Research Paper

DESIGN AND ANALYSIS OF CHASSIS AND SPRING OF A LOAD-BEARING TRICYCLE

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ABSTRACT

The importance of chassis in a vehicle cannot be over-emphasized, as it forms the cross-section for the attachment of the various components as well as the body. Also, the suspension systems serve a dual purpose – contributing immensely to a vehicle's balance for enhanced safety and driving pleasure, as well as for isolating the occupants from unnecessary bumps and vibrations. The aim of this work is to design and analyze vehicular chassis and springs in order to fabricate an optimized load-bearing tricycle. In the design consideration for the chassis, selection of suitable shapes and cross section of chassis members were adopted. Moreover, the reinforcement of the chassis side and cross member joints, as well as various fastening methods were achieved. In the design, the spring rate K was calculated to be 24273 N/m, which is the amount of energy required to compress the chosen spring by one meter. The force exerted by a compressed spring upon the tricycle for equilibrium restoration was calculated to be 1699.11N, while 228.96mm was calculated and adopted as the spring free length. The careful and meticulous selection of the materials used to produce the chassis yielded optimum performance at low cost, it was produced with a 2.5mm thickness mild steel hollow square pipe, with high yield strength to provide the tricycle the support it requires to be able to carry the stipulated load of 755 kg.

KEYWORDS: transportation, tricycle, vehicle, piston, engine, chassis, transmission, ergonomics, optimize, fabrication.

1. INTRODUCTION

Transportation can be defined as the movement of people, animal and goods from one location to another. The field of transportation can be divided into infrastructure, vehicles and operations. The importance of transportation cannot be neglected because it enables trade between persons, which is essential for the development of civilizations.

Transport plays an important part in economic growth and globalization, but most types cause air pollution and use large amounts of land. While it is heavily subsidized by governments, good planning of transport is essential to enhance traffic flow and restrain urban sprawl. According to Daniel and Gordon (2009), there were about 1,015 billion automobiles worldwide around the year 2009. Road transport offers a complete freedom to road users to transfer the vehicle from one lane to the other and from one road to another according to the need and convenience. This flexibility of changes in location, direction, speed, and timings of travel is not available to other modes of transport, as it is possible to provide door to door services only by road transport.

Some of the different vehicles used in land transportation include cars, lorries, trucks, buses, tricycles, motorcycles, bicycles etc.

2. TRICYCLES

Often referred to as Trikes, tricycles are three wheeled vehicles, which are either human powered or motorized. Human powered tricycles rely on pedal power to move between destinations whereas Motorized tricycles are based on the same technology as motorcycles, and powered by electric motors, motorcycleS, scooter or car engines. According to Quellin (2011), some tricycles, such as cycle rickshaws (for passenger transport) and freight trikes, are used for commercial purposes, especially in the developing world like Africa and Asia. In the west, adult-sized tricycles are used primarily for recreation, shopping, and exercise. Tricycles are preferred by children and senior adults alike for their apparent stability when compared to bicycles; however, a conventional tricycle has poor dynamic lateral stability, and the rider must take care when making a turn to avoid tipping the tricycle over.

Greene (2011), explained that the first tricycle was built in 1680 for a German paraplegic named Stephan Farffler, who lived near Nuremburg. He pointed out that it was in the form of a three-wheeled wheelchair which was built because Farffler wanted to be able to maintain his mobility. Since he was a watch-maker, he was able to create a tricycle that was powered by hand cranks.

The major systems of a tricycle are the engine, fuel system, exhaust system, cooling system, lubrication system, electrical system, transmission, the chassis, and the body. These systems will be found in every form of tricycle and are designed to interact with and support each other. As engines are designed to convert one form of energy into mechanical energy, heat engines, including internal combustion engines and external combustion engines (such as steam engines), burn fuel to create heat, which then creates a force. According to Geneson (2005), the internal combustion engine was invented and developed in the 19th century. He also observed that it offers a relatively small, lightweight source for the amount of power it produces. Tricycles basically use the Internal Combustion engine.

Internal Combustion engines are seen every day in tricycles, trucks, and buses. The name internal combustion refers also to gas turbines except that the name is usually applied to reciprocating Internal Combustion (I.C.) engines like the ones found in everyday tricycles. There are basically two types of I.C. ignition engines, those which need a spark plug, and those that rely on compression of a fluid. Spark ignition engines take a mixture of fuel and air, compress it, and ignite it using a spark plug.

Figure 1 shows a piston and some of its basic components. The name `reciprocating' is given because of the motion that the crank mechanism goes through. The piston cylinder engine is basically a crank-slider mechanism, where the slider is the piston in this case. The piston is moved up and down by the rotary motion of the two arms or links.

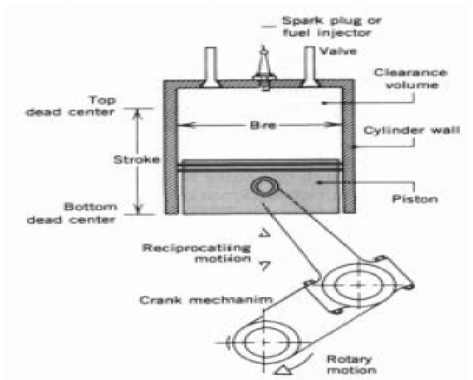

Figure 2.1: Internal Combustion Engine's Piston

Engines are also divided into four stroke and two stroke engines. In four stroke engines the piston accomplishes four distinct strokes for every two revolutions of the crankshaft. In a two stroke engine there are two distinct strokes in one revolution. For this work, a two stroke engine was adopted.

According to Crouse and Anglin (1994), the 4-stroke engine is more efficient in burning fuel when compared with the 2-stroke where a residue of unburned fuel remains inside the cylinder thereby hindering combustion. The two-stroke engine also ignites its fuel twice as often as a four-stroke engine which increases the wear on the engine's parts. Compared to four-stroke engines, two-stroke engines have a greatly reduced number of moving parts, and so can be more compact and significantly lighter.

3. TRICYCLE'S CHASSIS

In the tricycle, the chassis and frame or structure forms the cross-section for the attachment of the various components as well as the body. It carries the power train, i.e. the engine, the frame which supports the engine, wheels, body, transmission, the braking system and the springs. They also provide the basis upon which loads are carried.

The chassis layout of a modern tricycle is depicted in figure 2.

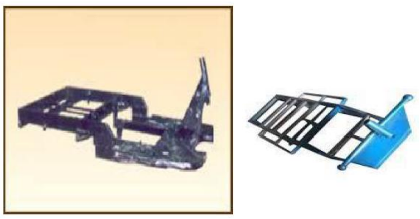

Figure 2: Chassis Layout of a Tricycle.
Source: Indiabizclub

Principally, the two types of auto body construction of a modern tricycle are the uni-body construction, and the body and chassis frame construction. The major difference between the two is that the uni-body or integral construction involves having individual metal parts joined mainly by welding to make up the body assembly and also provide overall body rigidity through an integral all steel welded construction, while the body and chassis framer construction prepares the body separate from the chassis frame and afterwards join both of them at some reinforced points.

However, In their study, Sri and Kumar (2001), classified chassis frames into three type, namely conventional frame, integral frame, and semi-integral frame. The Chassis forms the back bone of the tricycle as it provides the main mounting for all the components including the body. This explain why Giri (2013), referred to it as a tricycle's carrying unit.

In the existing tricycle design, a good practice is that frame must be light but also sufficiently strong to withstand the weight and rated load of the tricycle without having appreciable distortion. This is because rigidity must not be compromised considering the fact that the various components attached are subjected to the action of different forces. In the design consideration for the chassis, selection of suitable shapes and cross section of chassis members were adopted. Moreover, the reinforcement of the chassis side and cross member joints, as well as various fastening methods was achieved.

4. SPRING DESIGN AND ANALYSIS

The suspension is the system of tires, tire air, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. Suspension systems serve a dual purpose – contributing to the vehicle's road holding and braking for good active safety and driving pleasure, as well as for keeping vehicle occupants comfortable and a ride quality reasonably well isolated from road noise, bumps, vibrations, etc. For the work, the suspension system adopted is shown in Table 1.

Table 1: Suspension System

SUSPENSION	TYPE
Front	Solo-arm Dual coil spring shock absorbers
Rear	Fully floating axle shaft & Different Unit, Swing Arm, Cylindrical Springs, Assisted by Two Telescopic Shock Absorbers

The other spring parameters adopted for the research is depicted in table 2.

Table 2: Other Spring Parameters

Spring material UTS	143	Kgf/mm^2
Wire diameter (D)	8.00	Mm
Mean Diameter (D)	50.00	
Free Length (Lf)	245.00	Mm
No. of active coils (Na)	13.50	
Modulus of Rigidity (G)	80000.00	N/mm^2

Parameter Identification

When taking into account the lever arms, the adopted spring stiffness of the front and rear suspension units is 25N/mm and 21N/mm respectively. The rear dampers were set to a maximum to reduce the rear module roll in transient states. To evaluate the damping coefficients with this setting, a damper was tested separately on a test bench at several operating frequencies. The data was used to obtain a linear coefficient for the damping in compression and in rebound.

The front and back suspensions' configuration is shown in figures 3 and 4 respectively.

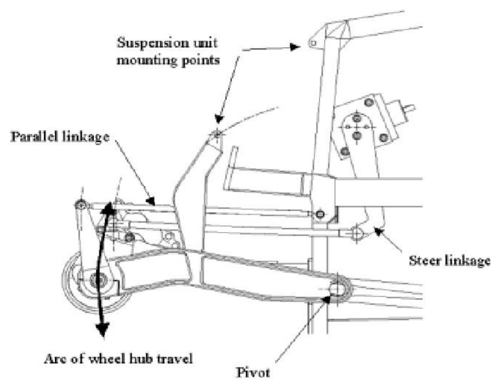

Figure 3: Front Suspension

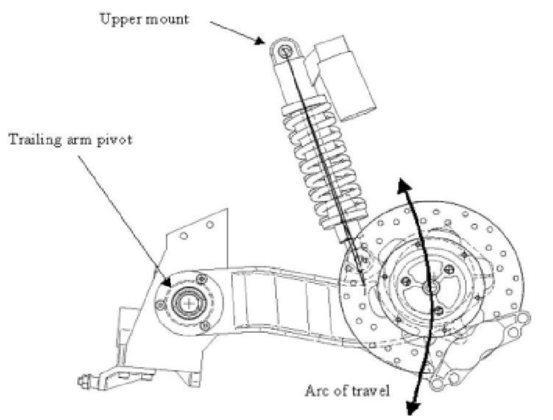

Figure 4: Rear Suspension

Calculation of Spring Rate (K) and Spring Force (F)

Spring rate refers to the amount of energy that is needed to compress a spring one inch. It is a measure of how stiff or strong the spring is. If the rate of the spring is linear, its rate is not affected by the load that is put on the spring.

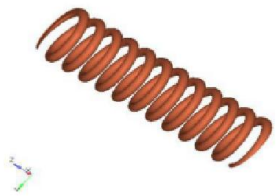

Figure 5: Suspension Spring Model

Spring Rate $K = \frac{d^4G}{8ND^3}$ (1)

Where d = wire diameter = 8mm, G = spring shear modulus = 80000N/mm^2

D = diameter of the coil = 50 mm

$$K = \frac{8^4 \times 80000}{8 \times 13.5 \times 50^3} = 24.273\ \mathrm{N/mm}$$
$$= 24273\ \mathrm{N/m}$$

From the above calculation, the amount of energy required to compress the chosen spring by one meter is 24273N/m.

Spring Force refers to the restoring force; it always acts to restore the spring towards equilibrium. It is the force exerted by a compressed or stretched spring upon any object that is attached to it. An object that compresses or stretches a spring is always acted upon by a force that restores the object to its rest or equilibrium position.

Spring Force $F = Kx = K(L_f - L_s)$ (2)

Where K = spring rate, X = deflection of the spring from its equilibrium position, L_f = spring free length = 245 mm, L_s = spring full compressed length = 175 mm

$$F = 24.273(245 - 175) = 1699.11\ \mathrm{N}$$

Calculation for Spring Stability

The equations for stability help to select the exact diameter, free length during designing of suspension spring. It is always necessary to check if the design of the spring is safe, to determine if the spring designed will be stable.

a) Critical deflection (y_{cr}): $Lf < c'1 \times \left[1 - \left(\frac{c'2}{\Lambda_{eff}}\right)^{\frac{L}{2}}\right]$ (3)

Where c'1 and c'2 are elastic constants

$$c'1 = \left(\frac{E}{2(E-G)}\right) \quad (4)$$

and $c'2 = \frac{2 \times \pi^2 (E-G)}{(2G+E)}$ (5)

The critical deflection (y_{cr}) is the deflection corresponding to the onset of instability. During the calculation, the critical deflection value derived was 212.6 whereas the spring deflection value gotten during designing of the spring is 114.5 which mean that the spring will not become unstable on deflection.

a) Λ_{eff} is the effective slenderness ratio and is given by
$\Lambda_{eff} = \frac{\alpha \times Lf}{D}$ (6)

b) Equation (6) contains the end condition constant. This depends upon how the ends of the spring are supported. In the equation of critical deflection, whenC'2/ λeff2 is greater than unity the spring is absolutely stable. Thus by getting a value of 1.15, this proves that the spring is stable.

Therefore, the condition for spring stability is given as:

$$Lf < \left(\frac{\pi \times D}{\alpha}\right) \times \left[\frac{2(E-G)}{2G+E}\right]^{\frac{1}{2}} \quad (7)$$

For a spring to be safe (stable), the free length of the spring should be less than 263mm.

The free length of a spring formula is given in equation (8).

$L_{free} = p \times n_a$ (8)

Where L_{free} = Spring Free Length, p = pitch, n_a = number active of coils,

$$L_{free} = 16.96 \times 13.5 = 228.96\ \mathrm{mm}$$

From the calculation, the free length of the spring adopted for the work is 228.96mm. This is less than 263mm, thus the design of the spring is safe and stable.

5. CHASSIS DESIGN AND ANALYSIS

The chassis generally experiences four major loading situations; vertical bending, longitudinal torsion, lateral bending, and horizontal lozenging. These various conditions are represented diagrammatically in the figures below. Understanding these conditions is the key to designing a better chassis.

When the chassis frame supported at its ends by the wheel axles and acted upon by an equivalent weight due to the tricycle's equipment, passengers and luggage around the middle of its wheel base, the side members are caused to sag in the central region. This sagging is known as vertical bending.

Longitudinal Torsion

Consequent upon the simultaneous rolling of the diagonally opposite front and rear road which over bumps, twist occurs in the two ends of the chassis in opposite direction so that both the side and the cross-member are subjected to longitudinal torsion. As a result, the chain distorts as shown in figure 6.

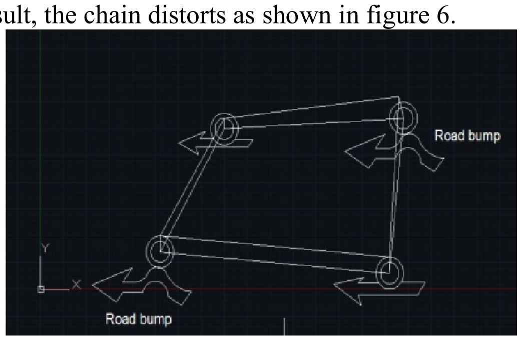

Figure 6: Longitudinal Torsion of Chassis.
Source: Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka

The camber of the road, side wind, centrifugal force while the tricycle negotiates a corner or collision with some object exposes the chassis to external (side) force. As the road wheel tyres opposes that external forces due to adhesion reaction, a nut bending moment acts on the chain side members so that the chassis frame tends to tow in the direction of the force. This reaction is called lateral bending and shown in the figure 7.

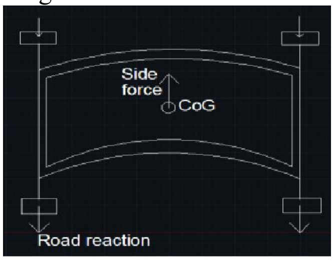

Figure 7: Lateral Bending of Chassis.
Source: Department of Mechanical Engineering, NnamdiAzikiwe University

A chassis frame if driven forward or backwards is continuously subjected to wheel impact with road obstacles such as pot holes, road joints, surface humps and curbs while other wheels produce the propelling thrust. These condition cause the rectangular chassis frame to distort to a parallelogram shape, known as lozenging as shown in figure 8.

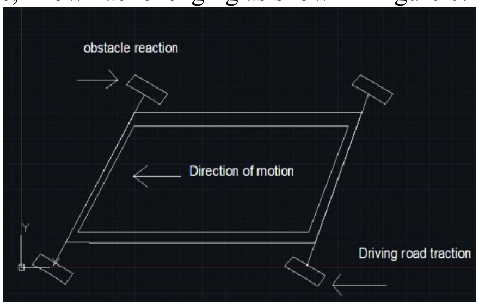

Figure 8: Horizontal Lozengingof Chassis.
Source: Department of Mechanical Engineering, NnamdiAzikiwe University

According to Giri (2013), the various loads acting on the frame may also be classified as short duration load, momentary duration load, impact loads, inertia load, static loads, and over loads.

Chassis Frame Selection

The chassis frame undergoes both bending and torsional distortion during movement of a tricycle over normal road surfaces. At such, the various chassis member cross section shapes which find application include: solid round or rectangular cross section, enclosed thin wall hollow round or rectangular box-section, and open thin-wall rectangular channeling such as ‘C’, ‘T’ or ‘top hat’ section.

Forces Acting on a Chassis Frame

1. Side Member Bending Resistance

The chassis side member must be so stiff as to resist their natural sagging tendency. The chassis side-member span the wheel base between the front and the rear axles, and must take the maximum of the sprung weight.

Adopting either pressed-out open-channel section or enclosed thin wall hollow round or rectangular box-section can provide the maximum possible bending stiffness of chassis member relative to their weight. The relative bending stiffness for the common section considering a stiffness of 1 ranges from 0.95 (round bar) to 7.2 (square hollow section).

2. Side and Cross-Member Torsional Resistance

Excellent bending resistance and little twist resistance are both characteristics of open-channel sections. Thus, these sides and cross-members of the chassis must be designed to resist torsional distortion along their length. According to Heisler (2002), relative torsional stiffness ranges from 1 (longitudinal split tube) to 105.0 (closed rectangular box-section).

From the foregoing, it can be deduced that the channel section is more advantageous relative to the hollow tube due to the high torsional stiffness. The chassis frame for this work, however, is not designed for complete rigidity but for the combination of both strength and flexibility to some degree.

Chassis Frame Design

A frame using a non-independent suspension system and consisting of two channel-shaped side members, which are joined together with the aid of a series of cross-member, stands suitable for light truck and minibuses. As a criterion, deflection must be minimized while cross-members are placed at high stress points. Most frames of light tricycles are made of low-carbon steel having between 0.15 – 0.25% carbon content. In order to remain in the market lighter trucks are paramount. According to Giri (2013), the frame weight is reduced either by decreasing the depths of the channel or by making series of holes along the neutral axis.

More still, gusset plates or ‘X’ type bracings are fitted as reinforcements between side and cross-member to guide against lozenging. Otherwise, such problems like movement between doors and pillars, broken wind screen and cracking of the body panel may occur.

Individually, channel members lack adequate stiffness against twist; joining more than one gives a relatively rigid structure with both bending and torsional-loading withstanding capability. The type of joint used in the frame is also relevant in chassis design. Riveting, bolting and lap welding are the different methods of joining available.

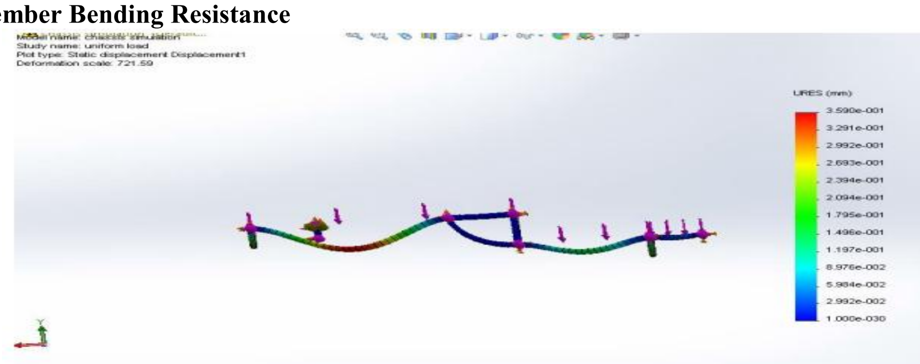

Fig. 4: Chassis frame static displacement

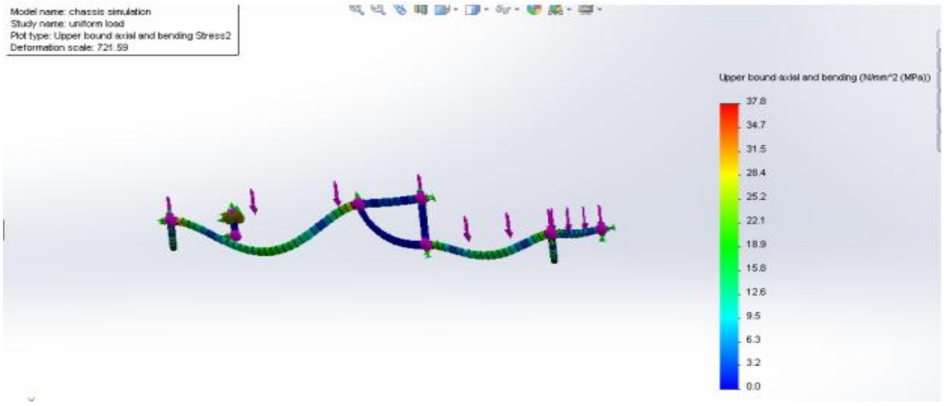

Fig. 5: Stresses acting on the chassis frame

From the result obtained from Figure 4, the chassis would undergo a maximum deflection of 3.59 mm. Figure 5 shows the stresses acting on the chassis. The stresses range from 3.2 MPa to 37.8MPa. The material used for the chassis frame (cold rolled steel) has yield strength of 220.6 MPa. The point of maximum stress is shown in the figure as 37.8 MPa giving a factor of safety (FOS) of about 5.0 which is within a safe range.

Assuming the vehicle when fully loaded, started from rest, attained a speed of 122.4km/h (i.e. 34m/s) within 10 seconds then, had a head-on collision.

Dead load of tricycle = 755Kg

Driver/passenger (2 persons) × 75kg = 150kg

Mass of vehicle when fully loaded (m) = 1144.4 kg

Final velocity (v) = 34m/s

Initial velocity (u) = 0m/s

Time (t) = 10s

From momentum equation;

$$F = \frac{m(v-u)}{t} \quad (1)$$

$$F = \frac{1144.4(34-0)}{10}$$

$$F = 3891 \text{ N}$$

From table 1, the following results were generated using the CAD software, static displacement on chassis

frame, upper bound axial and bending stress on chassis frame, shear force diagram on chassis frame; and shear moment diagram on chassis frame.

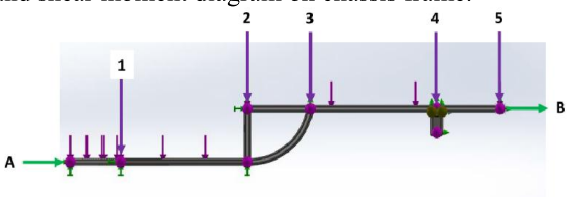

Fig. 6: Major Forces Acting Normal to the Chassis Frame

Table 1: Loads acting on a chassis frame and their distance from a reference

S/N	Major Loads	Distance from point A (mm)	Weight (N)
1	Driver/Passenger (2 persons)	336.8	1500
2	Cargo box load	1047.8	2000
3	Cargo box load	1446.36	2000
4	Engine and Gear box	2208.36	315
5	Cargo box load	2609.36	2000

2.3 Shear Force Diagram Calculation

Algebraic sum of upward and downward forces is zero (0)

$$F_a + F_b = F_c = F1 + F2 + F3 + F4 + F5 \quad (2a)$$

Where

Fa = force acting at point A

Fb = force acting at point B

Fc = total weight acting on the member

$$F_a + F_b = 1500 + 2000 + 2000 + 315 + 2000$$

$$F_a + F_b = 7815 \quad (2b)$$

Taking moment about A,

$$F_b \times L = (F_1 \times L_1) + (F_2 \times L_2) + (F_3 \times L_3) + (F_4 \times L_4) + (F_5 \times L_5) \quad (3.3)$$

$$F_b \times 2609.36 = (336.8 \times 1500) + (1047.8 \times 2000) + (1446.36 \times 2000) + (2208.36 \times 315) + (2609.36 \times 2000)$$

$$F_b \times 2609.36 = (505200) + (2095600) + (2892720) + (695633.4) + (5218720)$$

$$F_b \times 2609.36 = 11407873.4$$

$$F_b = \frac{11407873.4}{2609.36} = 4371.9\text{N}$$

From (2b), $F_a = 7815 - F_b$

$$F_a = 7815 - 4371.9$$

$$F_a = 3343.1\text{N}$$

The results of the calculations and the meticulous selection of right engineering materials led to the successful design and analysis of suitable chassis and springs for the fabrication of a load-bearing tricycle.

6. CONCLUSION

In order to achieve dramatic improvements in critical measures of performance such as cost, service and speed, the concept of the use of cheap locally sourced materials has been successfully adopted and implemented for the completion of this work. The problem statements which are majorly over dependence on foreign technology for the manufacture of automobile in Nigeria, limited load carrying capacity and high cost has been resolved as the tricycle so developed compensate these deficiencies. All of the chassis components and the entire vehicle were designed and fabricated at the school workshop and it functions effectively. For smooth plying on roads, the chassis setup was tested and confirmed to perform satisfactorily.

The careful and meticulous selection of the materials used to produce the chassis yielded optimum performance at low cost. The chassis was produced with mild steel hollow square pipe (2.5 mm thickness). The use of this material with high yield strength provided the tricycle the support it needs to carry the stipulated load of 755 kg.

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