in red color)
- The weight of motorcycle (mg) that acts at its center of gravity (descending force) (mentioned in green color)
- The driving force of the engine T, which the floor applies to the bike at the contact point of the rear wheel. (same direction of the wheel because we have maximum braking in the front axle) .(mentioned in blue color).

Using Newton second law of motion $\sum fx = M * a$ (For the diamond chassis)

$$N_{dr} - m_d g * \frac{(A - Gx)}{A} = 0; \quad \text{(Eq 15)}$$

$$N_{df} - m_d g * \frac{G_x}{A} = 0 \quad ; \quad \sum fx = M * a \; ; T_{dr} = T * \frac{G_Y}{A}; \quad \text{(Eq 16)}$$

On the rear wheel for diamond chassis N_r=N_{dr}-T_{dr}=m_dg*$\frac{(A-Gx)}{A}$ –T*$\frac{Gy}{A}$ (Eq 17)

On the front wheel for diamond chassis $N_f = N_{df}$–T_{dr}=m_dg*$\frac{G_x}{A}$ –T*$\frac{G_Y}{A}$ (Eq 18)

Knowing that during the maximum braking on front axle or the normal on the rear wheel will be approximately neglected.

N_r=N_{dr}-T_{dr}=m_dg*$\frac{(A-Gx)}{A}$ –T*$\frac{Gy}{A}$= 0 (Eq 19)

$N_f = \quad m_d\text{g} = 161 * 9.81 = 1579.41$ N (Eq 20)

$T_{df} = m_d\text{g} * \frac{G_x}{A} = 161 * 9.81 * \frac{610}{1370} = 703.2$ N (Eq 21)

Perimeter frame

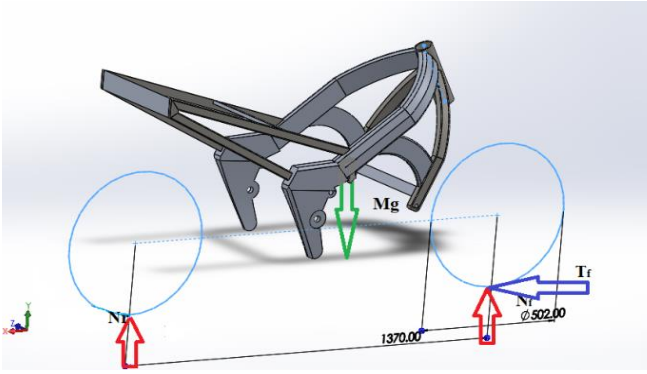


Figure 5. 6 External forces on the front part for perimeter chassis

Knowing that during the maximum braking on front axle or the normal on the rear wheel will be approximately neglected.

N_r=N_{pr}-T_{pr}=m_pg*$\frac{(A-Gx)}{A}$ –T*$\frac{Gy}{A}$=0 (Eq 22)

$N_f = m_p$g=150*9.81=1471.5 N (Eq 23)

$T_{pf} = m_p$g*$\frac{G_x}{A}$=150*9.81*$\frac{602}{1370}$ =646.6 N (Eq 24)

Table 5. 4 External forces in maximum acceleration and maximum braking on the front axle for both frames

	Diamond Chassis	Perimeter Chassis
Maximum acceleration	N_r=1579.41 N N_f= 0 N	N_r=1471.5 N N_r= 0 N
	T_{dr}=3158.82 N	T_{pr}=30.96.2 N
Maximum Braking On front axle	N_f=1579.41 N N_r=0 N	N_f=1471.5 N N_r=0 N
	T_{dr}=703.2 N	T_{pr}=646.6 N

We conclude that the braking values are less than the acceleration values, that's because of the Position of center of mass (the center of mass is near to front axle than rear axle so braking will be more critical because less force will be allowed to spend on It.) and the result will verify this, and also we can conclude that the external forces witch as acting on perimeter frame are less than the diamond one, due to center of gravity (in perimeter frame the center of gravity is closer to the ground) and due to mass of the chassis, all this parameter can affect the stability of the driver .

5.3 Internal forces and analysis

After finding and calculating the external forces, internal forces will be calculated using these external forces and the effect of these loads on the CRB250R motorcycle chassis is concluded (on the two models –Diamond and Perimeter) at maximum acceleration, at maximum braking on the front axle by using SOLIDWORKS Software to design the frame and ANSYS18.1 Software to analysis and compare the result of stresses and deformations.

5.3.1 Maximum acceleration

(Diamond Chassis)

Here we have all the force that will act on the frame when the motorcycle went on maximum speed or acceleration, we need to take into account the chain force, so that during acceleration, it also transmits all load to the chassis in high amount.

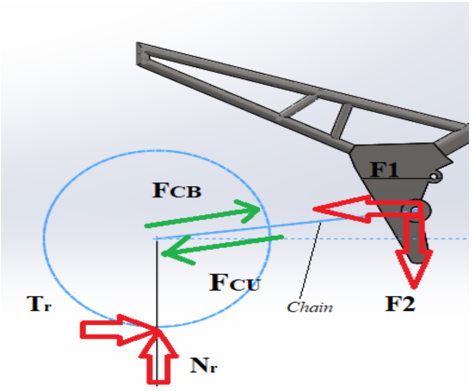


Figure 5. 7 Rear part when the maximum acceleration occurs (diamond chassis)

$\sum fx = M * a$; At equilibrium$\sum fx = M * a = 0$; (Eq 25)

T_r –F_1+$L * F_{CB}$cos (10)- F_{CU}cos(10)=0; (Eq 26)

$\sum fy = M * a$; at equilibrium $\sum fx = M * a = 0$; (Eq 27)

N_r - F_2+F_{CB}*L*sin (10)-F_{CU}*L*sin (10) =0; (Eq 28)

3 unknowns are missed (F_{CB}; F_2; F_1); $F_{CU} = 1800\ N$;

Vmax= maximum velocity of motorcycle = 135 km/hr=135/3.6=37.5 m/s;

Vmax=Wwheel*Radius →\Wwheel = Vmax/Radius = 37.5/0.29 = 129.31 rad/s (Eq 29)

Vjoin = Wwheel*Rcrown = 129.31*0,121 = 15.64 m/s (Eq 30)

$F_{CB} = 19500/15.64 = 1246.28$ N (Eq 31)

Solving these two equations $F_1 = 2613.43\ N$; $F_2 = 1483.23\ N$;

Maximum acceleration (Perimeter Chassis)

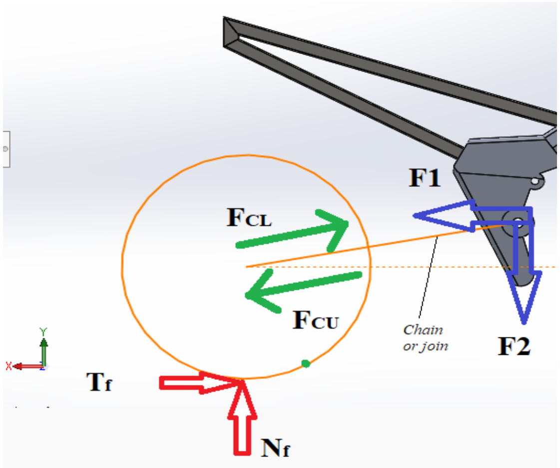


Figure 5. 8 Rear part when the maximum acceleration occurs

T_r $-F_1$+$L * F_{CB}$cos (10)- F_{CU}cos(10)=0 (Eq 32)

$\sum fy = M * a$; At equilibrium$\sum fx = M * a = 0$;

N_r - F_2+F_{CB}*L*sin (10)-F_{CU}*L*sin (10) =0; (Eq 33)

3 unknowns are missed (F_{CB}; F_2; F_1); $F_{CU} = 1800\ N$;

Vmax= maximum velocity of motorcycle = 135 km/hr=135/3.6=37.5 m/s;

Vmax=Wwheel*Radius →\Wwheel = Vmax/Radius = 37.5/0.29 = 129.31 rad/s

Vjoin = Wwheel*Rcrown = 129.31*0,121 = 15.64 m/s

F_{CB} = 19500/15.64 = 1246.28 N here

Solving these two equations $F_1 = 2550\ N$; $F_2 = 1375.3\ N$;

5.3.2Maximum braking to the front axle

Diamond Chassis

Forces act on the motorcycle (diamond chassis) (Figure 5.9):

1. Normal force Nf exchanged between the road and the tires (ascending force) (mentioned in red color)

2. The driving force of the engine T, which the floor applies to the bike at the contact point of the front wheel. (Same direction of the wheel because we have maximum braking in the front axle).(mentioned in red color).
3. Two internal forces that act on the steering of the frame (F1 and F2 opposite direction and mentioned in green color).

AB=0.29m; BC=0.475m; CD=0.253m; BD=0.705m; T_{df}=703.2 N; N_f=1579.41 N;

To calculate F1 and F2 Newton Second law will be used: $\sum fx = M * a$; $\sum fy = M * a$; $\sum moment = I\ddot{O}$ At equilibrium $\sum moment = 0$;

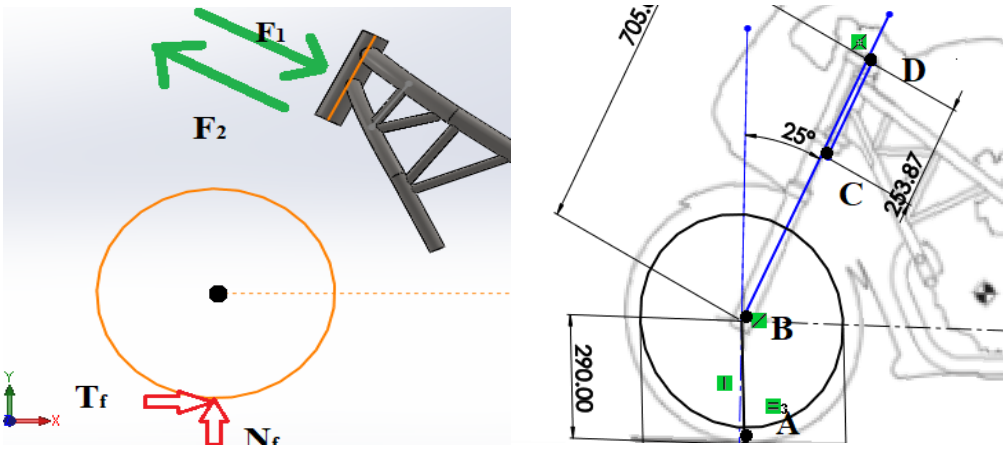


Figure 5. 9 Free body diagram when the maximum braking in the front axle occur (tubular)

$\sum moment\ at\ point\ B$ =0

T_f*AB+F_2*BC -BD*F_1 =0; (Eq 34)

$\sum moment\ at\ point\ D$ =0;

F_2*CD+N_f*BD*sin (25)-T_{dr}*(AB-BD)*cos (25) =0; (Eq 35)

Solving this two equation $F_1 = 768.3$ N; $F_2 = 711$ N;

Perimeter Chassis

AB=0.29m; BC=0.475m; CD=0.253m; BD=0.705m; T_{pf}=646.6 N; N_f=1471.5 N;

To calculate F1 and F2 Newton Second law will be used: $\sum fx = M * a$; $\sum fy = M * a$; $\sum moment = I\ddot{O}$ at equilibrium $\sum moment = 0$;

$\sum moment\ at\ point\ B$ =0; $\sum moment\ at\ point\ D$ =0; respectively

T_{pf}*AB+F_2*BC -BD*F_1 =0; (Eq 36)

F_2*CD+N_f*BD*sin (25)-T_{pr}*(AB-BD)*cos (25) =0; (Eq 37)

Solving this two equation $\mathrm{F}_1 = 689.77$ N; $\mathrm{F}_2 = 629$N;

We remark the forces in perimeter chassis are less than Diamond one and this due to the position of the new center of gravity (in Perimeter one)

5.4 Finites elements method

5.4.1 Maximum acceleration (tubular frame)

Now a static simulation on these two chassis (Diamond, Perimeter) using previous forces (when the bike went at maximum acceleration) is analyzed by using ANSYS18.1 Software. Steering axle is fixed and forces were applied like in the figure shown below

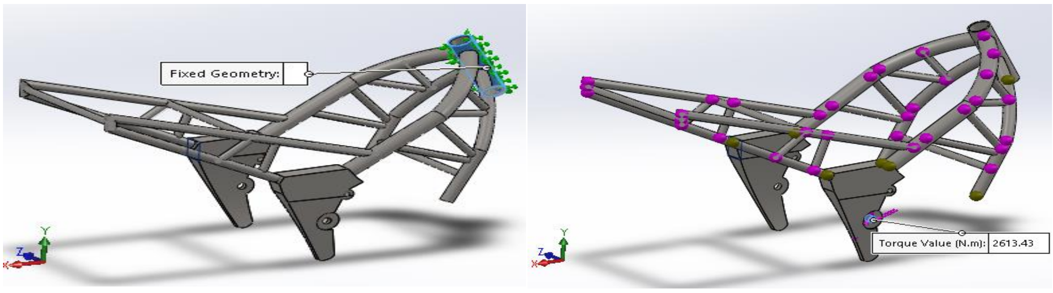


Figure 5. 10 Fixture and applied load for tubular frame

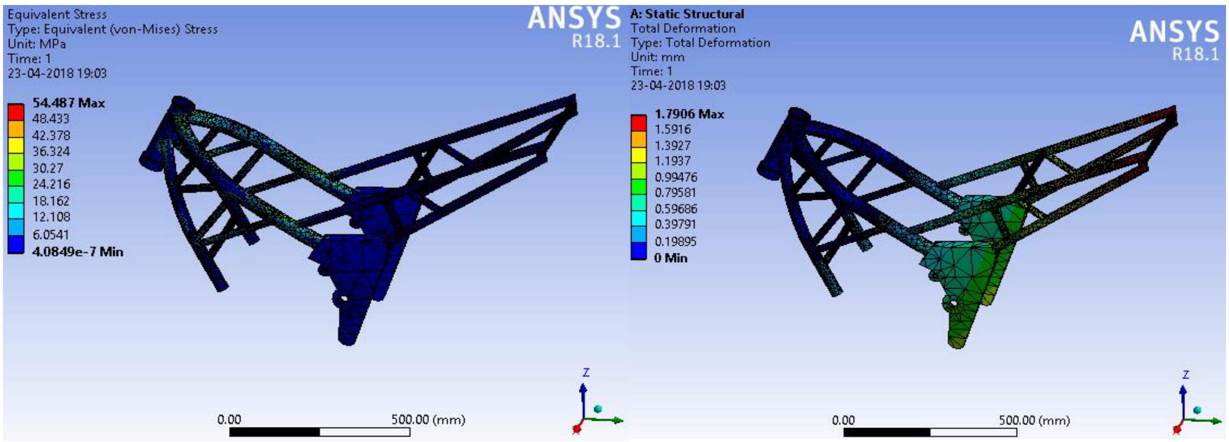


Figure 5. 11 Case 1 results extracted from ANSYS R, deformation and stress of tubular chassis

Deformation: biggest cell at a displacement reaches mm1.7906 mm approximately 1.8 mm.

Sticking get strained at 54.487 MPa, and the lowest rate of 0.408 Pa

Maximum acceleration (perimeter chassis)

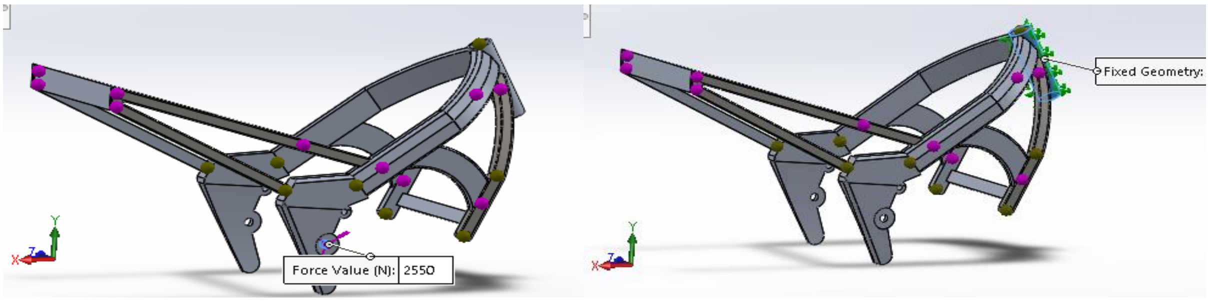


Figure 5. 12 Fixture and applied load for perimeter frame

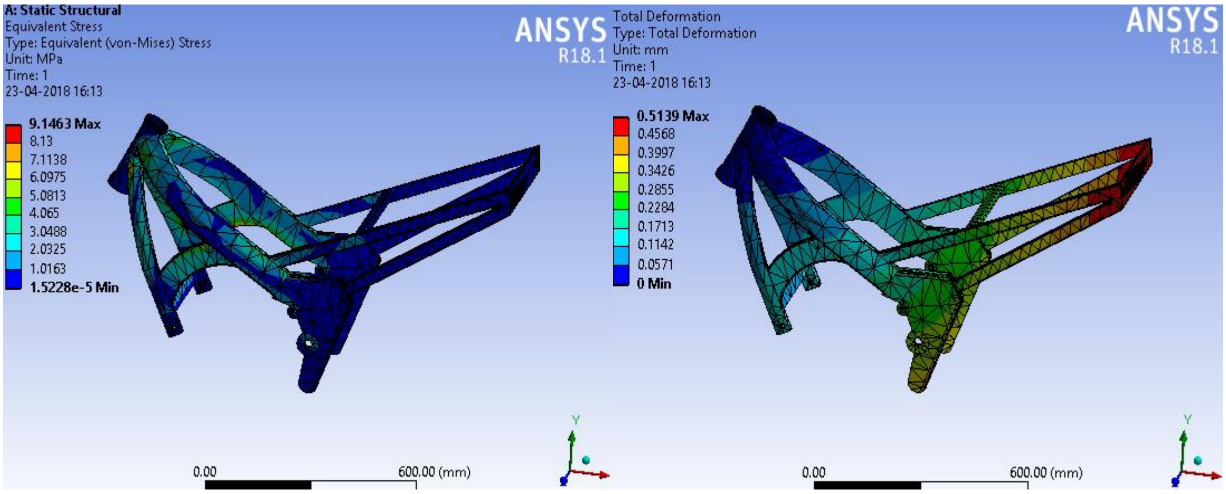


Figure 5. 13 Case 1 results extracted from ANSYS R Workbench 18.0 shows the stresses and deformation of Perimeter chassis

Frame cell at a displacement and cash distribution shown in Figure 5.13. Total displacement is plotted on the y axis direction. In this direction we get the frame and the biggest cell at a displacement reaches mm0.5139 mm. Sticking get strained at 9.1463 MPa, and at the lowest rate of 15.2Pa. The greatest truth held in place. Lowest point, furthest from anchors and power.

The stiffness can be calculated dividing the load applied for the displacement (Equation 43) or in the case of a moment, divided by the rotation (Equation 44).

$K_b=\frac{F}{\delta}$ (bending Stiffness) ;$K_t=\frac{M}{\theta}$(torsion rigidity); F=$\sqrt{F1^2+F2^2}$;$\delta=$ 0.5139 mm

Parts	Lateral(KN/mm)
Main Chassis	1-5
Swing-arm	0.8-0.16

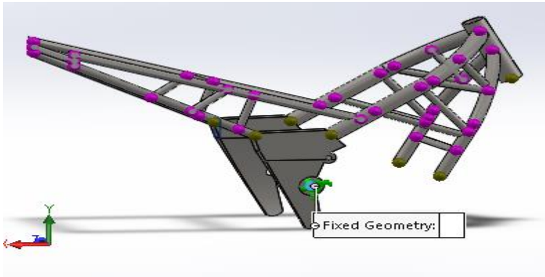
Using MATLAB Software Bending Stiffness K_b=5460 N/mm=5.46KN/mm;

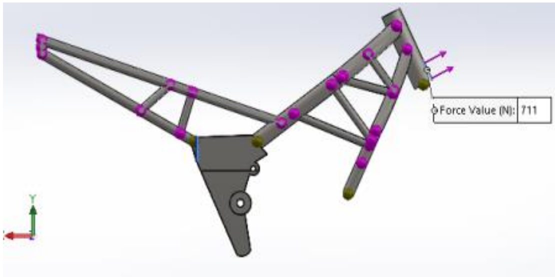
Remark: our results is too close to the average and is bigger than the diamond one that means the Perimeter chassis can support more load than the diamond chassis when the bike travels at maximum acceleration(this was based on the Table 12 specified by Vittore Cossalter in his "Motorcycle Dynamics" book) .

Remark that the Stress in the other chassis (our design, perimeter one) has decrease due to the new shape (tubular to shell), and also due to changing the material (steel to aluminum).

5.4.2 Maximum braking to the front axle

(tubular)





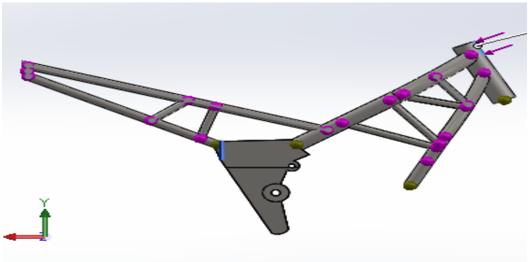


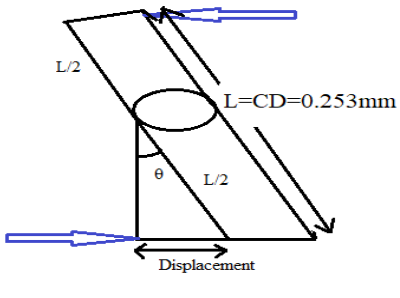
Figure 5. 14 Fixture and torque for tubular

Now a static simulation on these two chassis (Diamond, Perimeter) using previous forces (when the bike went at maximum acceleration) was analyzed by using ANSYS18.1 Software

The two pins that link the frame by the wheels are fixed and two opposite internals forces are applied on the steering axle

Using sine law, the displacement and the angle θ is calculated, and then the torsion rigidity will be found.$K_t = \frac{M}{\theta}$(torsion rigidity), M is the moment; θ is the angle of deformation. M =Force*d,

On this part, two opposites force are applied on the steering axe (F1 and F2 was calculated in the previous page). Frame elements shifts and their distribution are shown in Figure 5.15. Total displacement is plotted on the y axis. The maximum displacement equals to 0.4128 mm.



$$\theta = \text{arctg}\left(\frac{d}{L/2}\right);\ \theta = \text{arctg}\left(\frac{0.4128}{0.253/2}\right) = 0.187 \qquad \text{(Eq 38)}$$

Figure 5. 15 Free body diagram of steering axle

M=F1*d=768.3*0.253 / 2=97.189 N.m;

$K_t = \frac{M}{\theta}$(torsion rigidity)=97.189/0.187

K_t=519 N/º=0.519 KN/º. (Eq 39)

Sticking get strained at 23.071 MPa, and at the lowest rate of 631Pa

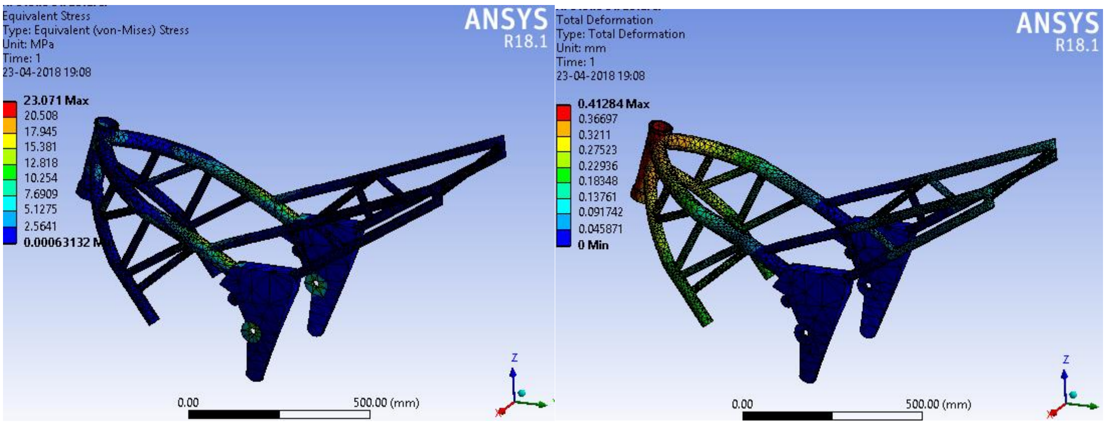


Figure 5. 16 Case 2 (maximum braking) deformation ,stress of Diamond chassis (tubular Frame)

Maximum braking to the front axle (perimeter)

Using the same procedure and the same calculations, we need to change the force F1 according to the previous calculation for the maximum braking (perimeter chassis)

$$\theta = \arctan\left(\frac{d}{L/2}\right);\ \theta = \arctan\left(\frac{0.2636}{0.253/2}\right) = 0.1193 \qquad \text{(Eq 40)}$$

M=F1*d=689.77*0.253 / 2=87.255 N.m (Eq 41)

$K_t = \frac{M}{\theta}$**(torsion rigidity)=87.255/0.11939 =730.82 N/º.**

(Eq 42)

Sticking get strained at 9.878 MPa, and the lowest rate of 296PaClarifying strained path shown in figure 38

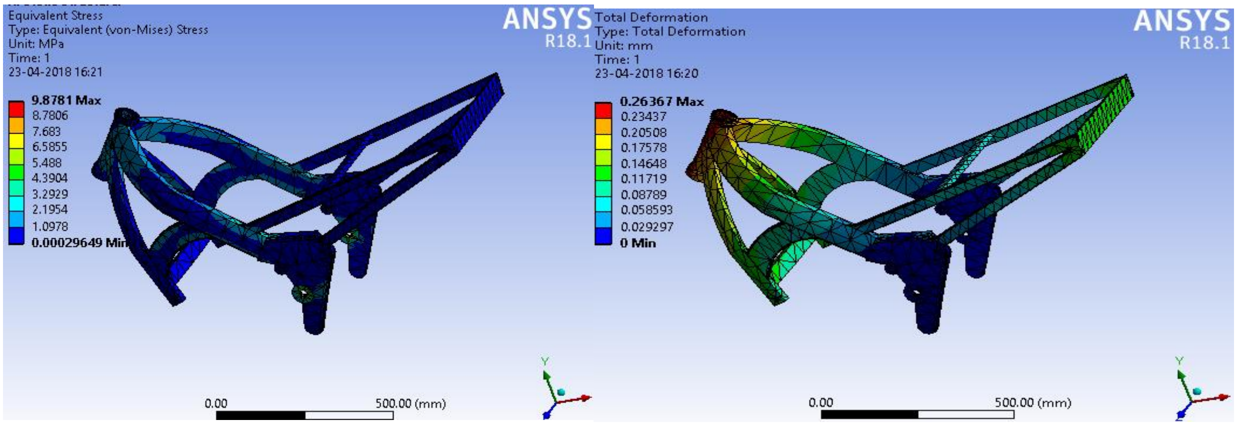


Figure 5. 17 Case 2 (maximum braking) deformation ,stress of Perimeter chassis (tubular Frame)

Table 5. 5 Entire test, forces, stiffness between this two chassis (small comparison between Diamond and Perimeter chassis at maximum acceleration and braking in the front axle).

Type of chassis	**Test**	**Max Acceleration**	**Max braking in the front**
Diamond Chassis (Tubular)	**External Forces(N)**	N_r=1579.41 $N_F = 0$	N_f=1579.41 $N_r = 0$
		T_{dr}=3158.82	T_{dr}=703.2
	Internal Forces (N)	$F_{1=}$2613.43	$F_{1=}$768.3
		$F_{2=}$1483.23	$F_{2=}$711
	Material used	Steel	Steel
	Deformation (mm)	1.7906	0.4128
	angle θ (º)	0º	0
	Stress (Pa)	54.487	23.071
	External Forces (N)	N_r=1471.5 / $N_F = 0$	N_f=1471.5 / $N_r = 0$
		T_{dr}=3096.2	T_{dr}=646.6
		$F_{1=}$2550	$F_{1=}$689.77

Perimeter Chassis (Shell)	**Internal Forces (N)**	$F_{2=}$1375.3	$F_{2=}$629
	Material used	Aluminum	Aluminum
	Deformation (mm)	0.5139	0.263
	Stress (Pa)	9.1463	9.878

Chapter 6

6. Dynamical characteristics of both frames

Laboratory work is to modify a Honda CBR250R motorcycle frame to withstand major loads. Further to find the frame construction, displacement and stress by applying all the specific tests.
For this purpose, a layout of CBR250R is drawn. As per the frame drawing, I created the frame in 3D using SOLID WORKS and applied all these tests and simulations on it using ANSYS R Workbench 18.0(this would lead to a simpler interface to create the different studies). The design of a given frame was performed by numerical analysis, find variations when the frame is exposed to masses of the motorcycle strength and torsional Frame, after all this work we can conclude where the weakness of this frame is. Then a new layout is re-designed by changing the shape of chassis and the material.

The load applied on the chassis in all these tests approximately equals to 4000 N, considering the total motorcycle weight around 160 kg and a rider with 110kg. The 110kg for the rider may be considered a big weight, but more than often, the rider carry extra loads on their bike (Motorcycle Helmets, Jackets Gloves Saddle, Bags, Suit, and Winter Motorcycle Gloves).
Applying a security coefficient of 1.5 and approximating the gravitational acceleration 9.81 m/s^2, a force with 4000 N was calculated.

But according to Vittore Cossalter in his "Motorcycle Dynamics" book they compare the result by applying a load equal to 1KN.[7]
In this part, a lot of tests were applied (lateral, rig, vertical and longitudinal), We also devised in addition to the cases recreating the various situations extracted from the normal usage of an off-road motorcycle. This was based on the Table 12 specified by Vittore Cossalter in his "Motorcycle Dynamics" book.
In each case we can calculate the stiffness (bending or torsion). The stiffness can be calculated by dividing the load applied for the displacement (Eq 43) or in the case of a moment, dividing the moment applied by divided by the rotation (Eq 44).

$K_b=\frac{F}{\delta}$ (bending Stiffness); (Eq 43)

$K_t = \frac{M}{\theta}$(torsion rigidity); (Eq 44)

Table 6. 1 Stiffness Value for all component by Vittore Cossalter in his "Motorcycle Dynamics" book[7]

Component	Torsional(KN/º)	Lateral(KN/mm)	Vertical(KN/mm)
Main Frame	3-7	1-3	5-10
Swing-arm	1-2	0.8-0.16	n/a
Fork	0.1-0.3	0.07-0.08	n/a

6.1 Mesh

The mesh used in this analysis was made using the the tetrahedrons method using a lot of patch conformed algorithm included in ANSYS R workbench 18.0.

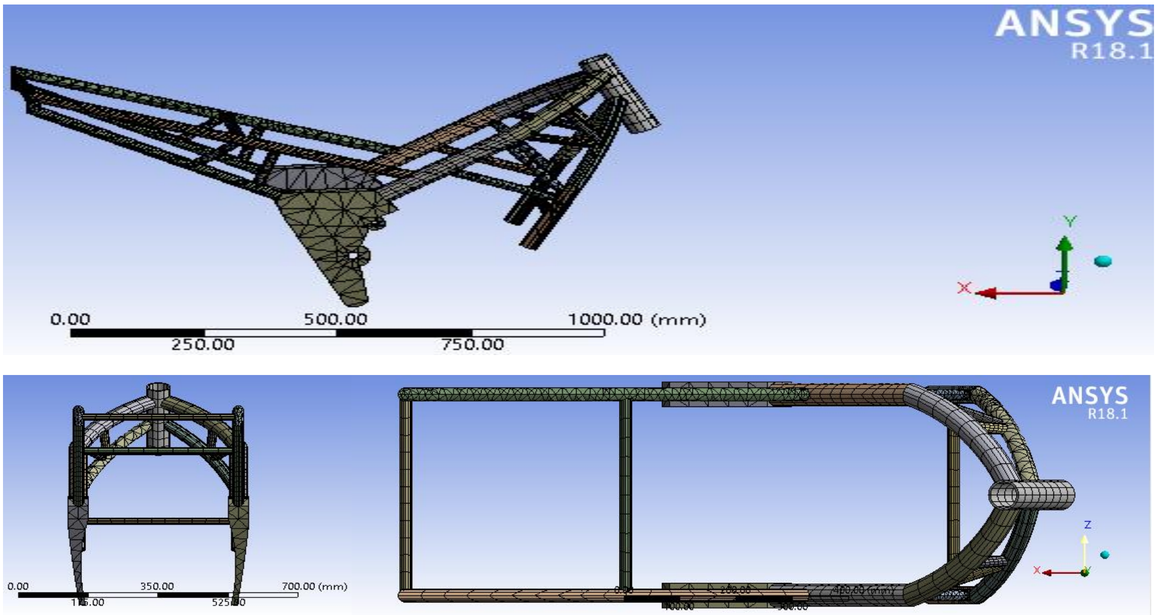


Figure 6. 1 Mesh used in the analysis, generated by ANSYS Workbench 18.0

On this part ,the mesh provided perfect results and the running time for each case take a little bit time (because of circular shape, there a lot of filled and holes). It has 146.654 tetrahedral elements and 259.864 nodes by using ANSYS Workbench 18.0

6.2 Frame's structural stiffness

In this section, a lot of tests were applied to get different stiffness of each frame (Diamond, Perimeter). Here we have three tests:

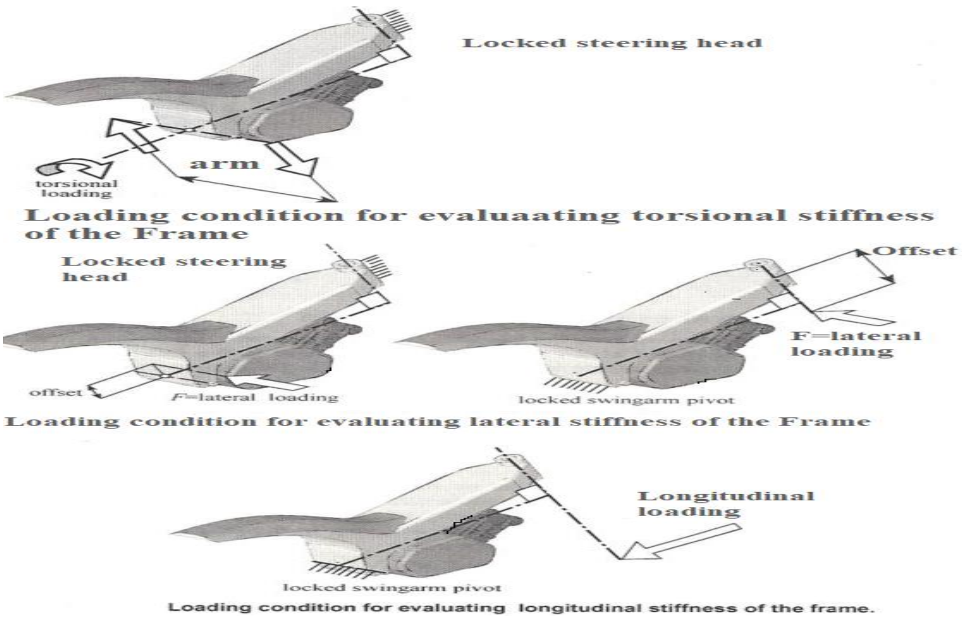


Figure 6. 2 Lateral ,longitudinal and vertical stiffness on the frame [COSALTER, Vittore. Motorcycle1 dynamics. 2n edition. 2006. Page.334].

-Torsion stiffness of the chassis is measured with the engine fitted (in our case the engine is not considered).we do the calculation about an axis at a right angle to the steering axle and passing through the swinging arm pivot axis and applying a torque or to opposite forces around this axis. In torsion case, we divide the moment applied by the rotating angle θ.

- Lateral stiffness can also be represented by the radio between the force applied on the chassis and the lateral displacement measured in that direction (direction of load). In order to avoid torsion deformation we will apply the forces with an offset. It varies depending on the type of frame and the method of engine attachment.

- Longitudinal stiffness occurs when we apply force on the steering axle (perpendicular forces to avoid shear stress) and by fixing the swinging arm of the bike.

6.3 Test for tubular chassis

6.3.1 Lateral frame stiffness (tubular chassis)

In this part, a lateral force F to the center of steering axle is applied transversely, fixing the swinging arm and then the rigidity is calculated upon the deformation produced, by putting all the stress and displacement results in the equation 43.

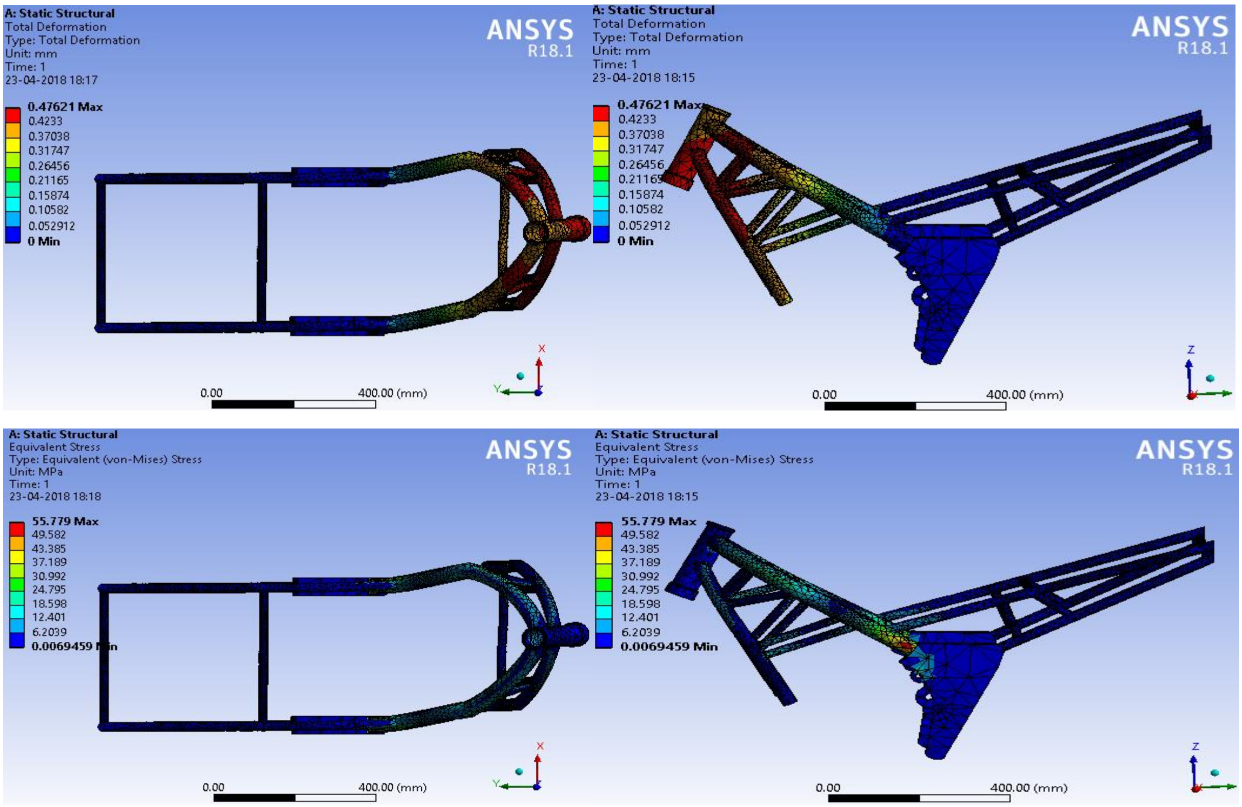


Figure 6. 3 Results from ANSYS R Workbench 18.0 shows the deformation and tress of diamond chassis.

From the results of the test shown above in the figure, the Diamond chassis can resist such amount of forces; on the other hand, some weakness between the support and the steel tube also appeared (to take into account when a new chassis will be re-design)

According to the result, the maximum deformation equals to 0.476 mm and the maximum stress equals to 55.7 MPa. The stiffness can be calculated by dividing the load applied by the displacement (Equation 43) or in the case of a moment, divided by the rotation (Equation44).

Table 6. 2 Vittore Cossalter in his "Motorcycle Dynamics" book

Component	Lateral(KN/mm)
Main Frame	1-3

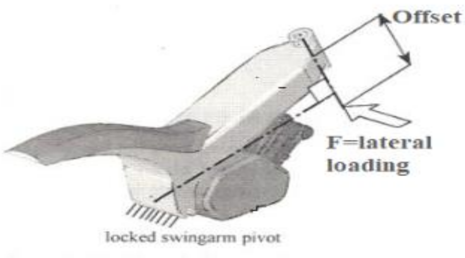


Figure 6. 4 Fixture and load (lateral)

$K_b = \frac{F}{\delta}$ (bending Stiffness) =2100 N/mm=2.1 KN/mm

(Eq 45)

According to Stiffness Value for all components by Vittore Cossalter in his "Motorcycle Dynamics" book, our calculated value is between the intervals

Longitudinal frame stiffness (tubular chassis)

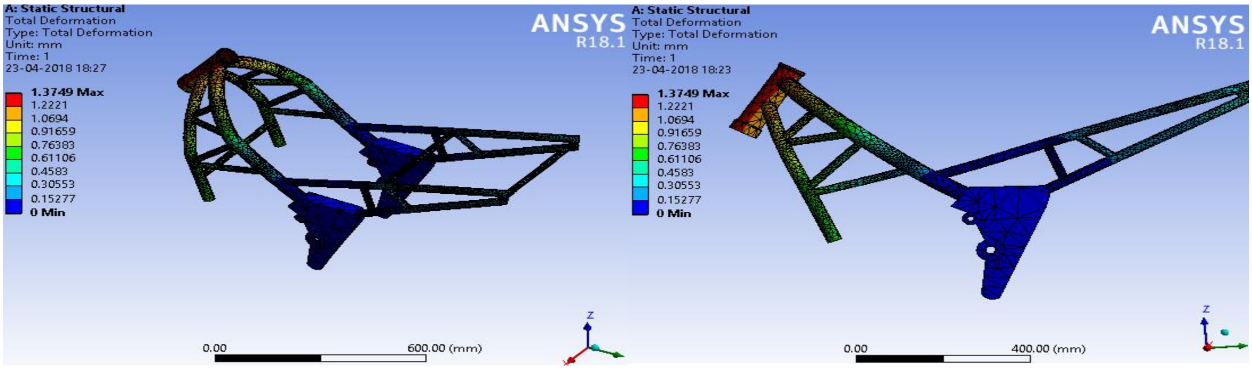


Figure 6. 5 Results extracted from ANSYS R Workbench 18.0 shows deformation of diamond chassis

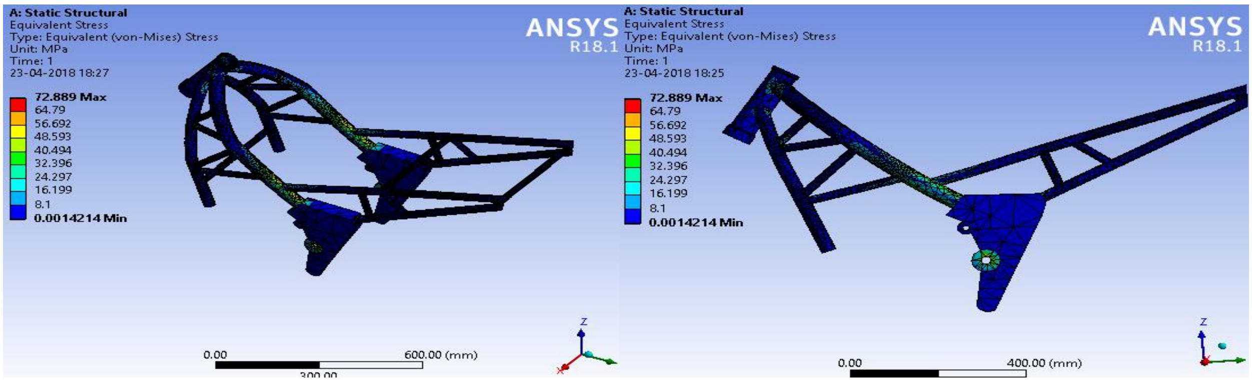


Figure 6. 6 Results extracted from ANSYS R Workbench 18.0 shows stress of diamond chassis

For a static chassis, a frontal impact force is applied on the steering axle by fixing swinging arm. After applying this resultant force, we can observe the following chassis deformation and stress.

During the acceleration and braking longitudinal forces are generated along the (x-z axis).

The load applied on the chassis in all the tests equals to 4000 N, considering the total motorcycle weight around 160 kg and a rider weighing 110kg. Applying a security coefficient of 1.5 and approximating the gravitational acceleration to 9.81 m/s^2, a force with 4000 N was calculated.

According to the result, the maximum deformation equals to 1.374 mm and the maximum stress equals to 72.889MPa. K_b=$\frac{F}{\delta}$ (bending Stiffness) =2911.2 N/mm approximately 3 KN/mm

Referring to Stiffness Value for all components by Vittore Cossalter in his "Motorcycle Dynamics" book, our calculated value is under the average ,the longitudinal stiffness of the chassis studied is a little under the values specified. This may cause some discomfort or a poorer handling than the manufacturer wants (that means we have week part on this chassis and we can know this by checking the result of ANSYS [red color])

Table 6. 3 Part of table Stiffness Value for all components by Vittore

Component	Longitudinal (KN/mm)
Main Frame	5-10

Figure 6. 7 Fixture and load (longitudinal)

Torsion frame stiffness (tubular chassis)

The vehicle body is subjected to a moment at the axle center lines by applying upward and downward loads at each axle in this case. As the vertical loads always exists due to gravity,and the condition of pure torsion cannot exist on its own.

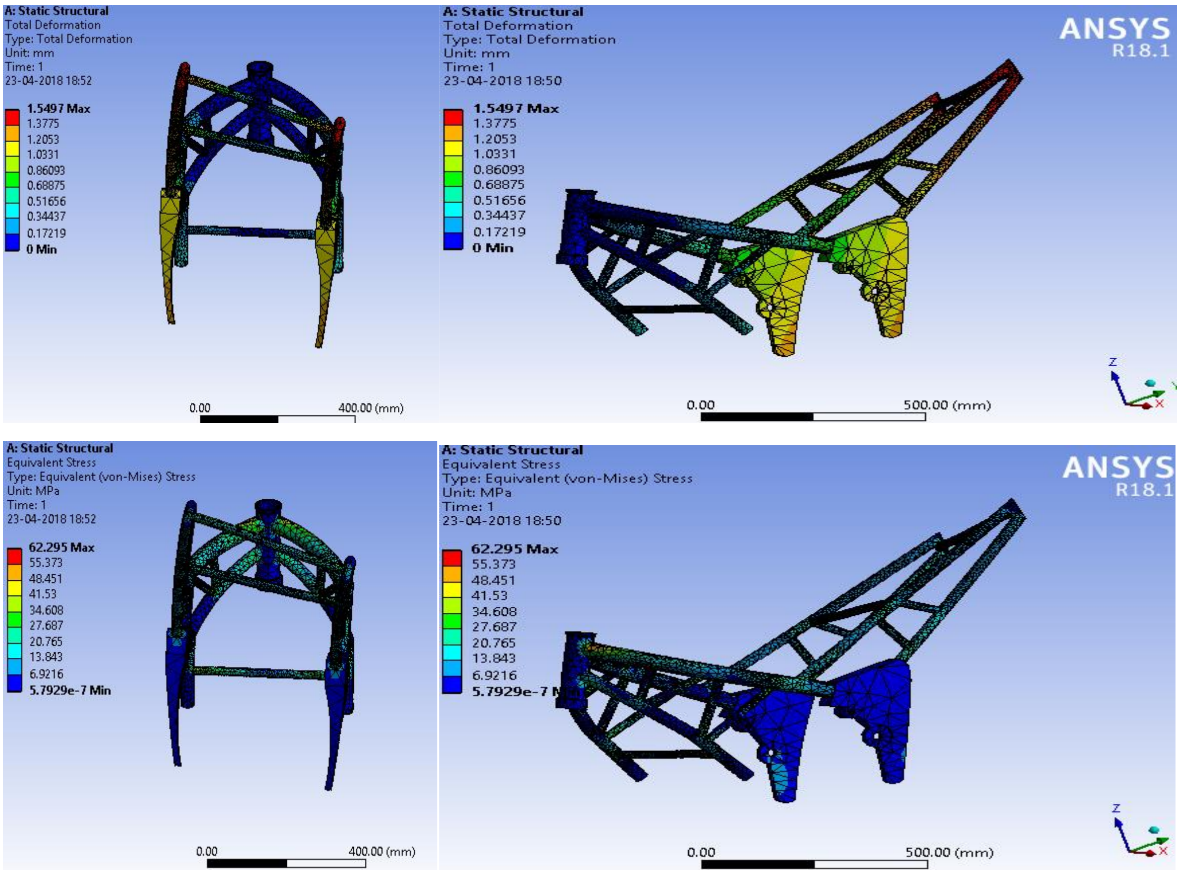


Figure 6. 8 Results extracted from ANSYS R Workbench 18.0 shows the deformation and stress of diamond chassis

Table 6. 4 Stiffness Value for all component by Vittore

Component	Torsional(KN/º)
Swing-arm	1-2

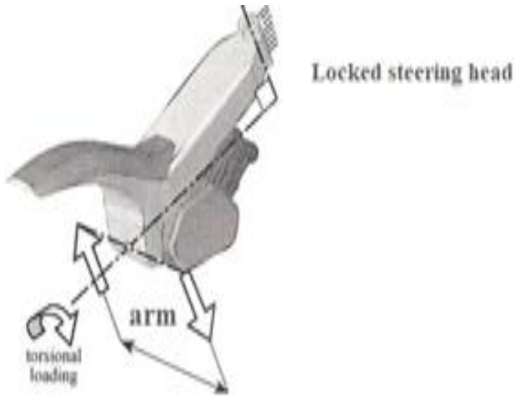


Figure 6. 9 fixture and load (torsion)

According to the result, the maximum deformation equals to 1.55 mm and the maximum stress equals to 62.296MPa. K_t=$\frac{M}{\theta}$(torsion rigidity);

M=F*d/2=4000/0.2=20 KN/m, M is the moment; F is the force; d is distance between 2 arms.

θ =arctan ($\frac{deformation}{d/_2}$)=0.429; θ is the angle of deformation. (Eq 46)

K_t=$\frac{M}{\theta}$(torsion rigidity)=1864.8 N/º=1.8648 KN/º (Eq 47)

6.3.2Test for Perimeter chassis

Lateral frame stiffness (perimeter chassis)

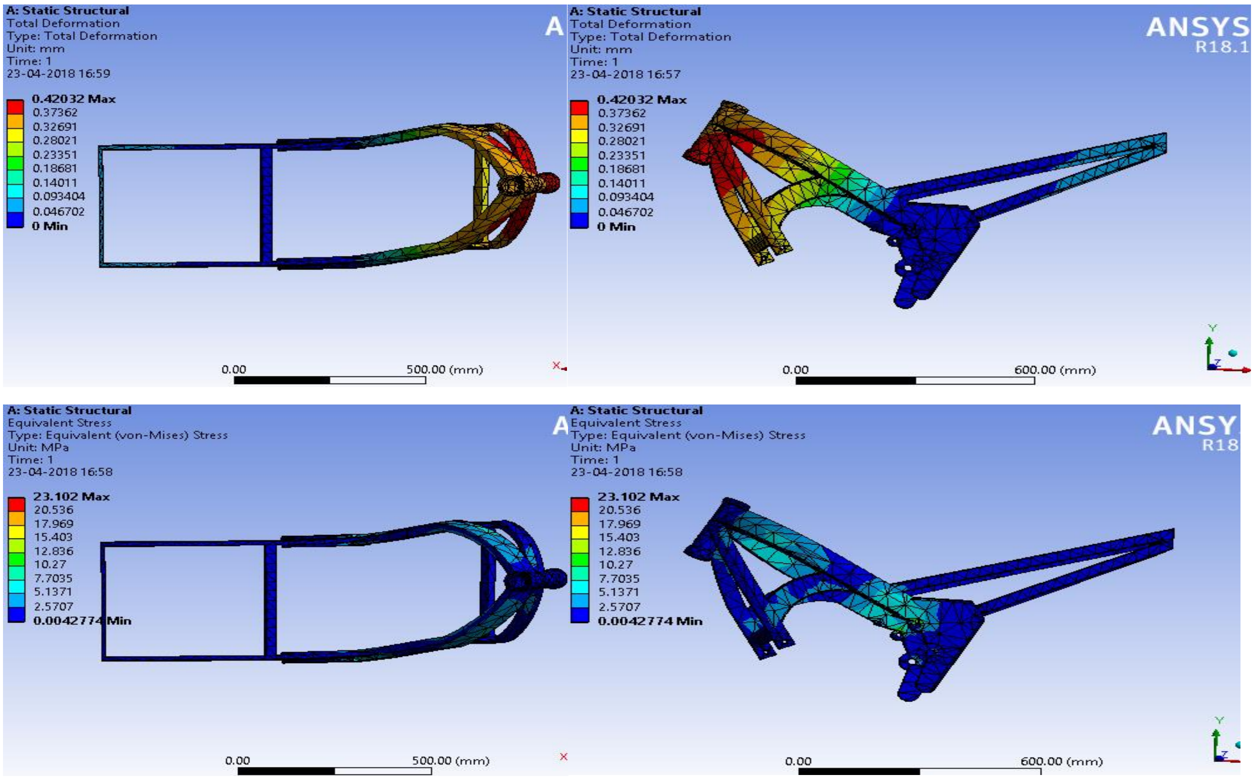
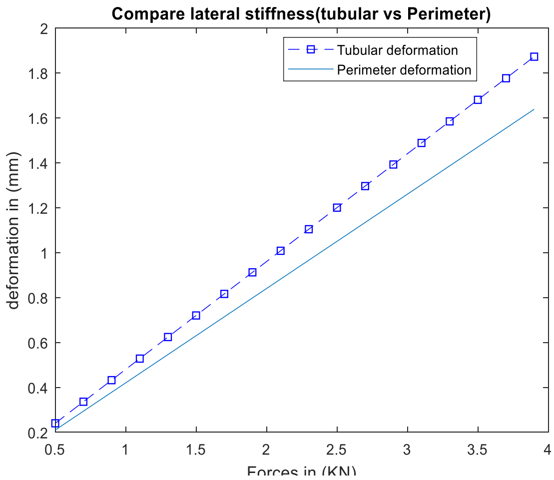


Figure 6. 10 Results extracted from ANSYS R Workbench 18.0 shows the deformation and stress of perimeter chassis

Doing the same procedure but on a perimeter chassis, the maximum deformation equals to 0.42 mm and the maximum stress equals to 23.102MPa.

$K_b = \frac{F}{\delta}$ (bending Stiffness) =2380 N/mm=2.38 KN/mm.

Referring to Stiffness Value for all components by Vittore Cossalter in his "Motorcycle Dynamics" book, our calculated value is between the intervals



		Forces (KN)						
		0.5	1	1.5	2	2.5	3	4
Tubular Frame	Deformation (mm)	0.24	0.48	0.36	0.96	1.2	1.44	1.92
	Lateral rigidity (kN/mm)	2.1						
Perimeter Frame	Deformation (mm)	0.21	0.42	0.63	0.84	1.05	1.26	1.68
	Lateral rigidity (kN/mm)	2.38						

Graph6. 1 Deformation when we apply force for both frames in lateral simulation Using MATLAB Software,Appendix A

Longitudinal frame (perimeter chassis)

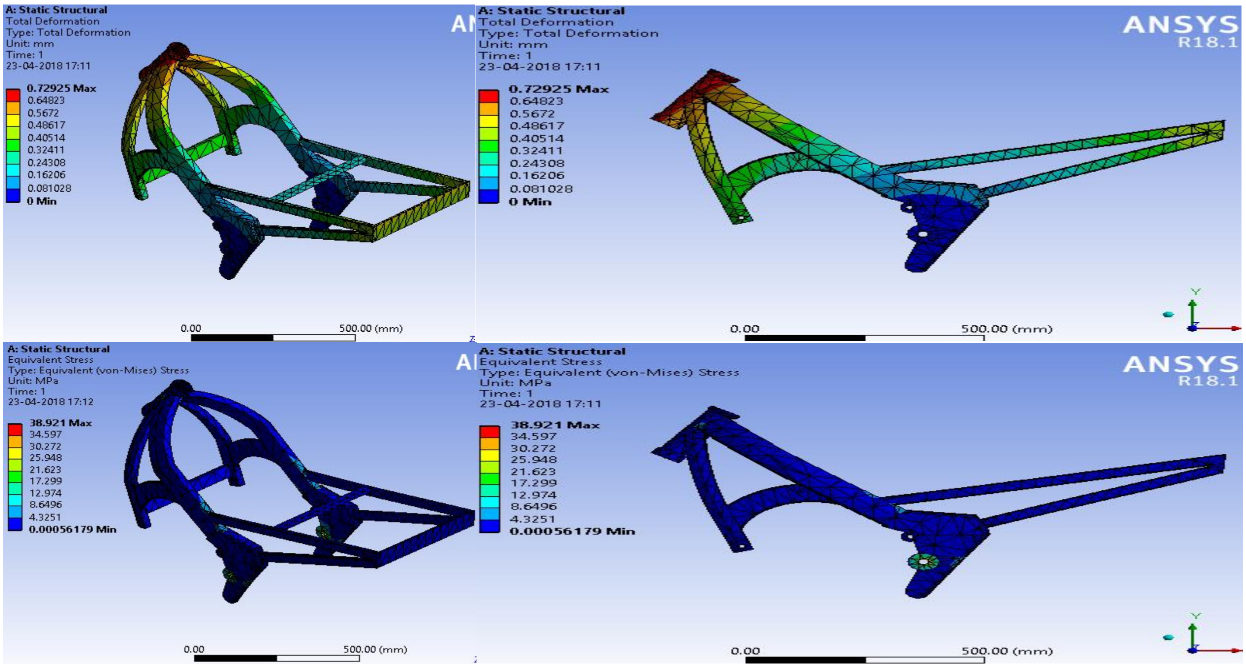
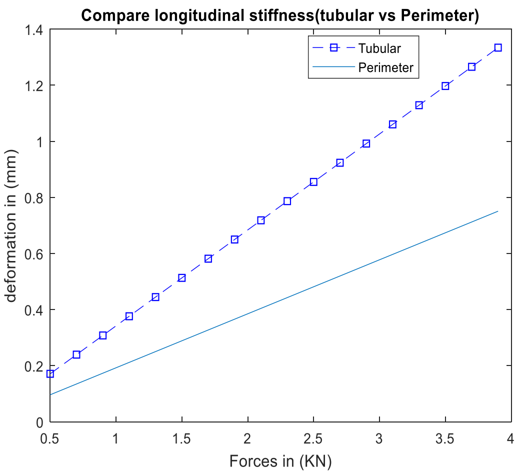


Figure 6. 11 Results extracted from ANSYS R Workbench 18.0 shows the deformation and stress of perimeter chassis.

The maximum deformation equals to 0.729 mm and the maximum stress equals to 38.921MPa. $K_b=\frac{F}{\delta}$ (bending Stiffness) =5479 N/mm=5.479 KN/mm. Referring to Stiffness Value for all components by Vittore Cossalter in his "Motorcycle Dynamics" book, our calculated value is between the intervals.



Graph6. 2 Deformation when we apply forces for both frames in longitudinal simulation (Using MATLAB Software) Appendix A

		Forces (KN)						
		0.5	1	1.5	2	2.5	3	4
Tubular Frame	Deformation (mm)	0.171	0.343	0.515	0.687	0.858	1.03	1.37
	Longitudinal rigidity (kN/mm)	2.9						
Perimeter Frame	Deformation (mm)	0.091	0.1825	0.273	0.365	0.456	0.547	0.73
	Longitudinal rigidity (kN/mm)	5.479						

Torsion frame stiffness (Perimeter chassis)

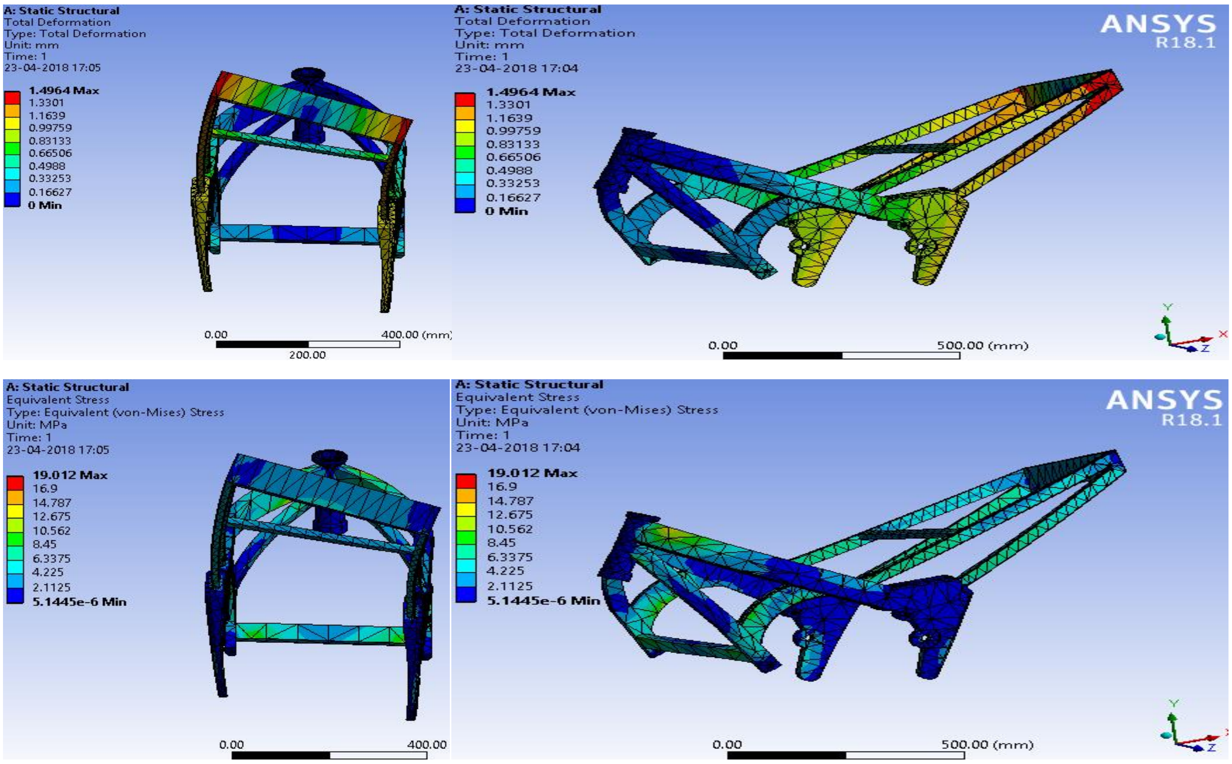


Figure 6. 12 Results extracted from ANSYS R Workbench 18.0 shows the deformation and stress of perimeter chassis

According to the result, the maximum deformation equals to 1.55 mm and the maximum stress equals to 62.296MPa

$$K_t = \frac{M}{\theta}\,\text{(torsion rigidity);} \qquad \text{(Eq 48)}$$

M=F*d/2=4000/0.2=20 KN/m, (Eq 49)

M is the moment; F is the force; d is distance between 2 arms.

$$\theta = \text{arctg}\left(\frac{deformation}{d/2}\right) = 0.429; \qquad \text{(Eq 50)}$$

θ is the angle of deformation.

$$K_t = \frac{M}{\theta}\text{(torsion rigidity)} = 1890.8\ \text{N/º} = 1.8908\ \text{KN/º} \qquad \text{(Eq 51)}$$

Table 6. 5 Results for all stiffness analysis for both frames

	Lateral rigidity (kN/mm)	Longitudinal rigidity (kN/mm)	Torsion rigidity KN/º
Tubular Frame	2.1	3	1.864
Perimeter Frame	2.38	5.479	1.89

6.4 Rig Test

It's important to know how the main chassis of a bike plays an advance rule in vehicle dynamics. In order to know the principle influences of this component, a dedicated test rig was design and realized. Numerical analysis was done, to identify static stiffness (rig test applied on the steering axle of the CBR250R motorcycle and the re-applied on the new frame (Perimeter one) to compare results between both of them), natural frequencies of a motorcycle frame. So a test rig was designed and realized in order to load the chassis in flexural and torsional configuration.

Many previously studies were done to investigate frame importance on dynamic response on the previous chapter (5and 6), but also we need to apply rig test to compare both frames and to be more accurate.

Test rig can be used for the identification both of flexural and torsional stiffness.

Two opposite load or a moment are apply on the steering head with a "[" shaped link, the rear frame is linked in swing arm's with two fixtures and a central one that ties up suspension's link.

Two opposite forces equal to 0.5KN was applied in the steering head that have a distance d =0.23 m

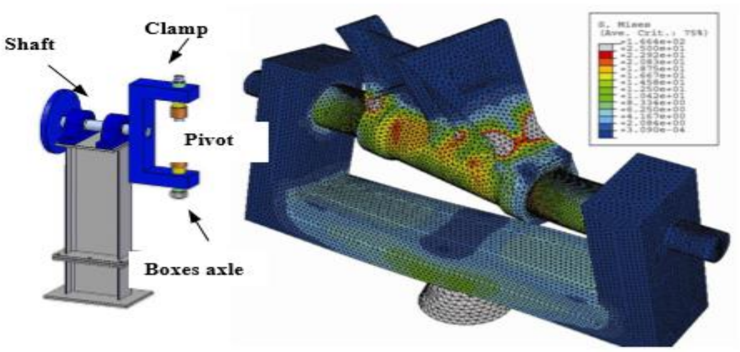


Figure 6. 13 Clamp's components and loading system, results of FEM analysis

$$K_t \text{ for Diamond frame} = \frac{M}{\theta} \text{(torsion rigidity)=4347.8/0.134=32.446 KN/º} \quad \text{(Eq 52)}$$

$$M = F * d/2 = 500/0.230/2 = 4347.8 N/mm \quad \text{(Eq 53)}$$

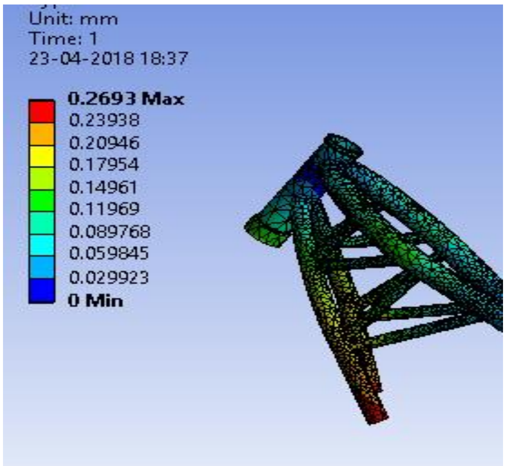
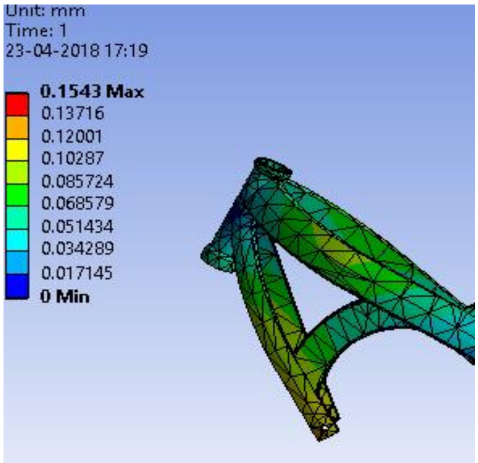
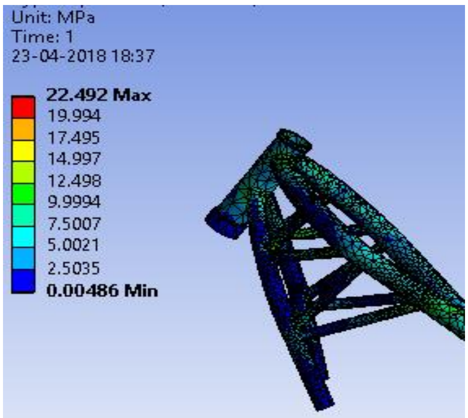
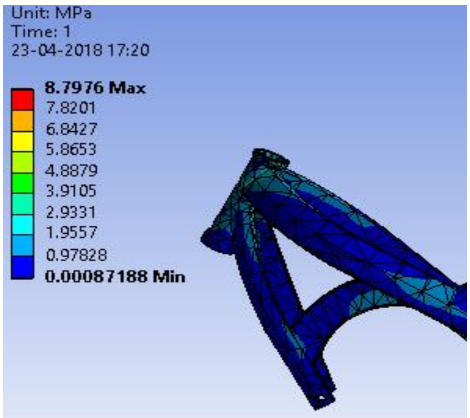
$$\theta = \operatorname{arctg}\left(\frac{deformation}{d/2}\right) = 0.134º \quad \text{(Eq 54)}$$

Same procedure for the Perimeter chassis

$$K_t \text{ for Perimeter frame} = \frac{M}{\theta}(\text{torsion rigidity}) = 4347.8/0.0384 = 113KN/º \quad \text{(Eq 55)}$$

Here we have a comparison between both chassis (Diamond, Perimeter) by applying rig test. According to the table, the torsion rigidity in perimeter chassis is more than diamond one, this due to the shape of frame and the material used .

Table 6. 6 Results extracted from ANSYS R Workbench 18.0 shows the deformation and stress of both frames

<table>
<tr><td>Tubular frame</td><td>Perimeter frame</td></tr>
<tr><td>$K_t = 32.446\ KN/º$</td><td>$K_t = 113KN/º$</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Deformation 0.2693 mm</td><td>Deformation 0.1543 mm</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Stress 22.492 MPa</td><td>Stress 8.7976 MPa</td></tr>
</table>

Chapter 7

7 Natural Frequency analysis

A frequency response function is a mathematical representation of the relationship between the output and the input of a system. Talking about it, natural frequencies and vibration modes are really important to be studied and to know them because then it can be known when the system can vibrate so some dynamical problems can be corrected or fixed during designing or testing process modifying the original structure like adding more mass, changing materials, unions...the frequency response function displays the resonant frequencies of a system and to develop this frequency from an experiment, a load is applied to a body and the resulting displacement at any specific point is measured.

To generate the analysis over a range of frequencies, the frequency of the forcing function must vary across the span of frequencies [8].

Frequency response functions are most commonly used for single input and single output or single input and multi output. Peaks occur at locations where the resulting displacement is higher than the surrounding frequencies, and these peaks occur at the dampened natural frequencies of the system. To get this natural frequencies, the conversion from w_d to w_n is calculated using Equation 51.

For metal structures with very low damping, the value under the square root should be very close to one.

For metal structures such as the steel frame of the chassis like in our first chassis (Diamond chassis), the value of w_d is assumed to equal w_n when in a free-free configuration without integrated composite panels.[9]

Determining the damping ratio of the composite panels is not within the scope of this project.

$$w_n = \frac{w_d}{\sqrt{1-\zeta^2}} \quad \text{(Eq 56)}$$

w_n=Natural frequency in Hz;

ζ=Damping ratio;

w_d = Damping natural frequency in Hz;

The goal of the experimental setup was to design a modal test configuration where the chassis is as close to free-free boundary conditions as possible.

7.1Natural Frequency

7.1.1Natural Frequency for tubular frame

Natural frequencies, deflection modes and damping were identified. At the same time, a detailed numerical model of the main frame was developed. It was processed by the use of the finite element method in order to reproduce the experimental experiences.

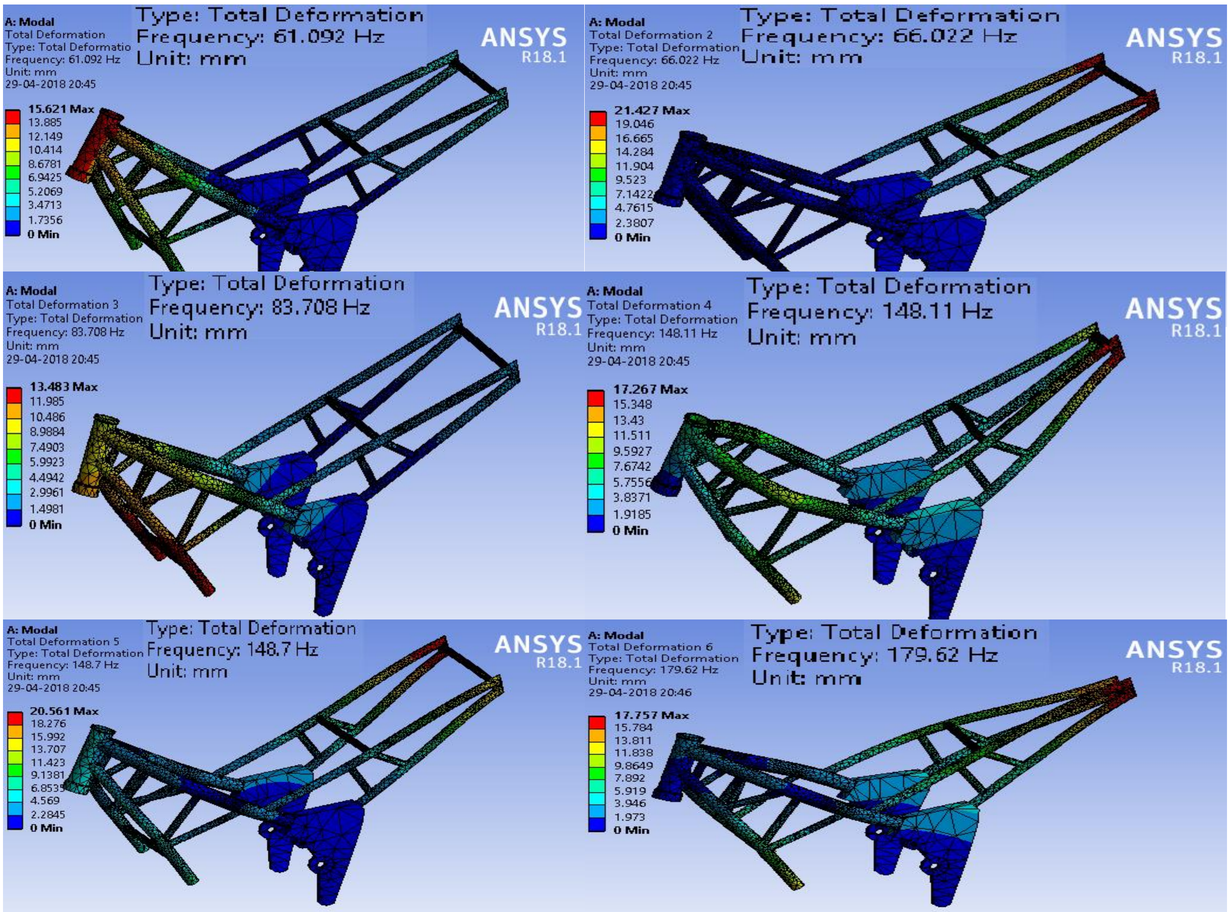


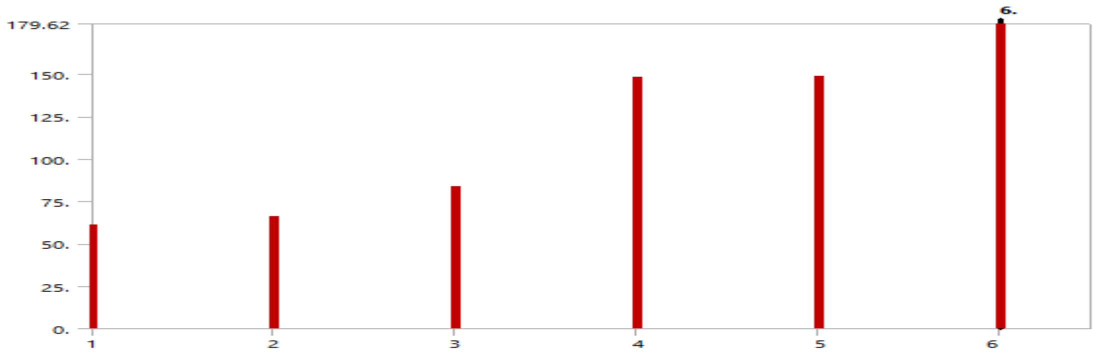
Figure 7. 1 Natural frequencies for tubular frame (6 modes) using ANSYS Software

The

figure below show the natural frequency for the tubular frame by using ANSYS R Workbench 18.0, according to results, total deformation start when the frequency approximately equal to 60 Hz and finish at 180 Hz on the rear part of motorcycle

Table 7. 1 The maximum and minimum deformation for every mode (natural frequency)

	Tubular Frame					
Nodes	1	2	3	4	5	6
Minimum displacement(mm)	0					
Maximum displacement(mm)	15.621	21.427	13.483	17.267	20.561	17.757
Frequency (HZ)	61.092	66.022	83.708	148.11	148.7	179.62



Graph7. 1 Natural frequency of tubular chassis (6 different frequency)

7.1.2 Natural Frequency for perimeter frame

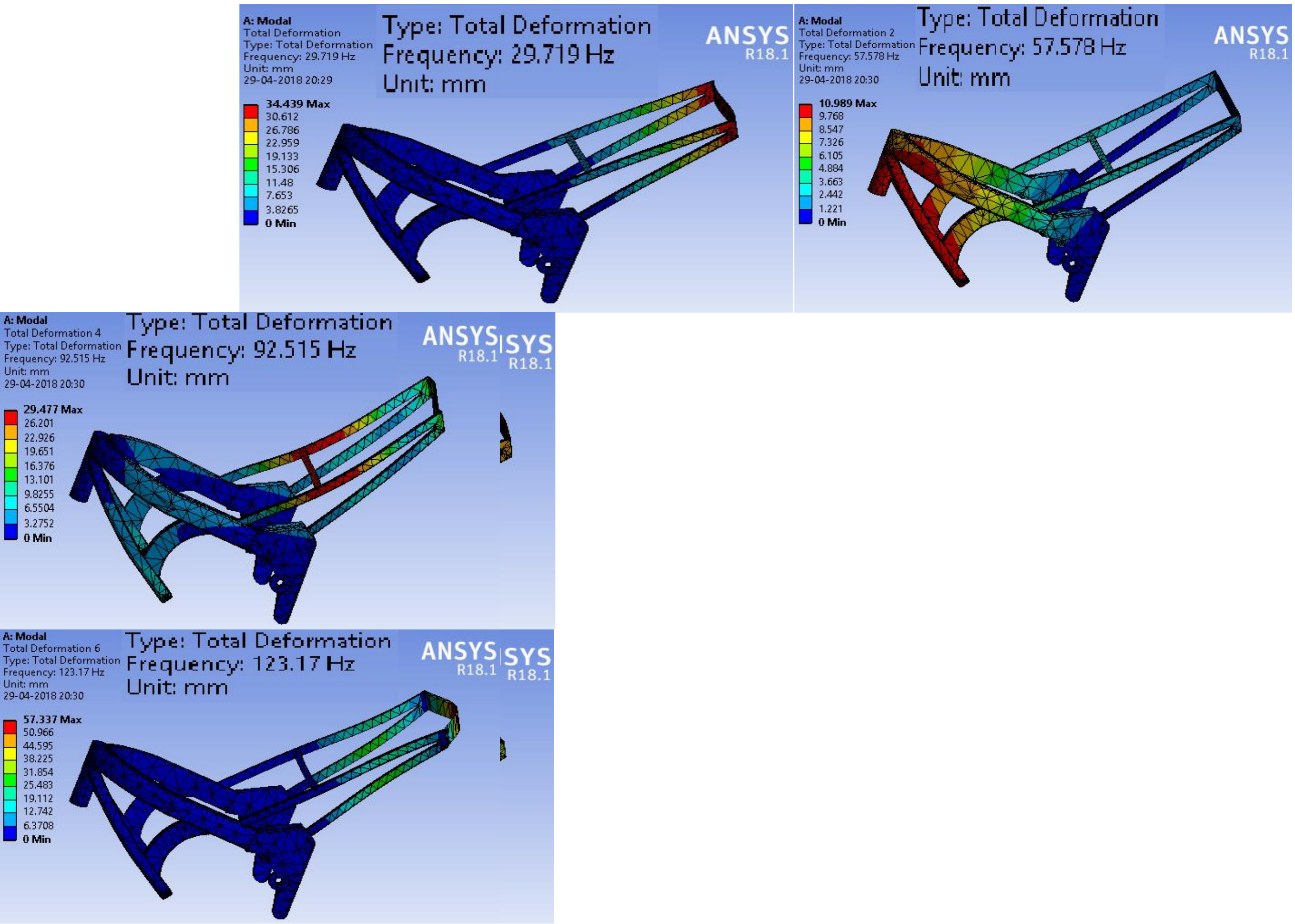
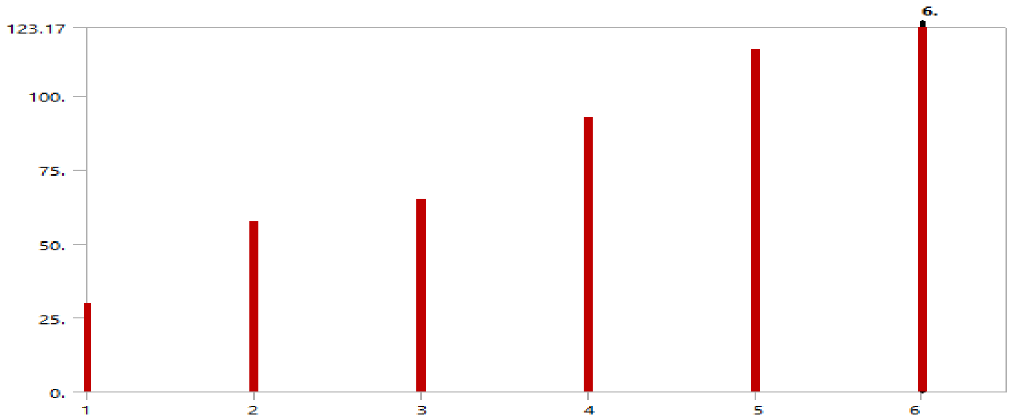


Figure 7. 2 Natural frequencies for perimeter frame (6 modes) using ANSYS Software



Graph7. 2 Natural frequency of perimeter chassis (6 different frequency)

Table 7. 2 The maximum and minimum deformation for every mode (natural frequency) for both frames

	Tubular Frame					
Nodes	1	2	3	4	5	6
Frequency (HZ)	61.092	66.022	83.708	148.11	148.7	179.62
	Perimeter Frame					
Nodes	1	2	3	4	5	6
Frequency (HZ)	29.719	57.578	64.969	92.515	115.69	123.17

Here we have a comparison between both of Chassis (diamond, perimeter) by applying a natural frequency test (6 values are considered), according to our results we can see that natural frequencies (6 value shown on the table) of Diamond chassis are much higher than Perimeter chassis, although the first value frequency on perimeter frame is too low comparing to the other one (due to small thickness on rear part of the motorcycle).the next frequency value is quite similar in both of them but then there is a big decrease of them.

We know that as much low the natural frequencies are, more problems will affect the frame, and here we reefer this low value (natural frequencies) to rear part, on other hand out study require the front part of motorcycle where all the forces are applied on it(as we can see on in previous chapters).

7.2 Mechanical fatigue

Metallic alloys have a distinct behavior characterized by a plastic behavior preceded by an elastic one. Usually, structures are intended to work under elastic behavior, which means that the yield stress must not be exceeded. To analyze if the stresses don't exceed the yielding threshold the Von Mises criterion.

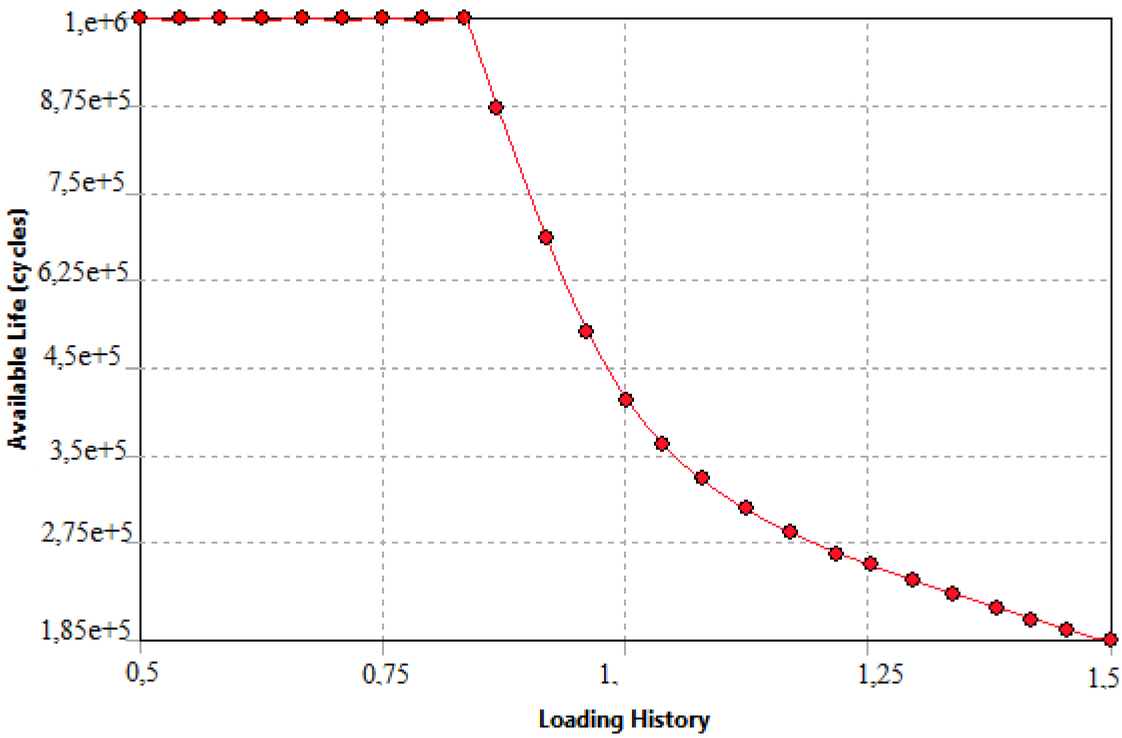
$$\frac{S_y}{n} > \sqrt{\frac{(\sigma_{xx}-\sigma_{yy})^2+(\sigma_{xx}-\sigma_{zz})^2+(\sigma_{yy}-\sigma_{zz})^2+\partial({\sigma_{xy}}^2+{\sigma_{xz}}^2+{\sigma_{zy}}^2)}{2}} \qquad \text{(Eq 57)}$$

Usually in mechanical engineering, structures aren't under static loads, which mean fatigue analysis must be performed in order to ensure that cracks are propagating in a controlled rate, which is critical mainly on aluminum alloys. Still, due to the fact that there isn't enough data about the metals, fatigue will only be taken into consideration as a way of evaluating details on the geometry [10]

The fatigue of materials is a phenomenon in which materials are destroy by low (take a long period), cyclic efforts and dynamic that constantly are applied to the body chassis and they are less important that any static force which could break the material in a short time.

7.2.1 Mechanical fatigue for Diamond chassis

If we suppose that the motorcycle travel 1 hours per day such a normal average, during this period, approximately 150 braking times and 150 acceleration will happen, so we have at least 300 forces was applied on the chassis in this small period of time (two hours).let assume that the motorcycle travel 300 days per year (autumn and summer time) we will have 300*200=60000 cycles per year with alternation between maximum acceleration and maximum braking with front axle for both frames.

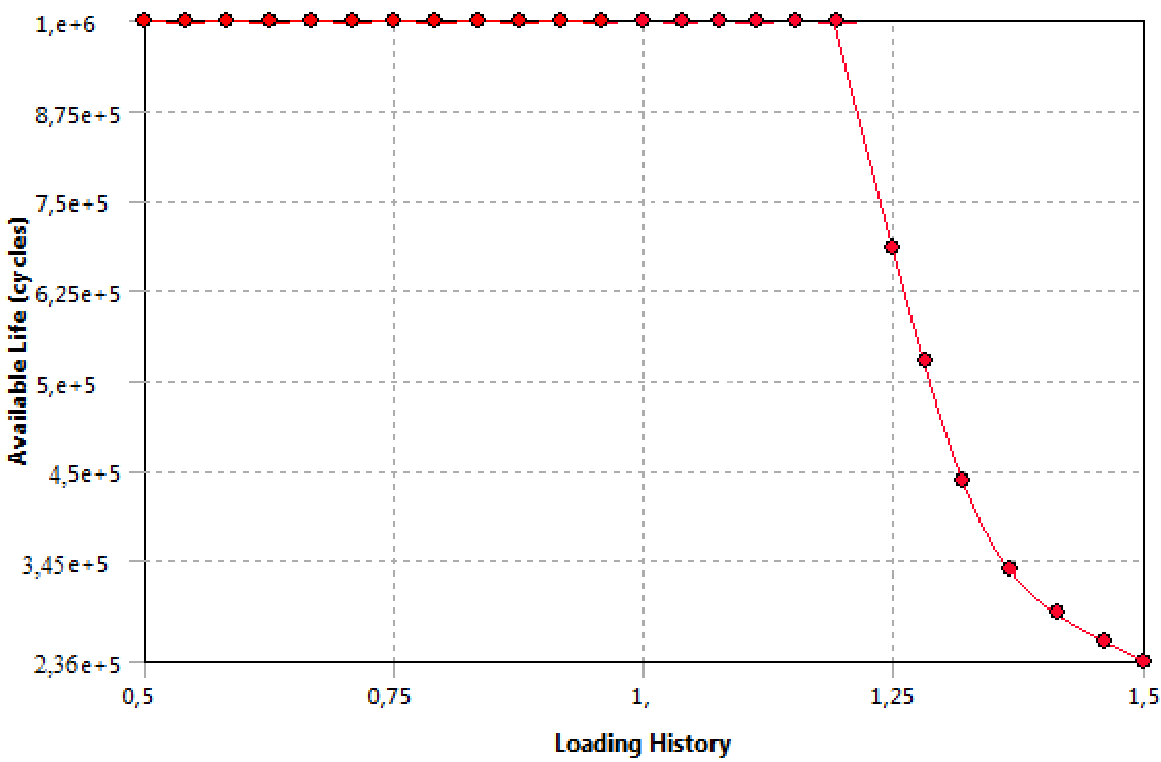


Graph7. 3 Life cycle for Diamond chassis (Fatigue test)

The results of fatigue tests obtained at low frequency cyclic loading. The number of cycles to failure also increases with decreasing stress amplitude.

If in one year approximately can be done 60000 cycle such us an average .According to the previous graph (fatigue test for Diamond chassis) when the loading history equal to one, we can get 410000 cycles, witch mean the diamond frame can resist 7 years if we used daily .(410000/60000=6.83)

7.2.2 Mechanical fatigue for Perimeter chassis



Graph7. 4 Life cycle for Perimeter chassis (Fatigue test)

If in one year approximately can be done 60000 cycle such us an average .According to the previous graph (fatigue test for Perimeter chassis) when the loading history equal to one, we can get 10^{+6} cycles, witch mean the diamond frame can resist 16 years if we used daily .(10^{+6} /60000=16 year). This frame seems to have a bigger live than the Diamond one (life time for Perimeter frame approximately twice life on tubular one)

According to results, the differences between both life cycles for each frame are quit bigger (approximately twice) due to the shape of chassis and also the material used to manufacture it.

Chapter 8

Conclusions

In real life situation safety is the major concern, so the idea of the thesis was to make the bike frame more secure and reliable so that it can bear all the driving conditions to the best possible. Also the major concern was on making bike frame strong enough to withstand crash conditions and maximum acceleration as well as braking. The weight reduction and fatigue life was also a major concern from shifting of conventional bike frame to a modified aluminum frame.

This thesis discusses about whole process of structural dynamic investigation of motorcycles chassis and a clear study of how to improve its functionality. For the proper analysis to be performed, a suitable mesh had to be generated (smaller mesh). Different sets of cases were created and studied, including three stiffness tests (lateral, longitudinal and torsion) which clearly shows how the perimeter chassis is well superior to the Honda CBR250R model (Diamond chassis). Also by improving the material used from steel S355J2G3 to aluminum A380, the frame has considerably increased its strength and durability with a slightly decrease in its overall weight. Steel may be less expensive but it's more heavier, on the other hand, aluminum allows a lighter frame.

Dynamical features can be really important to predict future behavior so an additionally modal analysis was performed for the structure and the values were compared to others previously tested on Honda CBR250R motorcycle (such as Stresses, Deformation, fatigue test and so on). It's vitally important to know the external forces better as possible in order to calculate internal forces acting on chassis at maximum acceleration and braking to do an accurate posterior analysis. Diamond frame has more deformation and stresses than perimeter frame during maximum acceleration and braking. About mechanical fatigue, number of cycles available is twice higher in perimeter frame than diamond one so the life cycle is longer for the former one than the latter.

List of references

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[7] Vittore Cossalter in his "Motorcycle Dynamics" book

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[9]Rajput, Y. S., Sharma, V., Sharma, S., & Saxena, G. (2013). A Vibration Analysis Of Vehicle Frame. International Journals Of Engineering Research And Application (IJERA), 3(2), 348-350.

[10]ÁlvaroF.M.Azevedo. Método dos Elementos Finitos. FaculdadedeEngenhariada Universidade do Porto, 2003Appendices

Title of the appendix

Appendix A

MATLAB Code

Editor - C:\Users\User\Pictures\Camera Roll\Untitled.m

Untitled.m

```
clear all
clc
%The stiffness can be calculated  by dividing the load applied by  the displacement
%(Equation above) or in the case of a moment,divided by the rotation (Equation above).
%K_b=F/δ (bending Stiffness) ;K_t=M/θ(torsion rigidity);  F=√( 〖F1〗^2+〖F2〗^2 )
x=0.5:0.2:4
%x is the forces
   Dt = [0.24 0.48 0.36 0.96 1.2 1.44 1.92]
   Dt=0.48*x;
   %Dt is the deformation of Tubular frame
   Dp=[0.21 0.42 0.63 0.84 1.05 1.26 1.68]
   Dp=0.42*x;
   %Dp is the deformation of Perimeter frame
   plot (x,Dt,'--bs',x,Dp)
   title ('Compare lateral stiffness(tubular vs Perimeter)')
   xlabel('Forces in (KN)')
   ylabel('deformation in (mm)')
hold on
```


Editor - C:\Users\User\Pictures\Camera Roll\Untitled.m

Untitled.m

```
clear all
clc
%The stiffness can be calculated  by dividing the load applied by  the displacement
%(Equation above) or in the case of a moment,divided by the rotation (Equation above).
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x=0.5:0.2:4
%x is the forces
   Dt = [0.24 0.48 0.36 0.96 1.2 1.44 1.92]
   Dt=0.48*x;
   %Dt is the deformation of Tubular frame
   Dp=[0.21 0.42 0.63 0.84 1.05 1.26 1.68]
   Dp=0.42*x;
   %Dp is the deformation of Perimeter frame
   plot (x,Dt,'--bs',x,Dp)
   title ('Compare lateral stiffness(tubular vs Perimeter)')
   xlabel('Forces in (KN)')
   ylabel('deformation in (mm)')
hold on
```
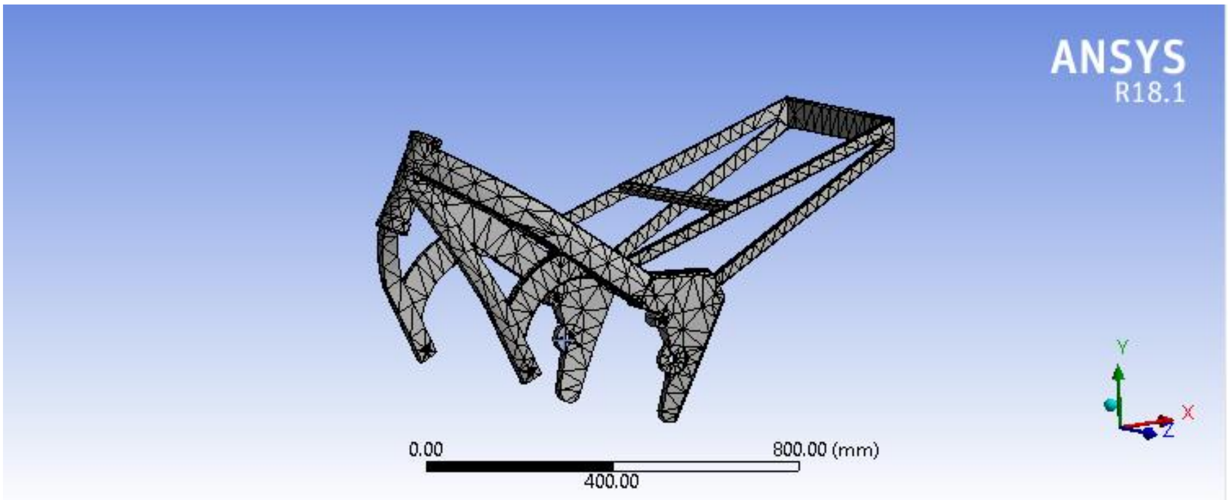
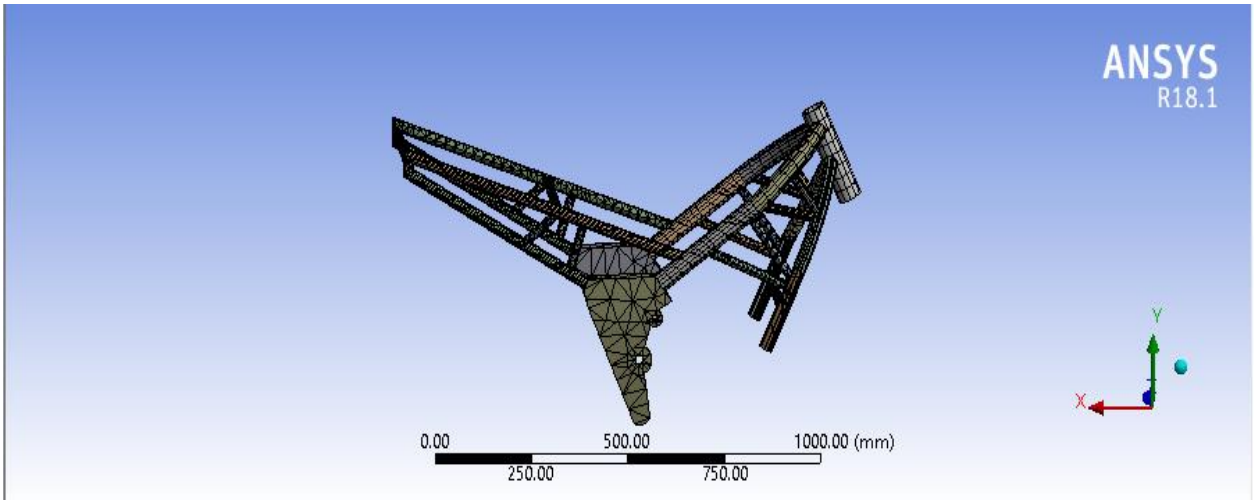

ANSYS R Workbench 18.0 Result for meshing





ANSYS R Workbench 18.0 Table

Results						
Minimum	0. mm					
Maximum	34.439 mm	10.989 mm	13.242 mm	29.477 mm	22.263 mm	57.337 mm
Minimum Occurs On	Solid					
Maximum Occurs On	Solid					
Information						
Frequency	29.719 Hz	57.578 Hz	64.969 Hz	92.515 Hz	115.69 Hz	123.17 Hz

Model (A4) > Modal (A5) > Solution (A6)

Mode	Frequency [Hz]
1.	29.495
2.	57.515
3.	65.006
4.	91.912
5.	115.24
6.	122.29

TABLE 12
Model (A4) > Modal (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0

Results						
Minimum	0. mm					
Maximum	15.621 mm	21.427 mm	13.483 mm	17.267 mm	20.561 mm	17.757 mm
Minimum Occurs On	Solid					
Maximum Occurs On	Solid					
Information						
Frequency	61.092 Hz	66.022 Hz	83.708 Hz	148.11 Hz	148.7 Hz	179.62 Hz

TABLE 14
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation

Mode	Frequency [Hz]
1.	61.092
2.	66.022
3.	83.708
4.	148.11
5.	148.7
6.	179.62

TABLE 20
Structural Steel > Constants

Density	7.85e-009 tonne mm^-3
Isotropic Secant Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	4.34e+008 mJ tonne^-1 C^-1
Isotropic Thermal Conductivity	6.05e-002 W mm^-1 C^-1
Isotropic Resistivity	1.7e-004 ohm mm

TABLE 21
Structural Steel > Appearance

Red	Green	Blue
132	139	179

TABLE 22
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
0