ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

AFRICAN RAILWAY CENTER OF EXCELLENCE– ARCE

FINITE ELEMENT ANALYSIS OF RAIL BENDING STRESS AND DEFORMATION UNDER THE EFFECT OF UNSUPPORTED SLEEPER

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A Thesis in Railway Engineering (Civil Infrastructure)

By

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A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment for the Degree of Master of Science in Railway Engineering, Civil Infrastructure.

The undersigned members of the Addis Ababa Institute of Technology under the department of Railway Engineering have examined the thesis entitled ***"FINITE ELEMENT ANALYSIS OF RAIL BENDING STRESS AND DEFORMATION UNDER THE EFFECT OF UNSUPPORTED SLEEPER."*** Presented by **Bethelhem Bekele**, a candidate for the degree of **Master of Science in Railway Engineering (Civil Infrastructure)** and hereby certify that it is worthy of acceptance.

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Certification

I, Bethelhem Bekele, declare that this thesis, submitted in fulfillment of the requirements for MSc in Railway Engineering, in the School of Civil Infrastructure, University of Addis Ababa Institute of Technology, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Bethelhem Bekele

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Abstract

Ethiopia, one of the developing countries in the world, has put large affinity towards basic infrastructures like buildings, roads, power supplies needed for the society wellbeing. Among these, railway is one mode of transportation. In several countries, the traditional railway track system is the ballasted track, i.e., consists of rail, rail pad, and concrete or wooden sleeper on ballast and sub-grade. Railway sleepers and ballast are the main structural elements of railway track. The ballast-sleeper interactions include pressure distribution and load transfer to ballast, railway sleepers are aimed to maintain track gauge, guarantee lateral stability of the track and contribute to better geometrical conditions of the track. However, in the case of lose sleeper-ballast contact, these function of the interaction will be affected.

This study examines the effect of rail vehicle speeds and unsupported sleeper as a result of ballast stiffness variation on rail stresses and vertical displacements.

The Finite element model which was composed of a single train wheel rotating on a rail supported by evenly spaced five sleepers, laid on a 300mm thick ballast layer, was used.

The results show that the decrease in ballast modulus leads to an increase in rail deflections. It is also found that increase in speeds results in an increase of rail deflection and stress.

For the deflection of the rail as the speed increases the deflection also increases. In this project considering the speed variation for example at ballast modulus of 120 MPa, for the speed of 20, 40 and 80Km/hr the deflection are 0.187, 0.207 and 0.266mm respectively.

In the presence of unsupported sleeper, the rail bending stress increased by 32% and the maximum von-mises stress on rail which is 181.52 MPa occurred when the ballast modulus is 90MPa with a rolling speed of 80Km/hr. For a train moving on 80Km/hr speed, the rail bending stress increases from 51.12 MPa to 72.23 MPa in the existence of unsupported sleeper.

Keywords: *Track stiffness, unsupported sleeper, rail deflection, von-mises stress, and rail bending stress.*

Abbreviations

AALRT	Addis Ababa Light Railway Transit
BOEF	Beam on Elastic Foundation
ERC	Ethiopian Railway Corporation
FEM	Finite Element Methods

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1 INTRODUCTION

1.1 Background

Railway transport is currently one of the most important transportation systems. It is highly effective in moving people and cargo long distances, and has better environmental friendly features than most other available transportation alternatives.

Nowadays, most railway tracks around the world are ballasted tracks with two parts, substructure and superstructure. The substructure mainly consists of three layers; ballast, sub-ballast and sub-grade which rest on the subsoil, normally the natural ground. The superstructure consists of rail, rail pad, fastening system and sleeper. All components interact and have different functions in the structure among which the roles of sleepers are perceptible.

Railway sleepers are essential beams that span across and tie together the two rails. They receive the load from the rail and distribute it over the supporting ballast at an acceptable ballast pressure level, hold the fastening system to maintain proper track gauge, restrain the lateral, longitudinal and vertical rail movement by anchorage of the superstructure in the ballast, and provide a cant to the rails to help develop proper rail-wheel contact by matching the inclination of the conical wheel shape.[1].

When a train has passed, the track will not return exactly to the original position but it will return to a position quite near the original one. After countless train passages, all of these minor non-elastic deformations will build up and affect the track in different ways at various points, changing the track's position and producing unequal support conditions.[2]

Many researchers have worked on this phenomenon and have attempted to assess the effect of full support, unsupported, and partially supported sleepers on the dynamic performance of the tracks. So, all the above researches show that sleepers are as significant components as other components. Inspection and maintenance of sleeper is therefore required to insure that the sleeper keeps in good condition.

In ballasted tracks where there is not enough ballast under the sleeper, it causes distance between sleeper and ballast to be created. In this condition one or more sleepers will be hanged from the rail and so the support of the sleeper will be partially or completely lost. Existence of such problem causes force changes in the area of track and contact force of track-train, and these changes cause vibration in vehicle.[3]

1.2 Statement of the Problem

Railway sleepers are one of the essential elements of the superstructures of railway tracks. As its main functions are to support the rails, keep the axis of the track constant and transmit loads of the axles of the vehicles to the ballast.

However, some sleepers may not be properly supported, due to inadequate drainage, low quality, and differential settlement of the ballast and components beneath which, have an impact on the functionality of the track system by increasing deflection and wheel-rail contact force. Nowadays, with increasing train speed and load, the unsupported sleeper may accelerate the degradation of the railway track, which in turn induces abnormal dynamic forces and undesired motions to the track and vehicle systems. These abnormal forces and motions may not only deteriorate the components in the vehicle track system, but also impose a safety risk to the operation.[4]

Most researches focused on the effect of unsupported sleeper on dynamic response of track structures but they ignored the specific effect of unsupported sleeper on the rail bending stress especially in case of AALRT. These rail bending stress and deflection causes rail defects.

To ensure sufficient capacity of sleepers to support design speed and axle load of railway tracks and to examine and improve current design practices different track structural responses under these conditions should be studied.

1.3 Objective

General Objective

The main objective of the research is to investigate the effect of unsupported sleepers on rail bending stress and rail deflection.

Specific Objectives

- Analyzing the effect of unsupported sleepers on rail deflection
- Investigating rail bending stresses due to unsupported sleepers.
- Examining the effect of speed increment on rail deflection in presence of unsupported sleeper.
- Evaluating the effect of speed increment on rail bending stress in presence of unsupported sleeper.
- Exploring track deterioration due to unsupported sleeper.

1.4 Scope and Limitation

It is very difficult to predict the exact distribution of contact stress under sleepers especially in case of the unsupported sleepers. In previous studies researchers like Augstin [5] conclude that about 50% of the sleepers are unsupported and this results in increased dynamic load and ballast settlement as well as speed up ballast degradation and track deterioration. In this study the track with unsupported sleeper and the normal track are modeled using a finite element method. And the existence of the unsupported sleeper in track is indicated by reduction of stiffness of the ballast beneath that sleeper.

Due to limited laboratory resources and its expensiveness, this research is conducted only by a computer model using finite elements method. In addition including all real track components and special features is very difficult as it needs more computational time and higher computer capacity. In this research main track components like a 3m length rail, sleepers and ballast are included for simulation.

1.5 Significance of the project

- ➢ The main objective of any project is to resolve an existing problem or to point out problems that may appear in the future and to provide a solution for them. So as a project this thesis indicates the problem associated with unsupported sleepers.
- ➢ It can also be used as a reference for future studies and predictive maintenance. For example, the computational results can be used to train a measurement system to detect an unsupported sleeper.

- This thesis is also an initiation for further investigation in the problem especially for the case of Ethiopian railway industry.
- It is also a remainder for the railway industry about track maintenance and field experiments related to unsupported sleeper and their counter measures when the problem appears.

1.6 Outline of the thesis

This thesis combines five chapters.

Chapter 1, is mainly the introduction and overall view of the project which includes the research background, the problem statement which is the description for the problem that initiated this study. The general and specific objectives, scope and limitation, structure of the thesis and significance of the study are also included in this chapter.

In chapter 2, the past studies associated with unsupported sleeper and related issues are reviewed under the section of literature review. In this chapter the track components, the effect of unsupported sleepers and track stiffness variation and pressure distribution and sleeper-ballast contact mechanisms are briefly described.

The modeling and simulation methodology called the commercial software ABAQUS/CAE has been introduced in **chapter 3**. In this chapter all the procedures starting from creating track parts to the analysis steps and procedures that are implemented to get the desired results have been clearly described

In Chapter 4, the results of the simulation from ABAQUS are presented and analysis of the results has been stated.

The last chapter contains the research conclusion and it gives some recommendation based on the findings in solving the specified problem. The gaps and suggestion for future studies are also described in this chapter.

2 LITERATURE REVIEW

2.1 Track Components and their characteristics

The purpose of a railway track structure is to provide a safe and economical transportation system. It requires the track to serve as a stable guide way with appropriate vertical and horizontal alignment. To achieve this role each component of the system must perform its specific functions adequately in response to the traffic loads and environmental factors imposed on the system.

The main components of ballasted railway tracks are grouped into two main categories; the superstructure and the sub-structure. The superstructure consists of rails, rail pads, fastening systems and sleepers (ties). The substructure consists of the ballast, sub ballast and the sub-grade.[6]

2.1.1 Rails

Rails are the longitudinal steel members that support and guide the train wheel in lateral direction and transfer concentrated wheel load to the supporting sleepers. Rails should have adequate stiffness to carry stress and distribute it to the sleepers without excessive deflection.[7]

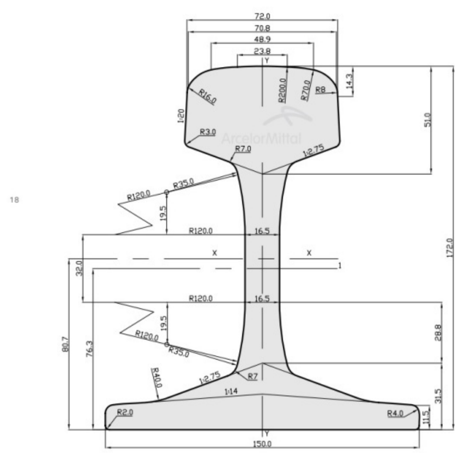


Figure 1 UIC 60 rail Profile [8]

Rail is the track element which is in direct contact with the rolling stock. It is therefore very important to ensure the proper functioning of rails in the track system, especially from safety point of view.

In rail analysis and design procedure, the most recommended criteria are mainly divided into two categories. Structural strength criteria include wheel-rail contact stresses and rail bending stresses. In addition, serviceability requirements should be completely met for a specific rail section to ensure its proper structural and operational performance.[9]

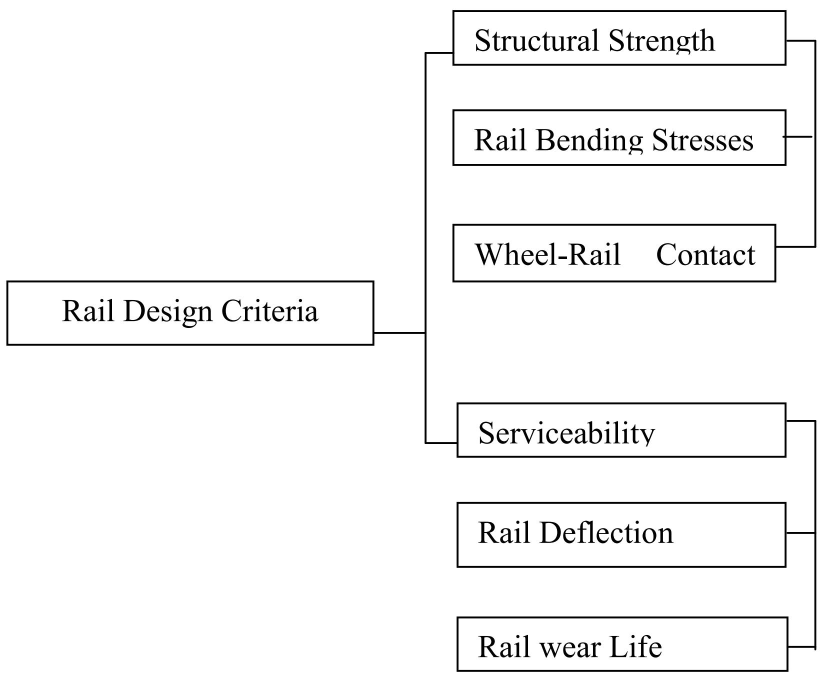


Figure 2 Recommended rail design criteria [9]

2.1.2 Rail Pads

Rail pads are elements that are laid between the steel rail and the sleeper. Rail pads transfer the rail load to the sleeper and reduce the high frequency force components. The elastic polyurethane material property of the pad protects the sleepers from wear. In a track the rails are fastened onto the sleeper. The rail pads also provide electrical insulation of the rails.[10]

2.1.3 Fastening Systems

Rail fastenings are some of the major elements of the top structure of the track. Traffic safety of the trains depends on their reliable work. They carry out the function of connection between the track way and the tie array. They carry out function of the primary amortization for dynamic interaction between a track and a rolling stock. Rail fastenings carry out also the important function of fixation of long welded tracks at the temperature influence on the rails.[11]

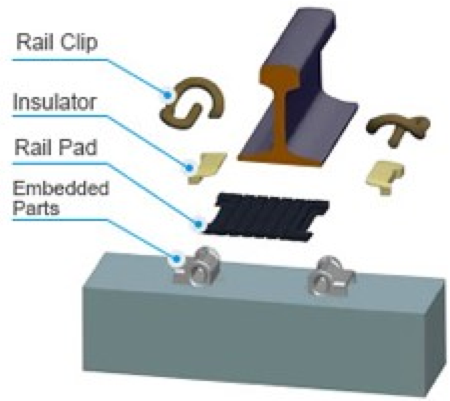


Figure 3 Fastening system[12]

2.1.4 Sleepers

Sleepers (or ties) can be made from timber, concrete and steel. Timber sleeper are used in different countries worldwide. But due to the scarcity of the timber, concrete sleepers are introduced in the system and nowadays precast concrete sleepers are preferred due to their longer service time and low maintenance cost. Although steel sleepers have longer life time, great dimensional accuracy, they used in small areas due to insulation problem, high price and badly behavior during tamping.[7]

Sleepers secure the track, reduce rail vibration and the influence of sound and impact waves on the environment, hold the fastening systems to keep the proper track gauge and alignment of the track, distribute the load from the rails over large area of ballast underneath, provide elastic medium between the rails and ballast and also sleepers help to provide proper super elevation to rails for the development of proper wheel/rail contact.[6]

2.1.5 Ballast

Ballast is the broken stone placed or packed below the sleepers to transmit load from sleeper to the formation and at the same time allowing drainage of the track.

Functions of ballast include providing firm and level bed for the sleepers to rest on and allow for maintaining correct track level without disturbing the rail road bed. Ballast is also used to drain off the water quickly and to keep the sleepers in dry conditions. The crushed granular material property of the ballast absorbs noise and discourages the growth of vegetation.[6], [7]

2.1.6 Sub ballast

Sub ballast is an aggregate placed between the ballast and sub-grade which uses the fine materials of the sub-grade not migrate into the ballast. The sub-ballast reduces the induced stress at the bottom of the ballast layer to an acceptable level for the top of sub-grade.[6]

2.1.7 Sub-grade

Sub-grade is a platform where the rail track structure is built. It can be natural ground soil or a combination of filler material and it must provide a stable base for the track structure.[6]

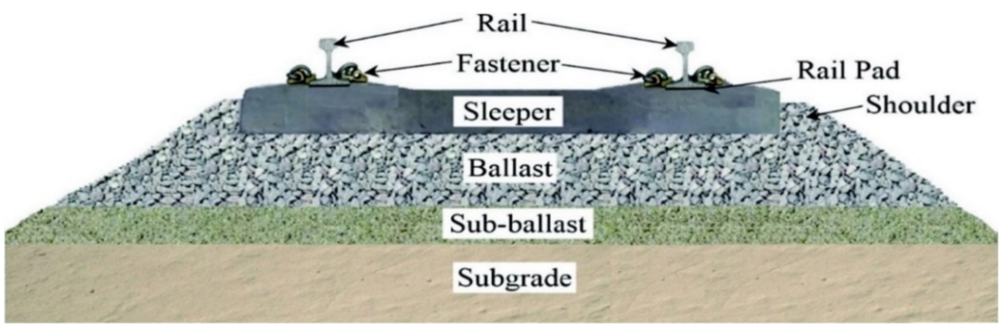


Figure 4: Ballasted Railway Track Components [6]

2.2 Historical Development of Sleepers

In earlier years timber was the first material used to manufacture railway sleepers. But due to the difficulty in their availability and sensitive behavior of the material and also environmental issues the world start to use steel and concrete sleepers as an alternative. Concrete sleepers have very advantageous in their simplicity to manufacture and also have a better capacity to withstand climatic influences.

2.2.1 Advantages and drawbacks of concrete sleepers

The scarcity of wood is one of the reasons for the introduction of concrete sleeper in Second World War. The following are some of the advantages and drawbacks of concrete sleepers.[7]

Advantages;

- In continuously welded rails (CWR), heavy weight of concrete sleepers are useful for stability on the connections.
- As the fastenings are good and easily replaceable, the service life of concrete sleepers is long.
- They are relatively easy to manufacture.
- Great freedom of design and construction.[7]

Drawbacks;

- Less elastic than wood. On poor formation, Pumping may occur.
- Susceptible to corrugations and poor quality welds
- Risk of damages from impacts (derailment, loading/ unloading, tamping etc...)

Concrete sleepers can be either reinforced twin block or pre-stressed mono-block concrete sleepers. [7]

2.2.2 Pre-stressed concrete sleeper

Pre-stressed concrete sleepers are crucial to the structural integrity of railway track structures, redistributing rail wheel loads to underlying ballast bed while securing rail gauges for safe train operation and they also have an enhanced structural capacity and serviceability as compared to conventional reinforced concrete.[13]

Even though there are some draw backs of mono-block pre-stressed concrete sleepers, they have an advantage to keep all cross sections of the sleeper's fully in compression, under either pre-camber or design service loads. Hence, their design approach ensures that tension cracks do not occur which can allow access of moisture and corrosion of the embedded steel bar. In addition the self-weight of the sleepers gives stability to the track; provides good longitudinal and lateral resistance and better load distribution to the underlying ballast bed.[7],[14]

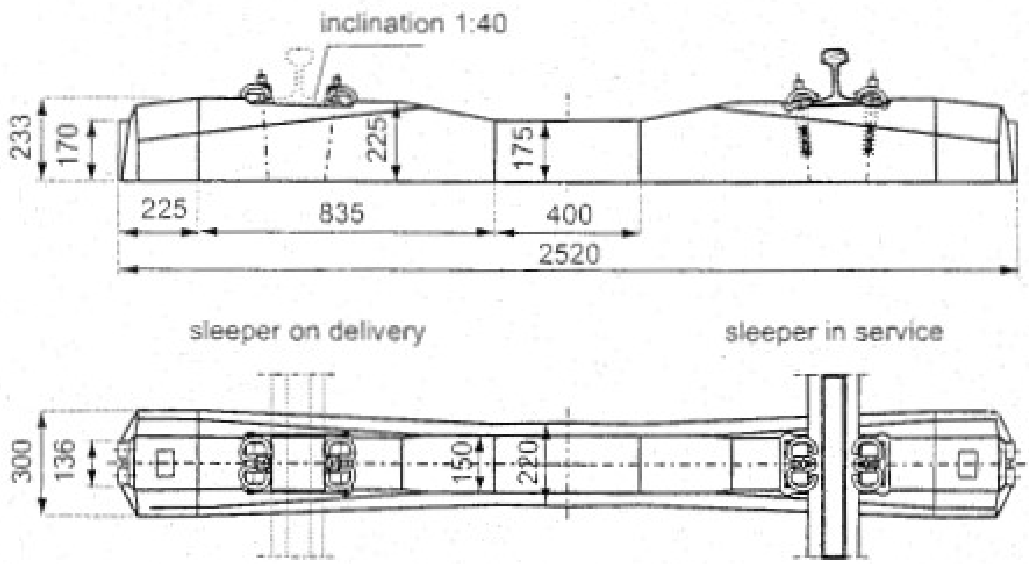


Figure 5 Pre-stressed mono-block sleeper [7]

2.3 Pressure distribution under the sleepers

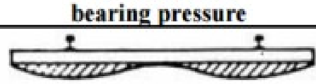
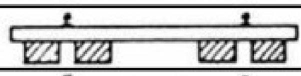
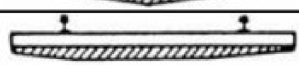
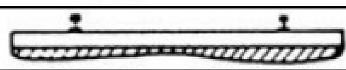
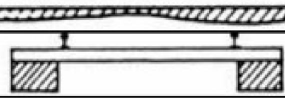
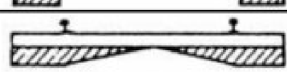
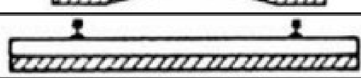
Sleepers are essential components of a railway track for transferring train loads into the ballast beneath. Every component of track structure does not function independently and interact with each other in response to the applied load. Among the interaction of track components one of the important interaction is the sleeper-ballast interaction. Practically, the sleeper-ballast interaction is complicated than other sections, and the interaction is neither uniformly distributed, nor fixed and usually the actual contact condition between sleeper and ballast is not easily predicted.[14]

The sleeper support condition and the corresponding contact pressure distribution between the sleeper and the ballast must be determined before the structural behavior of the sleeper under the train loading can be calculated. The degree of voiding of the ballast below the sleeper controls the pressure distribution and as voiding occurs gradually under the repeated train loading; the pressure distribution will vary over time depending on the level of maintenance.[15]

The quality of the ballast aggregation, the mechanical properties of the concrete sleeper (rigidity), the quality of track maintenance operations, the volume of passing traffic, and the time passed after the tamping operation are all factors that affect the contact pressure distribution beneath the sleeper.[14]

During tamping of the track, the contact area between the sleeper and the ballast occurs below each rail seat and as the tracks give service the contact pressure distribution between the sleeper and the ballast tends towards a uniform pressure distribution. This condition is associated with a gap between the sleeper and the ballast surface below the rail seat. In current practice in order to interpret how the vertical force exerted by the rail on the sleeper is transmitted to the ballast, various hypothetical contact pressure distributions between the sleeper and the ballast are presented as shown in Table 1.[16]

Table 1 Hypothetical distribution of sleeper bearing pressure (current practices)[16]

Distribution of bearing pressure	Developers	Remarks
	ORE[16],Talbot[7]	Laboratory test
	ORE[6],Talbot[8],Battelle[9],Clarke[10]	Tamped either side of rail
	ORE[19],Talbot[8]	Principal bearing on rails
	ORE[19],Talbot [8]	Maximum intensity at ends
	Talbot[8]	Maximum intensity in middle
	Talbot[7]	Center bound
	Talbot[7]	Flexure of sleeper produces variations form
	ORE[19],Talbot[8],kerr[11],Schramm[12]	Well tamped sides
	ORE[19],Talbot[8]	Stabilized rail seat and sides
	AREA[13],Raymond[14],Talbot[8]	Uniform pressure

2.4 Track Stiffness variation

Track stiffness is the capacity of a track to withstand deflection under loading. It is an important track property constituted from the properties of the sub structure and super structure of track components.

Track stiffness k is the defined as ratio of a concentrated vertical force, P and the maximum deflection of the rail (δ_m), as

$$k = \frac{P}{\delta_m} \quad \text{.......................................Equation 2-1}$$

Railway track structure has stiffness to provide elasticity in transferring the train load. The track structure comprises different components with their own stiffness. Track stiffness must not be high nor small. When the track stiffness is too big it makes the track to have more brittle behavior and leads to more stress and therefore resulting in plastic behavior of the track which there is no longer back to the original shape. And also small track stiffness makes the track more flexible and increases the vibrations of the system which has a contribution in track deterioration and safety issues. As a result there should be a designed optimal stiffness of the system for a satisfactory operation & serviceability. [17]

The track rigidity varies longitudinally and vertically since it is a composite structure made of many parts. The track stiffness is made up of the rail stiffness, rail pad stiffness, crosstie stiffness, ballast stiffness, and sub-grade stiffness in the vertical direction. But because of the nonlinear behavior of the ballast stiffness and the rail pad stiffness, stiffness is likewise nonlinear in the vertical direction. Track stiffness variation is mainly caused in transition zones like bridges, level crossings, tunnels, culverts, and switch panels. In addition, track stiffness varies in the structure due to ballast compaction, variation of soil properties, supports under sleepers, and sleeper bays. [18]

2.5 Effect of Unsupported Sleepers

Most of the time, after the track is under service where there is a repeated force of the vehicle, the ballast became in a poor state to support the sleeper above it in which the sleeper lost its support fully or partially. Due to an inconsistent ballast bed surface, hanging or unsupported sleepers will form in a track. The non-uniform ballast settlement may have caused the ballast bed irregularities, and the non-uniform settlement may have resulted from non-uniform track loading, non-homogeneities in the ballast, and sub-ground or both.[19] , [2]

2.5.1 Effect on displacements and forces

To investigate the dynamic response of railway track with unsupported sleepers, Grassie and Co[19] executedthe experimental analysis and mathematical model.

They find out that the loose pack of ballast around the sleeper makes the ballast ineffective in damping the vibration. In addition, the existence of unsupported sleeper in the track results in larger fastening deflection and higher dynamic contact force in the unsupported region of the track. [19]

The gap between the sleeper and the ballast can cause an increase in the sleeper/ballast contact force and displacement on the adjacent sleepers. As the number of consecutive unsupported sleeper's increases, the displacement at this zone also increases which results in reduction in the ride comfort. Another consequence is that the adjacent sleeper to the unsupported ones carries additional load and increase in wear of components and damage to the substructures. The existence of unsupported sleeper increases the variation of dynamics of train-track interaction force which leads increased track deterioration. In addition to that increases in rolling speed of the train will also be an accelerator of the contact force, deflection and stress increase.[2], [20]

The magnitude of the maximum wheel-rail contact force is also depending on the speed of the train and the number of unsupported sleepers. The wheel/rail contact force initially reduces when the vehicle enters the unsupported area, then increases, then decreases once more. Rail deformation in an unsupported section is what causes the first reduction in contact force. Wheel passing when pulling out of the unsupported area is what is causing the contact force to increase. The reason for the second reduction is that the previous step's increase in contact force caused the wheel to start rising, which leads to the second decrease in contact force. The unsupported sleepers can induce the impact load between the wheel and the rail. The amplitude of the impact load depends on multiple factors such as the number of unsupported sleepers, vehicle speed and the gap size between sleepers and the ballast underneath. At high speed, the unsupported sleeper can induce significant wheel–rail impact load.[3], [4]

The nearby normal track's stiffness is significantly reduced by the hanging sleepers, and as a result, normal load reduction begins before the wheel enters the isolated portion of track with the hanging sleepers. The significant normal load reduction affects how safely the vehicle operates at high speeds.[21]

2.5.2 Effect on track performance

.With increasing train speed and load, the deteriorated sleeper support may result in the accelerated degradation of the railway track, which in turn induces abnormal dynamic forces and undesired motions to the track and vehicle systems. These abnormal forces and motions may not only deteriorate the components in the vehicle track system, but also impose safety risk to the operation.[4]

There is a rapidly increase in the magnitude of the vehicle accelerations and the axle load decrement ratio for the wagon as the number of unsupported sleepers is increased. The fluctuating amplitude of rail displacement and sleepers on unsupported sleeper zone increases when the number of unsupported sleeper increases. Moving sleepers in the track may induce pulverization and cracking of the ballast stone and reduce the fatigue life of the sleeper. The sleepers next to the unsupported ones are carrying an additional load, causing the underlying substructure to experience greater stresses that could lead to the premature failure.[22]

A further study is carried out by Mehmet et.al.[23] on the influence of unsupported sleeper in the dynamic behavior of turnouts systems under impact loads. And findings shown that unlike a typical railway track, the turnout system with unsupported sleepers responds dynamically and behaves in an unconventional manner. Turnout's unique design imposes a variety of support requirements, which in some instances causes considerable stresses to be placed on unsupported bearers. Additionally, bearers subjected to high frequency, high magnitude impact forces are strongly pressed in two directions, increasing the possibility that the top and bottom surfaces of the bearers would get fatigued.

In another study by Kaewunruen and Remennikov[24], the impact of ballast voids and pockets on the properties of in-situ railway concrete sleepers' free vibration response were investigated. A dynamic model of the railroad track with concrete sleepers was created using finite element modeling. The free vibration studies of the in situ railway concrete sleepers in this model take into account the dynamic interaction of the sleepers and the ballast. The imperfections in the sleeper and ballast contribute to soften the dynamic behavior of the in situ sleeper in the track system for the symmetrical contact patterns. With increasing void sizes, the normalized frequencies decline, which results in less support stiffness.[25]

According to Shahraviet.al [26], track irregularities due to unsupported sleeper leads to derailment and in their investigation in case of increasing speed, the maximum rail displacement does not significantly vary in the existence of three or less unsupported sleepers. However, for a higher number of unsupported sleepers, the speed effect is noticeable.

2.6 Stresses in Rail

The rail is subjected to very complicated stresses that occur during routine operating conditions. Flexural, contact, thermal and residual stresses are some of the stresses that act on rail during each passage load from the vehicle.

2.6.1 Flexural Stresses

Flexural stresses are caused from the bending and twisting of the rail under wheel loads. When a rotating wheel of the vehicle approaches a particular point on the rail head, that location experiences a tensile bending stresses caused by the reverse flexural action of the rail on the elastic foundation of the ties, ballast, and sub-grade.as the moving wheel comes closer to the point the stress becomes compressive stress which is greater than the tensile stress. The dynamic effect of wheel irregularity and wheel loads affects this stresses.[27]

Since the longitudinal stress varies with depth, the contribution from rail flexure would be greatly reduced at the base of the rail head while the head-on-web bending contribution would be virtually the opposite of that at the top of the rail head. The associated shearing stresses differ as well. Thus, simple vertical loads cause extremely complicated bending stresses in the rail head.

The analytical formula for the vertical bending stress is:

$$\partial = \frac{M}{W} = \frac{QL}{4W}\mu(x/L) = \frac{QL}{4W}\mu(x/L) \quad \text{Equation 2-2}$$

The bending stress of the rail head on the rail web:

$$\partial_h = \frac{Q(h_c - z)L_c}{4I_c}\mu(x/L) \quad \text{Equation 2-3}$$

$$L_c = \sqrt[4]{\frac{4}{I_c}} \quad \text{Equation 2-4}$$

I_c is moment of inertia of the rail head

h_c is distance between rolling surface and neutral axis

$Q -$ effective wheel load

2.6.2 Contact Stresses

When a wheel load is within an inch of a point in the rail head, large contact stresses are imposed. These stresses generally reach much larger magnitude than do the flexural stresses. The majority of the contact stresses are compressive, with the exception of the transverse shear stresses that come from the rolling load passing. Rolling and shear stresses are main wheel-rail contact stresses.[27]

$$\delta_c = 1374\sqrt{\frac{Q}{r}} \text{ .... Equation 2-5}$$

2.6.3 Thermal Stresses

Thermal stresses are caused from the contraction and expansion of rails. The stresses due to temperature change are small in comparison with those that are developed due to the wheel load.

$$\delta_{tm} = \alpha . E . \Delta\theta \text{ .... Equation 2-6}$$

2.7 Track Deterioration

Deterioration is the reduction of the original quality of a track due to different reasons. The main cause of track deterioration is the dynamic load which is induced by the axle load and track geometry.

The main processes of track deterioration are:-

- Wear
- Fatigue
- Settlement

Some of the major factors for the track deterioration are the wear due to the physical interaction track components during operation, environmental conditions, drainage problem and faulty in components and bad construction. The track geometry deteriorates dramatically as a result of the poor condition or quality of track components. Bad track geometry produces higher dynamic loads on the track components, which accelerates their degradation.[1]

2.7.1 Effect of unsupported sleepers in track deterioration

The deterioration of the sleeper and fastenings is influenced by operational and traffic factors such axle loads, speeds, cumulative tonnage, and routine maintenance. Concrete sleeper deterioration includes cracking in the sleeper, loosening of fasteners when the support for the sleeper is insufficient, and abrasion of the soffit from excessive sleeper movement or poor ballast conditions.

In case of unsupported sleepers, they will not provide the expected support of the rail. The result of this will be an increase of the variations of the dynamic train/ track interaction forces, and this accelerates the track deterioration process. Uneven loading of the ballast causes irregular settlement of the track.[2], [1]

2.8 Effect of irregularities in the ballast track

Ballasted track in homogeneities are challenging to prevent or even reduce. Thus, a highly homogenous sub-grade, a homogeneous ballast layer, and rails with a good running surface can be attained, resulting in high output quality. The initial (output) quality of a ballasted track is crucial for the development of settlements in the track.

The contact problem between the sleeper and the ballast results in voids under the sleeper. The voids of the sleeper are appeared in different positions.[1]

a. **Central hollow/ void-** the central hollow existed at the center of the sleeper and assumed to expand at both sides until the sleeper became fully unsupported. This problem can be visualized easily during inspection.

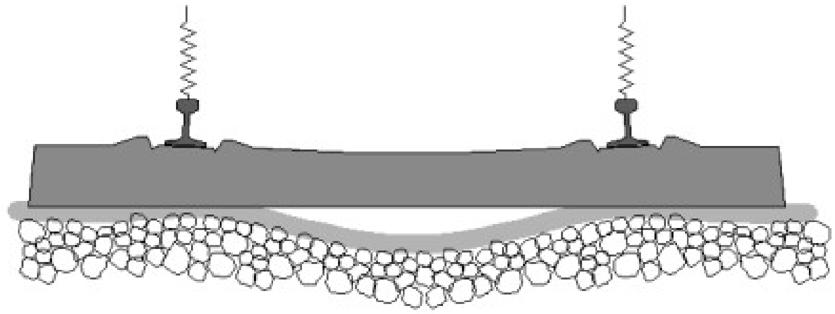


Figure 6 Central hanged sleeper [1]

b. **Single side hanged sleeper**- in this case the hanging condition forms at one end of the sleeper. The hanging spaces increase from fully supported side towards the void ends.

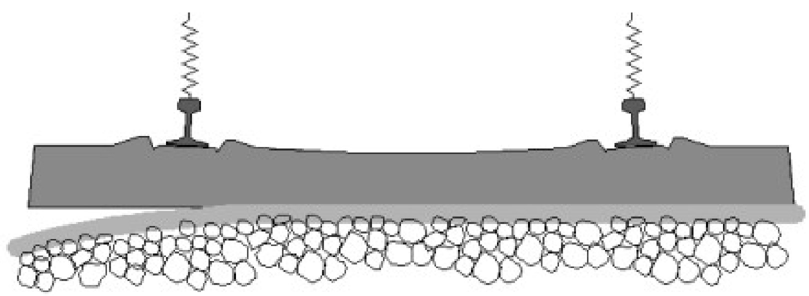


Figure 7 Single hanged sleeper [1]

c. **Double side hanged sleeper**- The double-side hanging can also occur when the gap between the sleepers and the ballast forms at both ends. The sleeper/ballast contact in this case remains only in the middle segment of the sleeper.

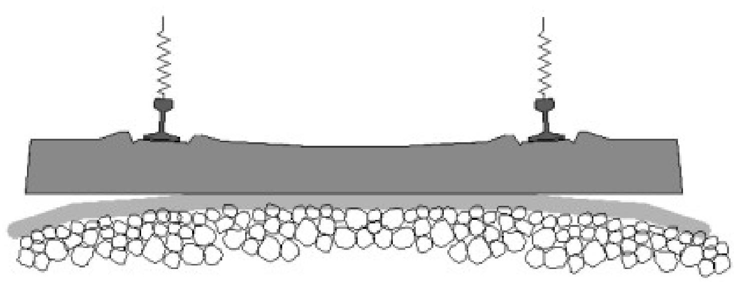


Figure 8 Double side hanged sleeper [1]

d. **Triple hanging sleeper**- the voids are occur not only on both ends but also at the center of the sleeper.

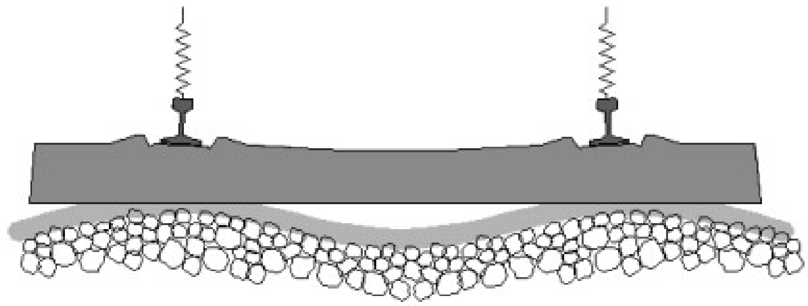


Figure 9 Triple hanged sleeper [1]

e. **Side-center voids**- in this type the voids at the center and one edge of the sleeper forms at the same time.

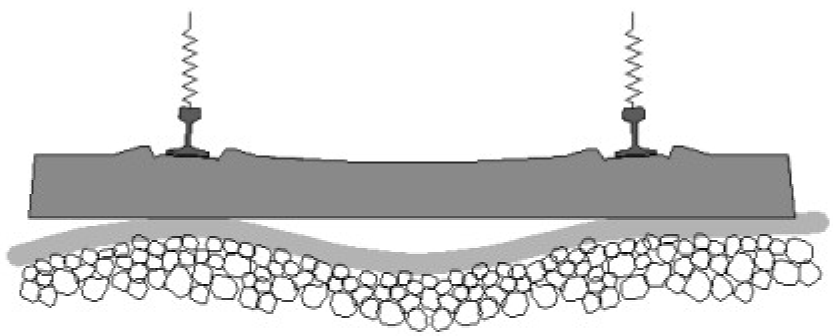


Figure 10 Side - center hanged sleeper [1]

3 Methodology

3.1 Track Modeling

Models of track dynamic behavior may be generally classified into two categories:

• Those that represent the track as a **continuously supported rail beam** and

• Those that represent the track as **a discretely supported rail beam**.[1]

3.1.1 Beam on Elastic Foundation Modeling (BOEF) or Winkler Method

Since the early age of railway engineering, the beam-on-elastic-foundation method (BOEF) or Winkler method has been used to analyze track mechanics. In this model the track rail is modeled as continuous beam supported by elastic foundation comprising continuous linear springs. Even though The Winkler model does not consider the individual structural features of all the track components, it is simple calculations and has become widely accepted by the railway industry for use in track design. In the Winkler model all the physical features of track components are represent by one parameter, track modulus 'k'.[28]

In current practices, calculation of rail bending moments and vertical deflection are mainly based on BOEF mode. The basic assumption in the Winkler model is that the deflection of the rail at any point is proportional to the supporting pressure under the rail.[9]

The Winkler method of analysis is based on the following differential equation for the rail deflection under load:

$$EI\frac{d^4w(x)}{dx^4} + kw(x) = q(x) \quad \text{........................ Equation 3-1}$$

Where; w (x) - vertical deflection of the rail at point x from the applied wheel load

EI - flexural rigidity of the rail beam

q (x) - distributed load equivalent to the wheel load and

k –Railroad track modulus per unit length stiffness of the elastic foundation

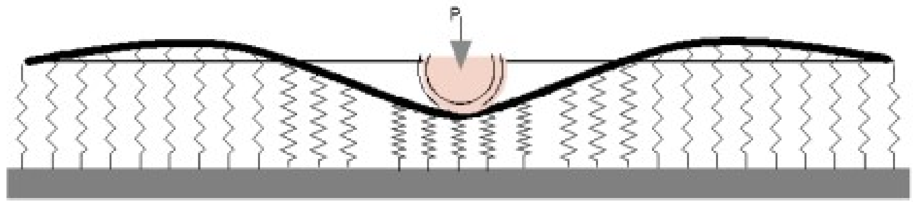


Figure 11 Beam on Elastic foundation loaded with a point force from the wheel [1]

3.1.2 Discrete Rail Support

The Winkler model neglected some railway track real conditions such as actual discrete support provided by cross sleepers, interaction between support materials (i.e. ballast, sub-ballast, and sub grade materials) and track supporting layers are not also included in the model. The discrete supported model considers the discrete spacing of sleepers and the components of the track such as Rail pads, sleepers, ballast, sub-ballast and sub grade are presented as a multiple layers. In this method the spring-damper system in which rail modeled as a beam, the rail pads are modeled by spring – damper systems, the sleepers are rigid masses and the ballast and the sub grade modeled by spring-damper system.[1]

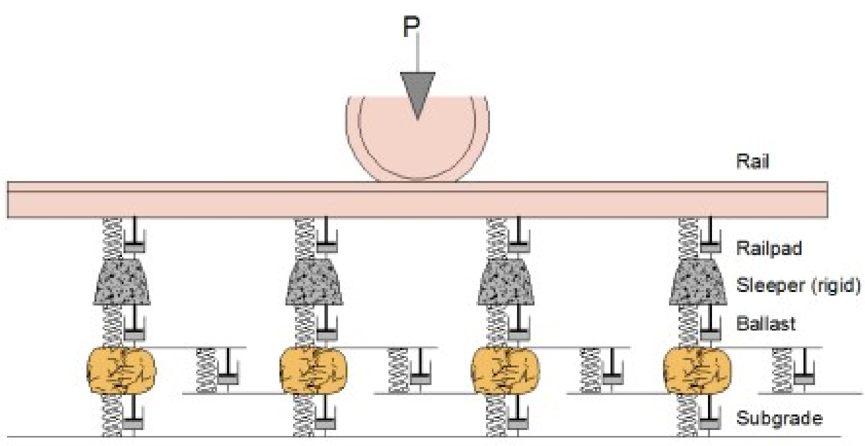


Figure 12 beam on discrete support loaded by point wheel load[1]

3.1.3 Finite Element Modeling

Finite element methods (FEM) are now widely used in most engineering analysis. The finite element analysis is used to reduce unknowns in engineering problems by dividing the solution region into small parts called elements and each element have its own shapes that can be defined with polynomial functions. This polynomial functions are determined by the interpolating functions called shapes functions which are weighted by the nodal global coordinates of the elements. Therefore each node corresponds to a shape function. [29]

This section describes the modeling techniques that are used to analyze the railway track in the commercial software ABAQUS. ABAQUS which is utilized in this research is one of finite element method with different modules to simulate the given problem.

3.2 Overall modeling Procedures

3.2.1 Program used

The track model is built up using computer-aided engineering application called SOLIDWORKS, and the track components interaction and analysis of the effect of unsupported sleeper is solved by a commercial finite element software ABAQUS.

The first procedure is creating parts separately in the part module. These different parts have their own material properties which are defined in the property module. The model is then assembled from the separated parts to make the overall track structure. But the software does not recognize this assembly unless the interaction of each part is defined. Step module is also another procedure that configures the analysis steps and output requests. The loads acting on the model and the boundary conditions and their variation with time and step are described in the load module. Then the whole model is meshed with mesh module to generate the finite elements. The meshing technique that ABAQUS uses to create the mesh, the element shape, and the element type are different from one part to another for the precision of the result. When the number of nodes increases or when the mesh size is small, the result accuracy improves.

3.3 Materials and Material Properties

Technical and general characteristics of track system are in accordance with the Ethiopian Railway Corporation (ERC) design standard and they are used as an input data for modeling. Material and Physical Properties of the track components used in the analysis are listed below.

Table 2 Geometrical and Mechanical parameters of track model

Track Components	Dimension and material properties	Remarks
Wheel	• Outer Diameter=330mm • Young's Modulus = 210,000MPa • Density =7800kg/m3 • Poisson's ratio=0.3	
Rail	• Length = 3000mm • Young's Modulus = 210,000MPa • Density = 7800kg/m3 • Poisson's ratio = 0.3	UIC60 or 60 kg/m rail
Sleeper / Tie	• Length = ½*2500 =1250mm • Young's Modulus = 36000MPa • Density = 2400kg/m^3 • Poisson's ratio = 0.2	0.6m Spacing
Ballast	• Thickness = 300mm • Young's Modulus = 90MPa – 180MPa • Density = 1900kg/m^3 • Poisson's ratio = 0.27	• Use 180MPa, 120MPa and 90MPa ballast stiffness to analyze the effect of unsupported sleepers.

3.3.1 Unsupported sleeper modeling parameters

The effect of unsupported sleeper on track structure calculated using ABAQUS by introducing all track elements is difficult as it needs more computational time and computer capacity. In this research the model consist a rotating wheel on rail which is tied on five consecutive evenly spaced sleepers and the middle sleeper became unsupported at different values for the analysis.

The sleepers are laid on ballast bed. The effects of the unsupported sleepers are examined by ballast modulus variation. The ballast young's modulus considered for normal track ($E_{ballast}$) is 180MPa. So the ballast beneath the middle sleeper is varied to 120MPa (2/3* $E_{ballast}$) and 90MPa (1/2* $E_{ballast}$) to investigate its effects on rail deflection and bending stress. Also the effect of speed of trains with a value of 20Km/hr, 40Km/hr and 80Km/hr were studied.

3.3.2 ABAQUS Procedures

3.3.2.1 PARTS

In this research the first procedure in ABAQUS analysis was creating the track components such as UIC-60 rail, one rotating wheel, five sleepers spaced in 600mm and the 300mm thick ballast bed separately.

3.3.2.2 PROPERTY

The material properties described in

Table 2 of each part were defined in the material module. The actual properties of the material in which every track components are made of should be described properly to get the accurate results from the software.

3.3.2.3 ASSEMBLY

In this module of ABAQUS, the individual parts are assembled to create the complete track structure that is the same with the field.

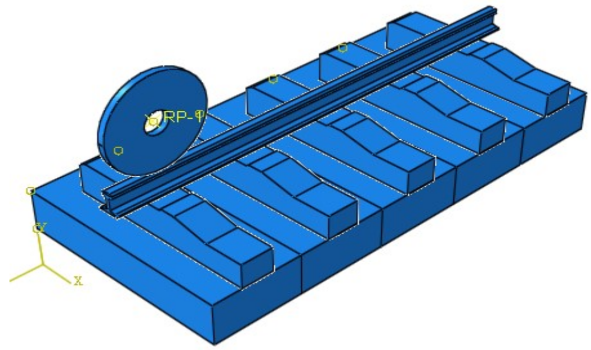


Figure 13 Assembled model from ABAQUS

3.3.2.4 STEP

The analysis steps and output requests were defined in step module. The effect of the applied load through time was created in this module. The first step was the load application step in which it takes 0.05 sec of time. The second which is the wheel rotating step is dependent on the vehicle speed.

3.3.2.5 INTERACTION

After the model is assembled, the interaction was set; the interaction between the wheel and the rail is set to be penalty contact method which means that the penetration between the two parts is negligible. The sleepers' connection both with rail and ballast is a tie constraint to tie the two separate surfaces together so that the relative motion between them will be restricted. The center of the wheel is constrained by MPC beam with the inner edge of the wheel; the motions of other nodes of the wheel are constrain with the central point of the wheel.

3.3.2.6 LOAD

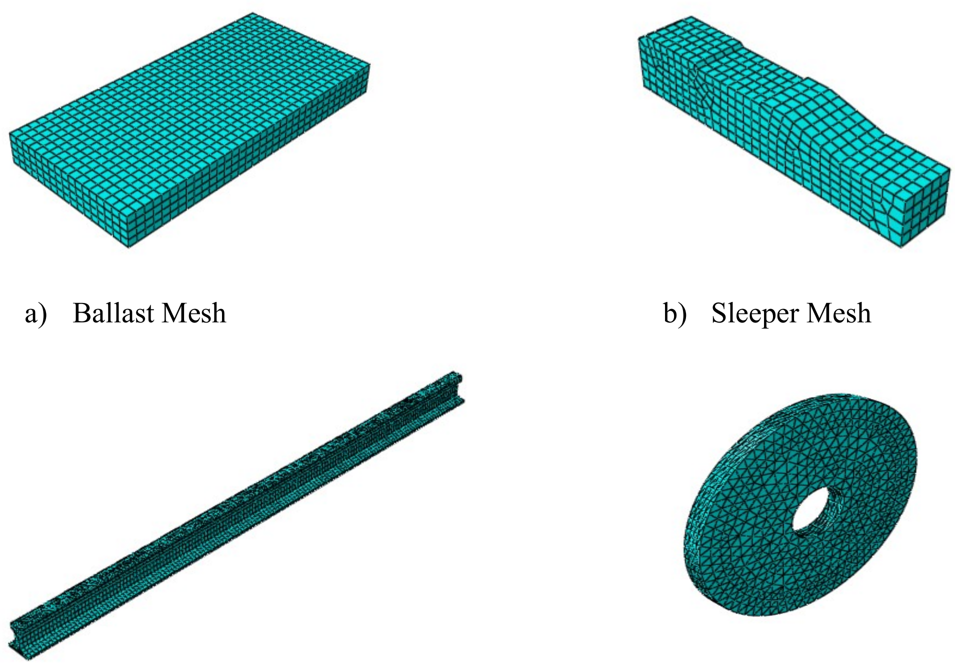
The other module is the load that describes the prescribed conditions, such as loads and boundary conditions which are depend on the step in which they become active. The axle load and the torque which helps the wheel to rotate are defined in the load module. They are applied at the center of the wheel. The boundary conditions that are used in the analysis include the following:

- The rail is symmetry in both ends to represent the infinite length of the rail in the actual track condition.

- As the half section of the track is used with one longitudinal rail placed in half length of sleepers, the sleepers and ballast are symmetry in the half side. The other end of both the sleeper and the ballast are fixed.
- The ballast bottom is fixed by the encastre boundary condition to imply the ballast is placed on the formation.
- The center of the wheel is fixed to restrict its motion with the movement of the wheel.
- The velocity and angular velocity for the rotating wheel is also defined in the boundary condition.

3.3.2.7 MESH

The last procedure before the job is submitted was the mesh module. In the mesh module all parts are meshed into smaller elements. The rail and the wheel are meshed with fine mesh as we wanted the result on the rail. When the mesh becomes smaller, the result will be more reliable.



a) Ballast Mesh

b) Sleeper Mesh

c) Rail Mesh

d) Wheel Mesh

Figure 14 Meshed model parts from ABAQUS

3.3.2.8 JOB

After all the modules in the software are properly defined with necessary parameters, the job is submitted the get the analysis results. The time consumption to finish the analysis will be depending upon the mesh size and the model complexity. The output requests from the analysis and the capacity of the computer also affects the analysis time.

In this research nine (9) models are created. Three train speeds (20km/hr, 40km/hr and 80km/hr) are selected and the ballast modulus is varied to values of 180MPa, 120MPa and 90MPa to estimate the effect of the unsupported sleeper. The ballast Young's modulus (180MPa) and all other material properties of the track components are in accordance with the Ethiopian Railway Corporation (ERC) design standards.[30]

In this analysis, the effect of unsupported sleeper was defined by assuming the reduction of the ballast modulus into 120 MPa and 90 MPa.

The other feature of ABAQUS in which the results of the analysis are presented is the visualization module. The outputs are determined previously in the step module. The results are then extracted from ABAQUS.

After all the data are extracted, the final step was to plot the results in graph. The ORIGIN which is software that used to plot the results in graph and also merged graph of different data. Finally comparison of the results to display the effect of the existence of one unsupported sleeper and speed variation are plotted on origin for the rail displacement and bending stress.

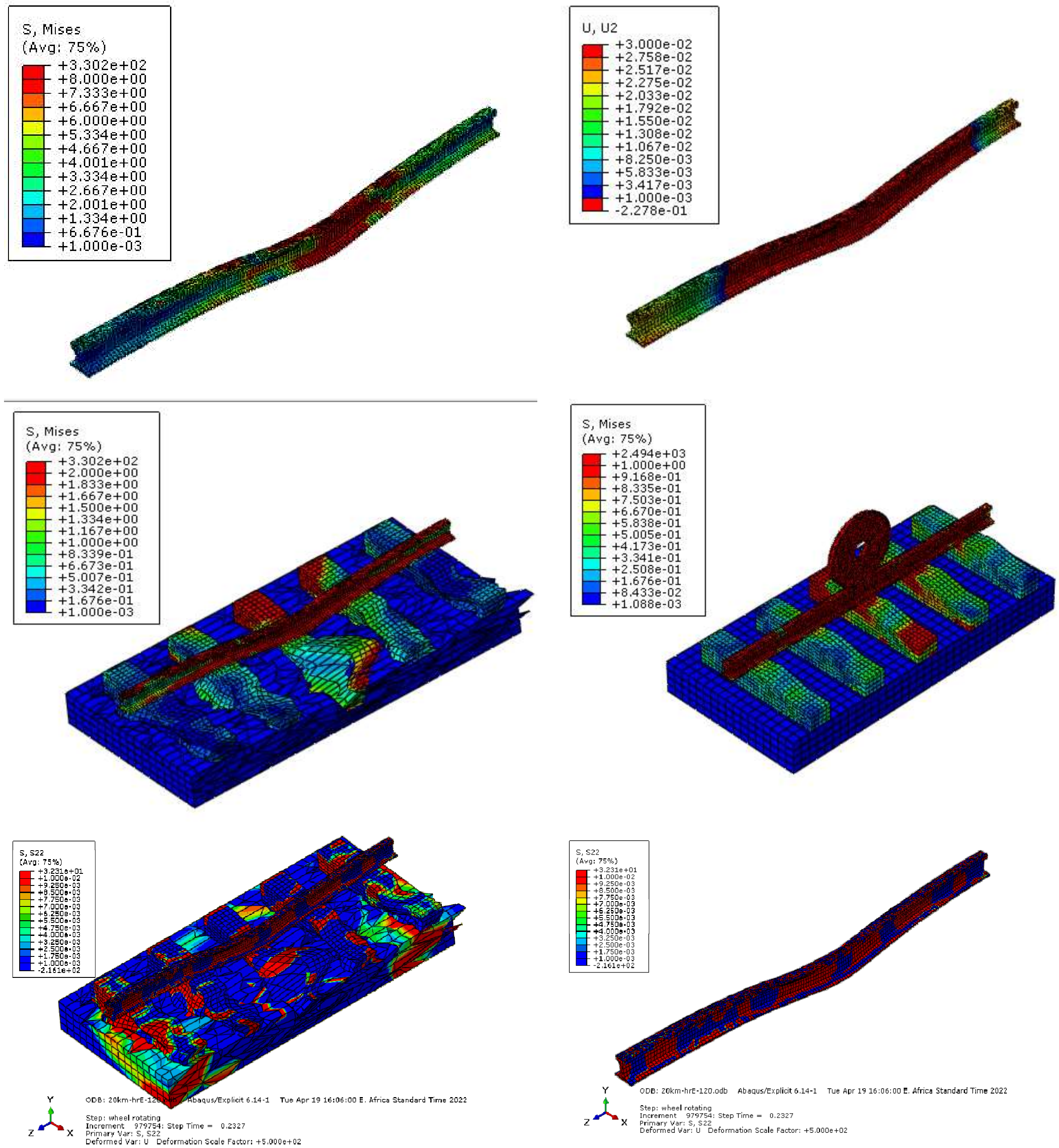


Figure 15 visualization of analysis result in ABAQUS

4 Result and Discussion

4.1 Validation

In Winkler foundation model, the track rail is modeled as continuous beam supported by elastic foundation. In this model, the rail deflection is only depend on the track modulus within a given rail section and vertical load.

According to a study on Winkler model conducted by Ngoan T.Do et.al.[32], the relation between track modulus and rail deflection was investigated. And due to the software's limitation the dynamic effect of the track-train interactions are not considered. But this is acceptable as the study was focused on the Canadian freight lines where speeds are most likely lower than 65 Km/hr.

As it can be seen from the results of Winkler model in figure 18 below, the deflection fluctuates between 0 to 5mm for a track modulus variation between 0 to 100 MPa along a wheel rolling distance of 180m. The results on figure 19 shown that the maximum deflection of 0.38mm for a wheel moving at a distance of 2.56m for a track modulus of 90 MPa. The result of the maximum vertical deflection is in good agreement with the Winkler model conducted by the literature.

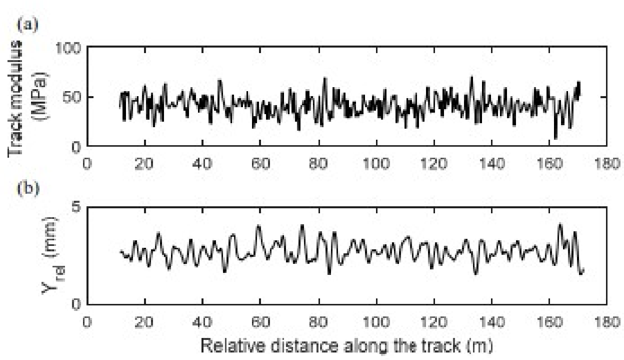


Figure 16 Track Modulus and rail deflection with Winkler Model [32]

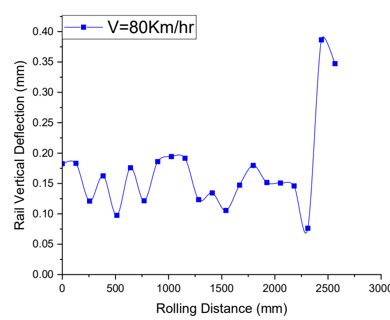
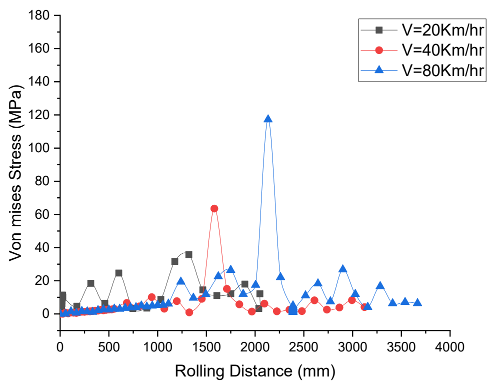


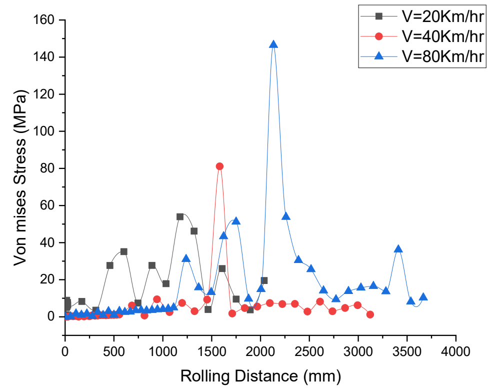
Figure 17 Rail Vertical deflection for track modulus of 90MPa

4.2 Effect of Speed increment on rail stresses

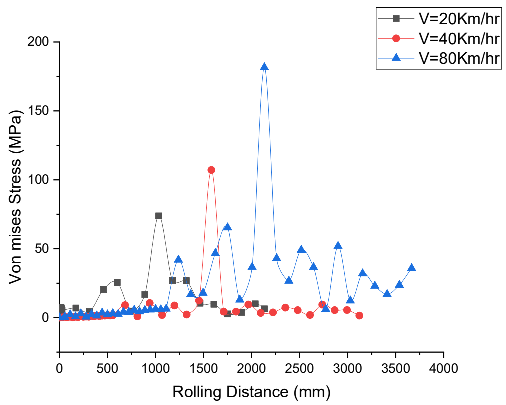
The effect of the coming wheel load on the rail is depending on the amount of the force and the material properties of the rail and also the support beneath the rail. From figure 19, the stress is different from one point to another. As the speed increases, the stress also increases.



a) $E_{ballast}$=180MPa



a) $E_{ballast}$=120MPa



c) $E_{ballast}$=90MPa

Figure 18Von-mises Stress for given ballast young's modulus, E for various speed

Table 3 Average von-mises stress at different train speeds

Train Speed	**Rail average von-mises stress (MPa)**	**Percentage (%)**
20 Km/hr	35.80	
40 Km/hr	63.51	77%
80 Km/hr	117.18	85%

(a)

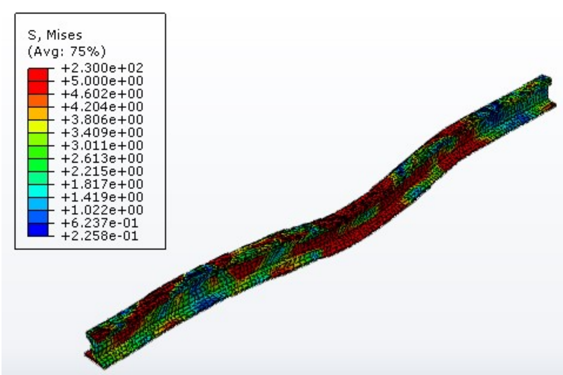
Train Speed	Rail average von-mises stress (MPa)	Percentage (%)
20 Km/hr	53.94	
40 Km/hr	81.09	50%
80 Km/hr	146.46	81%

(b)

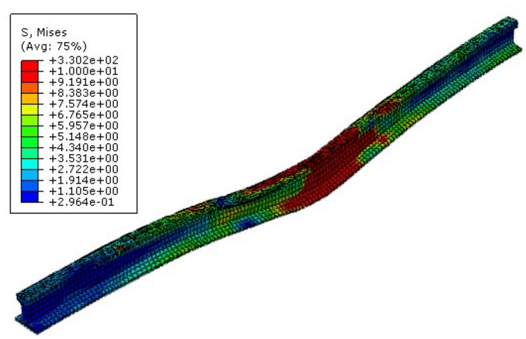
Train Speed	Rail average von-mises stress (MPa)	Percentage (%)
20 Km/hr	73.83	
40 Km/hr	107.10	45%
80 Km/hr	181.52	69%

(c)

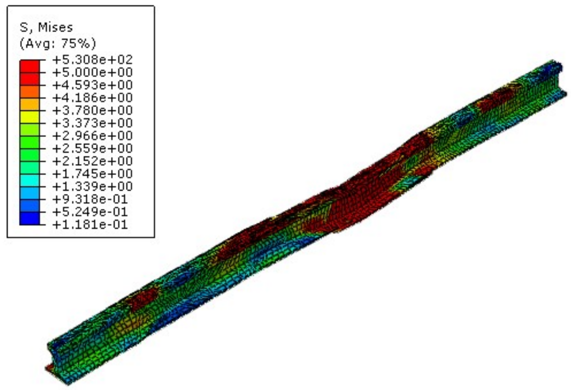
In figure 19, it is shown that for the speed doubled at each diagram, the von-mises stress has increased its amplitude. So it can be concluded that when the speed of the locomotive increases the stress also increases. As table 3 shows, the overall results of the FEM illustrate that the average stress on the rail is increased within 50% as the train speed increased from 20km/hr to 40km/hr. and as the speed of the locomotive moves with in 80km/hr, the stress also increased by 81% from a locomotive speed of 40km/hr.



a)V=20km/hr



b) V=40Km/hr

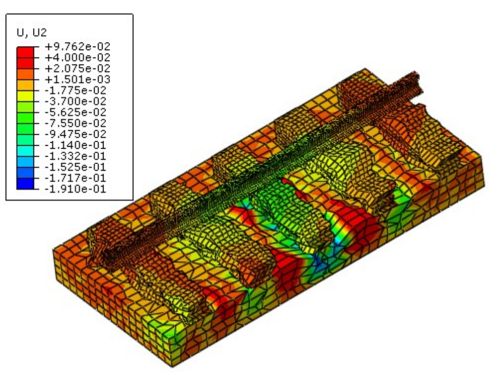


c)V=80km/hr

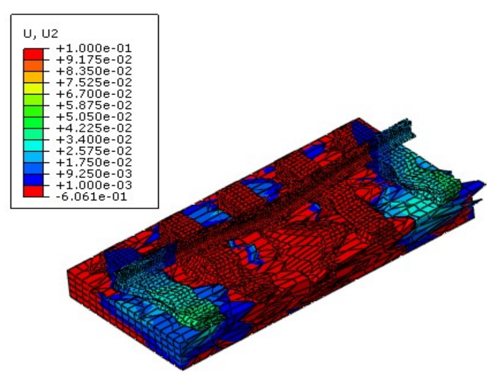
Figure 19Von-mises Stress for given ballast Young's modulus, E for various speed (FEM)

4.3 Effect of Speed increment on rail vertical deflection

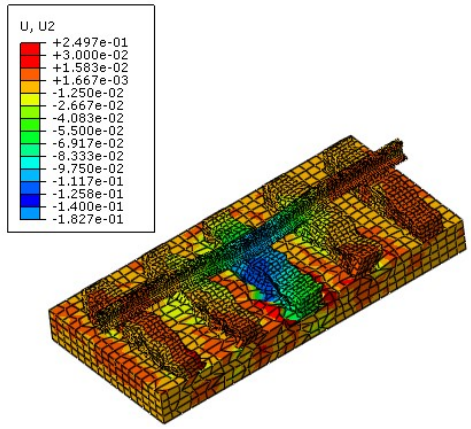
In this analysis, Due to the large computational time and the shortage of an advanced computer the simulation is done with a model which has a sample of track components like one rail, one wheel, five sleepers and a ballast bed. The half-track is symmetric with the remaining half and is represented by a symmetrical boundary condition. The circular wheel with outer diameter of 330mm is rolling over a 3m rail. The rail is like a continuously supported beam by evenly spaced sleepers. As the wheel moves with in the given speed, the rail is subjected to deflection and also stresses. As it is seen in figure 21 and figure 22, the rail deflection varies as the wheel rotates on the rail from one point to another.



a)V=20km/hr



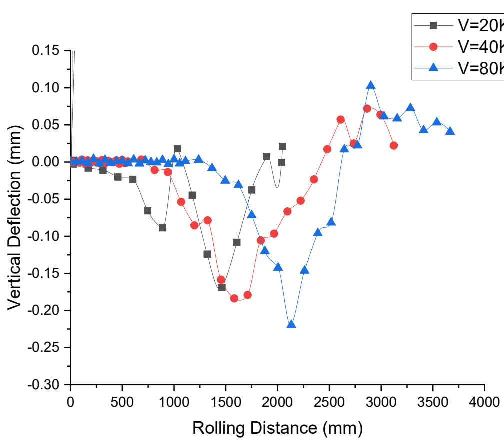
b) V=40Km/hr



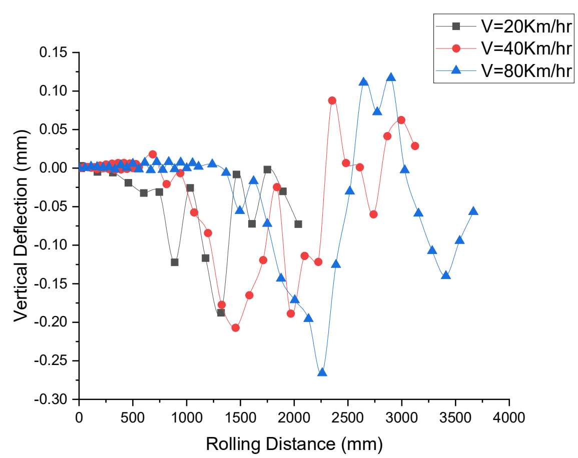
c)V=80km/hr

Figure 20 Vertical deflections at different speeds

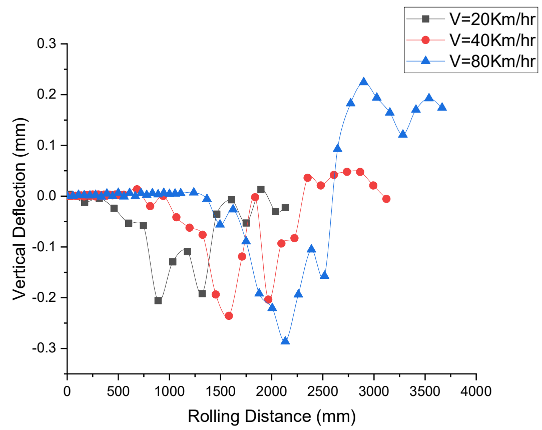
We can see the effect of wheel speed on the vertical deflection of the rail for a given ballast stiffness. The deflection results are different with changing of speed. When the speed of the locomotive increases the applied force is not damped quickly as compared to low moving speed.



a) $E_{ballast}$=180MPa



b) $E_{ballast}$=120MPa



c) $E_{ballast}$=90MPa

Figure 21 rail deflection for given ballast young's modulus, E for various speed

The speed is also responsible for the vibration of the rail and the faster moving vehicle takes smaller time to finish the given distance. When the wheel moves with a higher speed the vibration and the amplitude of deflection also increases.

Table 4 Average rail vertical deflection at different train speed

Train Speed	**Rail average vertical Deflection (mm)**	**Percentage (%)**
20 Km/hr	0.169	
40 Km/hr	0.184	9%
80 Km/hr	0.219	19%

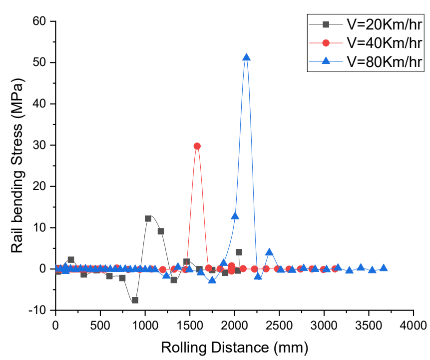
Train Speed	**Rail average vertical Deflection (mm)**	**Percentage (%)**
20 Km/hr	0.187	
40 Km/hr	0.207	10%
80 Km/hr	0.266	28%

Train Speed	Rail average vertical Deflection (mm)	Percentage (%)
20 Km/hr	0.205	
40 Km/hr	0.235	15%
80 Km/hr	0.286	21%

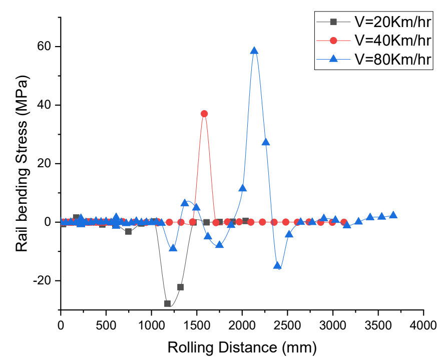
From all the ballast modulus, it is seen clearly that at each and every point, the deflection is increased by 9%and 19% for a speed increased from 20Km/hr to 40Km/hr and from 40km/hr to 80km/hr respectively.

4.4 Effect of Speed increment on rail bending stresses

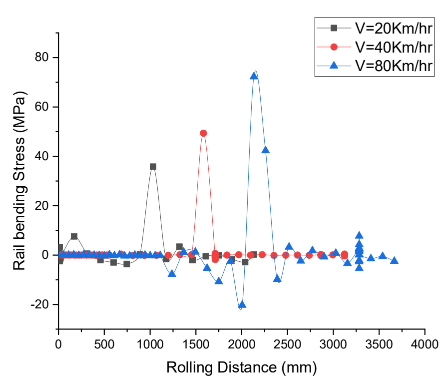
The speed of the rotating wheel affects the magnitude of rail bending stress. Increase of train speed results an increase in bending stress of the rail.



a) $E_{ballast}$=180MPa



a) $E_{ballast}$=120MPa



c) $E_{ballast}$=90MPa

Figure22Rail bending Stress for given ballast young's modulus, E for various speed

Table 5 Average rail bending stress at different train speeds

Train Speed	**Rail average bending stress (MPa)**	**Percentage (%)**
20 Km/hr	18.160	
40 Km/hr	29.756	64%
80 Km/hr	51.121	72%

(a)

Train Speed	**Rail average bending stress (MPa)**	**Percentage (%)**
20 Km/hr	27.852	
40 Km/hr	37.052	33%
80 Km/hr	58.395	58%

(b)

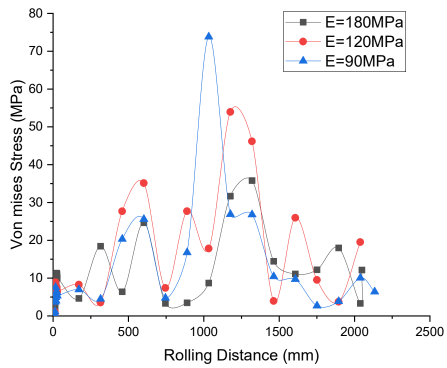
Train Speed	**Rail average bending stress (MPa)**	**Percentage (%)**
20 Km/hr	35.817	
40 Km/hr	49.339	38%
80 Km/hr	72.233	46%

(c)

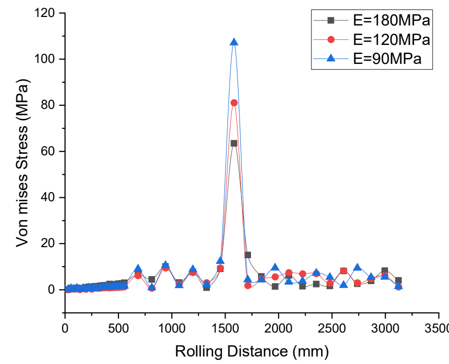
From figure 23 above, it is shown that wheel rotating speed has a direct relationship with the rail bending stress. The increase in speed from 40Km/hr to 80 Km/hr, results in an increase of 46% in rail bending stress.

4.5 Effect of unsupported sleeper on rail von-mises stress for a given vehicle Speed

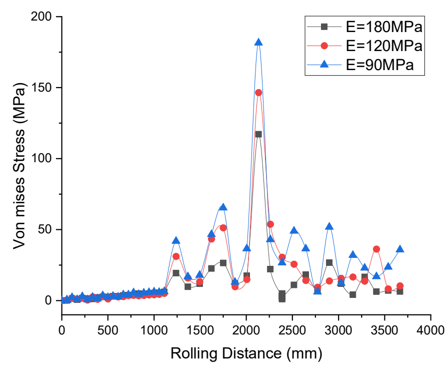
The unsupported sleepers which hang from the rail are phenomena for this study. So it is described in different investigation before, it is often to find isolated sections that are in bad contact with the ballast.



a) V=20Km/hr



b) V=40Km/hr



c) V=80Km/hr

Figure 23 Von-mises Stress for a given speed for various ballast modulus,E

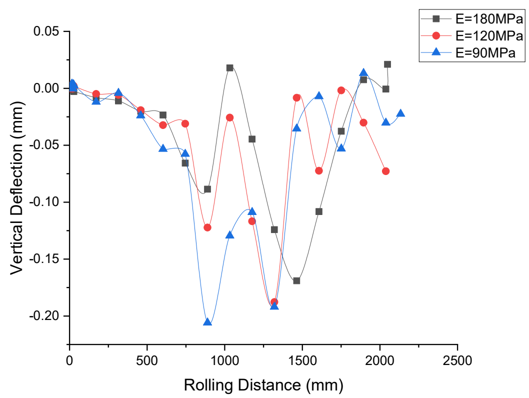
Table 6 Average rail von-mises stress for various ballast modulus with different speed

Train Speed (Km/hr)	**Ballast Modulus (MPa)**		
	180 MPa	**120 MPa**	**90 MPa**
20km/hr	35.80	53.94	73.83
40 Km/hr	63.51	81.09	107.10
80 Km/hr	117.18	146.46	181.52

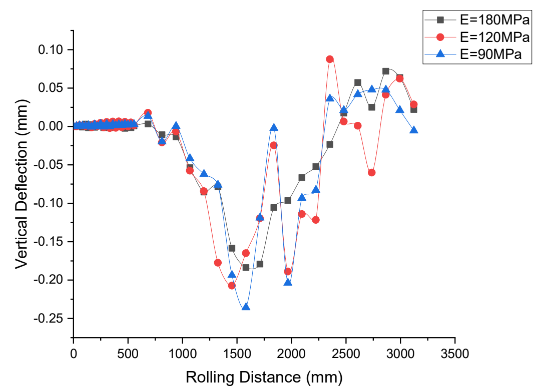
The existence of one unsupported sleeper in a given track model has an effect on the rail von-mises stress. The effect is smaller for the smaller train speed and as the speed increases the unsupported sleeper can increase the stress on average of 32%.

4.6 Effect of unsupported sleeper on rail deflection for a given vehicle Speed

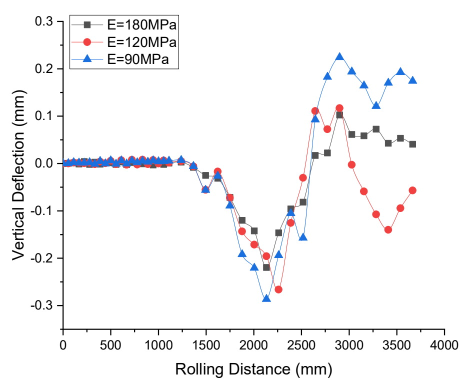
In this case the analysis is done for every speed by changing the ballast modulus parameter the young's modulus. And it has been seen that the ballast young's modulus taken in the analysis are 180,120 and 90 MPa with 5.56, 11.11 and 22.22 m/sec train speed. And as the values in below graph indicate, as the ballast modulus increases the rail deflection decreases.



a) V=20Km/hr



b) V=40Km/hr



c) V=80Km/hr

Figure 24 Rail deflection for a given speed for various ballast young's modulus, E

The rail vertical deflection is increased on average by 12% when the ballast modulus under the sleeper decreased. As it is shown in the above figures, the deflection and the stress are different from one point to another depending on the location of the contact. And as the wheel moves away from one point the rail almost returns to its original position.

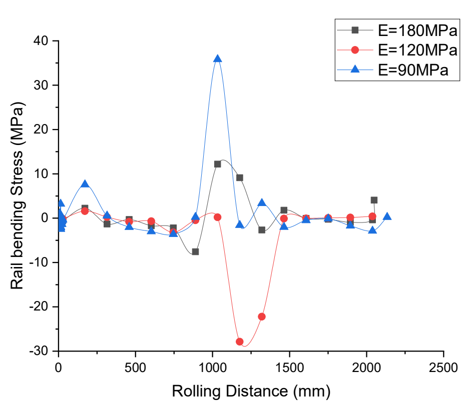
Table 7Average rail vertical deflection for various ballast modulus with different speed

Train Speed (Km/hr)	Ballast Modulus (MPa)		
	180 MPa	**120 MPa**	**90 MPa**
20km/hr	0.169	0.187	0.205
40 Km/hr	0.184	0.207	0.235
80 Km/hr	0.219	0.266	0.286

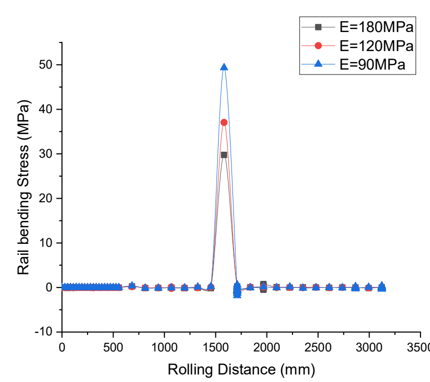
The accuracy of the result depends on the mesh size and the overall component parameters of the track. And it is not easy to get a general conclusion as the track length for the simulation is smaller compared to the actual track length.

4.7 Effect of unsupported sleeper on rail bending stress for a given vehicle Speed

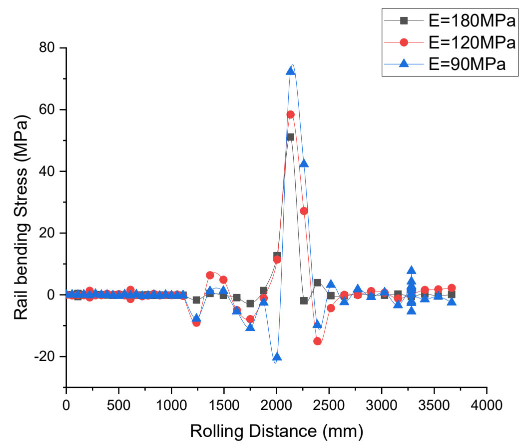
Rail as the most significant track element subjected to repeated wheel loads must be able to securely carry on these loads applied in vertical, lateral, and longitudinal directions and subsequently transfer them to the underlying supports.



a) V=20Km/hr



b) V=40Km/hr



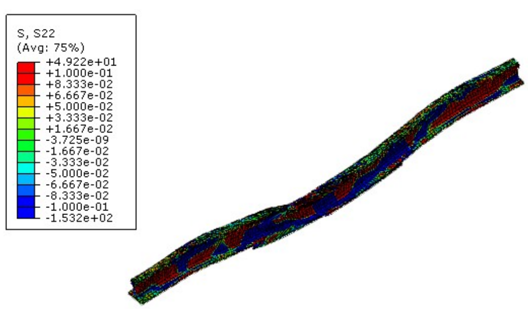
c) V=80Km/hr

Figure 25 Rail Bending Stresses for a given speed for various ballast young's modulus, E

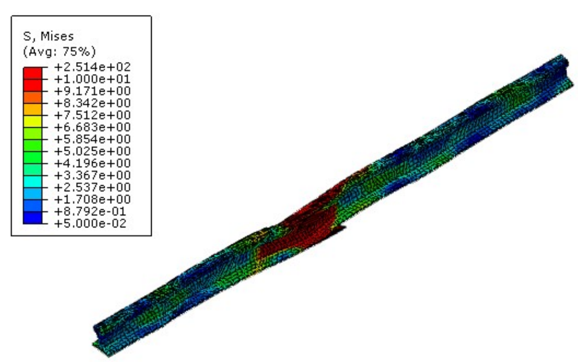
As the above figure illustrates, the average bending stresses are summarized in table below.

Table 8 Average Rail Bending Stress for various ballast modulus with different speed

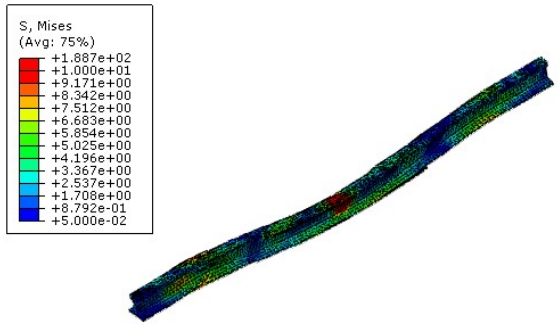
Train Speed (Km/hr)	**Ballast Modulus (MPa)**		
	180 MPa	**120 MPa**	**90 MPa**
20km/hr	18.160	27.852	35.817
40 Km/hr	29.756	37.052	49.339
80 Km/hr	51.121	58.395	72.233



a) E= 180MPa



b) E=120MPa



E= 90MPa

Figure 26 Rail Bending Stress for given speed at various ballast Young's modulus, E (FEM)

The rail bending stresses which resulted due to unsupported sleeper are increased as the ballast modulus decreases from 180 MPa to 90 MPa with in different rolling stock speeds.

It is shown from the above table that the rail bending stress is increased with an average of 30% when there is unsupported sleeper along the track.

5 Conclusion and Recommendations

5.1 Conclusions

A comprehensive model of ballasted track is put forward to investigate the effect of unsupported sleeper and train speed on the rail vertical displacement and stresses. In this project FE software (Abaqus) is used for analysis.

- The core objective of the research was to study the effect of unsupported sleepers on rail von-mises stress, bending stress and rail vertical deflection. Reductions of ballast modulus as a representation of unsupported sleeper were taken for the analysis.
- It is observed that in the case of supported sleeper when the speed of the train increases the vertical displacement and stress on the rail increases.
- Based on this study, when there is unsupported sleeper circumstance as the same train speed with that of supported sleeper passes on the rail the vertical displacement and stresses on the rail increases more on the unsupported sleeper situation.
- In addition, it has been identified that the variation of ballast modulus has more effect on rail deflection and stress at the value of 90MPa.
- The rail deflection is increased on average by 12% as the ballast modulus under the sleeper decreased from 180MPa to 90 MPa.
- Increase in train speed along the track results an average of 32% increase in rail stress.
- In addition, the rail bending stress is also increased on average at 29.5% when the ballast Young's modulus, E decreases from 180 MPa to 90 MPa.

5.2 Recommendations

- Researchers can model a longer track with all track elements including sub-ballast and sub-grade to examine the effect of unsupported sleeper.
- In this study, the simulation was performed by one of the FEM called ABAQUS. For further study it can be recommended to use other finite element software and also mathematical and experimental investigations and compare the results with the present research.

- Due to lack of high capacity computer, the model in this study is limited in mesh size and also only half of the track section is simulated by symmetrical approach. So, a more finer and full track can be simulated with a latest and more capable computer.
- The effect of unsupported sleeper on ballast stress and deflection and also sleeper displacement can be also another future works for future study.
- Field measurement especially for AALRT is also gab to be filled by future studies.

References

[1] K. Tzanakakis, The Railway Track and Its Long Term Behaviour- A Handbook for a Railway Track of High Quality, Athens, Greece, 2013.

[2] A. Lundqvist and T. Dahlberg, "Load Impact on railway track due to unsupported Sleepers," 2005.

[3] M. Azizi, M. Shahravi and J. A. Zakeri, "Investigation on Effect of Train Speed in Displacement of Railway Ballasted Track with Unsupported Sleepers," *AUT Journal of Mechanical Engineering,* pp. 107 - 112, 2019.

[4] Z. Jian Jun, A. Ahmed, R. Subhash and A. Khajepour, "Development of a vehicle–track model assembly and numerical method for simulation of wheel–rail dynamic interaction due to unsupported sleepers," pp. 1535 - 1552, 2010.

[5] S. Audustin, G. Gudehus, G. Huber and A. Schuunemann, "Numerical model and laboratory tests on settlement of ballast track. System Dynamics and long-term behavior of railway vehicles, track and subgrade," 2003.

[6] T. S. Ernest and M. W. John, Track Geotechnology and Sub structure Management, England: Thomas Telford Publications, 1994.

[7] C. Esveld, Modern Railway Track, 2001.

[8] "Transport Rail 60E1 (UIC60) - ArcelorMittal," ArcelorMittal Europe Communications, [Online]. Available: https://rails.arcelormittal.com/types-rails/transport-rails/european-standards/rail-uic60-60e1.

[9] J. Sadeghi and P. Barati, "Evaluaton of conventional methods in Analysis and Design of Railway Track System," 2010.

[10] A. Demissie, *Analysis of Railway Track Stiffness Variation and Its Influence (Master of science in railway Engineering),* Addis Ababa, oct,2015.

[11] A. Sładkowski, "MODELING OF THE DEFORMATION OF ELASTIC PADS FOR RAIL FASTENINGS," 2009.

[12] "Rail fastening system ensures the safety of railway," [Online]. Available: http://www.rail-fastener.com/Rail-Fastening-System.html.

[13] "Damage and failure modes of railway prestressed concrete sleepers with holes/web openings subject to impact loading conditions, Engineering Structures," vol. 176, pp. 840-848, 2018.

[14] L. Shan, *Railway Sleeper Modeling with Deterministic and Non deterministic Support Conditions (Master Degree project, Department of transport science),* Stockholm, 2012.

[15] T. Jeffs and G. P. Tew, A review of track design procedures:sleepers and ballast" Vol. 2, Melbourne, Australia, 1991.

[16] J. M. Sadeghi and M. Youldashkhan, "Investigation of the Accuracy of the current practices in analysis of railway track concrete sleepers," vol. 3, March,2005.

[17] E. Berggren, Railway Track Stiffness-Dynamic Measurements & Evaluation for Efficient maintenance (Doctoral Thesis), 2009.

[18] C. Nkundineza, "INFLUENCE OF SPATIAL VARIATIONS OF AILROAD TRACK STIFFNESS AND MATERIAL INCLUSIONS ON FATIGUE LIFE," 2015.

[19] S. L. Grassie and S. J. Cox, "The dynamic response of railway track with unsupported sleepers," 1985.

[20] S. Jin, H. C. Andrew and P. B. Michael, "Influence of unsupported sleepers on the dynamic response of a heavy haul railway embankment," *Rail and Rapid Transit,* pp. 657-667, 2013.

[21] Z. Shuguang, X. Xinbiao, W. Zefeng and J. Xuesong, "Effect of unsupported sleepers on wheel/rail normal load," p. 662–673, 2007.

[22] S. Jin, A. Chan and M. Burrow, "Influence of unsupported sleepers on the dynamic response of railroad embankment below a heavy haul railway line using simulation techniques," *Journal of Rail and Rapid,* vol. 227, pp. 657-667, 2013.

[23] H. Mehmet, P. Mayorkinos, S. Mika and K. Sakdirat, "The Effect of Unsupported Sleepers/Bearers on Dynamic Phenomena of a Railway Turnout System under Impact Loads," 2020.

[24] S. Remennikov and A. M. Kaewunruen, "Investigation of free vibrations of voided concrete sleepers in railway track system," vol. 221, 2007.

[25] E. Morteza, M. Seyed-Ali and Z. Jabbar-Ali, "Ground-borne vibrations caused by unsupported railway sleepers in ballasted tracks," in *X International Conference on Structural Dynamics, EURODYN 2017*, Thran, Iran, 2017.

[26] A. Mojtaba, S. Majid and Z. Jabbar Ali, "Determination of wheel loading reduction in railway track with unsupported sleepers and rail irregularities," vol. 235(5), pp. 631-643, 2020.

[27] T. G. Johns, S. G. Sampath, J. C. Bell and K. B. Davies, Engineering Analysis of Stresses in Railroad Rails, 1981.

[28] P. B. Prakoso, "The Basic Concepts of Modelling Railway Track Systems using Conventional and Finite Element Methods," *INFO TEKNIK,* vol. 13, pp. 57-65, 2012.

[29] S. Bhavikatti, Finite Element Analysis, New Delhi: New Age International (P) Ltd., 2005.

[30] E. R. Corporation, "Ethiopia Railway Feasibility Study, Part I General Specification," 2012.

[31] T. Ngoan, G. Mustafa and F. Saeideh, "Continous Evaluation of Track Modulus from a Moving Railcar Using ANN-Based Techniques," 2020.

[32] W. Ferdous, A. Manalo, G. Van Erp, T. Aravinthan, S. Kaewunruen and A. Remennikov, "Composite railway sleepers - Recent developments, challenges and future prospects," vol. 134, pp. 158-168, 2015.

[33] J. Guoqing, L. Qi, W. Zijie and S. Yonggang, "Micro-analysis of hanging sleeper dynamic interactions with ballast bed," January, 2015.

[34] A. M. Recuero, J. L. Escalona and A. A. Shabana, "Finite-element analysis of unsupported sleepers using three-dimensional wheel-rail contact formulation," 2010.

[35] B. Salim, Indraratna and Wadud, Mechanics of Ballasted Rail Tracks- A Geotechnical Perspective, London,UK: Taylor & Francis/Balkema, 2005.

Appendix

a) Von mises stress at speed of 80 Km/hr

Rolling Distance (mm)	Von-mises Stress (MPa)	Rolling Distance (mm)	Von-mises Stress (MPa)	Rolling Distance (mm)	Von-mises Stress (MPa)
E=180MPa		E=120MPa		E=90MPa	
0	0	0	0	0	0
55.55564	0.07867	55.55564	0.21272	55.55564	0.24912
111.11541	1.46982	111.11541	1.75336	55.55564	0.16899
166.6704	0.63895	166.6704	1.08629	55.55564	0.28798
222.22741	1.68835	222.22741	1.70299	55.55564	0.25028
277.78245	1.37971	277.78245	0.32877	55.55564	0.23167
333.33749	1.16721	333.33749	2.53665	55.55564	0.3056
388.88951	2.17992	388.88951	0.88712	55.55564	0.32125
444.44923	2.62066	444.44923	3.00056	55.55564	0.20506
500.00374	2.52431	500.00374	1.08699	55.55564	0.34239
555.55824	3.04815	555.55824	3.08611	55.55564	0.25619
611.11274	3.00346	611.11274	2.5573	55.55564	0.26711
666.66725	3.56739	666.66725	2.76392	55.55564	0.5744
722.22701	3.85713	722.22701	3.46651	111.11541	2.22166
777.78151	3.9145	777.78151	3.67232	166.6704	0.76729
833.33601	4.92646	833.33601	3.37797	222.22741	2.92124
888.89052	4.33143	888.89052	3.62907	277.78245	0.60903
944.44502	4.87759	944.44502	3.97157	333.33749	2.44262
1000.00474	5.30688	1000.00474	4.11248	388.88951	1.39363
1055.55924	5.42518	1055.55924	4.39365	444.44923	3.53936
1111.11102	6.12266	1111.11102	5.02667	500.00374	2.25519
1111.11102	6.12266	1111.11102	5.02667	555.55824	3.10631
1238.88896	19.34176	1238.88896	31.08747	611.11274	2.51188
1366.66905	9.69958	1366.66905	15.82426	666.66725	4.14753
1494.4489	11.85925	1494.4489	13.30129	722.22701	4.06884
1622.22634	22.62713	1622.22634	43.35417	777.78151	5.57636
1750.00379	26.47589	1750.00379	51.2205	833.33601	4.4247
1877.78123	11.98123	1877.78123	9.70554	888.89052	5.38332
2005.55867	17.49247	2005.55867	14.85265	944.44502	5.75245

2133.33612	117.18083	2133.33612	146.46744	1000.00474	6.14992
2261.11356	22.11978	2261.11356	53.78581	1055.55924	5.86772
2388.89101	3.18748	2388.89101	30.49824	1111.11102	6.41494
2388.89101	1.34274	2516.66812	25.6006	1111.11102	6.41494
2388.89101	4.99594	2644.44457	14.12729	1238.88896	41.89731
2388.89101	1.97661	2772.22632	9.39398	1366.66905	16.86344
2388.89101	1.0754	2900.00277	13.78797	1494.4489	17.93654
2388.89101	3.03937	3027.77922	15.67633	1622.22634	46.64466
2388.89101	3.3668	3155.55567	16.54392	1750.00379	65.36593
2388.89101	3.13251	3283.33742	13.67454	1877.78123	12.96715
2388.89101	4.14443	3411.11387	36.23169	2005.55867	36.60725
2388.89101	2.59043	3538.89033	8.17561	2133.33612	181.51768
2388.89101	2.71304	3666.66645	10.32844	2261.11356	43.01197
2388.89101	1.89915			2388.89101	26.66219
2516.66812	11.06145			2516.66812	49.02329
2644.44457	18.28921			2644.44457	36.54212
2772.22632	7.4783			2772.22632	6.08692
2900.00277	26.74063			2900.00277	51.81808
3027.77922	11.94395			3027.77922	12.30458
3155.55567	4.15316			3155.55567	31.9821
3283.33742	16.67579			3283.33742	23.00027
3411.11387	6.3685			3411.11387	16.94661
3538.89033	7.08596			3538.89033	23.63178
3666.66645	6.40431			3666.66645	35.81872

b) Vertical deflection at speed of 80 Km/hr

Rolling Distance (mm)	Vertical deflection (mm)	Rolling Distance (mm)	Vertical deflection (mm)	Rolling Distance (mm)	Vertical deflection (mm)
E=180MPa		E=120MPa		E=90MPa	
0	0	0	0	0	0
55.55564	3.97E-04	55.55564	2.52E-04	55.55564	4.01E-04
111.1154	0.00152	111.1154	0.00199	111.1154	0.00234
166.6704	-0.00109	166.6704	0.00149	166.6704	0.00157

222.2274	0.00401	222.2274	5.62E-04	222.2274	0.00127
277.7825	-0.00209	277.7825	0.00143	277.7825	0.00249
333.3375	0.0028	333.3375	-0.00147	333.3375	-0.00114
388.8895	-0.00143	388.8895	0.00398	388.8895	0.00494
444.4492	9.02E-04	444.4492	4.76E-04	444.4492	-1.17E-04
500.0037	0.00147	500.0037	0.00578	500.0037	0.00634
555.5582	-0.00194	555.5582	-0.00151	555.5582	-9.28E-04
611.1127	0.0033	611.1127	0.00702	611.1127	0.00614
666.6673	-0.00211	666.6673	-0.00257	666.6673	-3.47E-04
722.227	0.00201	722.227	0.00784	722.227	0.00585
777.7815	-8.24E-05	777.7815	-0.00212	777.7815	0.00224
833.336	-6.56E-04	833.336	0.00808	833.336	0.00545
888.8905	0.00271	888.8905	-0.00124	888.8905	0.00338
944.445	-0.00308	944.445	0.00734	944.445	0.00631
1000.005	0.00345	1000.005	3.28E-05	1000.005	0.00418
1055.559	-0.00203	1055.559	0.00643	1055.559	0.00473
1111.111	9.76E-04	1111.111	0.00186	1111.111	0.00556
1111.111	9.76E-04	1111.111	0.00186	1111.111	0.00556
1238.889	0.00293	1238.889	0.00497	1238.889	0.00694
1366.669	-0.00833	1366.669	-0.00603	1366.669	-0.00563
1494.449	-0.02517	1494.449	-0.05551	1494.449	-0.05607
1622.226	-0.03125	1622.226	-0.01686	1622.226	-0.02636
1750.004	-0.07178	1750.004	-0.07223	1750.004	-0.08926
1877.781	-0.12002	1877.781	-0.14321	1877.781	-0.19174
2005.559	-0.14244	2005.559	-0.17129	2005.559	-0.22051
2133.336	-0.21952	2133.336	-0.19563	2133.336	-0.28629
2261.114	-0.14642	2261.114	-0.26604	2261.114	-0.19388
2388.891	-0.09606	2388.891	-0.12538	2388.891	-0.10511
2516.668	-0.08161	2516.668	-0.03016	2516.668	-0.1571
2644.445	0.01697	2644.445	0.11087	2644.445	0.09275
2772.226	0.02234	2772.226	0.07252	2772.226	0.1827
2900.003	0.10248	2900.003	0.1169	2900.003	0.22423

3027.779	0.06134	3027.779	-0.00261	3027.779	0.1938
3155.556	0.05853	3155.556	-0.05878	3155.556	0.16449
3283.337	0.07246	3283.337	-0.10745	3283.337	0.12109
3411.114	0.04266	3411.114	-0.13991	3411.114	0.17021
3538.89	0.05319	3538.89	-0.09433	3538.89	0.1926
3666.666	0.04061	3666.666	-0.05676	3666.666	0.17428

c) Rail bending stress at speed of 80 Km/hr

Rolling Distance (mm)	Rail bending stress (MPa)	Rolling Distance (mm)	Rail bending stress (MPa)	Rolling Distance (mm)	Rail bending stress (MPa)
E=180MPa		E=120MPa		E=90MPa	
0	0	0	0	0	0
55.55564	-0.02207	55.55564	-0.20378	55.55564	0.082
111.1154	0.07349	111.1154	-0.04818	111.1154	-0.01456
111.1154	0.01497	166.6704	-0.16254	166.6704	0.07673
111.1154	0.17164	222.2274	0.29763	222.2274	-0.15393
111.1154	0.00266	222.2274	0.51887	277.7825	0.27991
111.1154	0.0594	222.2274	0.48106	333.3375	-0.0267
111.1154	0.16172	222.2274	-0.21152	388.8895	-0.05614
111.1154	-0.10508	222.2274	-0.32222	444.4492	-0.19954
111.1154	-0.59217	222.2274	-0.06149	500.0037	-0.35541
111.1154	0.36504	222.2274	-0.80835	555.5582	0.14299
111.1154	-0.1601	222.2274	-0.68303	611.1127	-0.20754
111.1154	-0.01218	222.2274	0.24798	666.6673	0.13691
111.1154	0.44973	222.2274	-0.82002	722.227	-0.3532
166.6704	0.0184	222.2274	-0.25538	777.7815	-0.31047
222.2274	-0.14226	222.2274	1.29562	833.336	-0.04714
277.7825	0.0485	277.7825	-0.15151	888.8905	-0.33406
333.3375	0.03511	333.3375	-0.12392	944.445	0.021
388.8895	-0.0828	388.8895	0.32586	1000.005	-0.25766
444.4492	-0.15406	444.4492	0.01365	1055.559	-0.29232
500.0037	-0.00438	500.0037	0.18828	1111.111	-0.1475
555.5582	-0.05009	555.5582	-0.18919	1111.111	-0.1475
611.1127	-0.06834	611.1127	0.3072	1238.889	-7.74949
666.6673	-0.11321	611.1127	-0.18482	1366.669	1.17015
722.227	-0.09474	611.1127	0.37782	1494.449	1.24408

777.7815	-0.03641	611.1127	0.5047	1622.226	-5.36369
833.336	-0.17258	611.1127	1.59985	1750.004	-10.7548
888.8905	-0.08621	611.1127	0.45818	1877.781	-2.53506
944.445	-0.11801	611.1127	0.29101	2005.559	-20.277
1000.005	-0.1359	611.1127	0.01232	2133.336	72.23299
1055.559	-0.13689	611.1127	-0.06023	2261.114	42.30811
1111.111	-0.16339	611.1127	0.36973	2388.891	-9.79272
1111.111	-0.16339	611.1127	0.67257	2516.668	3.2579
1238.889	-1.71509	611.1127	-1.3647	2644.445	-2.40331
1366.669	0.43554	666.6673	-0.05241	2772.226	1.76896
1494.449	-0.17214	722.227	-0.4551	2900.003	-0.72406
1622.226	-0.91262	777.7815	-0.24048	3027.779	0.75944
1750.004	-2.85022	833.336	0.29621	3155.556	-3.37494
1877.781	1.36069	888.8905	-0.16943	3283.337	2.76164
2005.559	12.68561	944.445	-0.05983	3283.337	0.25211
2133.336	51.12181	1000.005	-0.11336	3283.337	-2.65219
2261.114	-1.9289	1055.559	0.02531	3283.337	2.67282
2388.891	3.92672	1111.111	-0.3714	3283.337	7.7337
2516.668	-0.26821	1111.111	-0.3714	3283.337	4.2862
2644.445	-0.31271	1238.889	-9.05927	3283.337	2.44298
2772.226	0.12389	1366.669	6.32993	3283.337	-2.15465
2900.003	-0.09618	1494.449	4.8561	3283.337	-5.39079
3027.779	-0.15099	1622.226	-4.98156	3283.337	2.02826
3155.556	0.22327	1750.004	-7.91553	3283.337	1.53315
3283.337	-0.4807	1877.781	-1.08696	3283.337	0.10128
3411.114	0.24052	2005.559	11.39698	3411.114	-1.44237
3538.89	-0.39274	2133.336	58.39541	3538.89	-0.57126
3666.666	0.10249	2261.114	27.1353	3666.666	-2.49764
		2388.891	-15.0407		
		2516.668	-4.33641		
		2644.445	-0.03019		
		2772.226	-0.08708		
		2900.003	1.19764		
		3027.779	0.65964		
		3155.556	-1.22471		
		3283.337	0.08982		
		3411.114	1.55124		
		3538.89	1.74965		
		3666.666	2.20374		