Analysis of Failure of Hanger Pins in Pakistan Railways Carriages

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Declaration

I certify that this research work titled "*Analysis of Failure of Hanger Pins in Pakistan Railway's Carriages"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Ahmad Kamal Mustafa
2016-NUST-MS-Mech

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I would like to thank Allah Almighty without Whose help it would have been impossible to complete this work. All the help and support from my parents and teachers were only because of Allah’s Will.

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Dedicated to my exceptional father, mother and adored siblings whose support and help led me to this fascinating accomplishments

Abstract

The frequency of failures in hanger pins of Pakistan Railway carriages has risen to an alarming level. Such as hanger pins have become the reason for the highest number of cases regarding failures of Carriage and Wagons in Pakistan. The pins have been failing after only 3 months while the intended life of these pins was supposed to be 6 months at least. These fatigue stresses must be controlled to an acceptable level through an efficient process in order to prevent failures in carriages. Previously we have been using rectangular cross-section cotter pins in the hanger brackets. Studies have shown that instead a circular cross-section cotter pin can make a major contribution to the lower the value of these fatigue stresses. There have been no studies on this particular project due to which it is the first of its kind in Pakistan Railways. In this study, we compute and perform the stress analysis as well as the fatigue analysis on the hanger pin assembly using the Findley criterion procedure in-order to become more real to the problem. The Findley criterion was used as it most closely resembled in the properties needed to carry out our desired simulation.

We employ a three-dimensional COMSOL model to compute the stresses as well as do the fatigue analysis on the said model. Fatigue usage factor has been used in the COMSOL. The first part contains the analysis on the already in-effect hanger pins of rectangular cross-sectional area. While the second half contains analysis done by changing the cross-section to modified circular shaped hanger cotter pins. Permission to perform the said analysis and used the facilities in hand was taken from Divisional Mechanical Engineer.

If the project is a success it will be a major cause for reduction in the number of cases regarding derailment in Pakistan Railways as a whole.

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Chapter 1

Introduction

1.1 Background

Truss bar is a component of the under gear of conventional Bogie. Is an iron beam having two brake blocks one on either end. It is linked with a pull rod by means of floating lever. The force which comes out from vacuum cylinder reaches to the truss bar which transmits it to the brake blocks. Truss bar hanger is a strong lever used to hang the truss bar assembly. It is fastened with frame from one end and holds the truss bar from the other end.

Pakistan Railways has been facing a lot of difficulties in dealing with such issues. The truss bar along with its hanger pin had a life span of 9 months. But failure of hanger pins has been occurring at a faster rate than expected causing derailments as well as prolonged detentions to the trains.

This problem that had stemmed motivated myself to start this project which is the first of its kind. We decided to use Fatigue and stress analysis in COMSOL software to compute our results.

Currently, the number of cases to hanger pin failures have risen quite a bit in the past 2 years and are a cause of great concern for all administration. Apart from that there is no Research and Development Department in Pakistan Railways which has in-turn led to almost more research been done in the department and hence no proper solution is ever given out and instead a solution is presented without any analysis or proper experimentation.

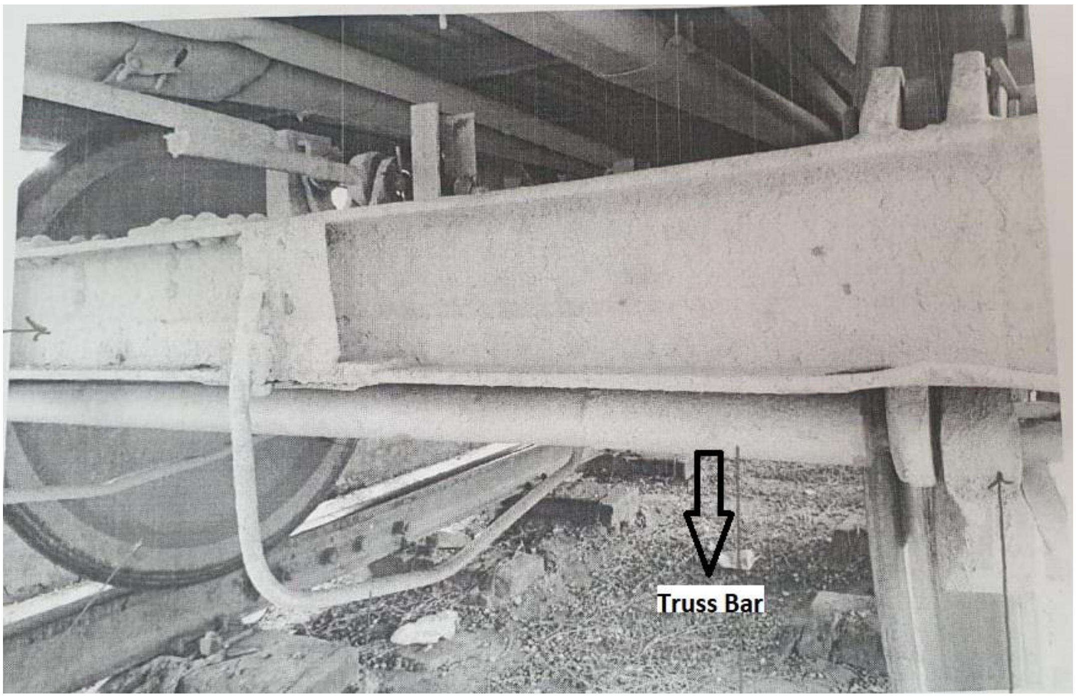

Figure 1.1 Picture of a Truss bar on 4-wheeler Bogie

Truss bar is an extremely vital component of a bogie as it transmits the braking power to the brake shoes and brake pads. The problem regarding the truss bar hanger pins have been in the system since long but in the past 1-2 years it has risen exponentially.

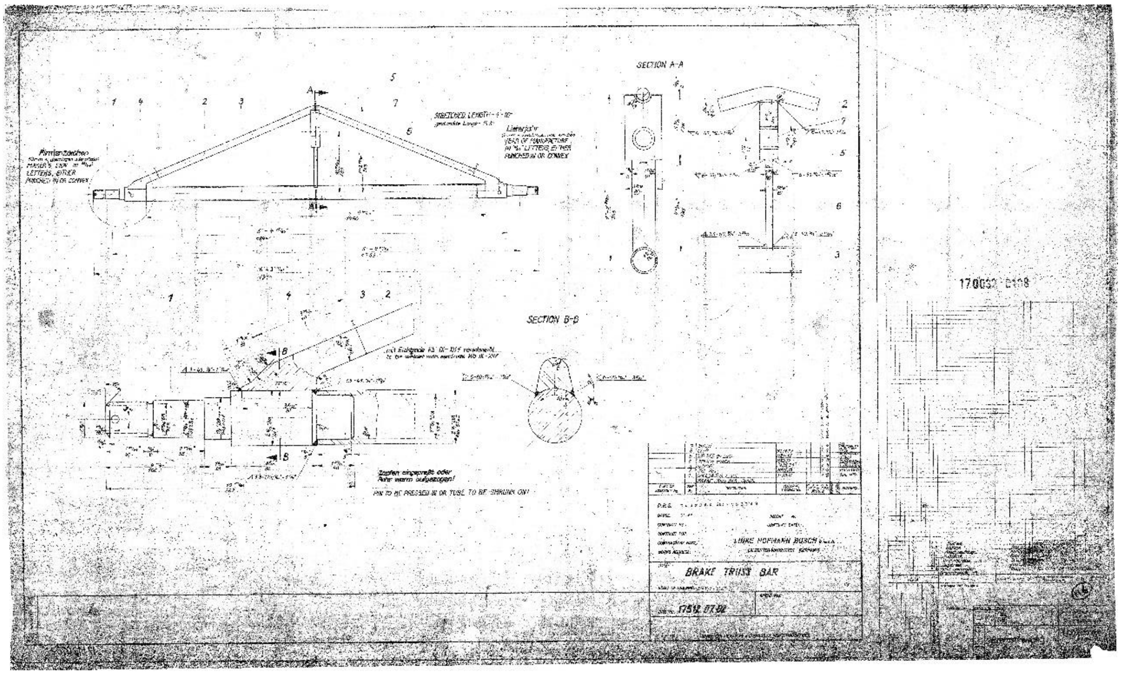

Figure 2.2 Truss Bar Assembly Drawing

In the hotter areas of Pakistan that the lower Punjab and the Sindh belt the temperatures are in the range of 45-50 degrees which are also a big concern. The bogies were originally made for vacuum-based braking system with the maximum speed of upto 65 km/hr but were later modified to run in air-brake system with the maximum speed increased to 105 km/hr without any subsequent changes in the material of bogie. Which obviously was bound to create some difficulties.

1.2 Problem Statement

Pakistan Railways has been facing a lot of difficulties in dealing with such issues. The truss bar along with its hanger pin had a life span of 9 months. But failure of hanger pins has been occurring at a faster rate than expected causing derailments as well as prolonged detentions to the trains. We have to increase the life span of the truss bar hanger pins so that they may atleast be able to survive till their life expectancy.

1.3 Objectives of Study

Aim of this research is to investigate the stresse involved in the truss bar hanger pin assembly and come with modification that might help us in improving its durability. The main aim of the study are:

a. Make and simulate the truss bar hanger pin assembly in COMSOL Multiphysics.

b. Modify the structure and perform the analysis on the modification to improve it.

1.4 Scope

The scope of this study is limited to the 4-wheeler bogies in the system of Pakistan Railways. However the number of 4-wheeler bogies in the system is more than 65%. This will help the Pakistan Railways in improving the overall standards and avoid and detentions as well as prevent accidents along the way. As this the first research of its kind done in Pakistan Railways hopefully it wont be the last and it will start the flow of many more researches to come in the future.

1.5 Research Hypothesis

The following methodology has been adopted to carry out the study and analyze the results.

1. The basic control unit for the thesis has been take as 4-wheeler BG-64 Germany made Bogie. The distance has been taken from Lahore Railway station to Karachi Cantt Railways Station.

2. Digitization of records, distances, charts, drawings and any other materials required have been obtained from Railways Documents with the administrative permission of Divisional Mechanical Engineer.

3. The dimensions and other measurement related details were taken from the Locomotive Workshop Mughalpura, Lahore.

4. The values of the stress and forces were taken on the average from various trips carried out.

5. The stress and fatigue modeling of the components have been carried out in COMSOL Multiphysics 5.5.

1.6 Dissertation Structure

Chapter 1 provides the introduction of the whole case study. The location of the study area including the stress and fatigue analysis is described briefly. The problem of failure of hanger pins and its causes and impacts are also overviewed. The scope of study, objectives to be achieved and the methodology that will be followed during the research is also outlined in this chapter. 5

Chapter 2 provides the literature review relating to (1) Hanger pin issues in Pakistan Railways; (2) Impact of these issues on the working of Railways; (3) Introduction and application of the COMSOL model.

Chapter 3 describes the location and conditions of the study area in detail including the salient features of 4-Wheeler Bogies.

Chapter 4 is composed of data source and methodology. It describes the framework adopted for stress modeling, development and fatigue usage scenarios and method of analysis of the data in detail.

Chapter 5 presents the integrated results derived from the methodology followed. It also includes the discussions on the results obtained and conclusion.

Chapter 2

Literature Review

2.1 General

Pakistan was created in 1947 and along with its independence the North-Western State Railways became Pakistan-Western Railways. In 1947 Quaid-e-Azam M. Ali Jinnah invited Frank D Souza to help bring the Railways up to the mark. The railway was extended to Mardan KPK in 1954, and two years later the Jacobabad–Kashmore was converted to broad gauge. In 1961 the North Western Railway became Pakistan Railways. The Kot Adu–Kashmoree line, constructed between 1970 and 1974, provided another route north from Karachi. China through CPEC is involved in the development of Pakistan Railways, and has been increasing its stake in Pakistan's communications sector. Freight and passenger service make up 60% of the railway's total revenue. Pakistan Railways carries 75 million passengers annually and operates 228 mail, express and passenger trains daily. It introduced new mail and express trains between major terminals from 2004 to 2006. The railway has entered developmental agreements with Chinese rail companies. In early 2000s, Pakistan Railways signed a 90 plus million dollar contract with CNMIEC to manufacture 170 high-speed passenger coache. Forty passenger coaches have been received, and 105 were scheduled to be assembled in Pakistan Railways' carriage factory. The coaches are in use on Pakistan Railways' Rawalpindi-Karachi, Lahore to Faisalabad and Rawalpindi to Quetta mail and express trains. The manufacturing kit for the remaining 35 coaches have been received, and 12 are assembled.

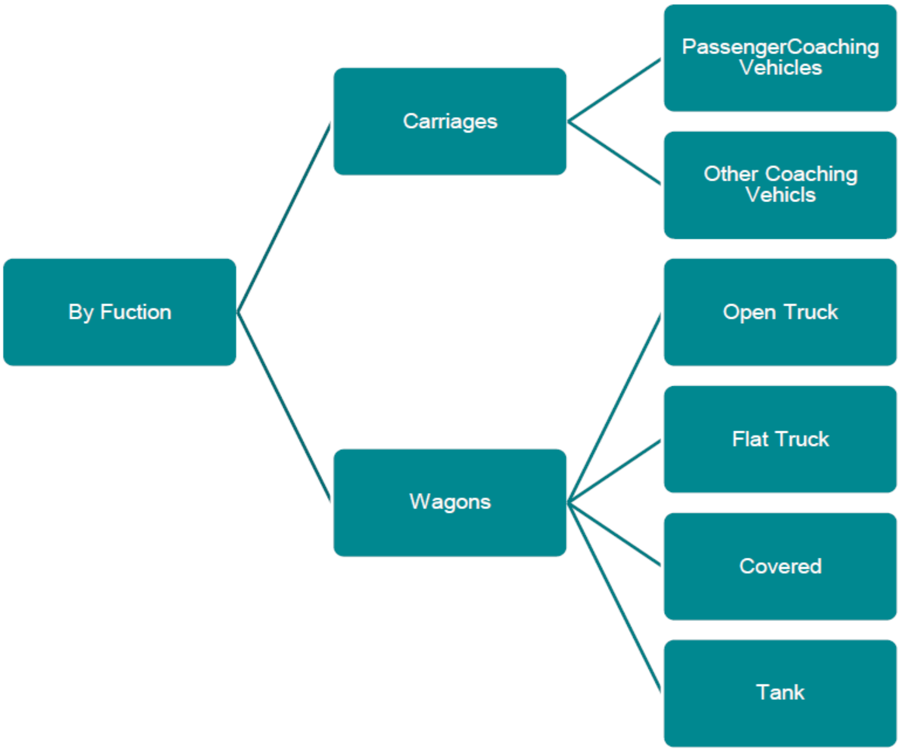

Figure 2.1 Types of Rolling Stock

2.2 Hanger Pin Issues in Pakistan Railways

Pakistan Railways was regarded as having immense resources from the time of its construction to early 2000s. The lack of management to preserve those resources has created a stress situation. Currently, the number of cases to hanger pin failures have risen quite a bit in the past 2 years and are a cause of great concern for all administration. Apart from that there is no Research and Development Department in Pakistan Railways which has in-turn led to almost more research been done in the department and hence no proper solution is ever given out and instead a solution is presented without any analysis or proper experimentation.

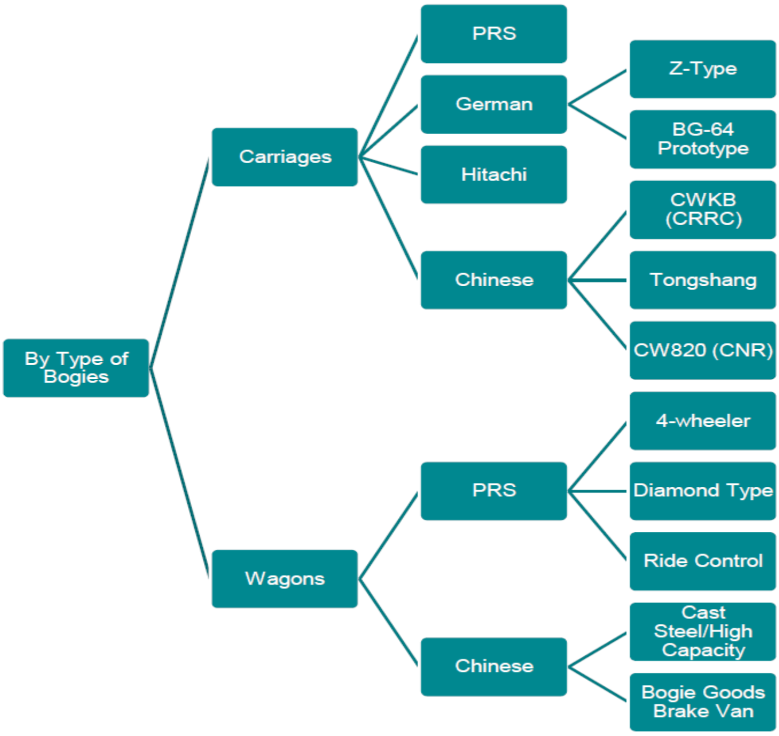

Figure 2.2 Types of Bogies

2.3 Impact of Track on the Components

The track that is spread out all around Pakistan is out dated and even though it has been changed in parts from time to time due to no fencing around the track and people living beside the railway line as led to weakening of the ballast underneath the track. Which in-turn has led to uneven tracks and more pressure and forces on the components. The hanger pins has to bear extra jerks and vibrations due to it as well.

2.4 Probable Causes of Failure

There are various probable causes that might be the reason of the reduced life of the hanger pins in Pakistan Railways Some of them are explained as follows:

2.4.1 Uneven Track

The track although has been repaired many times in parts but it is still not upto the mark and as the ballast underneath becomes weak with time the tracks at places sink.

Although primary and secondary suspension systems are present in the system they cant cancel the effect as a whole. Resulting in spikes in the loading bore by the pins and causing failure

2.4.2 Loose Coupling

Due to uneven track with respect to time the coupling becomes loose. Resulting in the creation of horizontal forces and rough ridings.

2.4.3 Lack of Supervision

Even though all the safety rules and standards are provided the people in-charge of them sometimes don’t adhere to them resulting in late spotting of a fault and subsequent failure. The supervisors should be more vigilant to avoid each situations.

2.4.4 Lack of Spare Parts

There is a huge shortage of material available as well in the railways due to which the part has to be used for more than the intended period of time and hence it getting out of the safety limits and failing during the working of the train.

2.4.5 Humidity

The humidity in the air is different in different areas of the country. Especially when the train is terminated in the Karachi City the humidity is quite high there and thus is a big reason for the corrosion and then ultimately failure of the material at hand.

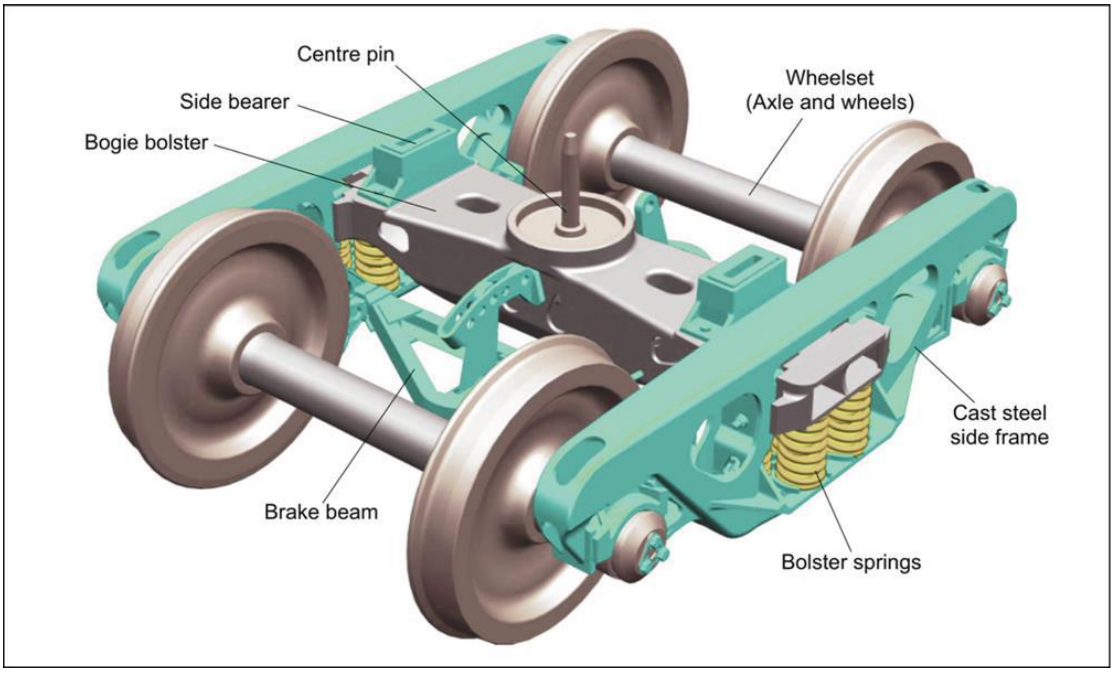

Figure 2.3 Basic Undergear of BG-64 4 Wheeler

2.5 Previous Studies

No studies have previously been carried out on the subject due to the following reasons:

- Absence of Research and Development department in the organization.
- Permission to carry out a research has to be taken from senior officers whom seldom have time to do divert their focus elsewhere.
- The technical specifications and parts details are often kept secret due to the sensitive nature of Pakistan Railways.
- The Officers are transferred a lot more in Pakistan Railways than in other organizations hence officers don't take much interest as they would be replaced in no time.

Chapter 3

Methodology

3.1 Numerical Calculations

The analysis presented in this study has taken an average value of forces. It does not involve variations due to friction and wasted energy due to heat loss from brake application.

The pressure inside the brake cylinders = 25 psi

Diameter of Brake cylinder = 7 inches

Calculating the Cross-Sectional Area = $A = \pi r^2$

$= \pi \times (7)^2 / 4$

$= 38.484\ in^2$

Force = Pressure x Area

= (25) x (38.484)

= 962.1 lbf

Note: The forces are being calculated at an angle of 30 degrees as it the maximum angle that the rod makes w.r.t the horizontal plane.

Forces in different planes:

Force in the x-axis : $F_x = 0$

Force in the y-axis : $F_y = 962 \sin(30)$

$= 481$ lbf

Force in the z-axis : $F_z = -962 \cos(30)$

$= -833$ lbf

These are the forces that we will use in our COMSOL Module as well.

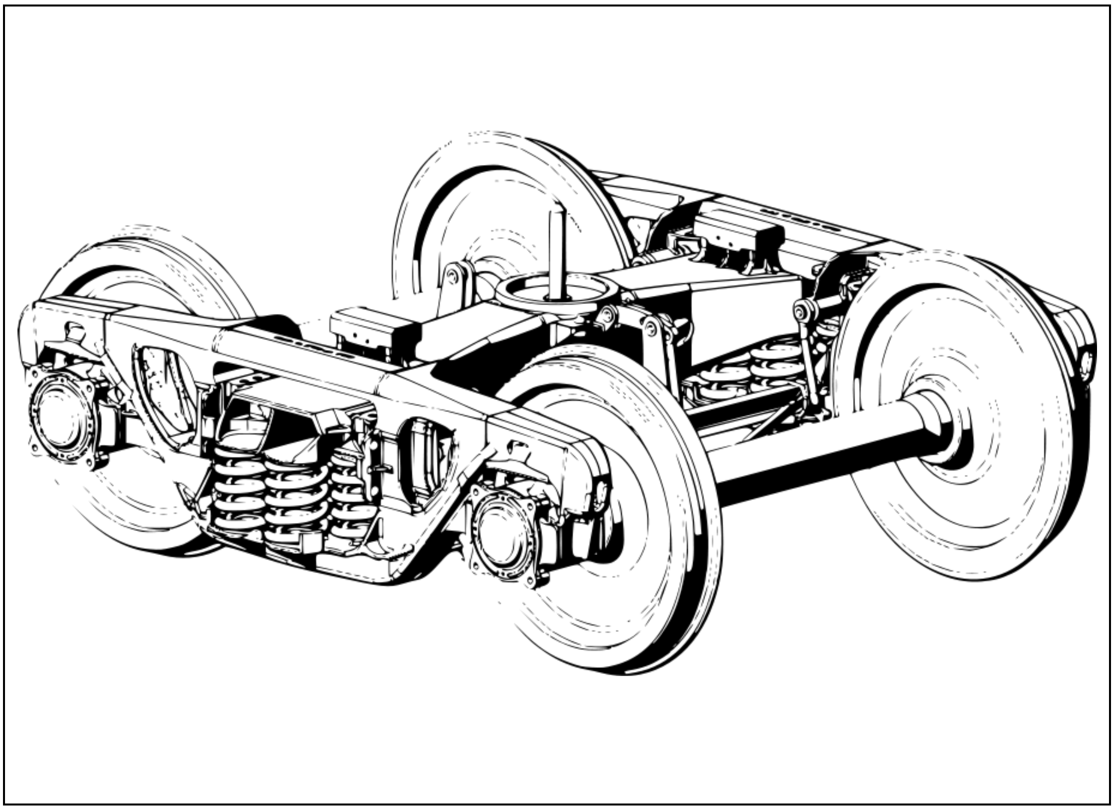

Figure 3.1 Picture of Under gear of a Bogie

3.1.1 Findley Criterion

The major cause for failure in these parts is the multiaxial fatigue. Fatigue failure occurs when a part is in long term service usage under dynamic load beyond the strength of material which in turn results in cracks/breakage known as fatigue. This happens due to improper processing method or uneven loading as well.

The Critical plane approach is being used which states that the critical plane approach is applied to model material fatigue behavior under any constant amplitude proportional loading. The most critical plane and the largest damage parameter are determined in closed form for six damage criteria that have been proposed in the literature [01].

There are a number of criterions that can be used to find the fatigue in multiaxial fatigue failure analysis based on critical plane approach

- Findley Criterion
- Matake Criterion
- Maximum Normal Stress Criterion
- Dan Van Criterion

For the Findley Criterion the orientation of the critical plane normally coincides with the plane where the maximum value of the linear combination occurs. For the Matake Criterion the critical plane would coincide with the maximum shear stress amplitude.

In this thesis we have used the Findley Criterion as it very closely resembled the model that we are analyzing.

$$f = \tfrac{1}{2}\sigma_{-1}\left(k + \sqrt{1 + k^2}\right) = \tfrac{1}{2}\sigma_0\left(2k + \sqrt{+(2k)^2}\right).$$

Using the values of stress as 962 and 657 in-order to compute the values of limit factor and the normal stress sensitivity coefficient factor.

$$\begin{array}{l} 657k + \sqrt{431649k^2 + 431649} = 2f \\ 962k + \sqrt{925444k^2 + 231361} = 2f \end{array} \quad \textbf{for } f, k.$$

$$f = \frac{21\sqrt{182060905}}{610} \approx 464.512931052252,$$
$$k = \frac{100144\sqrt{182060905}}{3823279005} \approx 0.353425019689735$$

Hence the value of normal stress sensitivity coefficient factor is 464.512 and the value of limit factor of findley is 0.353

3.2 Data Source

3.2.1 Numerical Data

All the stress and force values were taken from:

- the Maintenance manuals of BG-64 Bogie available in the Workshop Library in Mughalpura.
- Operation Manuals of BG-64
- Data collected from the daily trips as well

3.2.2 Selection of Suitable Station to Station Distance

The Distance was the data collected was taken from the Lahore Junction to Karachi Cantt Railway station as both of them are the major stations and most of the passengers trains either start or are terminated over there. The distance from Lahore Junction to the Karachi Cantt Railway station is of 1219 kms.

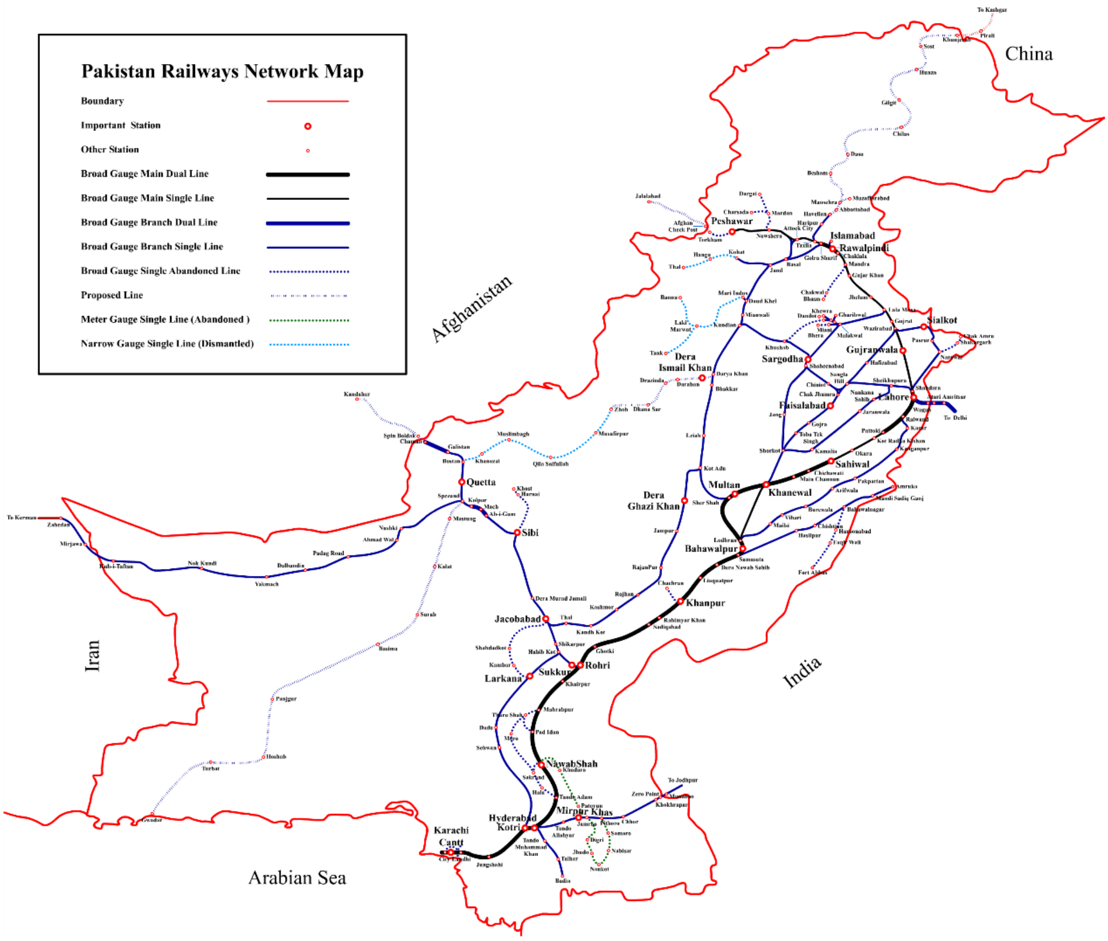

Figure 4.2 Pakistan Railways Track

3.2.3 Selection of Suitable Sample

The Sample was selected at random from one of the derailment sites on 12 November 2019. The sample's profile was fit was our analysis. A new hanger bar pin was put beside a damaged one for the purple of size and shape comparisons.

Figure 3.3 Closeup of both Pins

Figure 3.4 Pins and their samples used for the material analysis

3.3 COMSOL Modelling

The software used in the analysis was the COMSOL Multiphysics 5.5. It was used as it has very versatile features and is very user friendly. COMSOL uses java as a language. We can easily select our boundaries and surfaces for the simulations. The module of fatigue usage factor is also very significant. COMSOL has multiple modules to select from. Some of them are as under:

- Optimization Module
- Microfluids
- CFD
- Structural Mechanics
- Fatigue
- Non linear Structural Material
- MEMS
- Heat Transfer etc.

3.3.9 Material Definitions

The Material used in the calculations was Steel AISI 4340. Which was also confirmed from the Elemental Analysis done from the USPCAS-E Centre, NUST.
The characteristics of the material were taken as:

MATERIAL PARAMETERS

Name	Value	Unit
Density	7870[kg/m^3]	kg/m³

Name	Value	Unit
Young's modulus	205e9[Pa]	Pa
Poisson's ratio	0.29	1
Normal stress sensitivity coefficient	0.353	1
Limit factor	464.513[MPa]	Pa
Density	7870[kg/m^3]	Density

YOUNG'S MODULUS AND POISSON'S RATIO SETTINGS

Description	Value
Young's modulus	205e9[Pa]
Poisson's ratio	0.29

3.3.10 Solid Mechanics Module

As the values taken were of forces and we had to find the stresses applied as well as the fatigue analysis the Solid Mechanics module was the most preferred one and hence it was used here along with inputting the following properties:

3.3.10.1 Linear Elastic Material

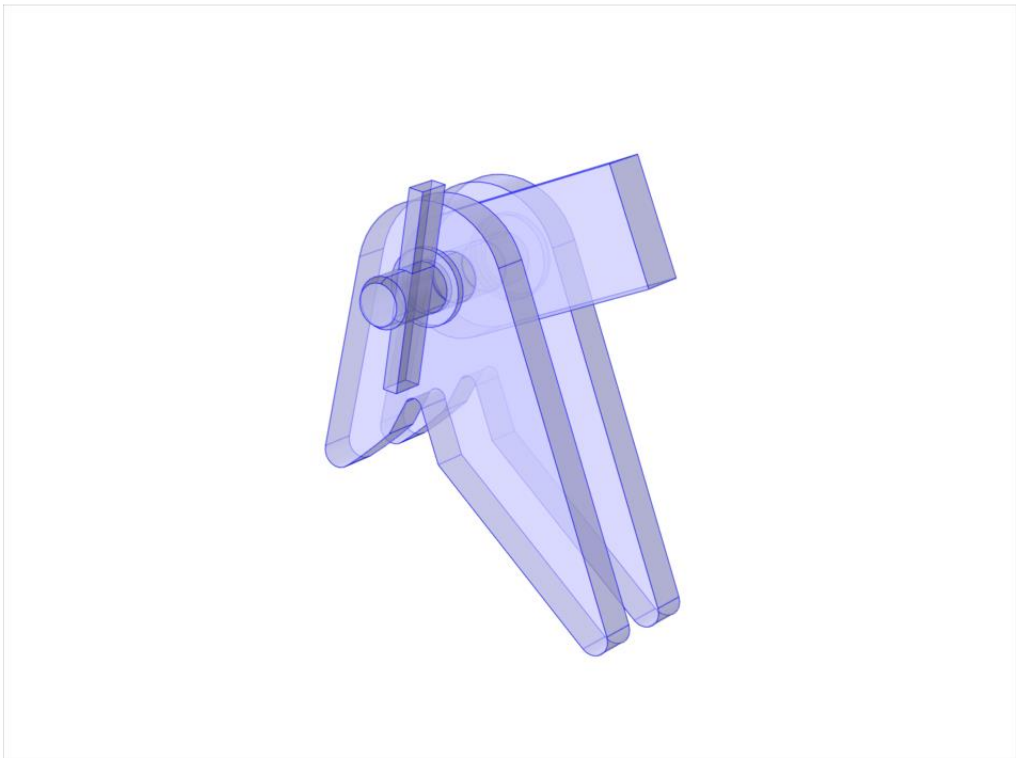

Figure 3.5 All domain selected

The model was taken as an linear elastic material with

- Solid model as isotropic
- Values of poisson's Ratio and young's modulus taken from the material and their values have been given in the avobe table
- Density of the model directly from the material parameters.
- Global coordinate system was used
- All the domains were selected in the sub section of elastic materials

3.3.10.2 Fixed Constraints

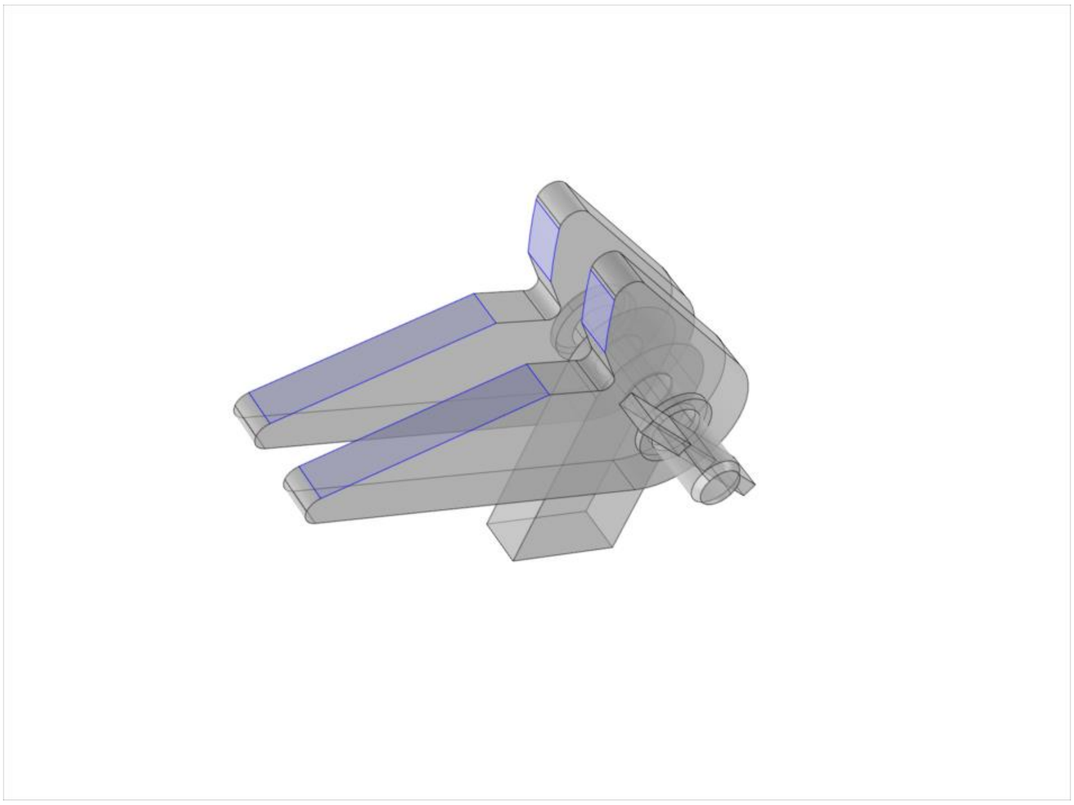

Figure 3.6 Surfaces on which Constraints are applied

The model was fixed from two points in the model. These are the points where it is attached to the truss bar of a BG-64 Bogie.

3.3.10.3 Boundary Load

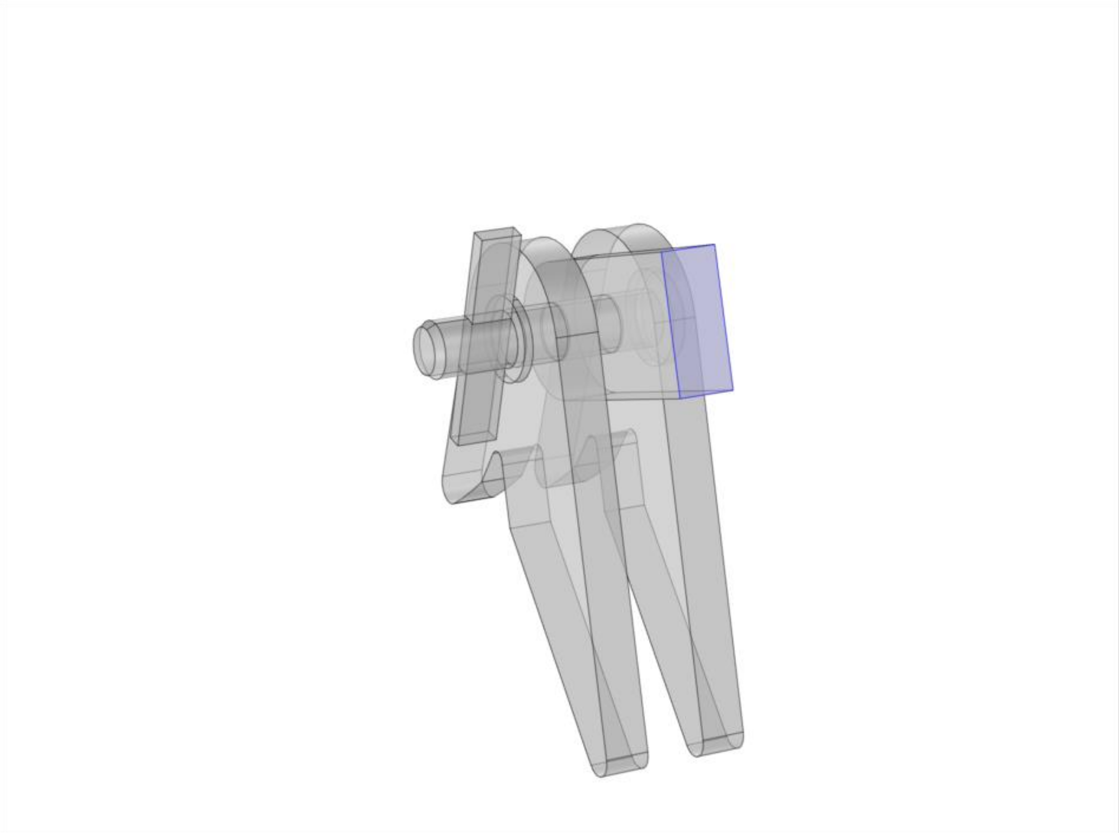

Figure 3.7 Surface of Boundary Load

The boundary Load was applied to the longitudinal rod that connects the brake cylinders with the truss bar as shown in the picture above. It makes an angle of 30 degrees. And the horizontal and vertical components of the forces have been calculated as 418 and 833 MPa.

3.3.11 Fatigue Module

The next step in our calculation was to calculate the fatigue and hence make its module on the COMSOL as required. The types of models we can use to predict the fatigue are many in COMSOL Multiphysics. Some of them are as below:

- Stress-Life
- Strain-Life
- Stress-Based
- Strain-Based
- Energy Based
- Vibration Fatigue

All of these can be taken as a surface-based calculations or volume based calculations.

In our model we have used the module of Stress-Based Surface Fatigue analysis.

3.3.11.1 Mesh Setting

The Mesh that has been used in the simulation is Free Tetrahedral Mesh with the predefined size taken as “Fine”.

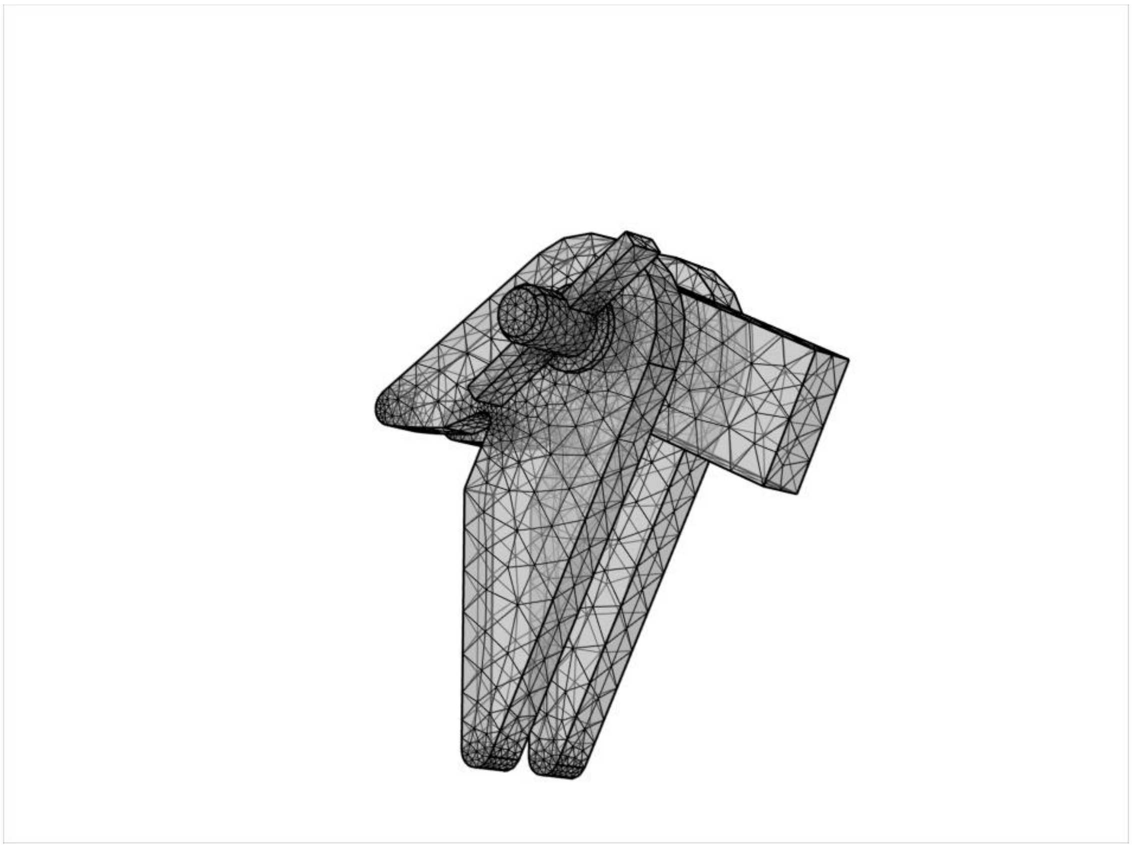

Figure 3.8 Mesh Settings

MESH STATISTICS

Description	Value
Minimum element quality	0.1503
Average element quality	0.6465
Tetrahedron	23280
Triangle	6552
Edge element	1009
Vertex element	122

SETTINGS

Description	Value
Maximum element size	0.0182
Minimum element size	0.00227
Curvature factor	0.5
Resolution of narrow regions	0.6
Maximum element growth rate	1.45
Predefined size	Fine

3.3.11.2 Findley Criterion

For the purpose of calculations Findley's Criterion was used as it best served our purpose.

For the Findley Criterion the orientation of the critical plane normally coincides with the plane where the maximum value of the linear combination occurs. For the Matake Criterion the critical plane would coincide with the maximum shear stress amplitude.

Fatigue model selection

SETTINGS

Description	Value
Criterion	Findley

Fatigue Model Parameters

SETTINGS

Description	Value
Normal stress sensitivity coefficient	From material
Limit factor	From material

The value of normal stress sensitivity coefficient factor is 464.512 and the value of limit factor of findley is 0.353 and were calculated earlier on in Chapter 3.1.1.

Chapter 4

Results and Discussions

4.1 COMSOL Model with Pre-existing Conditions

The Solutions are analyzed first with the pre-existing conditions and values.

The model was taken as an linear elastic material with

- Solid model as isotropic
- Values of poisson's Ratio and young's modulus taken from the material and their values have been given in the above table
- Density of the model directly from the material parameters.
- Global coordinate system was used
- All the domains were selected in the sub section of elastic materials

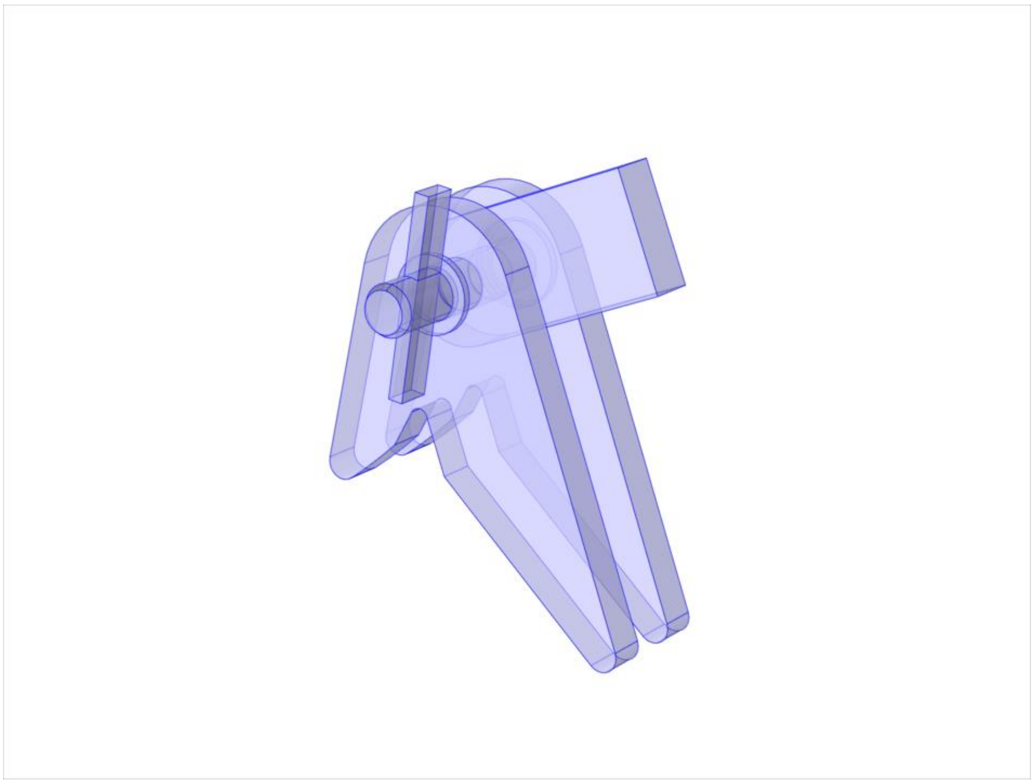

Figure 4.1 Original Model

4.1.1 Stress (Solid)

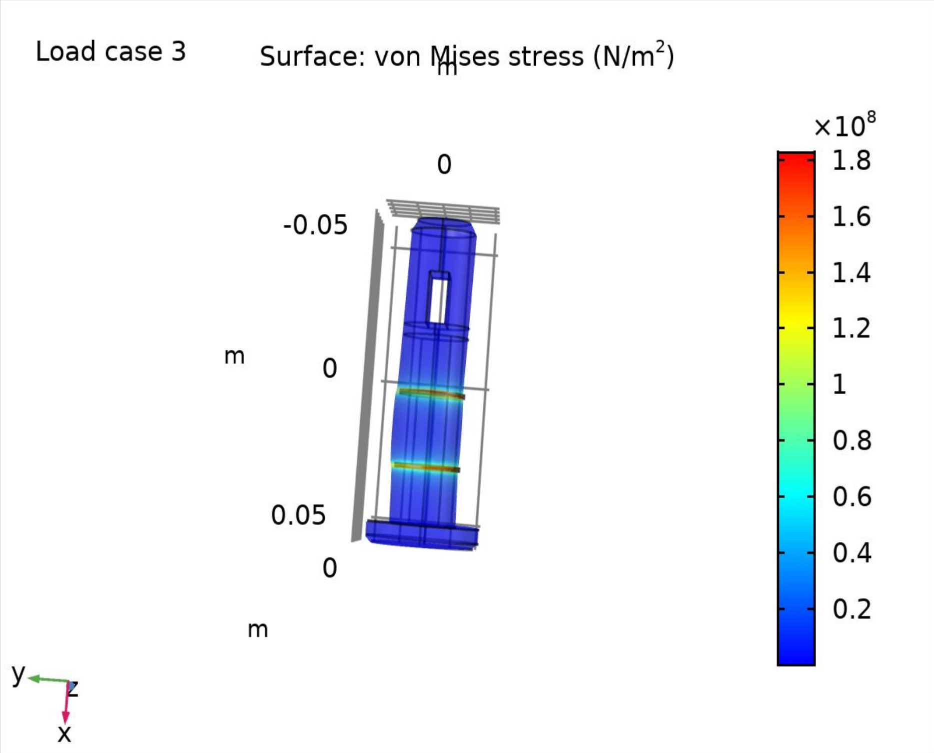

Figure 4.2 Von Mises Stress Solution

The maximum value of the Vons mises stress is 1.83x 10^8.The Yield Strength of the material is 2.65x 10^8 which is within its range. Which means that it is not breaking because of constant abnormal stress.

4.1.2 Fatigue Usage Factor

Fatigue Usage Factor maybe defined as the ratio of number of cycles that the part is expected to endure to the allowable cycles. This term is only used in the cases of stress-based evaluations.

By another definition it is also called as a prediction in the stress-based Fatigue models where it is the the fraction between the applied stress and stress limit.

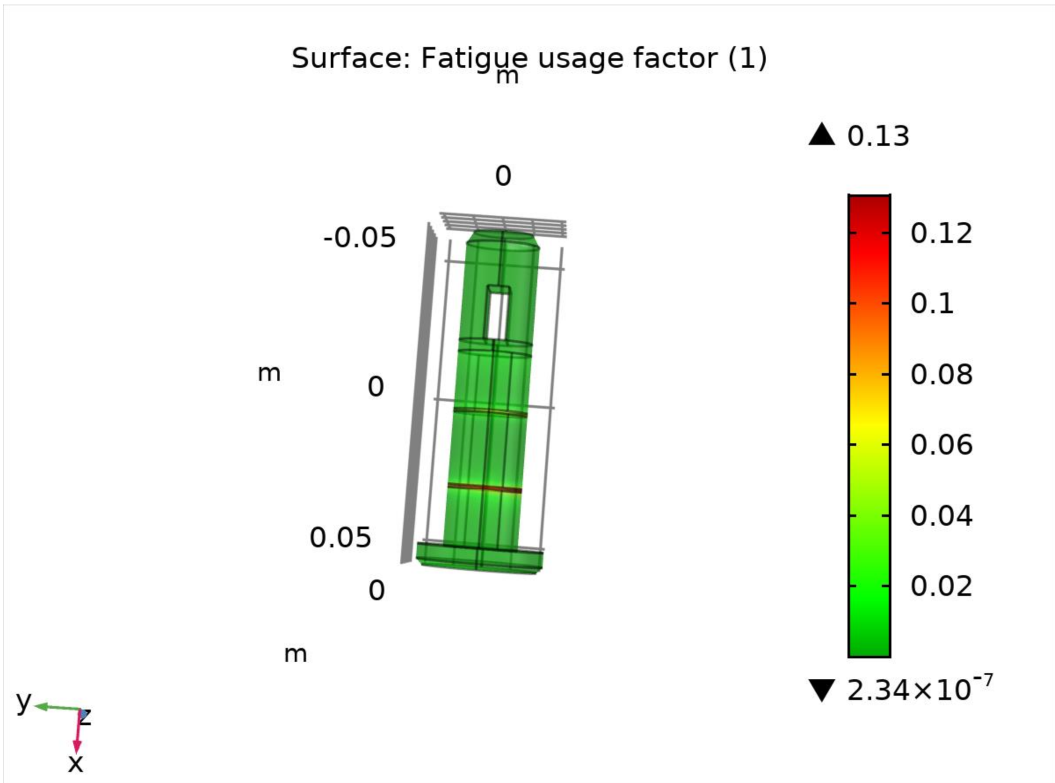

Figure 4.3 Fatigue Usage Factor Solution

Here the resulting factor is 0.13.The value of number of cycles in the Fatigue usage factor is taken as one million cycles.

The distance between Lahore and Karachi= 1220 kms

Approximate number of times the brake is applied and hence the movement of the longitudinal bar occurs per trip of a train = 815 (this is an approximation as calculated by drivers in 3 trips than taking the overall average)

Which implies that the material would probably fail in = 100000/815

= **123 days approx..**

The Life that these pins were made to last was 9 months and as we can see they are not even utilizing half of their life and are failing rather quickly.

4.2 Proposed Changes in the Model

Were a couple of changes that were implemented, and a new model was made and analysis was done on it.

4.2.1 The Cotter pin

The cotter pin was in rectangular shape in the original model as well as in the real railway bogies as well.

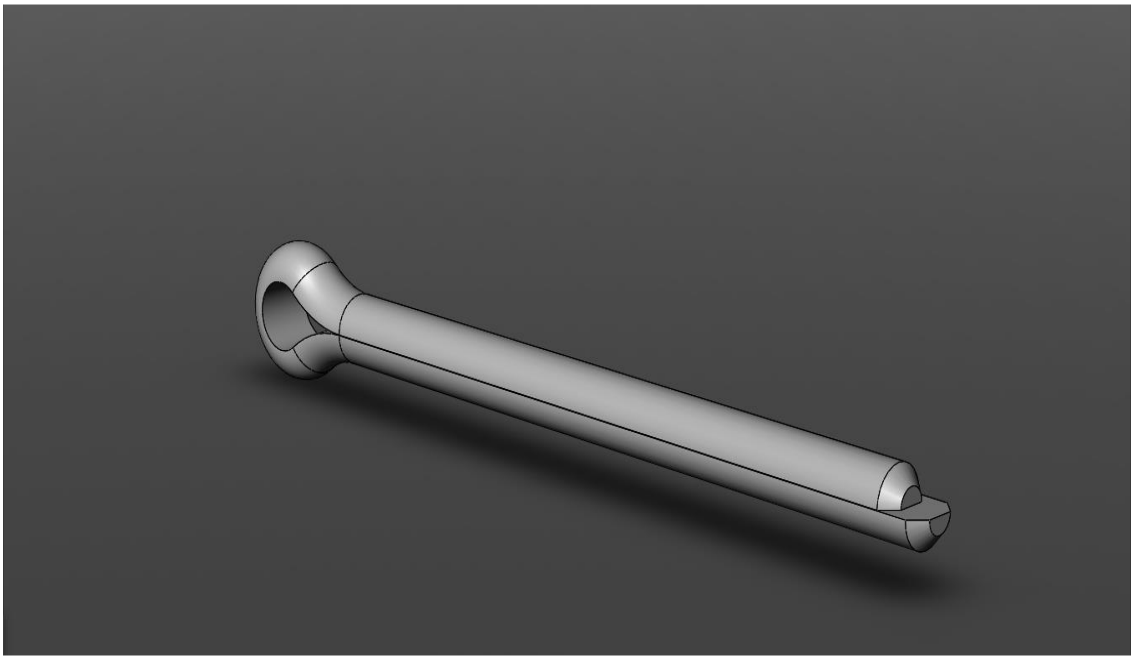

Figure 4.4 New Circular Cotter Pin

The modified cotter pin has a circular cross section with reduces the stresses induced in it due to the absence of corners.

4.2.2 Change of Material

The Material used in the calculations was Steel AISI 4340. Which was also confirmed from the Elemental Analysis done from the USPCAS-E Centre, NUST.

The characteristics of the material were taken as:

MATERIAL PARAMETERS OF STEEL AISI 4340

Name	Value	Unit
Density	7870[kg/m^3]	kg/m³
Young's modulus	205e9[Pa]	Pa
Poisson's ratio	0.29	1
Normal stress sensitivity coefficient	0.353	1
Limit factor	464.513[MPa]	Pa
Density	7870[kg/m^3]	Density

YOUNG'S MODULUS AND POISSON'S RATIO SETTINGS

Description	Value
Young's modulus	205e9[Pa]
Poisson's ratio	0.29

The new material tested was structural steel having the following properties and settings:

MATERIAL PARAMETERS OF STRUCTURAL STEEL

Name	Value	Unit
Density	7850[kg/m^3]	kg/m³
Young's modulus	200e9[Pa]	Pa
Poisson's ratio	0.30	1
Normal stress sensitivity coefficient	0.353	1
Limit factor	464.513[MPa]	Pa

YOUNG'S MODULUS AND POISSON'S RATIO SETTINGS

Description	Value
Young's modulus	200e9[Pa]
youngsmodulus_symmetry	0
Poisson's ratio	0.30
poissonsratio_symmetry	0

4.3 COMSOL Model With New Changes

The Solutions are analyzed first with the new conditions and values.

The model was taken as an linear elastic material with

- Solid model as isotropic
- Values of poisson's Ratio and young's modulus taken from the material and their values have been given in the above table
- Density of the model directly from the material parameters.
- Global coordinate system was used
- All the domains were selected in the sub section of elastic materials

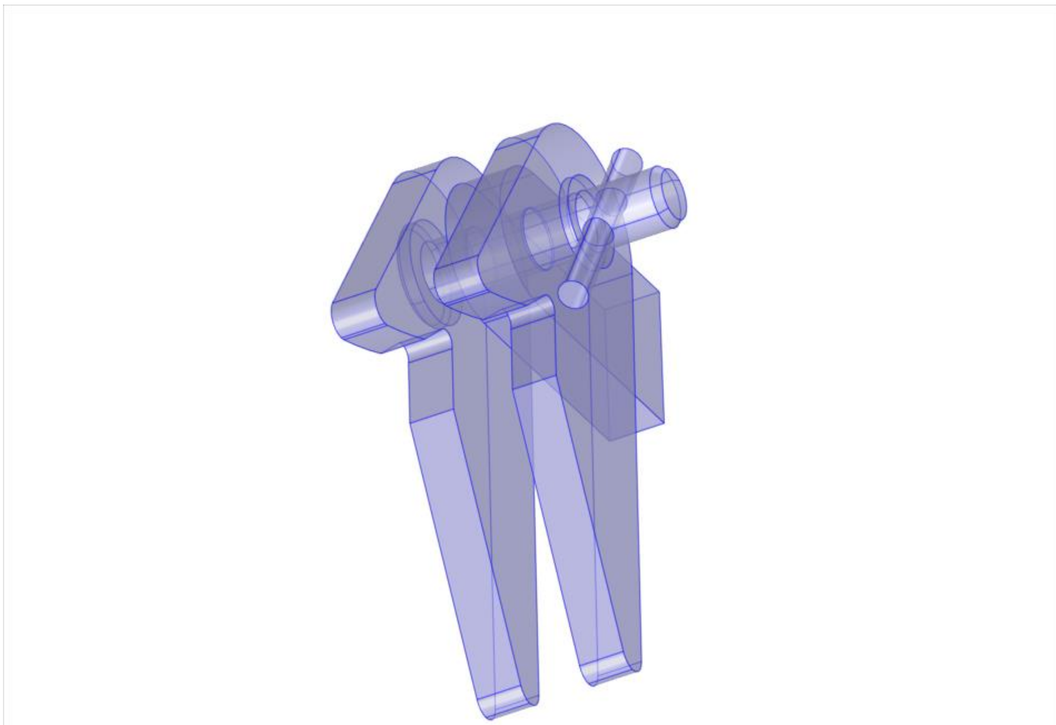

Figure 4.5 Modified Model

4.3.1 Stress (Solid)

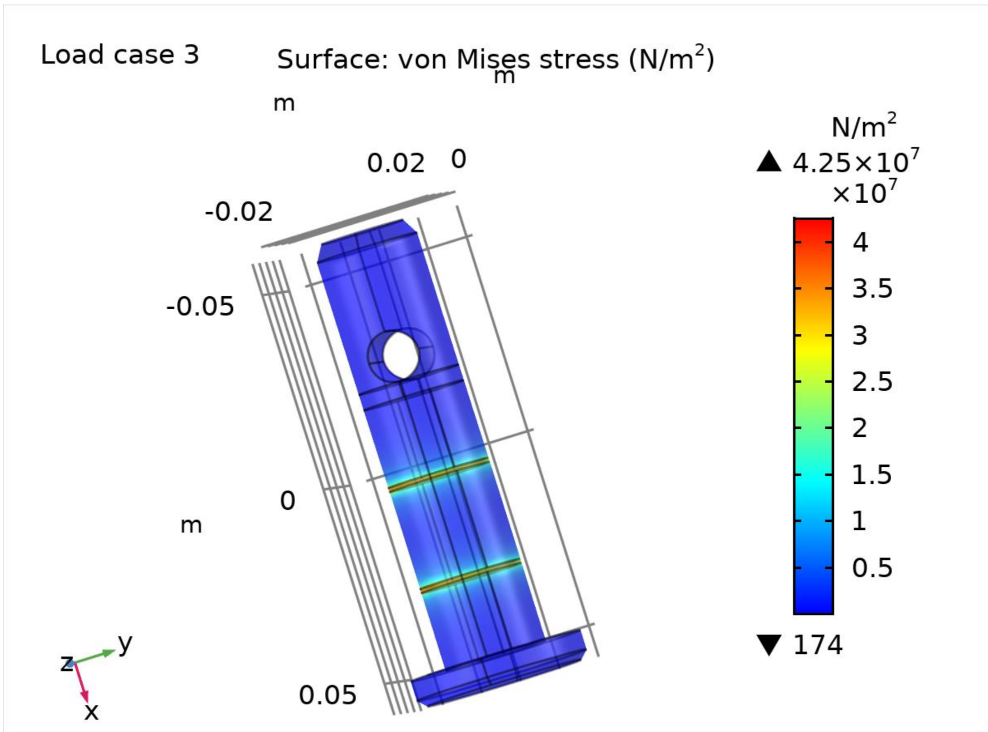

Figure 4.6 Von Mises Stress Solution

The maximum value of the Vons mises stress is 4.25x 10^7.The Yield Strength of the material is 2.65x 10^8 which is within its range. Which means that it is not breaking because of constant abnormal stress but its value has decreased significantly.

4.3.2 Fatigue Usage Factor

Fatigue Usage Factor maybe defined as the ratio of number of cycles that the part is expected to endure to the allowable cycles. This term is only used in the cases of stress-based evaluations.

By another definition it is also called as a prediction in the stress-based Fatigue models where it is the the fraction between the applied stress and stress limit.

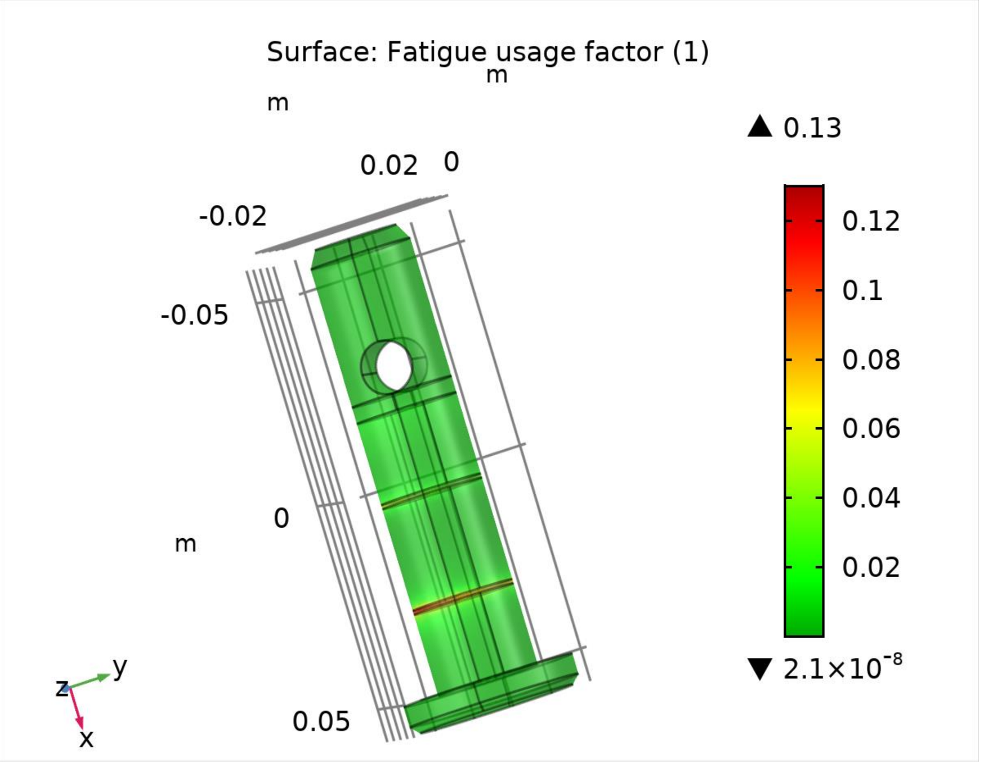

Figure 4.7 Fatigue Usage Factor Solution

Here the resulting factor is 0.13.The value of number of cycles in the Fatigue usage factor is taken as one million cycles.

The distance between Lahore and Karachi= 1220 kms

Approximate number of times the brake is applied and hence the movement of the longitudinal bar occurs per trip of a train = 815 (this is an approximation as calculated by drivers in 3 trips than taking the overall average)

Which implies that the material would probably fail in = 100000/815

= **123 days approx..**

The Life that these pins were made to last was 9 months and as we can see they are not even utilizing half of their life and are failing rather quickly. However the amount of stress is quite different in both the simulations and hence this new modified design would be certainly an improvement in the original design.

4.4 Future Areas of Research

Due to the absence of a Research and Development in Pakistan Railways there is a lot of scope for research in the organization. As far as future research in my proposed topic is concerned it can be further improved by following:

- The simulations can be tested experimentally in the Pakistan Railways.
- A larger set of data can be taken by taking proper permission from the Chief Mechanical Engineer.
- More Materials can be tested for better results
- Proper measurements of force and pressure can be obtained using proper measuring instruments instead of using approximate values.

Chapter 5

Conclusions and Recommendations

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5.1 Conclusions

- The number of failures of hanger pins in the truss bar assembly can be significantly reduced if the new modified model is used.
- The new proposed material proved to have decreased the stresses induced in the components thus increasing its life.
- COMSOL Muliphyics proved to be a great software for the simulations.
- However to implement the model in real life is really important and request for permission to implement has already been forwarded to the people concerned.

5.2 Recommendation

- It is recommended to have a bigger set of materials that should be tested inordfer to get an even better solution.
- It is also recommended to include experimentation in future as it was not possible to do so due to the shortage of time.

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