Project 1

Shivam Gupta

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Prof. Ravani

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Abstract

This project tries to reverse engineer a bicycle using the principal of mechanical designs. Reverse engineering allows us to increase our understanding of the design and make changes that increase the strength of the design and increase the life of the design. For this project the goal was to analyze a bike under three different loading conditions. For each loading condition then we had to find the critical components. Then analyze those components to find the safety factor of those critical components and their cost. This also included find the materials that these parts were made of. From all these loading conditions we found that the down tube absorbs the most stresses and torsion. Also, the bolt holding the pedals to the hub has tension that needs to be minimized otherwise the threads become striped. That means to improve the design steel should be considered over aluminum, and the diameter of the down tube and the spokes of the bike should be increased. To increase the life the brake pads should be maintained and made sure that they are not in contact with the wheels while the bike is running. Also, the rider should replace any spokes that gets bent as soon as possible.

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Introduction

The goal of this project was to reverse engineer a bicycle to understand its design. The bike selected for this project was a fixie bike which means it has a fixed gear ratio and just a front brake [1]. This means that the gear ratio cannot be changed with help of a derailleur and gear setup. A general Fixie can be seen in Fig 1 below.

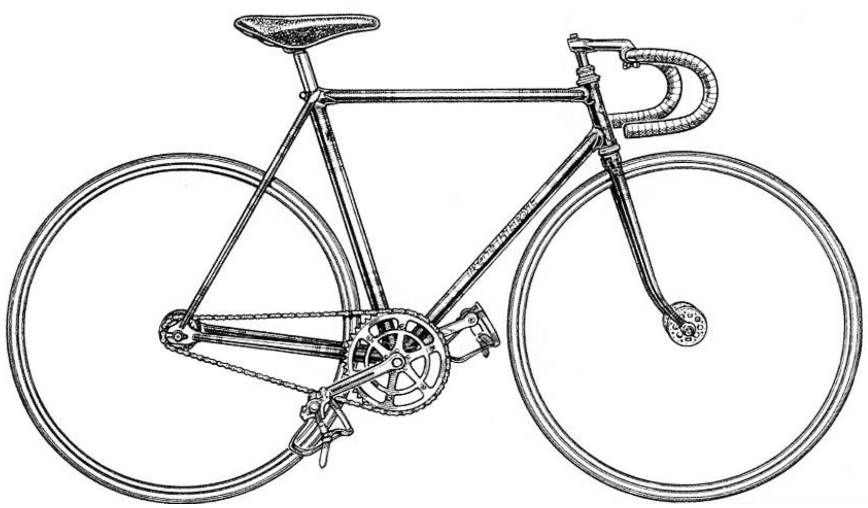


Fig 1. An Aesthetic Fixie Design [2]

To find the measurements of the bike a meter measure tape was used. The measurements were taken from weld to weld of the five main tubes to the frame. The measure tape was also used to find the perimeter of the rods and the tubes. Then this perimeter value was divided by the value of Pi to find the diameter of the tube.

Once the measurements were taken, we developed a 2D model of the bike with the dimensions. The figure of the bike can be seen in **Fig 2** below with dimensions in meters.

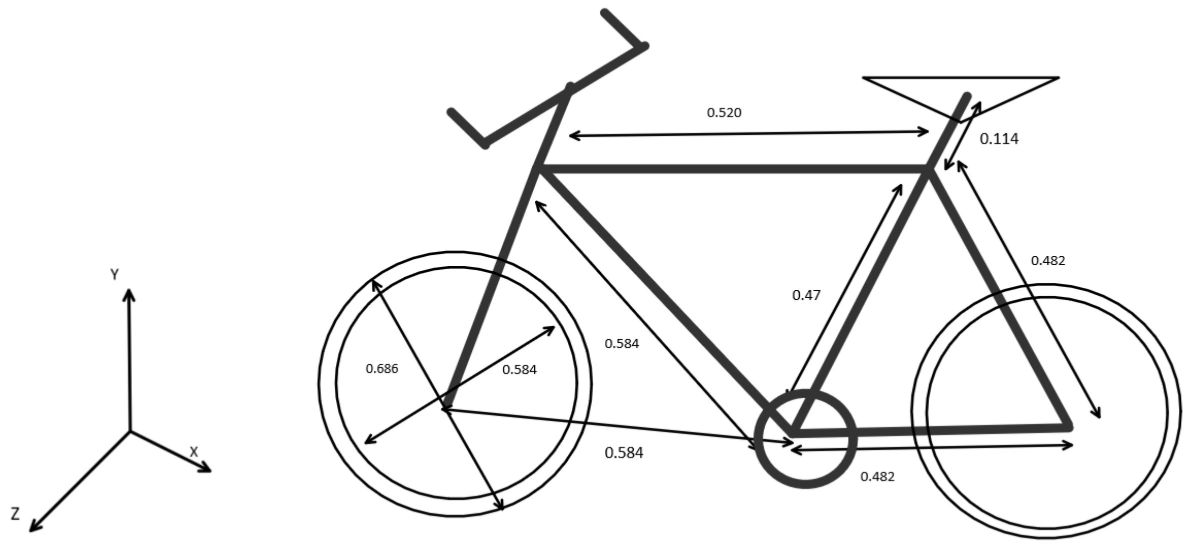


Fig 2. General Diagram of the Bike Chosen this Major Dimensions

As we can see in Fig 2 the dimensions of the frame were measured as it was assumed, they would ideally be used in load envelope analysis in the project.

The major frame design that exist in most bike’s today emerged in 1895 after decades of research and has remained the same since then [3]. It has a diamond shape and includes five major tubes which are top tube, down tube, down tube, seat stay, chain stay.

The Measurements for the major tubes in the frame can be seen in the table below –

Table 1.1

Tube	Length (m)	Diameter (m)
Top Tube	0.52	0.038
Down Tube	0.584	0.052
Seat Tube	0.47	0.038
Seat Stay	0.482	0.028 to 0.022
Chain Stay	0.482	0.028 to 0.022

Other major components whose dimensions were measured were the pedal and the crank configuration. The pedal configuration was also measured and designed as seen below in Fig 3.

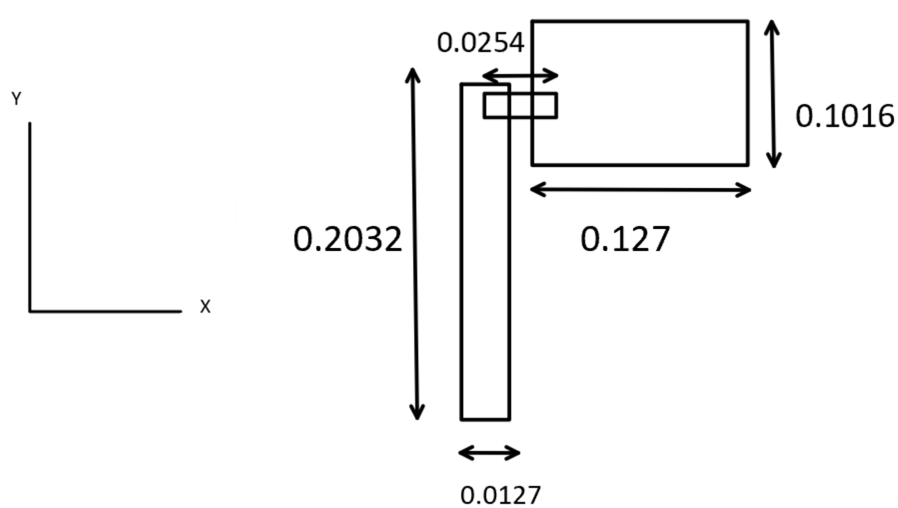


Fig 3. Top View of the Pedal and the Crank, Dimensions in Meters.

Another important component that was measured was the bike tires and the rim diameters. We can see the tires and the spokes design in Fig 4 below.

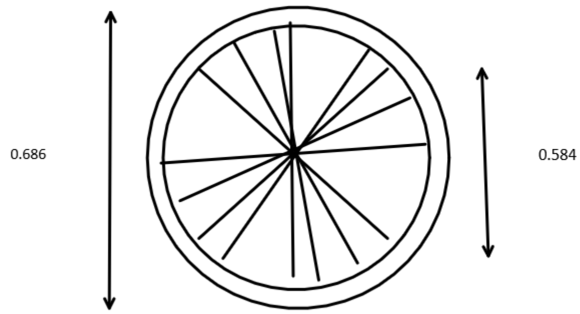


Fig 4. Side view of the wheel with outer and inner diameter dimensions.

For this project we will be using all these dimensions taken to analyze the bike and try to find the critical components using these analyses. After analyzing these parts, we will try to find ways to improve the life of these parts and improve the quality of the design.

Methodology

To understand the design, of the bike we must look at the major components that create the bike. These major components include frame, wheel and pedals. Theses major complex components can then be further divided into simpler components. Knowing these components help in finding the information on the design. To find information on the design we must find the physical properties of the design. This include measurements and material properties. Dimensions of the bike for the project can be found using a measure tape, however the material properties are unknown for this project as the bike is old and does not have any labels about the frame materials. So, taking that into consideration we will assume this bike to be made from the common bike frame SAE 4130 Steel.

For this project we will be taking the following assumptions that will be maintained for the whole course of this project:

- There is No Aerodynamic Drag on the bike.
- We assume that bike is making a 90-degree angle to the ground.
- The weight distribution of the rider is specific to the load envelopes.
- There are only three main points of contacts for the rider – Seat, Pedals, and The Handlebar.

After taking these assumptions we consider the load envelopes that will be analyzed. The two cases for load envelope analysis were selected using literature. From this literature we found that major stresses were applied when rider was getting in the seat and starting the bike, and when a case of severe braking happens [3].

Load Envelopes Considered and their Proper Analyses

The three loading conditions were used as a method to find the critical components and to see how the bike parts will behave under extreme conditions and unforeseen misuse of bike.

Load Envelope 1 – Getting on the pedal and starting the bike

For this case of Loading we assume that the only point of contact is the pedal and the full weight of the rider is applied at the center point of the pedal.

This can be seen in the Fig 5 with the dimensions in meters.

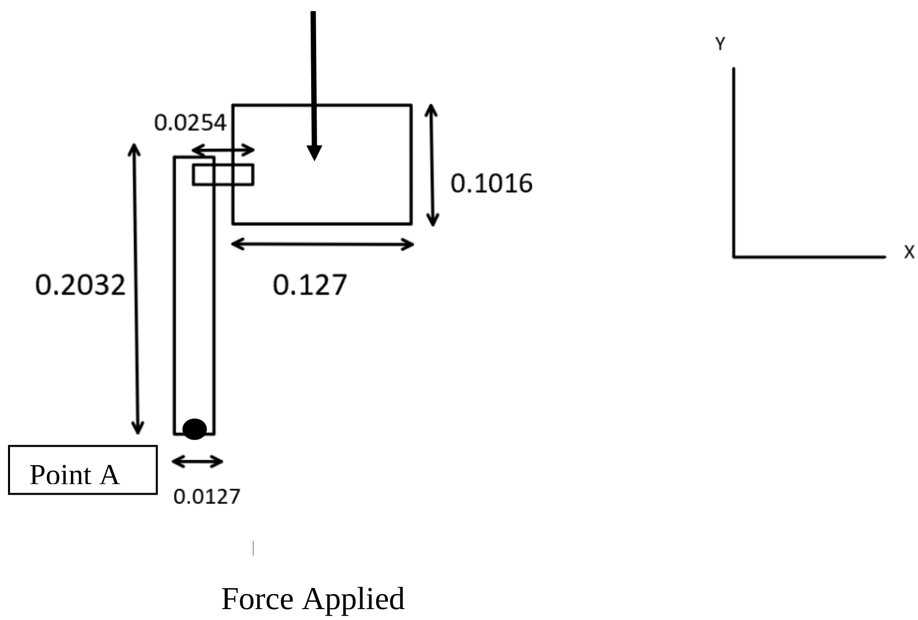


Fig 5. – Top view of the pedal

To understand the loading in this case we will try to find the principal stresses at point A which is the point where the crank is connected to the bike with a screw.

We will also assume that that the position of the pedal is 90 degrees to the vertical line and on the front side of the gear as the force applied on the pedal at this stage is maximum for this case [4].

We also know crank diameter is 0.026m which will be used to find Moment of Inertia of the crank shaft. When F is a load of 2000N we have a rider that is approximately 205 kgs in weight. Which would be a case of extreme loading as average American weights 90 kg [5].

The Force applied can be seen in the FBD in Fig 6.

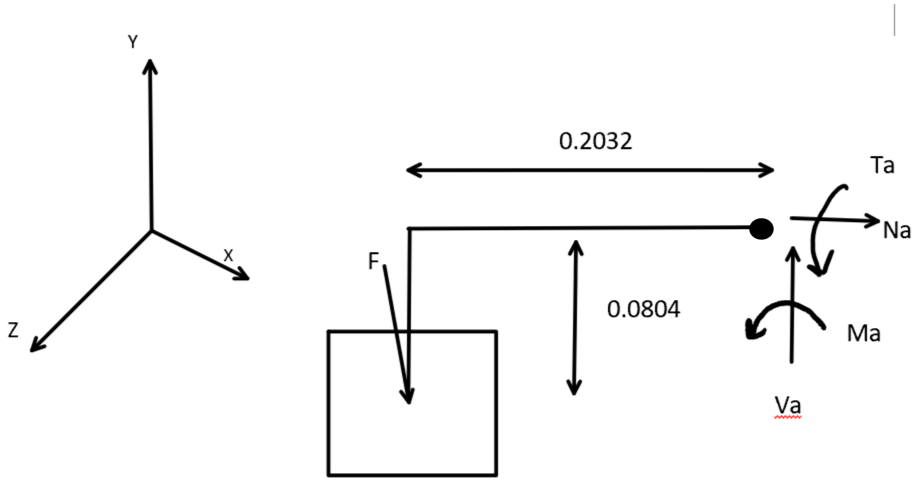


Fig 6. A FBD of the pedal with the forces at point A

Then we will use force equilibrium equations to find the reactions forces and the momentum at point A.

Along X axis

Total Fx = 0

Na = 0

Total Fy = 0

Va = 2000N

Moment about A =F*0.2032 = 406.4N*m

Torque Ta = F*0.0804 = 160.8N*m

To find Shear Stress

Stress in X direction = M*C/I

M = 406.4Nm

C = Crank Diameter/2 = 0.026/2 = 0.013m

I = pi*D^4/64 = pi * (0.026) ^4 / 64 = 2.24 * 10^-8 m^4

StressX = M*c/I = 406.4*0.013/2.24*10^-8 = 235.85 MPa

StressY = 0, No Bending stresses in Y direction

Next, we will find the Torsional Stress

Tau = Ta*C/2*I

Ta = 160.8Nm

C = 0.013m

I = 2.24*10^-8 m^4

Tau = 160.8 * 0.013 / 2 * 2.24*10^-8 = 46.66MPa

Using principal stresses formula

sigma_1 = (StressX + StressY)/2 + ((StressX + StressY)/2)^2 + tau^2)^1/2

StressX = 235.85MPa

StressY = 0

Tau = 46.66MPa

σ= 235.85/2 + ((235.85/2) ^2 + 46.66^2)^1/2 = 235.85/2 + 126.82 = 244.745MPa

= (StressX + StressY)/2 - ((StressX + StressY)/2)^2 + tau^2)^1/2

= 235.85/2 – 126.82 = -8.895MPa

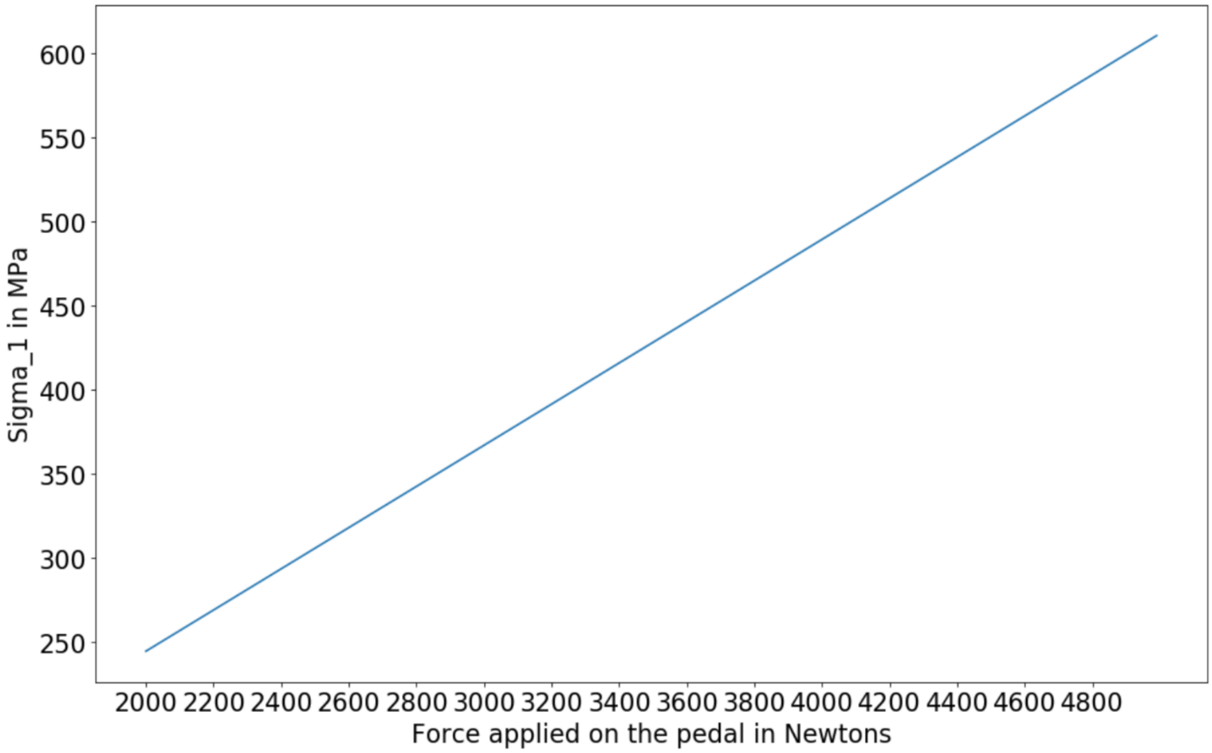
So max tensile stress is 244.745 MPa and max compressible stress is -8.895Mpa for this case of Loading as point A when a Force of 2000N is applied.

From this case we can see that the most critical component would be the screw that connects the crank to the front gear. As we had declared earlier the bicycle is made with 4130 steel which has a ultimate strength of 670MPa [6]. So, the safety factor right now is 2.7, or 2.5 when taken conservatively.

For more analysis we used python to find stress values when the forces are from 2000N to 5000N. The script written to find the values is below: -

```
import numpy as np
import math
import matplotlib.pyplot as plt
from pylab import *


f = np.arange(2000.00,5000.000,10.000)

Moment  = f*0.2032
Torque = f*0.0804

StressX = (Moment*0.013)/(2.24*10.0**(-8))
Tau = (Torque*0.013)/(2*2.24*10**(-8))
StressY = 0

sigma1 = (StressX/2)+((StressX/2)**(2) + (Tau**2))**(0.5)
sigma2 = (StressX/2)-((StressX/2)**(2) + (Tau**2))**(0.5)

fig=plt.figure(figsize=(16, 10), dpi= 80, facecolor='w', edgecolor='k')
plt.rcParams.update({'font.size': 20})
plt.xlabel('Force applied on the pedal in Newtons')
plt.ylabel('Sigma_1 in MPa')
plt.xticks(np.arange(2000,5000,step=200))
plt.yticks(np.arange(200,1000,step=50))
plt.plot(f,sigma1/1000000)
```

Using this script, we created a graph of the values of the major stress with the force applied.



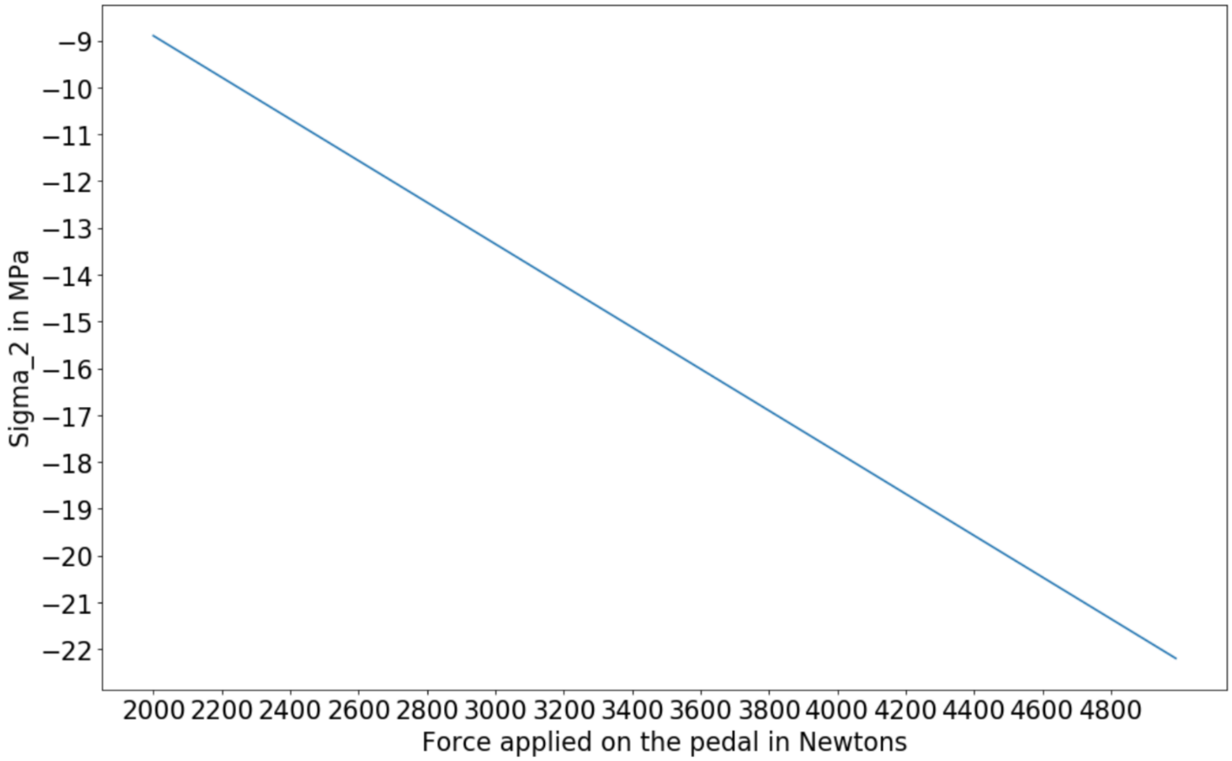
Then using this graph and linear regression we were able to find the equation of the line in the graph.

```
(m,b) = polyfit(f,sigma1,1)
```

```
print(m)
print(b)
# When Y = mx + b
# Equation for Sigma with Force applied is

print("sigma1 =",m,"*f","+", b)
```

```
122376.37095211071
5.506041232963807e-08
sigma1 = 122376.37095211071 *f + 5.506041232963807e-08
```

We can do the same with σ _2 to find the equation for tension.




```
print(m)
print(b)
# When Y = mx + b
# Equation for Sigma with Force applied is

print("sigma2 =",m,"*f","+", b)
```

```
-4447.799523539288
-1.7206378853011896e-09
sigma2 = -4447.799523539288 *f + -1.7206378853011896e-09
```

Using these equations, we can find the forces when the part breaks and further analyze the part and use it for material selection in future design.

Load Envelope 2 – Landing on the Front Tire

In this case we will see the reactions forces on the wheels and other members when the front wheel is landed on the ground after being in the air for a trick. As a lot of people use bicycles some will try to perform tricks with their bikes so this load envelope will act as an extreme condition.

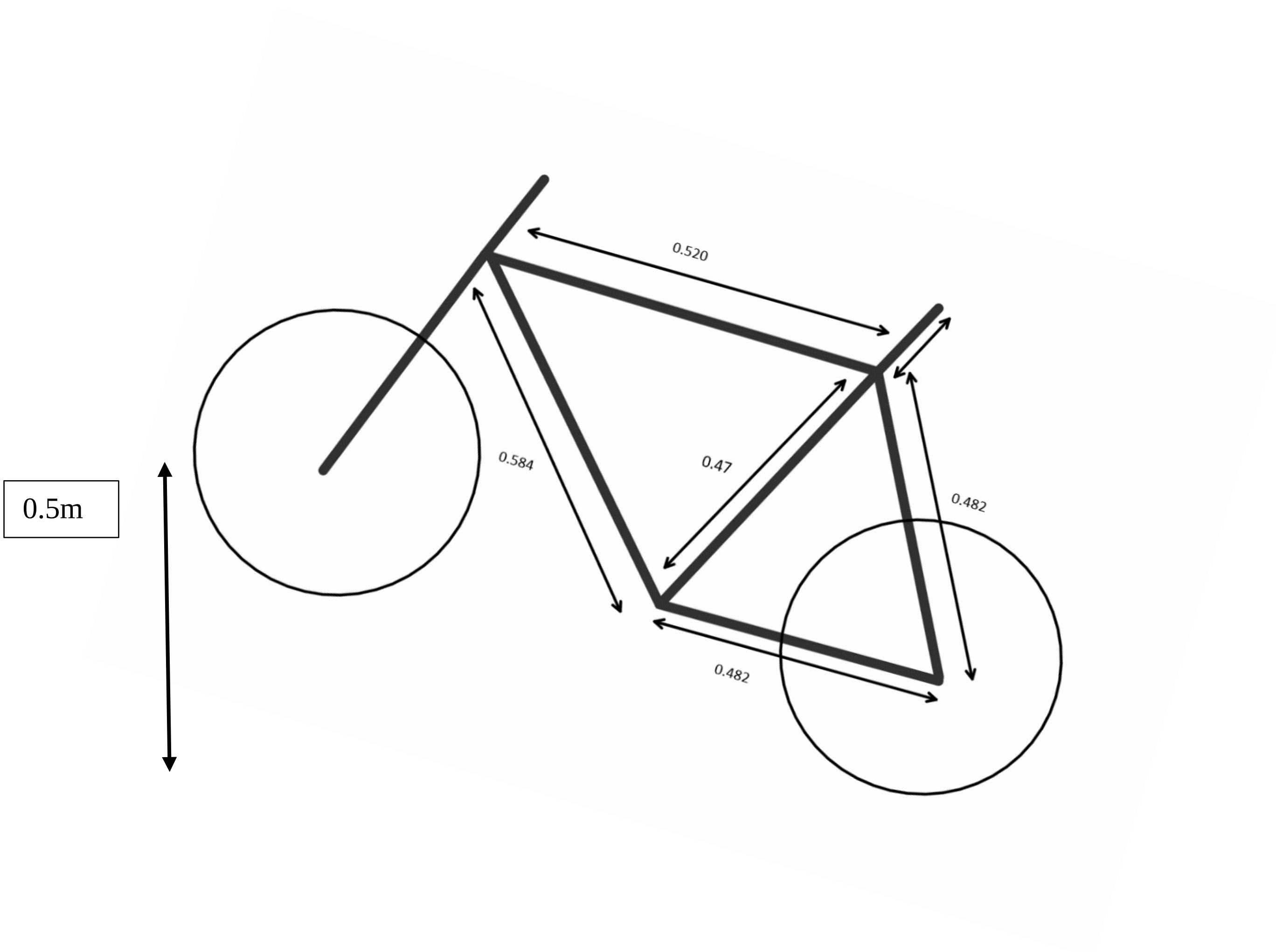


Fig 7. The position of the bike before landing on the front tire.

So, to solve this problem we will look at the front view of the bike

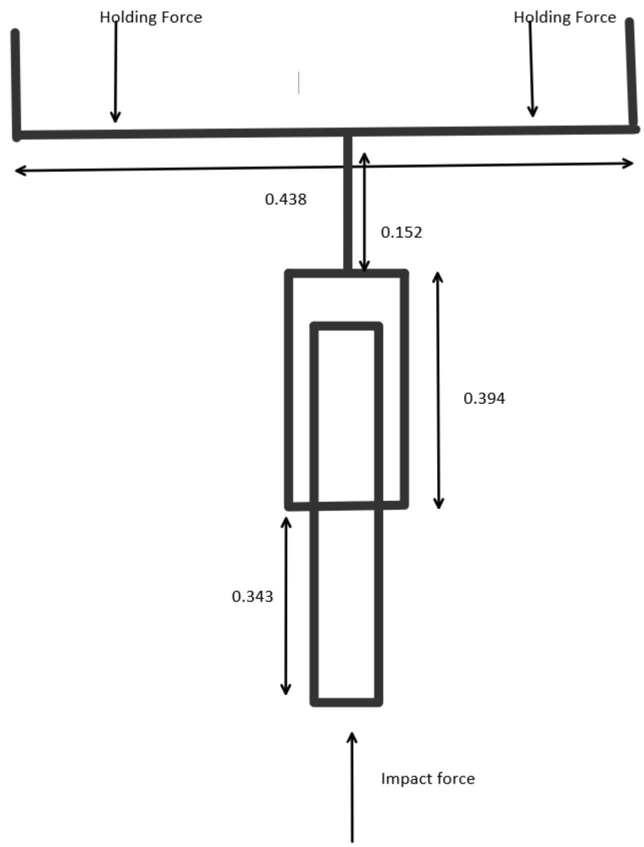


Fig 8. Showing the forces when landing the wheel.

The point of contacts for the rider in this case will be the seat and the handling bar so the weight will be divided between these contact points.

We will continue to use a rider of 205kg and from this we will assume that the rider applies 25% of their weight on the handlebars so the holding force will be

2000*25/100 = 500 Total

So, each holding force is 250N

Then we draw an Free Body Diagram of just the handlebar –

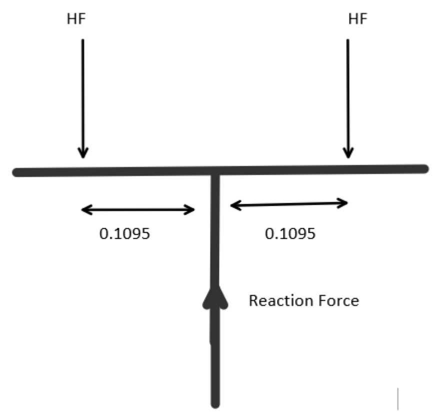


Fig 9. Fbd of the handlebar

Using this we can find the reaction force in the bar using moment at the connecting point between the handlebar and the fork –

Hf = 250N

Moment = 0

Reaction = 2*Hf = 500N

Then we find the impact force

Final velocity at the impact = (gh)^1/2 = (9.81*0.5)^1/2 = 2.2147m/s

D is the distance travelled by the type surface or the compression. We assume this to be around 0.01m.

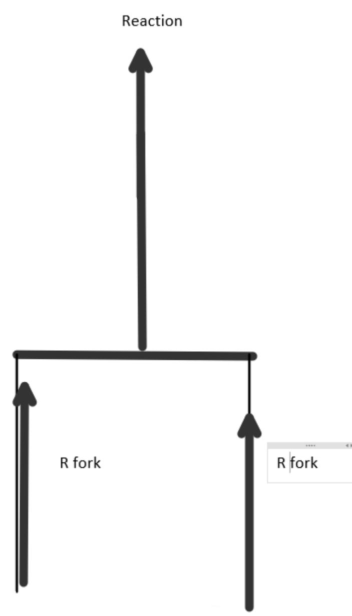


Fig 10. Fbd of the fork.

W = 0.5*Reaction force*V^2/d = 0.5*500*(2.2147^2)/0.01 = 115240.225 N/s^2 /g = 11747.2Nm

So, the torque from this is 11747.2N.m

Find StressY

We draw fork FBD

Rfork = R/2 = 250N

The to find stress in the bar holding the fork and the tire we need to find the Moment and Moment of Inertia

Moment would be zero as forces are identical around X axis

Stress X = 0

Moment about Y = 2*Rfork*distance to the rim = 500*0.295 = 147.5Nm

Then we find StressY = M*C/I

Where c = 0.035m

I = pi*3.58*10^-3/64 = 1.757*10^-4

StressY = M*c/I = 147.5*0.035/1.757*10^-4 = 29.38KPa

We use this to find the stress on the rim

Tau = T*0.325*16/ (0.325^4 - 0.295^4)*pi

= 11747.2*0.325*16/3.58*10^-3 * pi

= 5.43MPa

Principle stress = 1/2[StressY +- ((StressY)^2+(Tau)^2)^1/2]

= ½[29.38Kpa + - ((5.43))] = 2.73MPa

= -2.7MPa

Tension Principle Stress in the rim = 2.73MPa and compression stress is -2.7MPa

This means that the spokes connected to the rim will be mostly in compression and they will be designed accordingly as they can fail due to buckling and high compression stress when there is an impact from a higher ground.

Load Envelope – 3 Extreme Braking

The peak velocity for an average bike is 34.31 KPH or 9.53m/s [7]. It can also be found that the modern bikes have a higher braking capacity for the front brake [7]. From this statement we can try to find the braking force and how it affects the loading envelope.

For this case we will assume that the rider weighs 200kgs.

We can try to find the break force –

Let's assume that the bike is at peak velocity then V = 9.53m/s

For an extreme braking case the bike must stop within 1.5 to 2.5.

Let's take the most extreme conditions of 1.5 seconds the a = 9.53/1.5 = 0.647g

Then we get 0.647g deacceleration.

From this we draw the FBD of Breaking

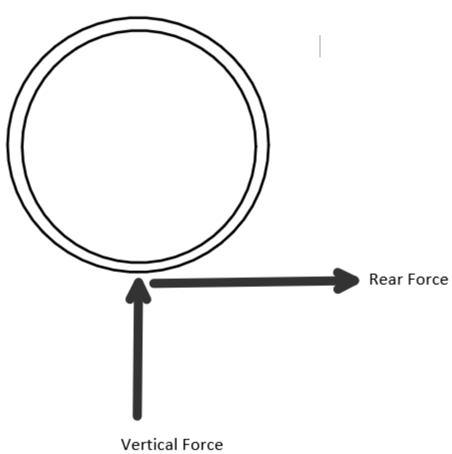


Fig 11. Fbd of the wheel when Braking

We can find Rear force that is 200 * 0.647*g = 1270N

Vertical force (All the weight will be on the front wheel as this is extreme braking on the front wheel) = 200*g = 1962N

From this we can find the torque on the wheel = 0.647*g*r *200 = 741.33N*m

So, for this case the forces on the frames are illustrated in Fig 12 below.

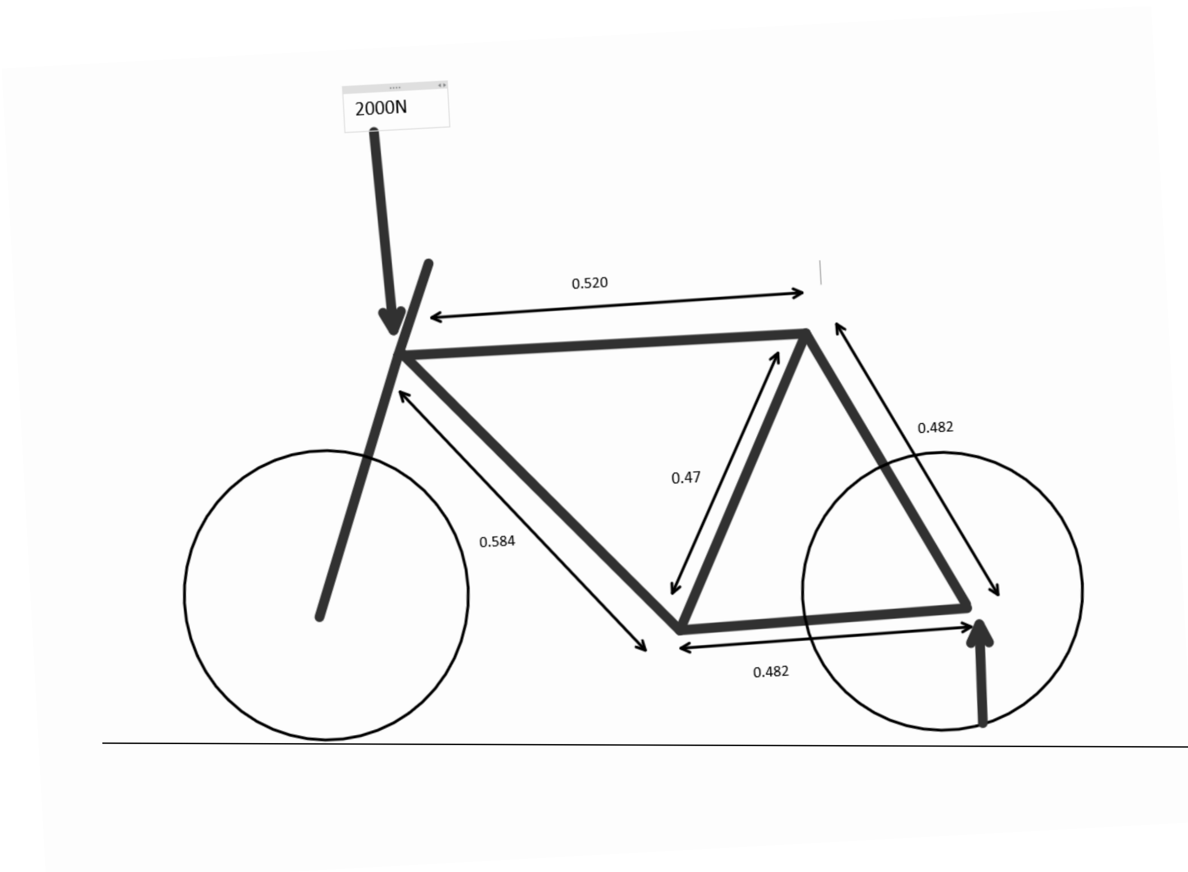


Fig12. Forces on the frame when extreme braking happens

From this we can further break down the frame

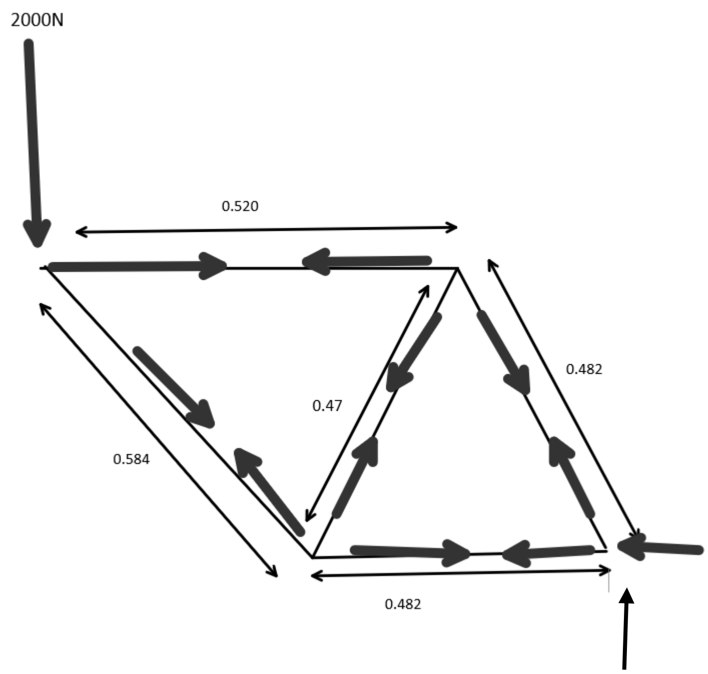


Fig 13. Forces in the members of the frame

From this diamond shape we can conceptually see that

Top tube, and seat stay will be in Tension

While down tube, seat tube, chain stay will be in compression.

From research literature we can also find the most important tubes for the frame. The most important being the down tube then at second the seat tube, and third being the top tube [8].

So, the down tube would be the most critical component in this design as it will absorb most of the energy from torsion and stresses. Which is the main force in the case of heavy breaking.

Analysis of Critical Components

Load 1

Screw connecting crank to the front gear

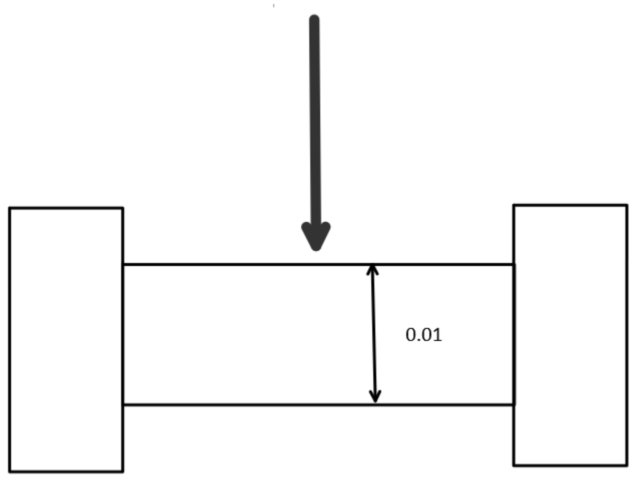


Fig 14. A Diagram of the bolt connecting crank to hub

As bolt is a critical component the amount of stresses will depend on the pitch diameter. However, as I could not find the pitch diameter, I will assume it to be a standard of 20tpi. So, the cost of this will bolt will be around 6$ [9]. To increase the life of this part we should make sure to select the highest stress has yield stress as it the part goes under permanent deformation it becomes useless as it is a joint and should be replaced if it has a permanent bent.

Load 2

The Spokes

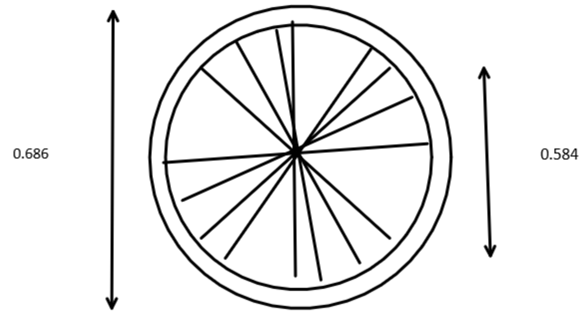


Fig 15. A Diagram of the wheel and the spokes

The diameter for the spokes is 0.002m. We can use this to find the buckling force where Pcr = pi^2 *E*I /(kL)^2

E for steel is 205GPa

I = pi*D^4/64 = 7.85 * 10^-13 = 4.7Nm

= Load/Area = Axial stress = 3.74Mpa

While the stresses found in the load 2 where is 2.7Mpa so the spokes have a safety factor of 1.38 when compare to the extreme condition of a landing impact.

So, to find the cost of the spokes for this bike will be

Spec	Unit	Cost
0.002 Diameter	1	$0.4166 [10]
0.002 Diameter	33	$13.75 [10]

As there are two wheels the total cost will be $27.5 for these specifications of spoke design.

Load 3

Down Tube

The critical component in this loading in the Down tube. The tube can be seen in the Fig no below

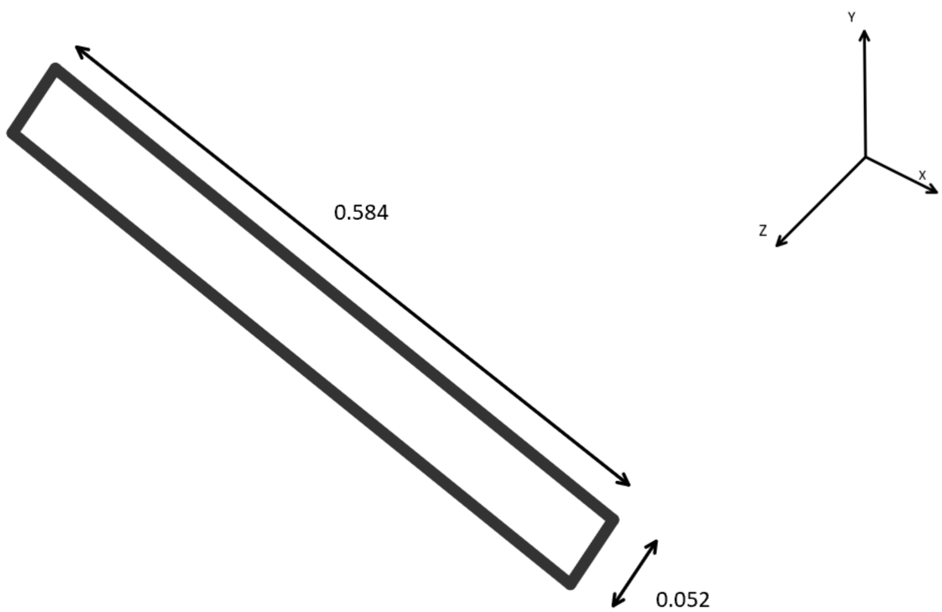


Fig 16. Diagram of the Down Tube.

The length of the tube is 0.584m and the outer diameter is 0.052. The member is in compression. The inner diameter is unknown so finding the stresses has not been possible. However, we can find values from literature which show that a 600N force when breaking creates a stress of 302MPa [3]. This is a stress of almost 50% of tensile stress of our material.

The cost of this part is $50.

Suggested Design Modifications

Load 1

Increase the pedal area so the forces are more evenly distributed, and the pressure is not on a single point. We can also decrease the amount of stress by decreasing the size of the crank arm, but this will lead less mechanical gain and less power generated from the pedaling. However, reducing the crankarm and using aluminum will be better as it will reduce the weight of the crank and help maintain the power from pedaling.

For this case we can also add gears to this bike to increase or reduce the gear ratio and then use this to generate more power from the pedaling. Finally, the original design is clearly safe for both normal use and extended misuse so most of the suggested design changes are based on the power generated by pedaling and not the forces on the hub by pedaling.

Load 2

For spokes the rider should check that the none of the spokes are bent before riding the bike each time. If a spoke is bent the rider should replace it as soon as possible. The rider should also make sure to not perform jumps with the bike as jumps of more than 1 meter will lead to the failure of the spokes in the front tire. We can also add a shock absorber to the fork which will absorb some of the impact forces when the bike is under extreme conditions or in an event of a an accident. Some of the stresses can also be eliminated from the front tire by increasing the diameter of the tires. As the flatter tires a bike would have the more compression in the tires would take place and less force would reach the rim and the fork.

Load 3

Make sure the front brake is not applying a force while riding the bike. This prevents from extra torsion on the frame and increases the life of the bike. It is better to brake and release than holding onto the brake as it will decrease the life of the brake pads and the rim.

The down tube needs to have the largest diameter. It has a good amount of safety factor so other parts of the frames needs to be analyzed further. Specially the chain stays, and the seat stay as they have the least diameter and the highest chance of failure. So, from this we can see in future projects that the two thin tube will be the critical components as they will decide when the bike becomes useless as they have smaller yield points and if they fail the bike fails [8].

Another thing that can be done to increase life is to maintain brakes. The United States federal government requires bicycle manufacturers to meet a minimum of -0.50g for braking [7]. So, the rider should make sure that a higher breaking force is applied for less time than a weaker braking force over a long time which will decrease the life of the bike.

Conclusions

From the load analysis we found that down tube was the main absorber was the torsion energy and the stresses energy [8]. We also found other components that experience heavy stresses them being the fork, the spokes and the bolt connecting the crank to the hub.

Form this analysis we can see that a bike is only as strong as the weakest part. There might be some parts that experience a large amount of stresses like the down tube in the frame. But as we saw in reverse engineering of the bike that the down tube had a large amount of safety factor so to increase the lifetime of the bike, we need to make changes to the seat stays and the chain stays by increasing their diameters [8]. We also understood how the the design absorbs force in an impact and how to protect the spokes. It can be done by adding a shock absorber. Furthermore, we understand that a steel bike can perform under heavy forces than an aluminum bike. Finally, the loading conditions analyzed also show that brakes should be maintained, and that parts like bolts should be replaced as soon as possible is they go under permanent deformation. Using these recommendations will increase the life of the bike by a lot and help keep the design from failing.

References

[1] 2019, “https://www.purecycles.com/pages/about-fixed-gear-bicycles”

[2] 2015, “https://janheine.wordpress.com/2015/10/16/aesthetic-choices/”

[3] D SODEN, P & A MILLAR, M & Adeyefa, Bodunrin & S WONG, Y. (1986). Loads, Stresses, and deflections in Bicycle Frames. Journal of Strain Analysis for Engineering Design - J STRAIN ANAL ENG DESIGN. 21. 185-195. 10.1243/03093247V214185.

[4] Hoes, M.J.A.J.M., Binkhorst, R.A., Smeekes-Kuyl, A.E.M.C. et al. Int. Z. Angew. Physiol. Einschl. Arbeitsphysiol. (1968) 26: 33. https://doi.org/10.1007/BF00696088

[5] 2017, “https://www.cdc.gov/nchs/fastats/body-measurements.htm”

[6] “http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=m4130r”

[7] Beck, RF (2004) Mountain Bicycle Acceleration and Braking Factors. Proceedings of the Canadian Multidisciplinary Road Safety Conference XIV, June 2004, Ottawa, Ontario, pp 27-30.

[8] Leisha Peterson, Kelly Londry, 1986, “https://www.sheldonbrown.com/rinard/fea.htm

[9] 2019, “https://www.chainreactioncycles.com/us/en/crank-bolts”

[10] 2019, “https://www.amazon.com/Stainless-Spokes-Mountain-233mm-257mm-Nipples/dp/B01FJ9BH26”