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ADDIS ABABA INSTITUTE OF TECHNOLOGY

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GRADUATE PROGRAM IN RAILWAY ENGINEERING

FATIGUE ANALYSIS ON WELDED RAIL JOINT USING FEM

BY

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A Thesis`s progress submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Masters of Science in Railway Mechanical Engineering

Advisor: DR DANIEL

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Fatigue Life Analysis on Welded Rail Joint using FEM

By: - Idil Houssein Ahmed

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Declaration

I hereby declare that the work which is being presented in this thesis entitled “Fatigue Life Analysis on Welded Rail Joint using FEM” is original work of my own, has not been presented for a degree in any other university; and that all the sources of the material used for the thesis have been duly acknowledged.

Idil Houssein Ahmed	____________________	_________________________
(Student)	Signature	Date

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NOMENCLATURES

NRNE: National Railway Network of Ethiopia

ERC: Ethiopia Railway Corporation

UIC: International union of railways

HCT: Hertz's Contact Theory

$R1$w: The Principal Rolling Radii of the Wheel

$R2$w: The principal transverse radii of the wheel

$R1$r: The principal rolling radii of the rail

$R2$r: The principal transverse radii of the rail

a: Major Semi-axis

b: Minor Semi-axis

P: Contact Pressure

Po: Maximum Contact Pressure

Fn: The Applied Normal Load at the Wheel/rail Contact

Kw: Constants that depend on the material properties of wheel.

Kr: Constants that depend on the material properties of rail.

$K3$: Geometrical Properties of both Wheel and Rail.

vw and Ew: Poisson's ratio and Young's Modulus of the railway Wheel Material

vr and Er: Poisson's ratio and Young's Modulus of railway Rail Material.

M and n: Hertz coefficients

Nf: Number of Load Cycles to Failure

CWR: continuous welded rail

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First of all I would like to thank God for given me all the extra energy in this work. It is not exaggeration to state that without insisting the Almighty God, I would not have been in a position to finalize successfully accomplished of this thesis paper. So, Glory to him.

I am extremely fortunate to be involved in this an exciting and challenging research project entitled "**fatigue life evaluation on welded rail joint**". It has enriched my view, giving me an opportunity to work in a new environment of the simulation packages like ANSYS workbench. This project increased my thinking and understanding capability as I have started the project from scratch.

I would like to express my greatest gratitude to my advisor **Dr. Daniel Tilahun,** his excellent guidance, valuable suggestions and endless supports were a great power to my work. He has not only been a wonderful supervisor but also a genuine person. I consider myself extremely lucky to be able to work under guidance of such enriched research guider. Actually he is willing to encourage me to proceed on this thesis idea giving me the basic considerations during my works for that my words will not be enough to express my thanks.

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ABSTRACT

The goal of this study is analyzing the fatigue on welded rail joint due to the wheel load and after to evaluate the fatigue life. The three dimensional model has been developed on modeling package of CATIAV5R19. In CATIAV5R19, different components of welded rail joint assembly i.e. rail, rail weld, sleepers are created separately then all components are assembled, and create a complete model of welded rail joint assembly. Assembly model has created in assemble workbench of CATIA after individual component of welding joint had created on part work bench. After the assembly is accomplished on CATIA, it was imported in to the ANSYS v15 to analyze the fatigue caused by vertical load. All the material properties and boundary conditions are being applied to estimate fatigue stress. The analysis using the software ANSYS includes fatigue stress, fatigue life, von miss stresses, shear stress and Normal strain. These values have been determined under the influence of the vertical load.

From ANSYS software simulation result, if we compare the yield strength to the maximum equivalent stress, the yield strength is higher than the maximum equivalent stress. That proves that the welded joint can resist to the stress because of is strengthens. Then the survival probability of the fatigue life is 97, 5%.

CHAPTER ONE: INTRODUCTION

1.1-Background

The track on a railway or railroad, also known as the permanent way, is the structure consisting of the rails, fasteners, railroad ties (sleepers, British English) and ballast (or slab track), plus the underlying subgrade. It enables trains to move by providing a dependable surface for their wheels to roll. For clarity it is often referred to as railway track (British English and UIC terminology) or railroad track (predominantly in the United States). Tracks where electric trains or electric trams run are equipped with an electrification system such as an overhead electrical power line or an additional electrified rail [1].

1.1.1-Traditional track structures

Notwithstanding modern technical developments, the overwhelmingly dominant track form worldwide consists of flat-bottom steel rails supported on timber or pre-stressed concrete sleepers, which are themselves laid on crushed stone ballast. Most railroads with heavy traffic use continuously welded rails supported by sleepers attached via baseplates that spread the load. A plastic or rubber pad is usually placed between the rail and the tieplate where concrete sleepers are used. The rail is usually held down to the sleeper with resilient fastenings, although cut spikes are widely used in North American practice. For much of the 20th century, rail track used softwood timber sleepers and jointed rails, and a considerable extent of this track type remains on secondary and tertiary routes. The rails were typically of flat bottom section fastened to the sleepers with dogspikes through a flat tieplate in North America and Australia, and typically of bullhead section carried in cast iron chairs in British and Irish practice. The London, Midland and Scottish Railway pioneered the conversion to flat-bottomed rail and the supposed advantage of bullhead rail - that the rail could be turned over and re-used when the top surface had become worn - turned out to be unworkable in practice because the underside was usually ruined by fretting from the chairs.

Jointed rails were used at first because the technology did not offer any alternative. However, the intrinsic weakness in resisting vertical loading results in the ballast becoming depressed and a heavy maintenance workload is imposed to prevent unacceptable geometrical defects at the joints. The joints also needed to be lubricated, and wear at the fishplate (joint bar) mating surfaces needed to be rectified by shimming. For this reason jointed track is not financially appropriate for heavily operated railroads.Timber sleepers are of many available timbers, and are often treated with creosote, copper-chrome-arsenic, or other wood preservative. Pre-stressed concrete sleepers are often used where timber is scarce and where tonnage or speeds are high. Steel is used in some applications.The track ballast is customarily crushed stone, and the purpose of this is to support the sleepers and allow some adjustment of their position, while allowing free drainage [2].

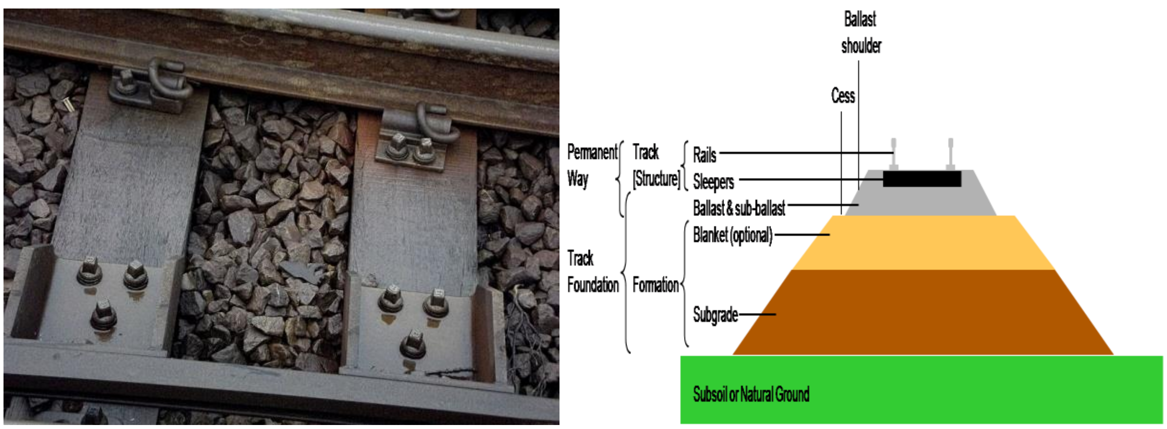


Figure 1.1: traditional track structures [2]

1.1.2- Ballast less high-speed track

In its simplest form this consists of a continuous slab of concrete (like a highway structure) with the rails supported directly on its upper surface (using a resilient pad).

There are a number of proprietary systems, and variations include a continuous reinforced concrete slab, or alternatively the use of pre-cast pre-stressed concrete units laid on a base layer. Many permutations of design have been put forward.However, ballastless track has a high initial cost, and in the case of existing railroads the upgrade to such requires closure of the route for a long period. Its whole-life cost can be lower because of the reduction in maintenance.

Ballastless track is usually considered for new very high speed or very high loading routes, in short extensions that require additional strength (e.g. rail stations), or for localised replacement where there are exceptional +3maintenance difficulties, for example in tunnels. Some rubber-tyred metros use ballastless tracks [3].

Figure 1.2: ballast less track [3]

1.1.3- Continuous longitudinally supported track

Early railways (c. 1840s) experimented with continuous bearing railtrack, in which the rail was supported along its length, with examples including Brunel's baulk road on the Great Western Railway, as well as use on the Newcastle and North Shields Railway, on the Lancashire and Yorkshire Railway to a design by John Hawkshaw, and elsewhere. Continuous-bearing designs were also promoted by other engineers. The system was trialled on the Baltimore and Ohio railway in the 1840s, but was found to be more expensive to maintain than rail with cross sleepers.

Later applications of continuously supported track include Balfour Beatty's 'embedded slab track', which uses a rounded rectangular rail profile (BB14072) embedded in a slipformed (or pre-cast) concrete base (development 2000s).The 'embedded rail structure', used in the Netherlands since 1976, initially used a conventional UIC 54 rail embedded in concrete, and later developed (late 1990s) to use a 'mushroom' shaped SA42 rail profile; a version for light rail using a rail supported in an asphalt concrete–filled steel trough has also been developed (2002).

Figure 1.3: Ladder track at Shinagawa Station [4]

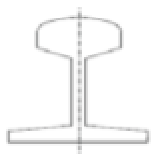
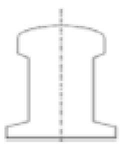
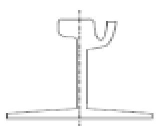
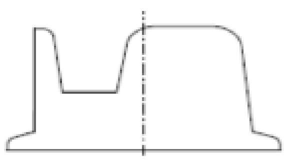
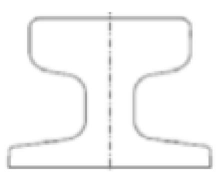
Modern ladder track can be considered a development of baulk road. Ladder track utilizes sleepers aligned along the same direction as the rails with rung-like gauge restraining cross members. Both ballasted and ballastless types exist [4].

1.2- RAIL

Rails are longitudinal members made by steel that are placed on spaced sleepers to guide the rolling stock. Their strength and stiffness must be sufficient to maintain a steady shape and smooth track configuration, and resist various forces by vehicles. The principal function of the rail is to accommodate and transfer the wheel loads onto the supporting sleepers. Esveld presented that a modern rail track also conveys signals and acts as a conductor on an electrified line [5].

Table 1.1 describes typical rail profiles and their applications. The most commonly used profile is flat-bottom rail, also called Vignole rail [6].

Table 1.1: Types of rail and their applications [40]

Shape	Profile type	Application
	Flat-bottom rail	Standard railway track
	Construction rail	Manufacturing of automobiles and switch parts
	Grooved rail	Railway track embedded in pavements, roads, yards
	Block rail	Railway track used in concrete slab as part of Nike-structure
	Crane rail	Heavy load hoisting cranes with high wheel loads

The principal parts of the rails are:

- The head that is in contact with the wheels,
- The foot that is connect with the sleepers and
- The web that connects together the head and foot part of the rail, and its help to connect the two rails at rail joint

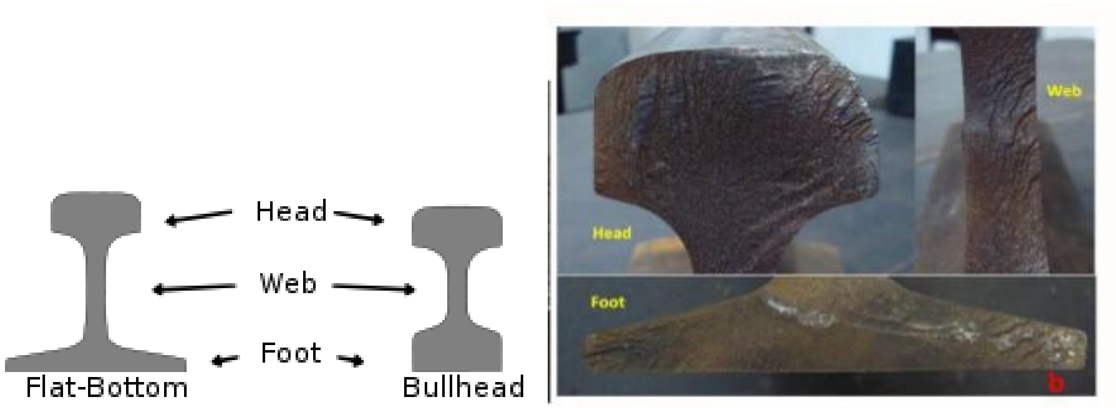


Figure 1.5: Rail profile [5]

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The rails used in rail transport are produced in sections of fixed length. Rail lengths are made as long as possible, as the joints between rails are a source of weakness. Throughout the history of rail production, lengths have increased as manufacturing processes have improved. The rail length increases from 11.8 meter to 25meter. In some country, they can produce at 122meter length of rail. Rail is graded by weight over a standard length. Heavier rail can support greater axle loads and higher train speeds without sustaining damage than lighter rail, but at a greater cost. In North America and the United Kingdom, rail is graded by its linear density in pounds per yard (usually shown as pound or lb), so 130-pound rail would weigh 130 lb/yd (64 kg/m). The usual range is 115 to 141 lb/yd (57 to 70 kg/m). In Europe, rail is graded in kilograms per metre and the usual range is 40 to 60 kg/m (81 to 121 lb/yd). The heaviest rail mass-produced was 155 pounds per yard (77 kg/m) and was rolled for the Pennsylvania Railroad. The United Kingdom is in the process of transition from the imperial to metric rating of rail [8].

1.2.1- Joining rails

Rails are produced in fixed lengths and need to be joined end-to-end to make a continuous surface on which trains may run. The traditional method of joining the rails is to bolt them together using metal fishplates (joint bars in the US), producing jointed track. For more modern usage, particularly where higher speeds are required, the lengths of rail may be welded together to form continuous welded rail (CWR) .There is two types of joined rails which will be detailed so below [9]:

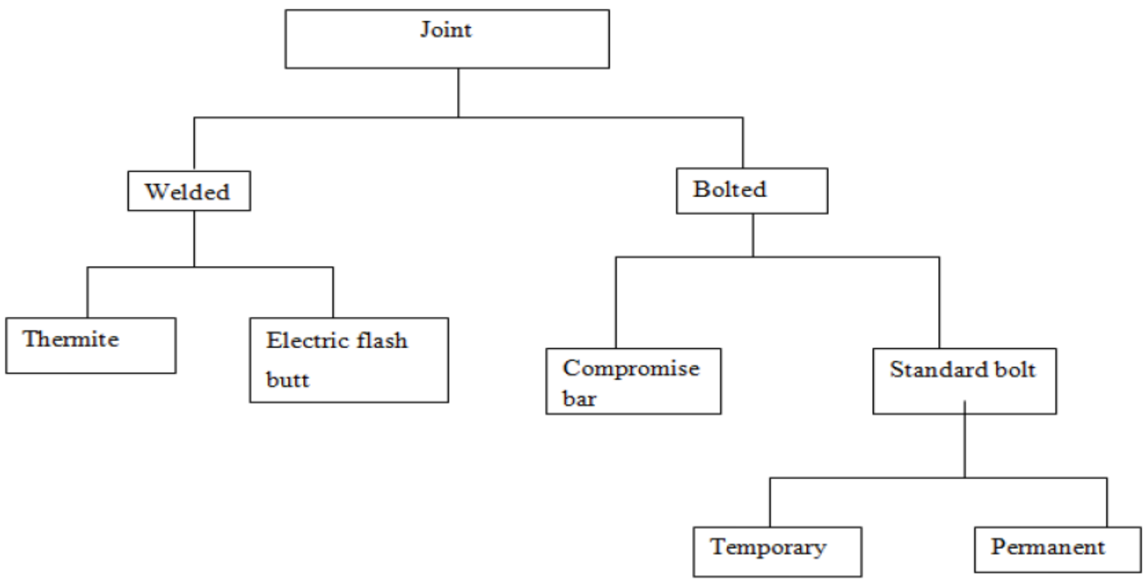


Figure 1.6: flow chart types of joints [9]

1.2.1.1-Bolted joints

Bolted joints are one of the most common elements in construction and machine design. They consist of fasteners that capture and join other parts, and are secured with the mating of screw threads.

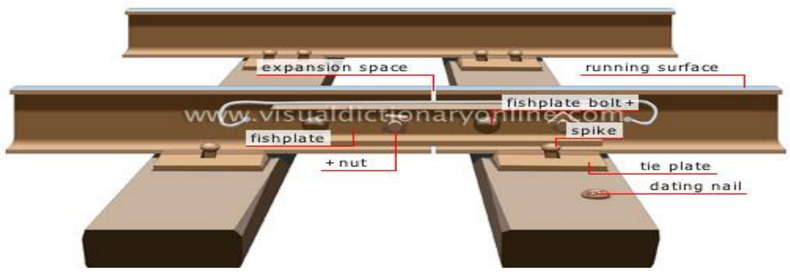


Figure 1.7: bolted joint [10]

There are three types of bolted joints [10]:

- Insulated rail joint
- Standard(non- insulated) rail joint
- Compromise bar

1.2.1.2-Welded joints

Welding is a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone, and with or without the use of filler material. Two advantages with welded rail sections in contrast to bolted ones are the lower maintenance cost and the improved dynamic behavior of the train-track-rail system. Because the railway fishplates are usually fastened with the help of track bolts. But sometimes, in order to ensure the immobility of the railway fishplates, the railway fishplates can also be welded to the tracks. So in that condition, there are no holes on the surface of railway fishplates just to improve the convenience for welding [11].

Thermite

Exothermic welding, also known as exothermic bonding, thermite welding (TW), and thermit welding, is a welding that employs molten metal to permanently join the conductors. The process employs an exothermic reaction of a thermite composition to heat the metal, and requires no external source of heat or current. The chemical reaction that produces the heat is an aluminothermic reactionbetween aluminium powder and a metal oxide. Thermite welding is used to repair or splice together existing CWR segments. This is a manual process requiring a reaction crucible and form to contain the molten iron. Thermite-bonded joints are seen as less reliable and more prone to fracture or break [11].

Figure 1.8: exothermic welding joint [11]

Flash Butt

Flash welding is a type of resistance welding that does not use any filler metals. The pieces of metal to be welded are set apart at a predetermined distance based on material thickness, material composition, and desired properties of the finished weld. Current is applied to the metal, and the gap between the two pieces creates resistance and produces the arc required to melt the metal. Once the pieces of metal reach the proper temperature, they are pressed together, effectively forging them together [12].

Figure 1.9: flash butt welding joint [12]

1.2.2-Rail Defects

Rail failures can be divided into three main groups:

- The rail manufacturing defects e.g. hydrogen cracks;
- Defects due to the inappropriate handling, installation and use;
- Defects caused by the exhaustion of the rail steels inherit to resistance to fatigue damage.

Due to the harsh working environment rails are susceptible to failure. In addition to bending and shear stresses, rails have to withstand dynamic loads, contact, thermal and residual stresses. The contact stresses between the wheel and rail are high with a very small contact area less than $1cm^2$. Residual stresses are also introduced into the rail during the straightening process during manufacturing.

Majority of rail failures are due to the transverse defects caused by the rail inner defects such as inclusions or fatigue cracks. The main reason for forming inner defects is hydrogen and oxygen. The hydrogen cracks within the steel that can lead to formation of kidney shape transverse defects upon traffic. Vacuum degassing and control cooling is used to extract gases [13].

1.2.2.1-Surface Initiated Defects

Head Checks: develop on outer rail of the shallow curves in the form of a series of cracks as shown in Fig. 1.10 and present the biggest problem in rails. These can also develop on sharp curves having limited or no wear. They result from accumulation of plastic strain increments, which eventually exhausts the ductility of the surface material, at which point cracks can initiate. The critical conditions for this to occur are high load and friction. These head checks have been found extensively on straight track also due to hunting. Bad weld geometry and closely conformal rail/wheel contacts have been the cause of extensive hunting on straight track [14].

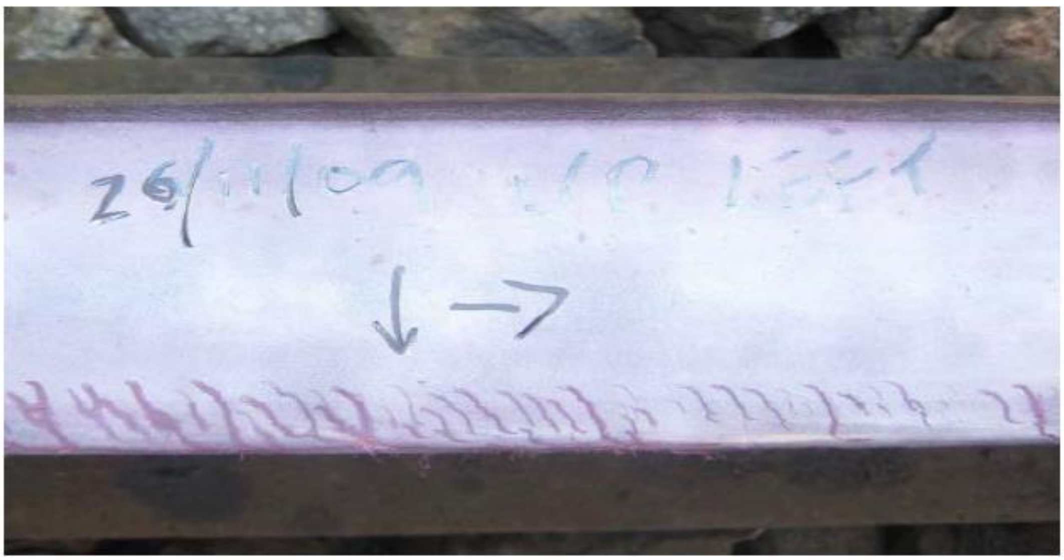


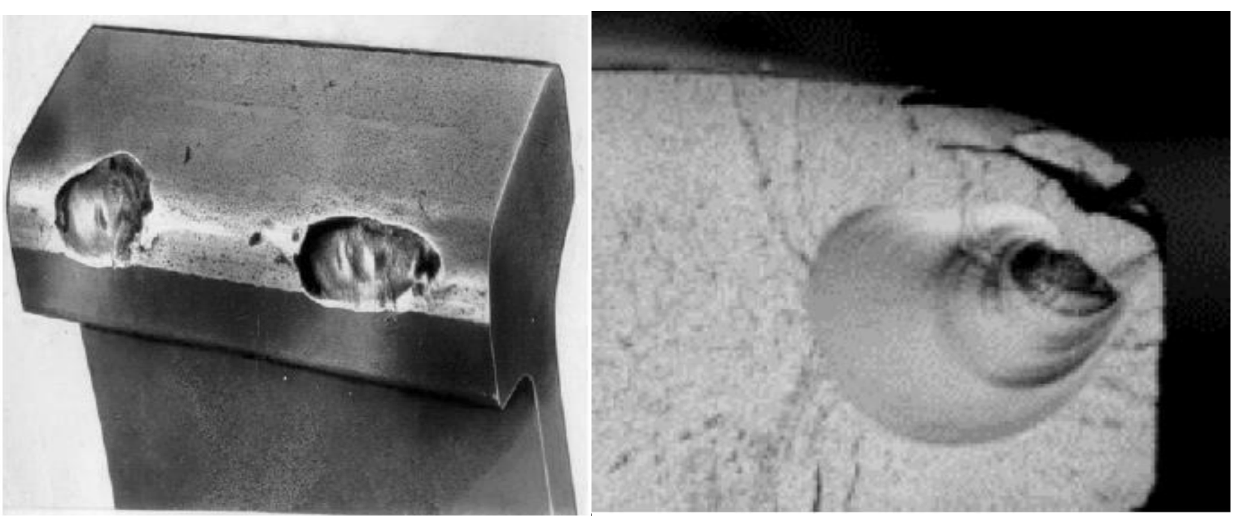
Figure 1.10: Head checks in rail

Squats: occur on tangent track and in shallow curves on the rolling surface of the rail head and are characterized by dark spots on the rail as shown in Fig. 1.4.Squats are surface initiated rolling contact fatigue defects and may propagate transversely across the rail. They can initiate as a result of ratcheting and fluid pressurization and also from white etching layers which result from modification of the microstructure of the rail surface material from perlite to martensite. Ultrasonic inspection of these defects is difficult since the transverse defect is shielded by the shallow horizontal crack.

Figure 1.11: squats in rail

1.2.2.2-Sub-Surface Initiated Cracks

Gauge Corner Defects: These effects are formed on the high rails in curves of sharper radius generally and on routes of heavy axle loads with moderate speeds. An elliptical shell-like crack with characteristic crack growth rings propagating transverse to rail section under the influence of contact stresses and shear stress develops at first. Later due to bulk stresses and residual stresses in the rails, cracks initiate from the shell either upward or downward. The upward cracks lead to shelling on the Gauge face, whereas downward propagation will lead to fracture/formation of kidney.



a) Upward cracks b) downward cracks

Figure 1.11: Gauge Corner Defects in Rail

1.3-STATEMENT OF THE PROBLEM

It has been known that the rail is one of the most important element of railway system. It connected with different types of rail joints to create continuous railway track. While many parts may be well initially, they often fail in service due to fatigue failure caused by repeated cycle loading.

Following to a repetitive load on the surface running the rail joint between two rails, wear fatigue will occur. This phenomenon takes a long time to appear at the surface, and it causes a failure at the surface. So this failure leads to a discontinuity of the rail. These discontinuities generate different types of stress alongside the rail .this causes a deflection at the rail joint which leads to a discomfort of the passengers and the security could be dubious. This may also be worst in the case of freight train due to their high weight.

While a welded rail joint may seem to be used endlessly, in reality, it is subject to various stresses as a result of train traffic and eventually becomes damaged or eroded and loses its function as a rail joint. The period of time from the laying of a rail to the loss of its function is called the "service life of a rail". The rail is a component that directly supports the weight of trains and for the sake of safety and stability, it is necessary to maintain a rail before the service life of the rail expires.

As vehicles have become more light weight and the fracture of jointed rail has decreased in recent years, we consider that the period of replacement can be extended. To reduce and avoid the discomfort of the passenger, welded rail joint wear and welded rail joint maintenance cost by using of different mechanism to decrease the fatigue stress on rail joint component.

This problem is very current in the railroad what could be possible in ethio-Djibouti line.

1.4-OBJECTIVES

- **General objective**

This study is analyzing the fatigue on welded rail joint of National Railway Network of Ethiopia due to vertical, lateral and longitudinal force, which cause failure using FEM and evaluate the fatigue life in state to various loads.

- **Specific objectives**
- Modeling the welded rail joint type
- Analyze the fatigue on welded rail joints at the position on the sleepers
- Evaluate the fatigue life

1.5-METHODOLOGY OF THE RESEARCH

To fulfill the objectives of the study there are many procedures that should be followed. Some of them are as follows:

1. Modeling the welded rail joint using CATIA.
2. Analyze the stress and fatigue using FEM and the ANSYS software.
3. Plot the diagram of fatigue sensitivity using ANSYS
4. Evaluate the fatigue using FEMFAT software

1.6-SIGNIFICANCE OF THE RESEARCH

This research has a large role for future analysis and uses of rail joint more precisely of welded joint, in general for newly constructing Ethio-Djibouti railway line by finding the new research. In the future, it will add new knowledge about existing one with analysis of welded joint stress, strain, deflection which cause fatigue failure, crack and deteriorations of the rail. This study try to figure out those problems related to the welding joint at one position of sleeper because Mrs sisay has already proved when the joint is located on the sleeper, the joint is stronger than the other position. So for that case I just do my analysis when the welded joint is on the sleeper.

1.7-SCOPE & LIMITATION

In this project the static analysis of stress and fatigue in welded joint has been carried out by using ANSYS version 15.Then the fatigue life will be evaluated.

- The dynamic and the thermal analysis are not considered.
- The experimental method is not required.
- The residual stress and the external effect are not considered on the analysis.

1.8-ORGANIZATION OF THE PAPER

The body of this study is divided into five main chapters. The first chapter discusses background, statement of the problem, and objectives. The second chapter covers the type of material, the method which will be to use as well as the adequate software with this analysis. Model and analysis of stress on welded rail joint is discussed in the third chapter. In addition, it covers discretization of the solid model of the welded rail joint used for the analysis and load condition. The results obtained from the static and dynamic analysis of the welded rail joint and discussions based on these results are included in the fourth chapter. Finally, the fifth chapter covers conclusions drawn based on the results of the analysis, recommendations and future work.

CHAPTER TWO: LITERATURE REVIEW

2.1- COMPONENT OF RAILWAY TRACK

2.1.1-Rail Pads

Rail pads are usually installed on rail supporting points to reduce and transfer the stress and dynamic forces from rails to the sleepers. Rail pads are very important because they reduce the interaction force between the rail and the sleepers. Further, the rail pads provides a resilience function between rail and sleeper that helps absorb shock and impact from the wheels to the rails, and reduce a damage of rail supporting point and contact abrasion. Several models of rail pads had been reviewed and introduced in the time or frequency domain, and the dynamic parameters of the rail pad were investigated experimentally [5].

2.1.2-Sleepers

Sleepers are transverse beams resting on ballast and support [15]. Wooden sleepers were used in the past because timber was used in several countries. However, pre-stressed or reinforced concrete sleepers, and to a limited extent steel sleeper, have been adopted in modern railway tracks over the past decades because of their durability and long service life. Esveld have introduced that classified of timber sleepers into two types: softwood (pinewood) and hardwood (beech, oak, tropical tree) [5]. Concrete sleepers are described as either twin-block or mono-block, and are shown in Fig. 2.3. The concrete sleepers are widely used, because they are relatively not affected by environmental effect (including circumstance effect).

Functions of the sleepers are holding rails in correct gauge and alignment, providing a firm and even support for rails, transferring load from rails to wider areas of ballast, absorb impact and vibration and providing lateral and longitudinal stability to the permanent way [16].

2.1.3-Ballast and Sub-ballast

The standard ballast has the depth of 0,3m. However, it is compacted to 0.5 m around the sleeper ends to maintain the lateral stability [5]. Year ago, the importance of ballast was not properly estimated, and the material placed beneath sleepers was not suitable for application. The old ballast was made from ashes, chalk and clay [17]. Nowadays the material to form high-quality ballast consist of angular, crushed, uniformly-graded hard stone and rocks such as granite or limestone. Ballast supports the track against the loads from the train and keeps the sleepers aligned. The sub-ballast is usually made from sand and prevents the penetration of ballast and subgrade.

2.2- RAIL-WHEEL INTERACTION

The dynamic behavior of railway vehicle is greatly affected by the rail-wheel dynamic interactions. This interaction (weel/rail) mainly depends on wheel/rail contact geometry. The changes in contacting geometry of rail/wheel depends on different parameters like the variation of wheel and rail profile, track gauge, track radius, rail inclinations, railhead surface irregularities, and flexibility of rail support. The main parameters influencing the wheel rail contact geometry are the profiles of wheels and rails, rail inclination and track gauge [18]. Analysis of the wheel/rail contact geometry by considering all affecting parameters will make it complex. Therefore for better understanding and analysis of the condition under consideration, the grouping of interrelated parameters will result meaningful final outputs.

Considering the other parameters constant and giving attentions to the analysis of wheel rail wear on curved track is the main work of this paper. The wheel/rail contact profile is characterized by using the equivalent conicity, contact angle, lateral movement of wheel set, the wheel/rail material properties (elasticity), axle load, vehicle speed and yaw angle. Any load from the train is assumed to be transmitted to the track through wheel and the rail head to the ballast without affecting the environment.

However, the large portions of these forces are distributed /dissipated in the wheel railhead contact surfaces. Therefore, from this general idea it is possible to conclude that the main failure of railway transport system is on these interacting interfaces. From the data observed in the developed countries using the railway transport system at a large extent, these failures are extremely a problem of developed world. This failure causes huge cost as a railway wheel rail maintenance and renewal.

As stated above this is due to high stresses at the wheel rail interfaces, which causes failure like wear, fatigue and a combination of the two.

Understanding of interaction between these surfaces indicates and predicts the way how to treat them and how to prevent them from failures which is a better guide to select the appropriate materials, geometry, design, orientation etc.

Figure 2.1: rail-wheel interactions [19].

2.3- LOAD ON THE TRACK SYSTEM

The wheel load acting on the rail can be divided into three components, which are vertical, lateral and longitudinal forces. The vertical force results from the weight of the wheel and the car bodies. The lateral force is generated due to the movement of the wheel set on the rail, and is especially high on the curve track. The longitudinal force is the traction force which is produced by the locomotives. In general, the magnitude of the forces acting between the wheel and the rail must be set to a limit by railway organizations. For instance, to avoid any initiation of surface damages on the rail surface such as crack or plastic deformation, the international unions of railways (UIC) sets the vertical wheel load to below 112.5 KN per wheel for static load, and from 160 KN to 200 KN per wheel for dynamic load depending on maximum speed of train. When a train running on a small radius curved track (less than 600 m), the force is set to a limit of 145 KN for the quasi-static vertical force and 60 KN for the quasi-static lateral force [20].

Likewise the forces at the contact patch also include normal and two tangential components (longitudinal component acting along the running direction, and lateral component acting in the plane normal to the running direction). Illustrated in figure 2.3 are the three elements of the contact forces.

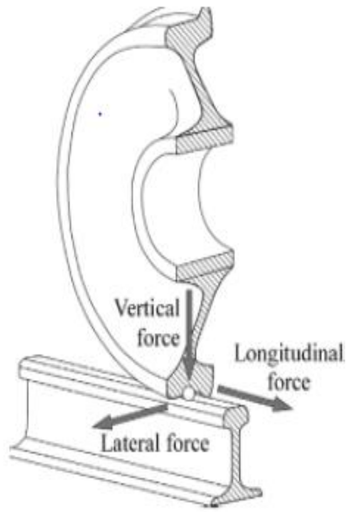


Figure 2.2: contact forces at wheel-rail contact zone [20].

2.4- WELDED JOINTS STRESSES

[21]: In this project the analysis of stress in welded joint in bending and in torsion has been carried out by using ANSYS version 12.1 and then the value of stresses and deflection obtained are compared with the values obtained by analytical solution. The rail material was steel and the load applied was 10kN. It is a type of eccentric loaded member on which load is applied at an eccentric distance on an asymmetric shaped member. For creating the diagram of the member, PRO-E is used and then imported into ANSYS where the analysis part is carried out. Companies in a wide variety of industries use ANSYS software. Stress concentration may occur due to abrupt changes of cross section of the member due to the presence of discontinuities like holes, notches, grooves or shoulders. It may also be due to the presence of internal cracks or air holes in the material. If stress concentration area increases, it results in development of cracks and failure of the model.

[22]: The residual stresses on the surface of a rail joined by flash butt welding are measured using a hole-drilling method and the thermal elastic-plastic deformation process considering the phase transformation are simulated using FEM code JWRIAN. The material of the rail is U71Mn. Two U71Mn rails with 1000 mm in length were welded by flash butt welding process using the same welding condition. The measured residual stresses can be seen that on the top and bottom, the longitudinal residual stress sigma z is compressive. The transverse stress sigma x is small and can be neglected. on the web surface both the height direction stress sigma y and longitudinal stress sigma z are in the tensile state and the longitudinal stress sigma z is higher. The biaxial tensile stresses on the web surface may increase the possibility of cracks. The residual stresses measured by experiments and computed by FEM have an acceptable agreement in accuracy. The simulation results shows that the phase transformation in the cooling stage has a significant effect on the residual stress distribution and its values.the tensile or compressive state for residual stresses near the welding section strongly depends on the phase transformation which occurred during the cooling process. The biaxial tensile stresses are produced at the web near the fusion line of the flash butt welded rail.

The biaxial tensile stresses increase the risk of cracks. Although the marten site phase transformation during the cooling process at top and bottom near the fusion line produces compressive stress, it increases the brittleness at the same time. Therefore, the proper heat treatment after welding is still necessary in order to improve the toughness.

[23]: Joints being the weakest elements in any structure/machine are likely to fail first. It is, therefore, imperative to understand the failure of these joints. Understanding a failure occurrence and its propagation will lead to a better appreciation of welded joints from reliability point of view. It may be possible that a few cause events or failure causes may be crucial and could be minimized at design or fabrication stage leading to failure minimization of such joints. In this process, stress concentration at the welded joints is analyzed. The type of joints considered is Tee Joint, Butt Joint and Lap Joint. Structural and Fatigue analysis is done on the welded joints in Ansys. The stress distribution in different welded Joints is investigated with a computer modeling technique. The finite element analysis is used for the analysis of joints in the plane - stress condition, under static load. Modeling is done in Pro/Engineer and analysis is done in Ansys. The types of joints are T - joint, Butt Joint and Lap Joint. Structural and fatigue analysis are done in Ansys. By observing the structural analysis results, all the joints are withstanding the applied pressure as the analyzed stress values are less than the yield strength of steel. Fatigue analysis is done to analyze the fatigue usage by applying cyclic loading. By observing the analysis results, the fatigue usage is more for Butt Joint, so the life of the Butt Joint is less than other two joints.

Table 2: Structural Analysis [23]

Type of Join	Results	
Tee Joint	Stress (N/nm^2)	34.3708
	Strain	0.164e-03
	Displacement (mm)	0.44e-0.3
Butt Joint	STRESS (N/nm^2)	22.0646
	Strain	0.106e-03
	Displacement (mm)	0.007917
Lap Joint	STRESS (N/nm^2)	33.7136
	Strain	0.163e-03
	Displacement	0.007917

[24]: Fatigue analyses of weldments require detailed knowledge of the stress fields in critical regions. The stress information is subsequently used for finding high local stresses where fatigue cracks may initiate and for calculating stress intensity factors and fatigue crack growth.

The method proposed enables the determination of the stress concentration and the stress distribution in the weld toe region using a special shell finite element modelling technique. The procedure consists of a set of rules concerning the development of the finite element mesh necessary to capture the bending and membrane structural stresses. The structural stress data obtained from the shell finite element analysis and relevant stress concentration factors are subsequently used to determine the peak stress and the non-linear through-thickness stress distributions. The peak stress at the weld toe is subsequently used for the determination of fatigue crack initiation life.The stress distribution and the weight function method are used for the determination of stress intensity factors and for the analysis of subsequent fatigue crack growth.

[25]: Butt welded joints have wide applications in industry as well as in offshore constructions. The assessment of butt welded joints is a major industrial problem for two reasons. Firstly these butt welds tend to be regions of weakness in a structure due to stress concentration effects as stresses associated with welds are more variable due to inherent presence of defects. Secondly it is difficult to predict their material properties. Thus these welds are the critical links in a fabricated structure. Many of the fatigue failures occur in these butt - welded joints involve fatigue cracking from several imperfections that are actually inherent parts of the joint. One of the imperfections in butt welds is referred as the LOP (lack of penetration) which is considered as a crack from fracture mechanics point of view. In the present work this is the subject of concern in butt welded joints. Lack of penetration occurs in most of the cases, as a gap remains between two joined plates of butt welded joints due to incomplete penetration of the weld metal i.e. weld metal fails to reach the root of the joint which is inevitable considering both the cost of edge preparation and machining time in to account. The LOP crack may initiate a crack when the welded joint is subjected to loading. States of stress at these highly stress concentration regions are evaluated by two important fracture parameters namely stress concentration factor and stress intensity factor.The SIF & SCF are discussed for different lack of penetrations defects with respect to different weld parameters to study the stress state. These include plate thickness, weld size, weld toe angle, and weld shape, gusset thickness and weld leg length for different butt welds. Relation between SIF range and crack length at toe and LOP root in butt welded cruciform joints is computed. Slit leg length with respect to slope angle of weld is also discussed for different butt – welded cruciform joints. The present work also discusses the stress concentration factors for both load carrying and non-load carrying butt – welded cruciform joints with different toe angles, different weld leg length to plate thickness ratios, different gusset thickness and depth of weld penetration. Both SCF and SIF are obtained for different butt – welded joints with varying defect lengths (LOP) to plate thickness ratios to find an "acceptable" defect length beyond which stress concentration increases rapidly, with the help of FEA package. Few comparisons are made with the previous existing experimental results. Hence present work becomes the first approach for approximation of typical weld penetration defects.

[26]: Brittle fracture occurs frequently in rails and thermite welded joints, which intimidates the security and reliability of railway service.
Railways in cold regions, such as Qinghai-Tibet Railway, make the problem of brittle fracture in rails even worse. A series of tests such as uniaxial tensile tests, Charpy impact tests, and three-point bending tests were carried out at low temperature to investigate the mechanical properties and fracture toughness of U71Mn and U75V rail steels and their thermite welds.

- The ductility indices (δ and φ) of U71Mn and U75V rail steels and their thermite welds all decrease as the temperature decreases. The proof strength RP0.2 of the two kinds of rail steels and their thermite welds increases with the decrease of temperature. The ultimate tensile strength Rm of the thermite welds decreases as the temperature falls down, while the result is opposite for U71Mn rail steel.
- The proof strength and ultimate tensile strength of U75V rail steel are higher than those of U71Mn, while the ductility indices of U75V are lower than those of U71Mn. This is in accordance with the higher carbon content in U75V rail steel.
- U71Mn rail steel has higher impact toughness than U75V rail steel from −60 to +20°C, which is consistent with the transition temperature result. The impact toughness values of the thermite welds are much lower than those of the rail steels, which are in accordance with the uniaxial tensile test results.

- The values of the plane-strain fracture toughness *K*IC of U71Mn and U75V rail steels decrease with the decrease of temperature. The *K*IC values of U71Mn are a litter larger than those of U75V from −60 to +20°C.

U71Mn rail steel and the corresponding thermite weld are recommended in railway construction and maintenance in cold regions, so as to obtain higher ductility and fracture toughness than using U75V rail steel.

[27]: This basic information on welded rail steel is very much essential to ensure the quality of weld. Thermite welding is mainly used in world. The reasons why the thermite welding method is widely used are that the equipment has good mobility and total working time of that is shorter than that of the enclosed arc welding method on site.

Moreover, the operating skill, which required for thermite welding, is less than that of for enclosed arc welding. In the present research work, heat treatment' technique was used improve the mechanical properties and weldment structure.

The specimens were cut in the transverse direction from as thermite welded and Heat treated Thermite Welded rails.

Specimens were prepared according to AWS standard and subjected to tensile test, Impact test and hardness and their results were tabulated. Microstructural analysis was carried out with the help of SEM. Then analyze to effect of heat treatment on Mechanical properties of their thermite welded rails. Compare the mechanical and microstructural properties of thermite welded rails with heat treated thermite welded rails.. Mechanical and microstructural response of heat treated thermite welded rail is higher value as compared to as thermite welded rail.

2.5- WELDED JOINTS FATIGUE AND FAILURE

[28]: The effect of welding residual and thermal stresses on fatigue crack growth in rail welds was studied. The residual stresses in a flash-butt weld were calculated by means of finite element (FE) analysis, and the redistribution of the residual stresses in the welded rail was simulated using an FE model developed for train-track-rail interaction simulation. The rail material was the pearlitic UIC grade 900A (R260) rail steel and the speed was 50km/h. Thus the normal force and the normal pressure were 147*10^3 N, 1401 MPA respectively. It was employed here for train traffic conditions at a straight track during heavy-haul operation conditions. The thermal stresses that occur in the rail due to variations in temperature between winter and summer were also accounted for in this FE model. The distributions were calculated according to the Hertz theory of rolling contact between two elastic non-conforming solids with smooth and continuous contact surfaces. The results from the flash-butt welding FE simulation were verified against residual stress measurements and there was good agreement. For the longitudinal stress field there were compressive stresses in the rail head and rail foot, and tensile residual stresses in the web. The train-track-rail interaction calculations showed large stress ranges due to global bending of the rail in the lower part of the rail head, whereas the stress ranges calculated in the web and rail foot were much lower. Apart from the contact zone at the rail head, the weld material experienced elastic shakedown after very few load passages. The results from the stabilized stress response in the rail, after several wheel-rail contact load passages, were used to investigate the sensitivity in crack growth in the weld region using fracture mechanics. A number of parameters were varied, for example, the axle load, crack location, crack size and rail temperature.

[29]: With welded joints, stress concentrations occur at the weld toe and at the weld root, which make these regions the points from which fatigue cracks may initiate. The material used in the present study was an extra high strength hot rolled steel with the minimum yield strength 550 MPa and the tensile strength minimum 600 MPa and maximum 760 MPa, respectively. The fatigue simulated with applied loading such that the maximum stress was maintained constant at 200 N/mm2 and 104 N/mm2 for cruciform and butt weld joints respectively.

Values of Poisson's ratio υ and the modulus of elasticity E were chosen as 0.293 and 210 kN/mm2 respectively. To calculate the fatigue life of welded structures and to analyze the progress of these cracks using fracture mechanics technique requires an accurate calculation of the stress intensity factor SIF. The existing SIFs were usually derived for one particular geometry and type of loading. In this study, the finite element method (FEM) was used to calculate the SIF. The stress intensity factors during the crack propagation phase were calculated by using the software FRANC2D, which is shown to be highly accurate, with the direction of crack propagation being predicted by using the maximum normal stress criterion. The appropriate solutions for most welded joints are still difficult to find. Therefore SIF at of welded joints have been evaluated using the FEM. The influence of the weld geometry was incorporated in the solution using FE analysis. The assumption was used that in the as-welded condition the crack remains open (mode-I) during the loading cycle due to the tensile residual stresses caused by welding are high enough. Therefore, the SIFs range corresponding to the nominal stress range is effective and independent of the R-ratio of nominal stresses. The FRANC2D software and quadrilateral elements were used to calculate the SIF of the joints from elementary of fracture mechanics. This program has the ability to analyze the cracked body and describes the singularity a head of the crack tip. Thus, it can be concluded that for specific crack propagation, the SIF can be calculated under mode I loading conditions. To demonstrate the efficiency of these calculations, two joints were investigated namely cruciform and butt weld joints. The SIF results from FRANC2D were compared with those from the International Institute of Welding-IIW, and literature. A good correlation was obtained and the work results have bench marked which made it possible to use FRANC2D to simulate different weld geometries.

[30]: Medium carbon steel rails are commonly jointed by means of a flash butt welding procedure. The steel used in studied rail is a microalloyed hipereutetoid steel with carbon content of 0,85wt% and V and Cr contents, respectively, of 0,095% and 0,438%. The welded joint presented a heterogeneous microstructure. In This study much of analysis were made such as Macrofractographic Analysis, Chemical Analysis, Metallographic Analysis, Mechanical Tests, Microfractographic Analysis. The base metal and weld bead are constituted mainly by fine pearlite. The heat affected zone presents pearlite fragmentation and the start of cementite globalization. In the middle of welded joint, proeutetoid ferrite is present between pearlite colonies. This work investigated the cause of a recurrent failure in a railway, with cracking always initiated in the rail in the region of the welded joint. All standard procedures of failure analysis were applied, with a careful assessment of the material characteristics and the fractured surface. Mechanical tests indicated that the studied steel has high mechanical strength. The tensile tests in specimen sampled in welded bead presented a recurrent fracture in the heat affected zone, which had the lowest yield and tensile strength. Crack nucleation occurred at the welded joint in a specific region where a rung is present at welding burr. The stress concentration effect was severe in the studied high strength steel, causing stable crack growth until one third of web thickness, from where it spreads unstably until the rail catastrophic failure. It was concluded that fatigue cracks initiated near the weld bead and spread in a brittle mode, leading to premature fracture of the material. An in-depth analysis of the early cracks showed that the surface finishing of the weld bead was not appropriate, generating undesirable stress concentration.

[31]: Some typical fatigue failures of butt-welded rails consist in fractures of the web. In the early stage, crack propagates parallel to rail surface but, after a while, it tends to propagate with a slant surface. The aim of the present work is to analyze the mechanisms involved in crack propagation in rail's web in order to be able to predict the crack path and, in a second step, the rail inspection intervals. From this point of view, FEM analyses of an observed fracture were carried out in order to determinate KI and KII history at different positions of crack tip during the passages of the typical loads induced by trains. The results have shown that the initial flaw tends to follow a path where DKII is close to maximum values and a small superimposed KI traction is present. Fractographic analyses have confirmed that propagation is mainly controlled by mode II and that mode I is prevalent only after the final bifurcation of the cracks. It was confirmed, by both SEM observations and Finite Element analysis, that this kind of crack, starting from welded joint, propagates firstly in mode II and then, by a crack path deviation realized in a kinking or branching, switches to mode I propagation. As the starting mode of propagation is mode II, it would be important to analyze the influence of the position of the welded joint in the rail on the variation of DKII. In all the cases considered here, the weld was always at the middle between two sleepers. Furthermore, it would be important to analyze crack grow rate, in order to define the inspection intervals for welded rails.

[32]: The fatigue evaluation of welded details is generally based on the notion of nominal stress, using the classified S-N curves with corresponding fatigue classes for typical details. An approach of this kind should be used with extra caution to ensure that the load effects for components are accurately captured, because an ever-increasing number of welded details are resulting in a limited number of possible treatable design cases.

The fatigue of welded structures is a somewhat complex and progressive form of local damage which can be evaluated more accurately using local failure approaches, such as the hot-spot and effective notch stress methods. Methods based on fracture mechanics can also be applied in cases where fatigue cracks are detected or can be assumed to exist. A large number of welded details with complex geometry and load conditions that are known to be critical with respect to fatigue can be found in welded steel structures.

Estimating more detailed and accurate information on the stress state of these details is very difficult without using finite element analysis. On the other hand, the result obtained from finite element analysis can be highly sensitive to the modelling technique, as the stresses obtained from the local failure approaches are often in an area of high strain gradients, i.e. stress singularities.

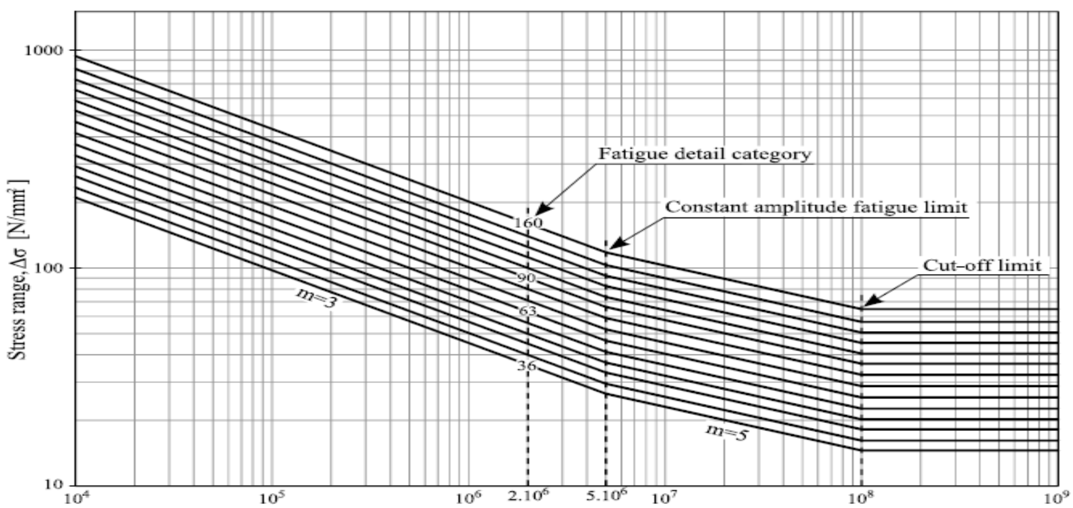


Figure 2.3: Fatigue strength curves for normal stress according to EN 1993-1-9 [27]

[33]: The objective of a fatigue test is generally speaking to determine the fatigue life and/or the damage points, i.e. the location of failure of a test-piece subjected to a prescribed sequence of stress amplitude. To determine the fatigue strength of materials, there are several kinds of fatigue tests, in different ways, for instance: single or rotating bending fatigue tests, tension or compression tests, torsion or even multi-axial fatigue tests (combined loadings). Fatigue tests show the time or number of cycles that a component will resist under cyclic loading, or the maximum bearable stress without failure before a given number of cycles. The method that is used for this experiment is constant amplitude test. This is the simplest sequence of amplitude obtained by applying reversals of stress of constant-amplitude to the test-piece until failure occurs. Different specimens of the test series may be subjected to different stress amplitude but for each individual item, the amplitude will never be varied.

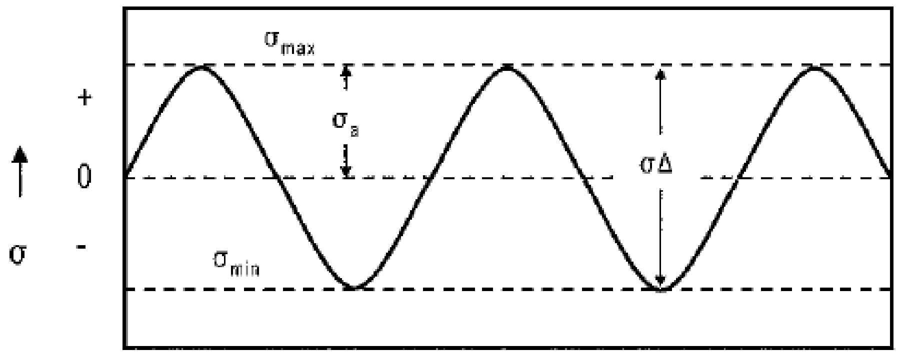


Figure 2.4: Fully reversed cyclic loading [33]

In fatigue testing, the applied stress, σa, is typically described by the stress amplitude of the loading cycle and it is defined as,

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

The stress amplitude is generally plotted against the number of cycle to failure to a linear-log scale, S-N plots. An S-N curve (Stress vs. Number of cycles) can be presented in terms of stress amplitude or maximum stress vs. the number of cycles (Figure 2.4). Such kind of curve is sometimes also called the Wohler curve, in attribution to the work of August Wohler in Germany in the 1850s.

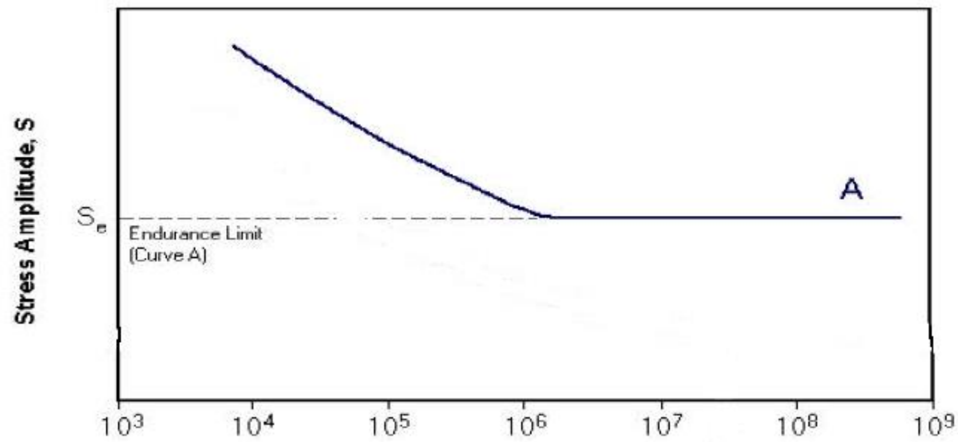


Figure 2.5: Stress vs. Number of cycles curve [33]

[34]: Although fatigue is related to cyclic or repetitive loading, the results used are based on linear static when we use ANSYS software. Even if nonlinearities may be present in the model, ANSYS fatigue analysis assumes linear behavior. Fatigue analysis is automatically performed by Simulation after a linear static solution.

The requirements for fatigue analysis are Young's Modulus and Poisson's Ratio, Mass and Density. Beside if thermal loads are present, thermal expansion coefficient and thermal conductivity are required. Mean stress effects in fatigue are usually presented as stress amplitude versus mean stress plot. For a particular given cyclic life it is usually observed that the load amplitude of the endurance limits decreases with growing mean stress or static load.

Typical Stress-Life Curve or S-N Curve that show the relationship of stress amplitude to cycles to failure plotted bellow.

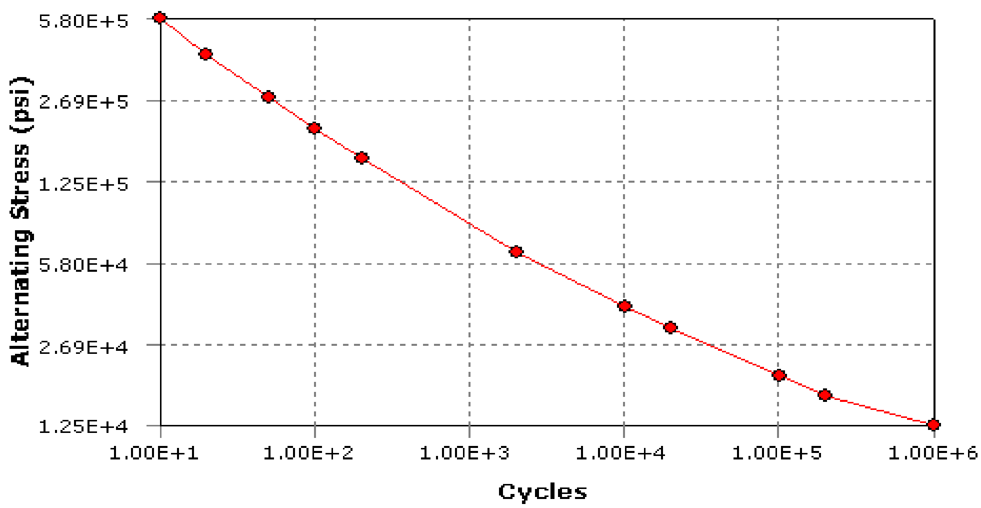


Figure 2.6: The Stress-Life (S-N) Curve draw to logarithmic plot [34]

CHAPTER THREE: ANALYTICAL METHODS and CONDITIONS

3.1- MATERIAL PROPERTIES

3.1.1-Rail

The railway tracks are mostly steel material in accordance to the (TB10082-2005), Steel is the most common and widely used metallic material in modern society. The weight of 60kg/m rail is 15% heavier than that of 43kg/m. The type of 60kg/m rail can significantly promote track strength, reduce track deformation and stress. In the same operating condition the duration of 60kg/m rail is 1.5-2 times of 43 and 50 kg/m. Therefore the adoption of 60kg/m rail can extend the maintenance cycle of the rail track and reduce vibration, which can enhance the stability of the rail track and reduce daily work for maintenance. Furthermore rail can also play function as current return circuit for tractive power supply. Therefore rail of large section can enhance the conduction of electricity. In this study, the material of rail used in NRNE is U71Mn, which is equivalent to R260Mn. Rail material rail property in accordance to (TB10082-2005) **[35].**

Table 3.1: Mechanical property of rail material

No	Mechanical property	Value
1	Poisons Ratio	0.3
2	Young's Modulus (GPa)	207 GPa
3	Ultimate tensile strength (MPa)	880 MPa minimum
4	Yield strength	640 MPa
5	Density	7800 kg/m
6	Elongation	>10 %

(Source: Ethiopian Railway Corporation, Technical Specifications of Vehicles.)

Table 3.2: Chemical composition of rail

No	1	2	3	4	5	6	7
Chemical element	C	Si	Cr	Mn	P	S	Al
composition	0.65-0.76	0.15-0.58	…….	0.70-1.2	≤0.04	<0.025	< 0.010

(Source: Ethiopian Railway Corporation, Technical Specifications of Vehicles.)

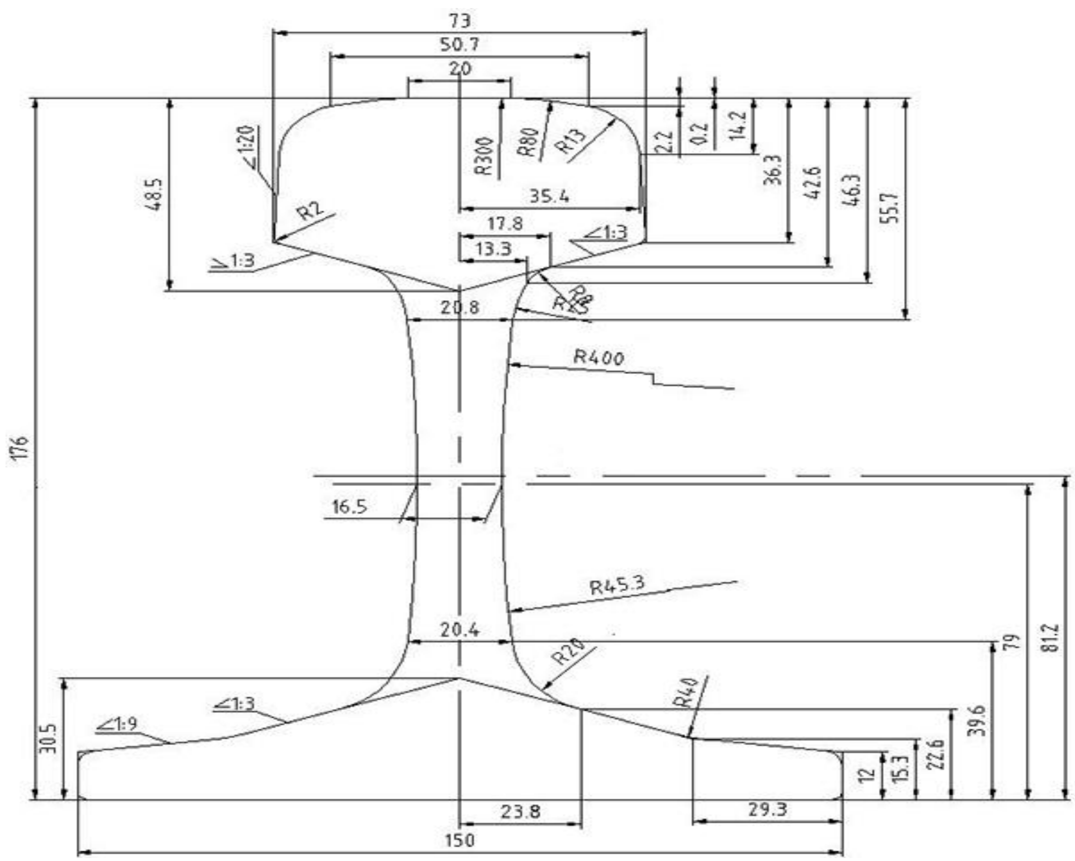


Figure 3.1: rail dimension, (Source: Ethiopian Railway Corporation, Technical Specifications of Vehicles.)

This picture describes us different dimension from the rail UIC 60 which will be able to help us to do the modeling of the rail.

3.1.2-Welding rail material

Thermite welding consumables ZTK-I (60U71Mn) was offered by a company under China academy of Railway Science. The chemical composition of thermite weld metal is given in Table 3.1.3. The standard thermite welding procedures and the welding gap of 25±2 mm between the two rail ends were adopted according to China Railway Standard TB/T 1632.3—2005 **[36].**

Table 3.3: Chemical composition of thermite welding material **[26]**

Materials	C	Si	Mn	P	S	Cr	Re
Thermite weld metal	0.75	0.95	1.20	<0.020	<0.020	0.15	0.10

Table 3.4: Mechanical property of thermite welding material **[26]**

No	Mechanical property	Value
1	Poisons Ratio	0.3
2	Young's Modulus (GPa)	207 GPa
3	Ultimate tensile strength (MPa)	996.7 MPa
4	Yield strength	675.7 MPa
5	percentage reduction of area	4.22
6	Percentage Elongation	3.09

3.2- LOAD and CONDITIONS

The forces applied to the track are vertical, lateral (parallel to the ties) and longitudinal (parallel to the rail).these forces are affected by train travel speed. An important point to recognize is that track design involves many force repetition. The rail should provide smooth running surfaces for the train wheel and they should guide the wheel set in the direction of the track. The rails also carry the vertical load of the train and distribute the load over sleepers. Lateral forces from the wheel sets and longitudinal forces due to traction and braking of the train should also be transmitted to the sleepers and further down into the track bed.

3.2.1-vertical force

The main vertical force is the repetitive downward action of the of the wheel load. In addition, this wheel/rail interaction produces a corresponding lift-up force on the tie away from the wheel load point.

The nominal vertical wheel force, also called the static force is equal to the gross weight of the railway car divided by the number of wheels.

The major factor affecting the magnitude of the dynamic vertical force:

- ✓ Nominal wheel load
- ✓ Train speed
- ✓ Wheel diameter
- ✓ Smoothness of the rail and wheel surfaces
- ✓ Track geometric
- ✓ Track modulus of vertical track stiffness

Vertically downward load is sum of 3% allowance, maximum axle load. Carrying capacity of vehicle has calculated by take average of 60kg/ person and the total rate of passenger inside of the tramcar is 118 (Source: Ethiopian Railway Corporation, Technical Specifications of Vehicles).

- Tram car weight = 44,7 ton=44700 kg

  $F=ma=mg$=44700kg$*$9,81m /s2=438507 kg

- The load apply on each wheel = 44,7/8=5.5875 ton =5587,5 kg
- Carrying Capacity = 60$kg/person$ $*$118 $person$ =7080 kg

7080/8=885 kg

- Over all capacity =$Tram\ car\ weight\ on\ each\ wheel + Carrying\ Capacity$ = (5587,5Kg+885Kg) $*$9.81m/s2= (6472,5Kg)$*$9,81m/s2=63495,225N=63,495KN
- Maximum Axle load=11160*9,81=109479,6N
- The total vertical load = maximum Axle load +3% maximum Axle load

  = (109479, 6N+3284, 4) =112763, 4 N=112, 7634 kN
- The load on each wheel =Static force =112,7634 /2=56,382 kN

3.2.4- Boundary condition

All the material properties and boundary conditions are being applied strictly as per the guidelines made available by National Railways in their manual. The wheel runs at constant speed of 120 km/hr. UIC 60 rail is used for analysis. The diameter of wheel is 840mm. The axle load is 56.832KN. Friction coefficient between wheel-rail is 0.3. The material's density is 7800 kg/m3. Material properties of the rail and wheel are assumed to be same. The material properties of the wheel and rail are considered to be bilinear kinematic hardening in ANSYS. Fig.3.2 below shows boundary conditions and load conditions on welded rail joint.

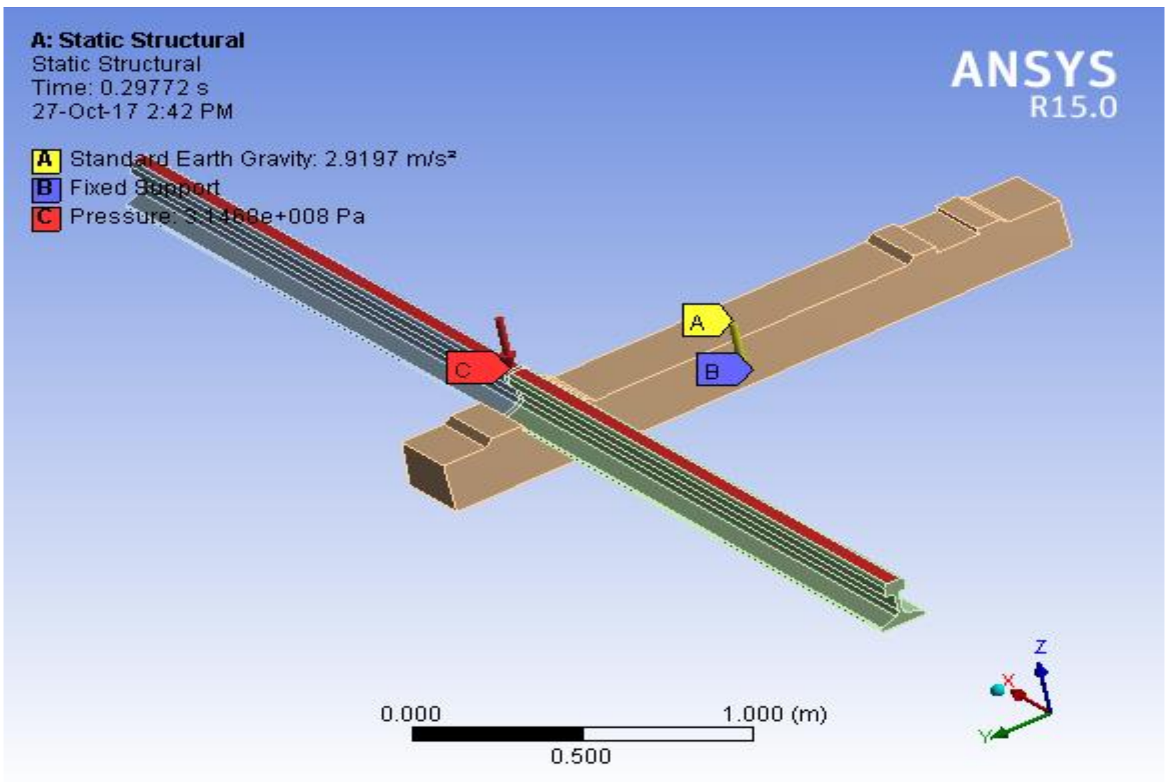


Figure 3.2: Boundary condition

3.3- MAIN TECHNICAL PARAMETERS USED on the STRESS ANALYSIS of WELDED RAIL JOINT

This research thesis is used to simulate the Addis Ababa-Djibouti line project welded rail joint stress analysis due to vertical force. For this simulation, national railway tramcar is considered. Currently this line uses one type of rail joint. This is standard rail joint.

Table3.5: Main Operations and technical conditions

Technical parameters	Values	Units
Gauge	1,435	Mm
Axle loading	11.16	Ton
Loading capacity	70	Ton
Maxi passenger train speed	120	Km/h
Maxi freight train speed	80	Km/h
Type of sleeper	type II concrete	-
Sleeper top width	220	Mm
Sleeper bottom width	250	Mm
Sleeper height	208	Mm
Sleeper length	2200	Mm
Distance between two sleeper pad	0,658 for mainlines and 0,625 for elevated	M

(Source: Ethiopian Railway Corporation, Technical Specifications of Vehicles)

Table3.6: Main parameters of lines

Technical parameters	Values	Units
Type of rail	60	Kg/m
Length of rail	25	M
Distance between two rail	<40	Mm

(Source: Ethiopian Railway Corporation, Technical Specifications of Vehicles.)

Table 3.7: Vehicles parameters

Technical parameters	Values	Units
Total tram car length	880	M
Total locomotives length	2*30	M
Tram car weight	44,7	Ton

(Source: Ethiopian Railway Corporation, Technical Specifications of Vehicles.)

3.4- SRESS MODEL USING HERTZIAN THEORY

Contact between two continuous, non-conforming solids is initially a point or line. Under the action of a load the solids deform and a contact area is formed as shown in Figure 1. Hertz contact stress theory allows for the prediction of the resulting contact area, contact pressure, compression of the bodies, and the induced stress in the bodies. In 1880 Heinrich Hertz developed his theory for contact stress after studying Newton's rings with two glass lenses. He became concerned about the effect of contact pressure between the two lenses and set out to analyze the effects. The result was the first satisfactory theory for contact mechanics and is still in use today. Hertz developed a theory to calculate the contact area and pressure between the two surfaces and predict the resulting compression and stress induced in the objects **[33]**.

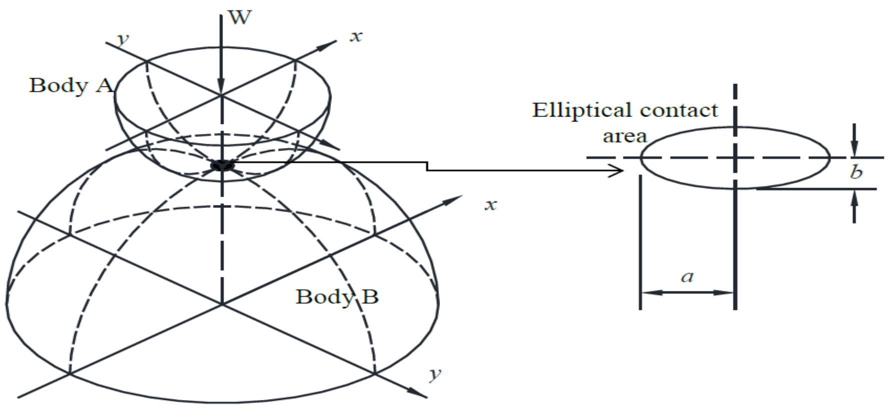


Figure 3.2: Geometry of two elastic bodies with convex surfaces in contact **[33]**.

- Assumptions:
  - The radii of curvature of the contacting bodies are large compared with the radius of the circle of contact.
  - The dimensions of each body are large compared to the radius of the circle of contact.
  - The contacting bodies are in frictionless contact.
  - The surfaces in contact are continuous and nonconforming.

According to Hertz theory, the normal pressure is distributed as an ellipsoid over the elliptic contact area. The ellipsoidal normal contact pressure distribution p (x, y) is expressed by:

$$P(x,y) = \frac{3Fn}{2\pi ab}\sqrt{\left(1-\left(\frac{x}{a}\right)^2-\left(\frac{y}{b}\right)^2\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

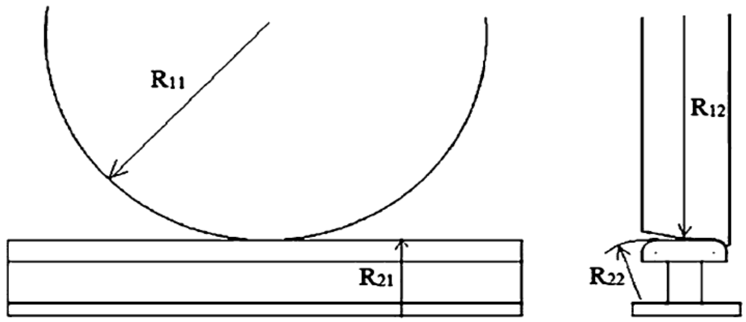


Figure 3.3: Wheel–rail configuration showing different principal relative radii of curvature **[33]**.

Radius of curvature of the wheel R1w=R11 = 420 mm,

Radius of the wheel profile R2w=R12 =∞

Rail with the radius of the head R1r=R21 = ∞

Radius of curvature of the rail in the plane of cross section R2r=R22= 300 mm

Depending on the size and orientation of the contact ellipse the positions of the contact point may be shifted in different directions based on the magnitude of x or y. However, based on the above general Hertz contact formula and assumptions, the stress due to wheel/rail contact decreases and becomes zero if it goes far away from the centerline of the rail head. Similarly, the wheel/rail contact stress is inversely proportional to the major and minor axis of the contact ellipse.

To calculate a and b, first let's find the values of Kw, Kr and $K3$. Kw and Kr are constants that depend on the material properties of railway wheel and rail respectively.

Where $Kw = \frac{1-(\vartheta w)^2}{\pi E w}$ .... (2)

And $Kr = \frac{1-(\vartheta r)^2}{\pi E r}$ .... (3)

Where vw and Ew are Poisson's ratio and young's modulus of the railway wheel material, and Er and vr are Poisson's ratio and young's modulus of railway rail material.

$Kw = \frac{1-(0.3)^2}{\pi * 210 * 10\hat{}9}$

Kw=1, 38*10^-12 m²/N

Also

$Kr = \frac{1-(0.3)^2}{\pi * 207 * 10\hat{}9}$

Kr=1, 40*10^-12m²/N

$K3$ is a constant and depends on the geometric properties of the two bodies and is defined as follows,

$K_3 = \frac{1}{2} * \left(\frac{1}{R_1 w} + \frac{1}{R_2 w} + \frac{1}{R_1 r} + \frac{1}{R_2 r}\right)$ .... (4)

R1w and R1r are the principal rolling radii of the wheel and the rail respectively and R2w and R2r are the principal transverse radii of curvature of the wheel and rail respectively.

$K_3 = \frac{1}{2} * \left(\frac{1}{420} + \frac{1}{\infty} + \frac{1}{\infty} + \frac{1}{300}\right)$

K₃= 2, 857*10^-3/mm

The coefficients m and n are Hertz coefficients and they are given as a function of the angle θ (0°− 90°) where θ is defined as:

$$\theta = \cos - 1\left(\frac{K_4}{K_3}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

And

$$K_4 = \frac{1}{2}\sqrt{\left(\frac{1}{R_1w} - \frac{1}{R_2w}\right)^2 + \left(\frac{1}{R_1r} - \frac{1}{R_2r}\right)^2 + 2 * \left(\frac{1}{R^1w} - \frac{1}{R^2w}\right) * \left(\frac{1}{R^1r} - \frac{1}{R^2r}\right) * cos2\varphi} \text{(6)}$$

φ is the angle of the orientation difference of the principle axes of the two bodies; also called yaw rotation. For a straight segment the curvature of the rail, φ=0°. Therefore,

$$K_4 = \frac{1}{2}\sqrt{\left(\frac{1}{420} - \frac{1}{\infty}\right)^2 + \left(\frac{1}{\infty} - \frac{1}{300}\right)^2 + 2 * \left(\frac{1}{420} - \frac{1}{\infty}\right) * \left(\frac{1}{\infty} - \frac{1}{300}\right) * cos2(0)}$$

K_4=4, 76*10^-4 /mm

For a straight rail segment, θ is defined as:

$$\theta = \cos - 1\left(\frac{2{,}048 * 10\hat{}-3}{2{,}857 * 10\hat{}-3}\right)$$

θ=80, 41°

By using the Hertz coefficient table and linear interpolation method the value of m and n for the selected rail can be easily obtained.

Table 3.8: Hertz coefficients **[33]**

θ (deg)	m	n	θ (deg)	m	n	θ (deg)	m	n
0.5	61.4	0.1018	10	6.6	0.311	60	1.49	0.72
1	36.89	0.1314	20	3.81	0.413	65	1.38	0.76
1.5	27.48	0.1522	30	2.73	0.493	70	1.28	0.8
2	22.26	0.1691	35	2.4	0.53	75	1.2	0.85
3	16.5	0.1964	40	2.14	0.567	80	1.13	0.89
4	13.31	0.2188	45	1.93	0.604	85	1.06	0.94
6	9.79	0.2552	50	1.75	0.641	90	1	1
8	7.86	0.285	55	1.61	0.678			

By interpolation method, we can calculate m and n

θ_1=80°; m_1=1, 13; n_1= 0, 89; θ_2=85°; m_2=1, 06; n_2=0, 94

$$m = m_1 + \frac{m2 - m1}{\theta 2 - \theta 1} * (\theta - \theta 1) \ldots\ldots\ldots\ldots \quad (7)$$

$$m = 1, 13 + \frac{1{,}06 - 1{,}13}{85 - 80} (80{,}41 - 80)$$

m=1, 124

$$n = n_1 + \frac{n2 - n1}{\theta 2 - \theta 1} (\theta - \theta 1) \ldots\ldots\ldots\ldots \quad (8)$$

$$n = 0, 89 + \frac{0{,}94 - 0{,}89}{85 - 80} (80{,}41 - 80)$$

n= 0, 894

Now, the values of a and b are:

$$a= m* \left(\frac{3\pi*Fn*(Kw+Kr)}{4*K3}\right)\hat{}\frac{1}{3} \quad \dots\dots (9)$$

$$a= 1, 124*\left(\frac{3\pi*56382*(1{,}38*10\hat{}-12+1{,}40*10\hat{}-12)}{4*2{,}857}\right)\hat{}\frac{1}{3}$$

a= 5, 66*10^-3

$$\mathbf{b}= n*\left(\frac{3\pi*Fn*(Kw+Kr)}{4*K3}\right)\hat{}\frac{1}{3} \quad \dots\dots (10)$$

$$b= 0, 894*\left(\frac{3\pi*56382*(1{,}38*10\hat{}-12+1{,}40*10\hat{}-12)}{4*2{,}857}\right)\hat{}\frac{1}{3}$$

b= 4, 50*10^-3

There are two contacts, the hertzian contact and the non-hertzian contact. In my case I used the hertzian cantact, one of the assumption of this contact tell us that we can only use the vertical or normal force that why in the pressure calculation below I just used the vertical force.

By using the values of a, b and the normal force, the maximum Hertz contact stress will be:

$$P= P_0= \frac{3*Fn}{2\pi*ab} \quad \dots\dots (11)$$

$$P= \frac{3*56382}{2\pi*5{,}66*10\hat{}-3*4{,}50*10\hat{}-3}$$

P=1056, 95 MPa

CHAPTER FOUR: RESULT and DISCUSION

4.1-PHYSICAL MODEL

In order to define the stresses on welded rail joint because of vertical force, a structural sketch is prepared using CATIA V5R19 modeling and analysis software. This model is exported to ANSYS -15 for final result analysis. The purpose of the structural sketch is to define the rail profile and welded rail joint for stress analysis. For this analysis, this research develop one model, this model is used to investigate the stresses developed on welded joint due to vertical force. The profile drawing includes rail profile and welded rail joint.

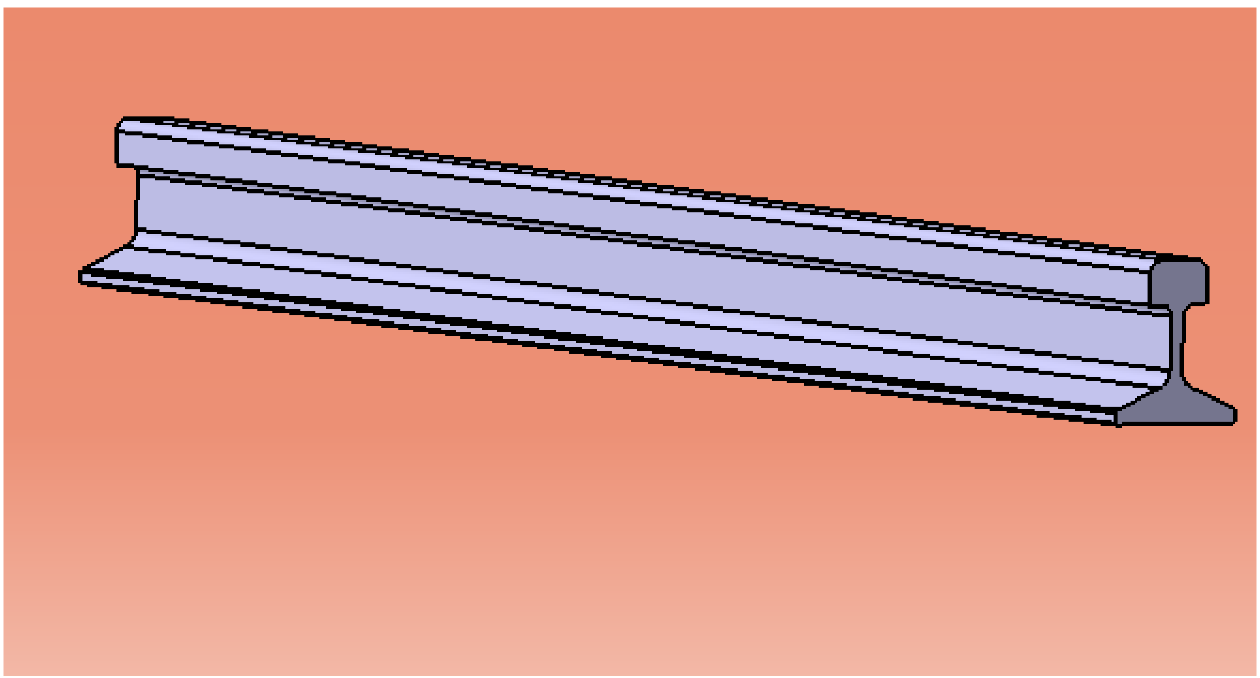


Figure 4.1: Standard rail profile used in the national railway (TB10082-2005 (60kg/m))

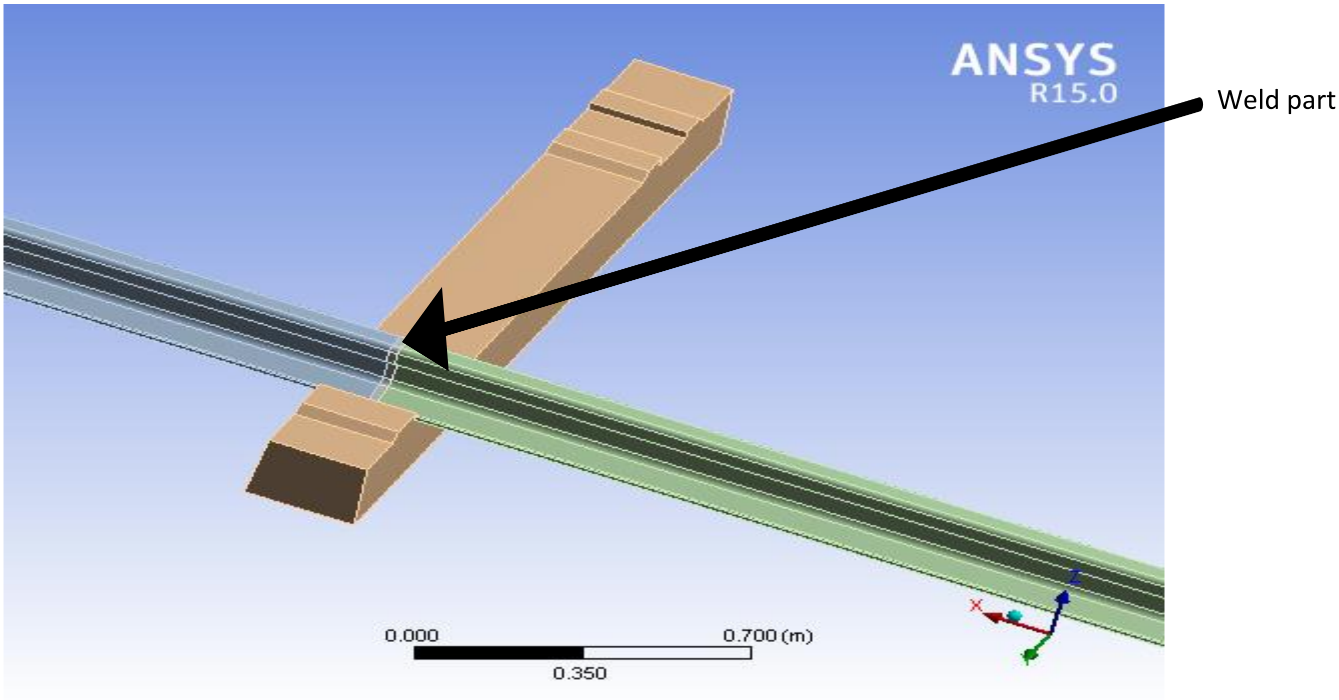


Figure 4.2: Welded rail joint in in ANSYS

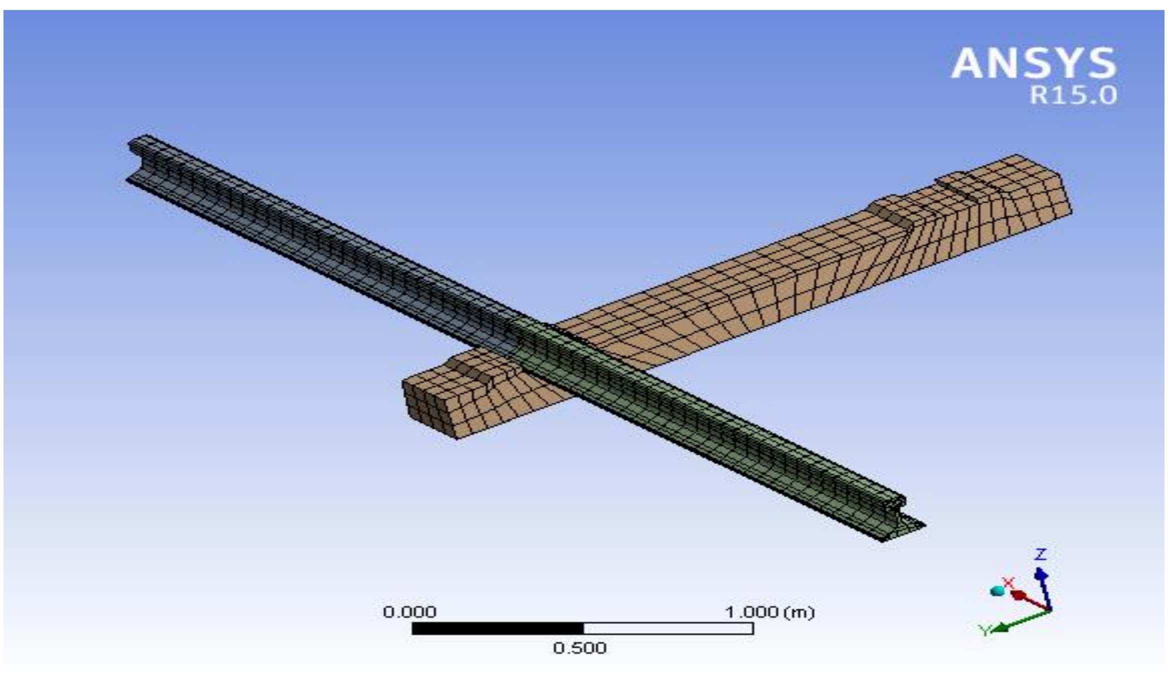


Figure 4.3: Mesh of assembled part on ANSYS workbench (element type: triangular, element size: fine and element number: 4776)

4.2- RESULTS

In this part the result of stress analysis, and fatigue life from the finite element model will be discussed in details.

4.2.1- Static Analysis:

A static structural analysis is determined the deflection, stresses, strains, safety factor, and fatigue wear of structures caused by loads that do not induces significant inertia and damping effects. The load and the structure responses are assumed to vary slowly with respect to time that means steady loading and response condition are assumed.

The type of loading that can be applied in a static analysis is Vertical wheel load (force).

I- Stress

Stress is defined as the average force per unit area that some particle of a body exerts on an adjacent particle, across an imaginary surface that separates them.

A) Equivalent (von- mises) stress(Pa)

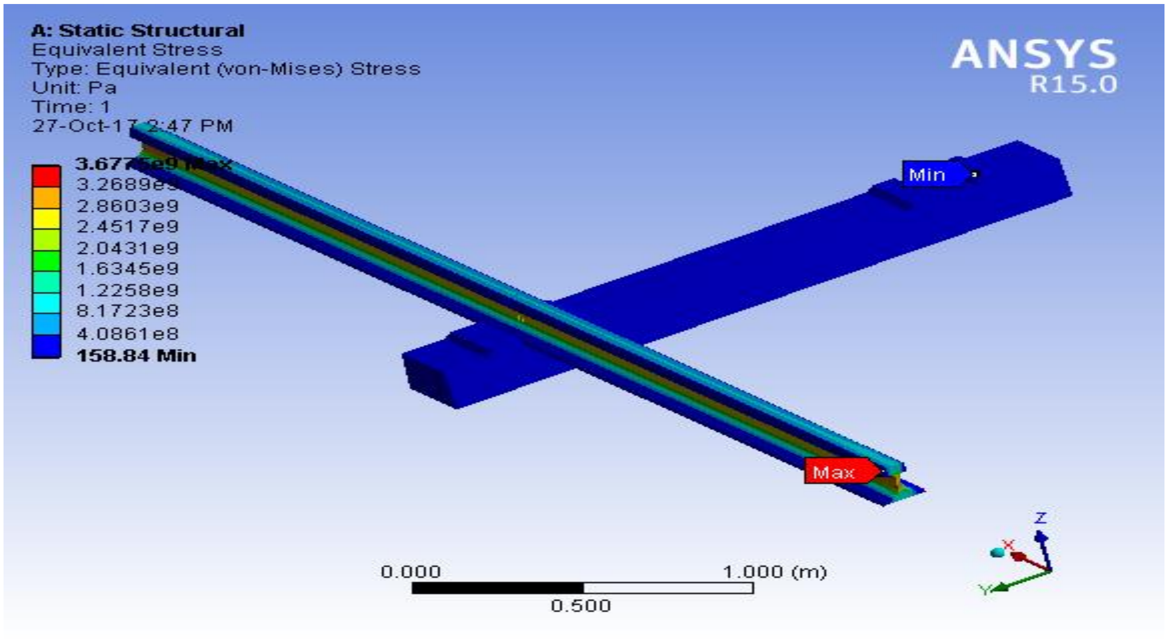


Figure 4.4: Von-mises stress

As shown in above figure, the maximum von-Mises stress is 367, 75 MPa and the minimum von –mises stress is 158, 84 Pa.

B) Normal stress(bending stress)(Pa)

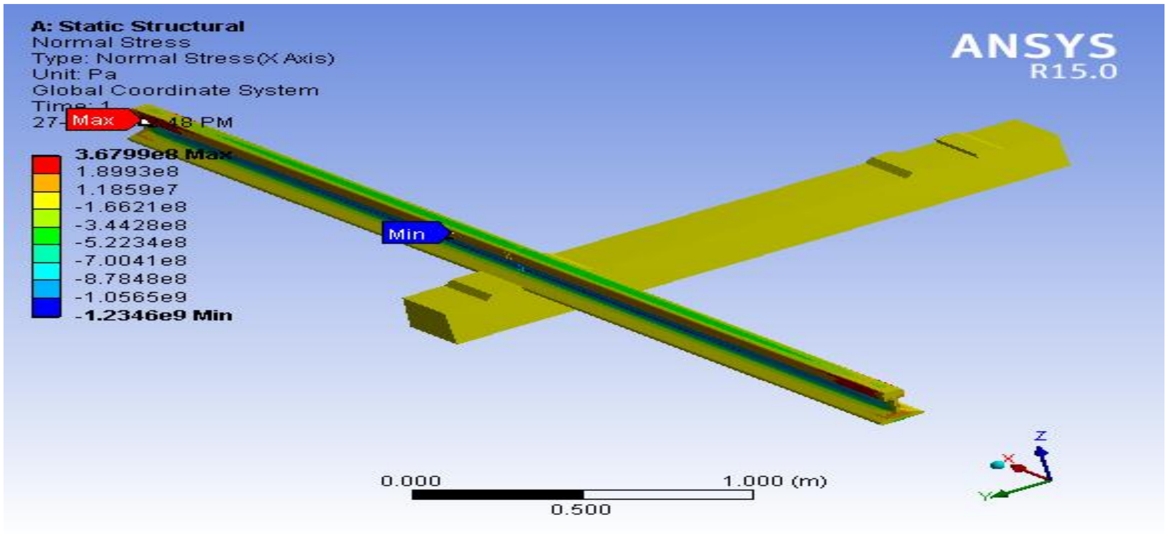


Figure 4.5: Normal stress

As shown in above figure, the maximum normal stress is 367, 99 MPa and the minimum normal stress is -1234, 6 MPa.

C) Shear stress(Pa)

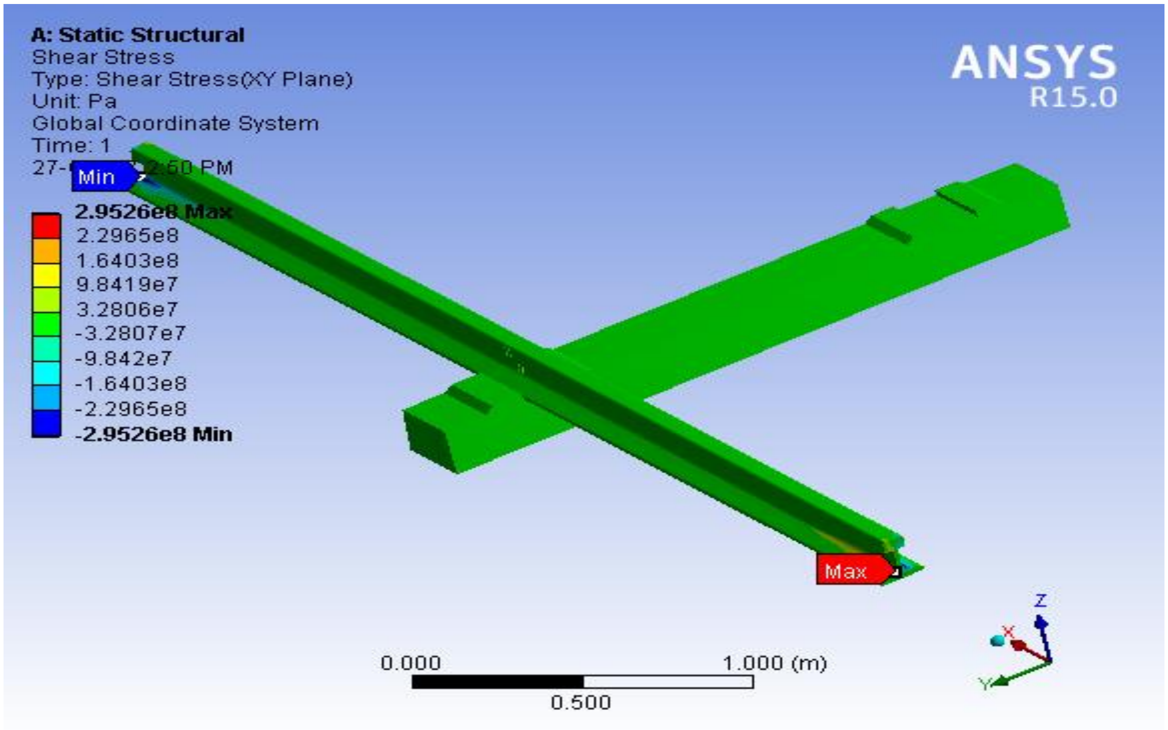


Figure 4.6: Shear stress

As shown in above figure, the maximum shear stress is 295, 26 MPa and the minimum shear stress is -295, 26 MPa.

II- General fatigue results

A) Fatigue life

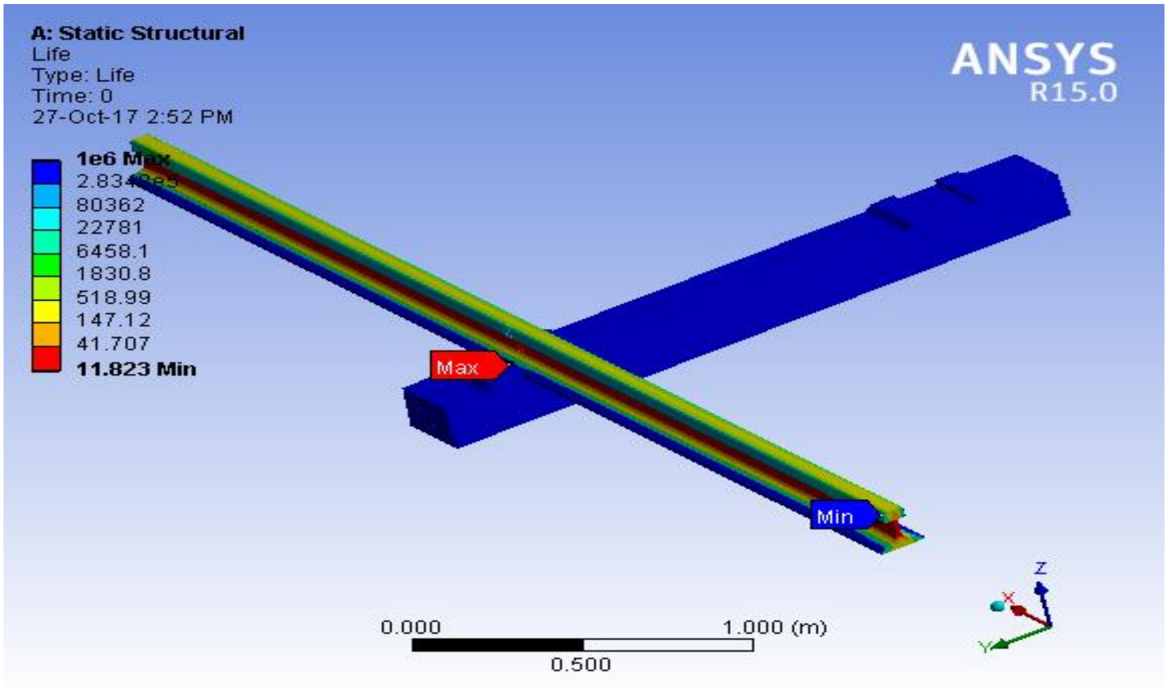


Figure 4.7: fatigue life

Fatigue Life can be over the whole model or scoped just like any other contour result in Workbench (i.e. parts, surfaces, edges, and vertices). Figure 4.7 shows the available life for the given fatigue analysis. The minimum fatigue is 11,823 and the maximum fatigue life is 1000000 cycles.

The Steps implemented for the fatigue life analysis approach are listed in the following way:

- Attaching Geometry
- Assigning Material Properties
- Defining Contact Regions
- Defining Mesh Controls
- Including Loads and Supports
- Requesting Results, including the Fatigue Tool
- Solving the Model
- Reviewing Results

B) Fatigue Damage

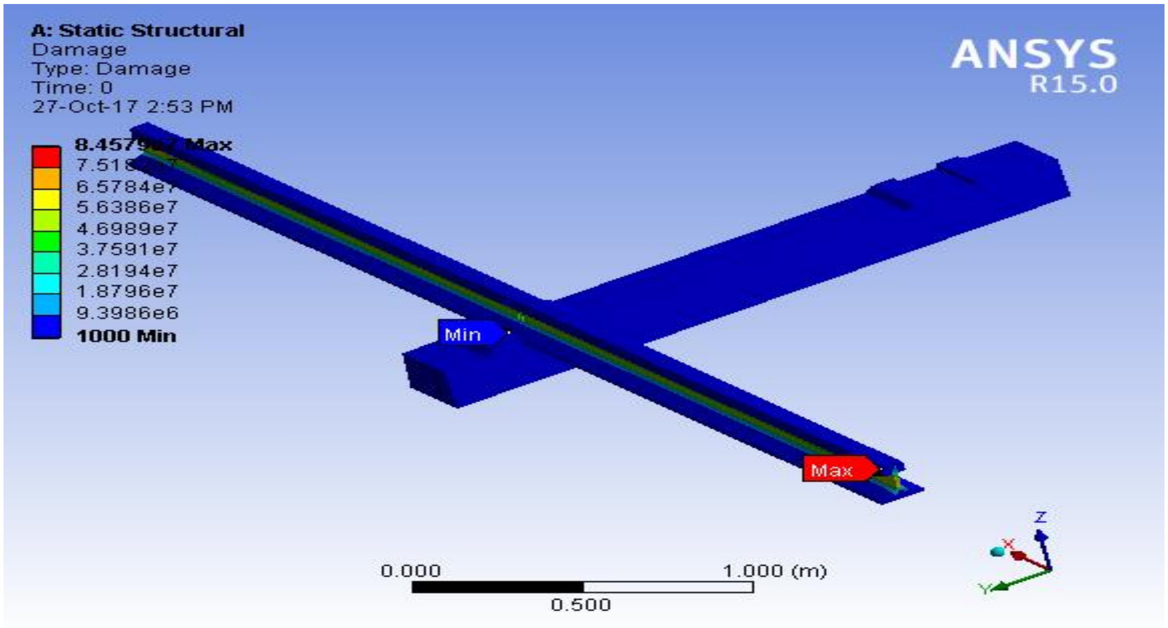


Figure 4.8: fatigue damage

As shown in above figure, the maximum damage value is 84, 58 MPa and the minimum damage is 1000.

C) Fatigue Safety Factor

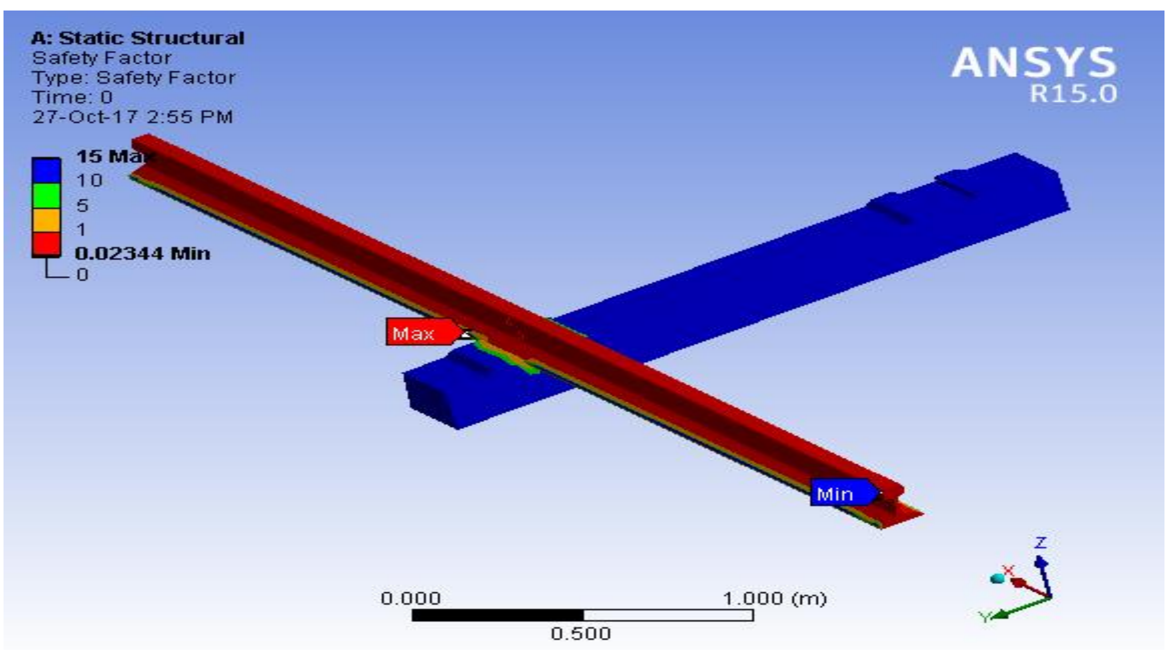


Figure 4.9: safety factor

As shown in above figure, the maximum safety factor is 15 and the minimum safety factor is 0, 02344.

4.2.2- Fatigue life evaluation (S-N curve):

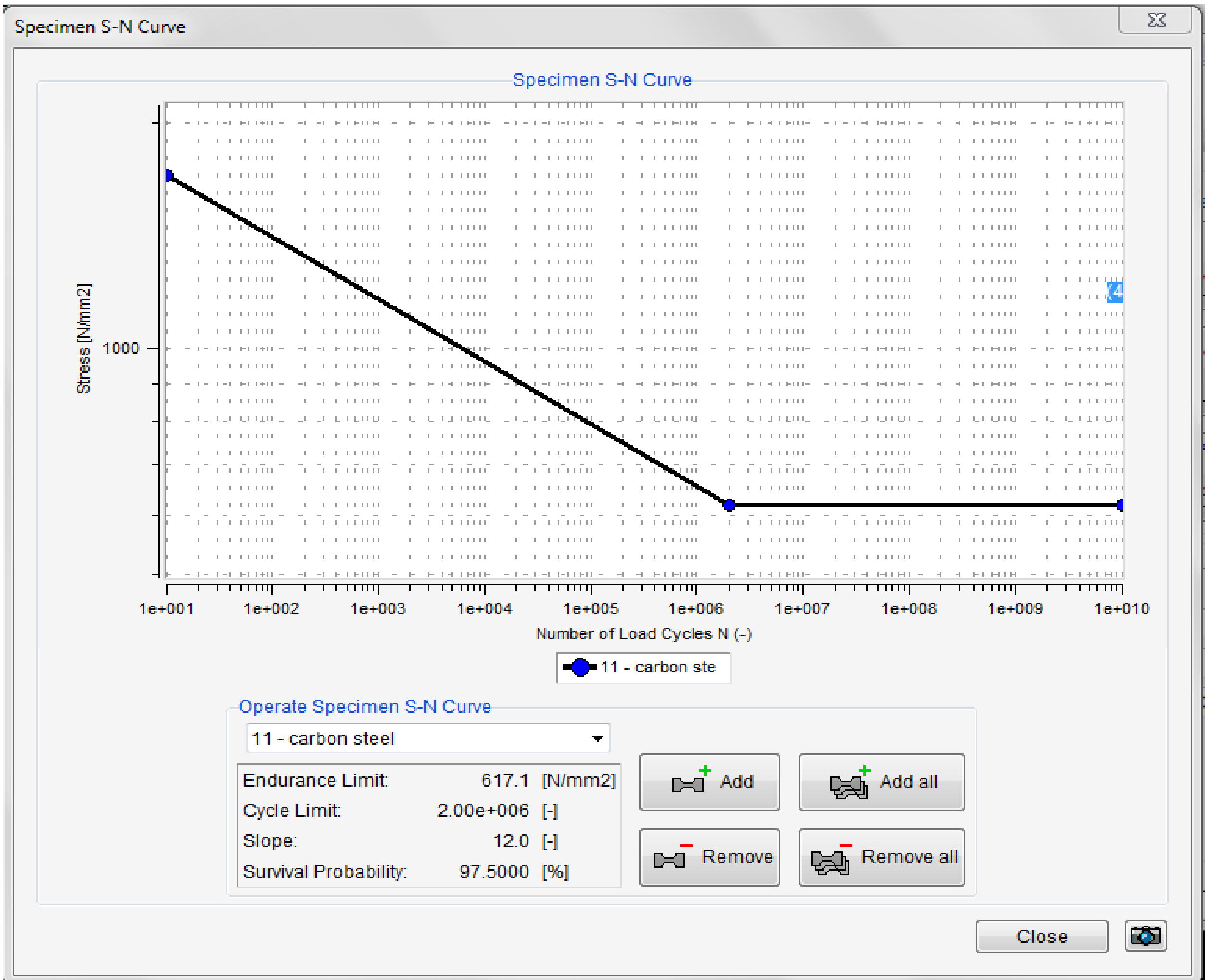


Figure 4.10: S-N curves

The endurance limit is 617.1 N/mm²; at that point there will be a failure.

4.3- DICUSSIONS

This section of the paper specifies the result obtained from the ANSYS software based on hertz contact theory. The above result shows different stress types and fatigue life due to various load applied at the welded rail joint Therefore, the concentration of stress (equivalent, normal and shear stress) is observed on the rail and on the sleeper as us shows it preceding simulation. And the value of maximum equivalent stress is 79, 54 MPa lower than the yield strength of the welded joint material.

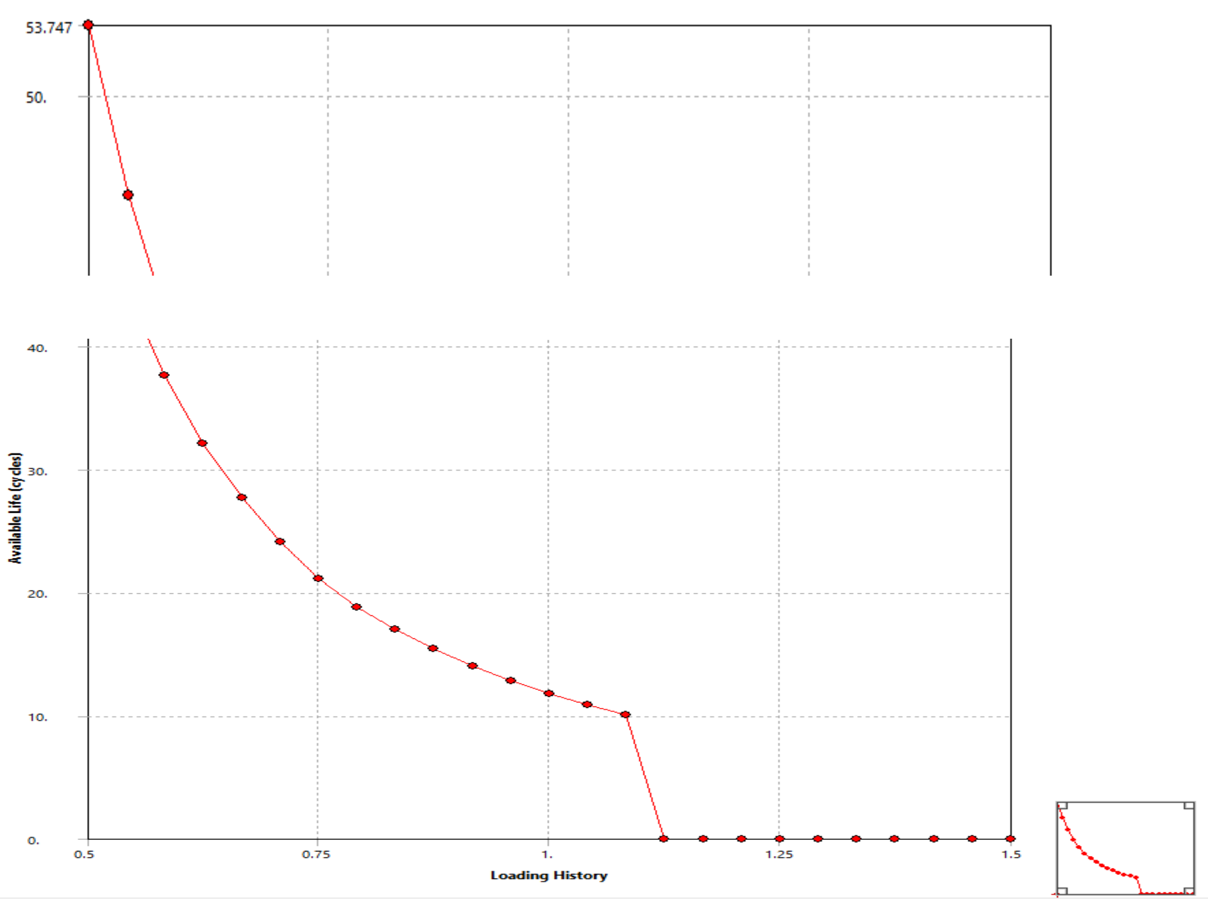


Figure 4.11: fatigue sensitivity

The diagram above show as the variation of life (cycles) according to loading history. Moreover the load increases and more the availability of life decrease. That returns to say that they are conversely proportional.

CHAPTER FIVE: CONCLUSION RECOMMENDATION and FUTURE WORK

5.1- CONCLUSION

Relatively simple models of rail sleeper were used for static analysis of the research. The prescribed method in this research may be used to evaluate the fatigue life of welded rail joints**.** In this study, the responses of a welded rail joint component are determined under static analysis, the results are assumed to be significant. The analysis can include stress and fatigue responses of welded rail joint caused by vertical wheel, lateral and longitudinal load. The load applied is only when the welded rail joint is on the sleepers. And if I compare the maximum equivalent stress with the yield strength of the welded joint, this last value of yield strength is larger than the maximum value of the equivalent stress obtained by the analysis. I can conclude from it that the welded joint material can support the various types of load.

5.2- RECOMMENDATION

This part of rail track needed more attention than other parts, to ensure the fatigue failure. This paper recommends, the welded joint on the sleeper because it can resist the stress. And also The Joint part of the rail track needs more attention to eliminate problem related to the wheel/ rail contact like fracture of rail and joint bar hole, looseness of bolt, nut, and dislocation and distorted of the rail joints. For that case it is better to use the welded joint.

5.3- FUTURE WORK

In this paper the analysis is limited to the fatigue life of welded joint by ANSYS software due to the mechanical effect load. Some suggestions are listed below for future work as extension and continuity of this paper.

- The experimental fatigue test of welded joint is necessary to plot S-N curve.
- thermal structural analysis must be studied

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