

# Modeling and Simulation of Rail End Bolt Hole and Bolted Rail Joint by FEM

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**Abstract:** The rail joint is typically considered to be one of the weakest part of the rail way track superstructure. There are a number of defects and failures around rail end joint including bolt hole cracks, head–web cracking or separation, broken or missing bolts, and joint bar defects have been found to start at rail joints and the area surrounding these joints. The initiation and propagation of these defects are primarily due to the discontinuities of both geometric and mechanical properties in the rail joint area. This research work studies on the effects of support condition, speed of wheel, and loading position on the rail end vertical displacement, stress distribution at the bolt hole and the upper fillet area under static and dynamic loading condition by using finite element method. Preliminary results of static load showed that when loading position varies, the response of rail end joint varies, the rail vertical displacement and stresses on the rail upper fillet and stress on the bolt hole were also varies. Preliminary results from dynamic loading indicated the contact force at the wheel-rail interface would not change monotonically with the changing train speed and the stresses calculated around the bolt-hole area were significantly smaller than the stresses around the upper fillet area. Therefore to conclude the center supported joint is strongly recommended because of its high stiffness causing smaller deflection and smaller bolt-hole stress around the rail end joint can reduce defects around the joint.

**Key words:** Rail end joint, static and dynamic loading, finite element method

## 1. INTRODUCTION

Ethiopia has invested a great deal in creating the road network that will support economic development and ensuring that Ethiopia has good connections to each of the neighboring states [1]. Among the various railway truck components, rail joint typically is one of the weakest elements of a track superstructure, this is primarily because of discontinuities in its geometric, mechanical properties and the high-impact loads induced by these discontinuities. The development of continuously welded rail has significantly reduced the number of rail joints, but many bolted joints remain installed in rail transit systems especially in Ethiopia [2]. Because of the unique loading environment of a rail transit system (especially high-frequency, high-repetition loads), defects related to bolted rail joints (e.g., joint bar failures, bolt hole cracks, and cracks in the upper fillet) continue to cause service failures and can pose derailment risks [3].

## 2. RELEVANT LITERATURES

Rail joints are the weakest part of the track, where their life ranges between a third and a half of the life of the rails, [4]. Due to the above facts different researchers are done great jobs to solve problems around rail end joints by using FEM as their basic tool and method of computation. This paper work is same in many aspects with the relevant literatures discussed below and only three things makes this paper different, these are study area, considers only effect of vertical static and dynamic wheel load on rail end joint, would fill knowledge voids relating to how support conditions, bolt conditions and speed of rail wheel affect the stresses around the rail-end bolt hole.

<i>Authors</i>	<i>Modeling Techniques</i>	<i>Discussion</i>	<i>Limitations</i>
<i>Kaijun Zhu, et al, 2017</i>	3D FEA Stress distribution was investigated at the rail-end bolt hole and upper fillet areas	Comprehensive parametric analysis performed with finite element modeling.	Considers static analysis only
<i>R.Kasanna. et al.,2017</i>	3-D FEA Elastic Frictional Element Model	Modal analysis is done to calculate the Modal shapes, natural frequencies. Shows super-elevation have significantly effects on contact stress, life, damage, safety factor.	Focused only the interaction between left and right wheels.
<i>Grossoni I. et al., 2014</i>	2D FEA vehicle track coupling model,	2D model includes 3 parameters of IRJs (joint max deflection, joint angle and joint length) by using a mathematical idealization of dipped beam in 2D.	The model does not allow looking in neither the interfaces of RJ components, nor the structural investigation of the RJ.
<i>Sunil Patell, et al., 2013</i>	3D FEM, Model for RJ	The static and dynamic loads are being applied to estimate fatigue life and endurance strength at the section. The material properties of the rail and wheel are assumed to be same.	The combined effect of vertical and lateral bending; which is not included in the beam theory approximations.
<i>Patel Q., Kumar V. and Nareliya R., 2013</i>	Wheel-rail dynamic 3D FEA, standard RJ.	Model included a mechanical non-insulated RJ on a two sleeper configuration on elastic support.	Lack of symmetry and short length of model may affect the result, mesh is not presented.
<i>Zong N. et al.,2013</i>	Wheel rail contact impact model, 3D FEA	Account for wheel-rail frictional contact, 200 KN bolt preload, elastic support per rail end. Model examines the contact and impact force, contact pressure, validated against vertical strain in rail web with field test.	It doesn't present structural performance of the joint in terms of deflection, stresses on fishplate, and does not comment on how the rail-fishplate interfaces were modelled.

Table1. Relevant literature summery

## 3. THEORY OF ANALYSIS

The knowledge of contact mechanics as the Hertz's theory provides a closed-form solution to the normal contact problem. Therefore, during rail wheel and rail end joint contact analysis the following assumptions are taken from the Hertz theory are:

- ✓ Displacements and strains are small.
- ✓ The bodies in contact are homogeneous, isotropic and linearly elastic.
- ✓ Smooth surfaces where the surface roughness is neglected (frictionless contact)
- ✓ The dimensions of the contact patch are significantly smaller than the dimensions of the bodies in contact.
- ✓ The curvature of the bodies in contact is constant.
- ✓ The materials of the bodies are quasi-identical, [4].

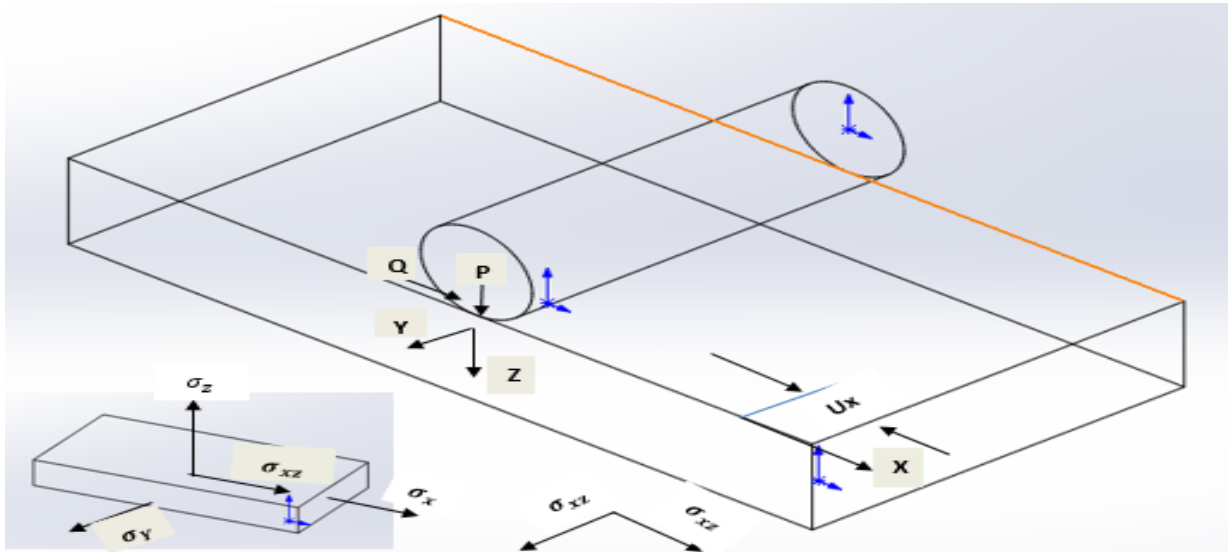


Figure 1. Cylinder in rolling-sliding contact with an elastic half-space, [4].



Figure 2. Rolling –sliding of train wheel on rail

#### 4. MODELING OF RAIL WHEEL CONTACT

The wheel profile consists of a flange to guide the trains along the rails and a conical tread that contacts rail head, and rail has many curvatures to guide wheel properly. The contact positions of the wheel / rail are different in the Different situation. However, this paper uses the contact between the wheels tread and rail head. The contact area between wheel and rail are very small compared to their dimension, [6].

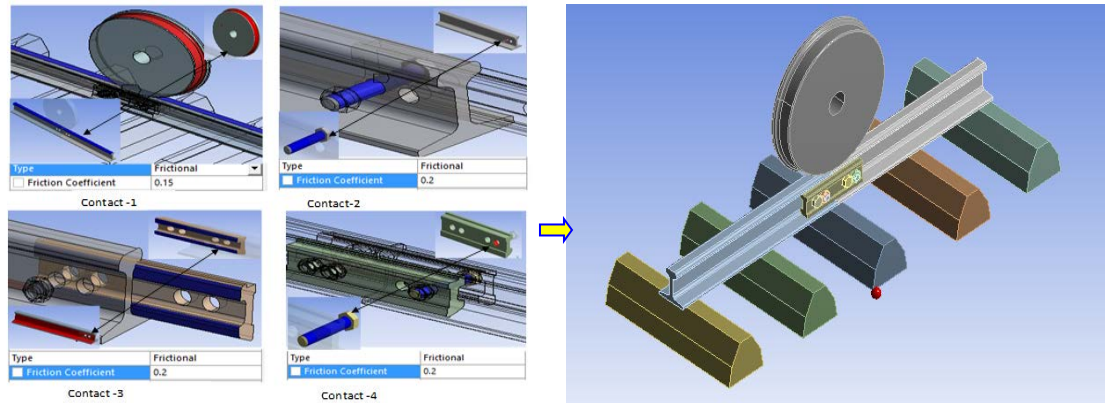


Figure 3. Setting wheel and rail contact as per UIC 60 standard, model used in research

### 5. SIMULATION WITH ANSYS WORK BENCH VERSION 19.2

Generally, there are two kinds of analysis one is experimental and other is simulation analysis. The biggest problem with experimental analysis is the cost and time. Therefore, commercial simulation software's have been used in different engineering fields, because it just needs a computer and the suitable software. Moreover, simulation software can offer the results in much shorter time period. The ANSYS workbench software is carried out in three basic principles. They are:-Preprocessor>> Processor >>Postprocessor.

**Geometric Model specification:** - The model was done as per UIC 60 rail standard.

Track Gauge	1435mm
Type of Rail	60 Kg/m
Wheel Diameter	≤ 660mm
Fish Plate length and thickness	820mm×19mm
Sleeper Gap	625mm
End Joint Gap	5mm
Standard Joint Bolt and Nut	M28
Operation Parameters	Speed
Maximum operating speed	70km/hr(20 m/s)
Travelling speed on minimum curve radius	≥ 12km/hr (4m/s)
Operating speed during car wash	3~4km/hr

Table 2. UIC 60 Design Rail Specification [2, 5, 7]

**Mechanical forces considered in the analysis:** Vertical Force: The vertical force ( $F_v$ ) acting on the wheel is due to the passenger and payload. These forces are transferred to the wheel through the axle. A static and dynamic load of 55600N on each wheel is considered in this study.

**Material Selection:** For each supper structures around rail end joint the following tabular materials are used.

Part Name	Mechanical Properties of the Selected Material					
	Poison's Ratio	Young's Modulus (GPa)	Ultimate tensile strength (MPa)	Yield strength (MPa)	Density (kg/m <sup>3</sup> )	Maximum Deformation
Rail	0.3	207	780	640	7800	12%
Fish Plate	0.3	207	780	640	7800	12%
Bolt and Nut	0.3	207	780	640	7800	12%

Table 3. Material used for rail supper structure, these elements generally include carbon, manganese, silicon, chromium, phosphorus, Sulphur [5, 7].

**Finite Element Modeling:** Finite element method is used to analyze the response of the rail joint to the static and dynamic load. The Finite Element analysis is performed using structural analysis of the ANSYS R19.2 workbench software after imported 3D assemblies form SOLIDWORKS 18 software.

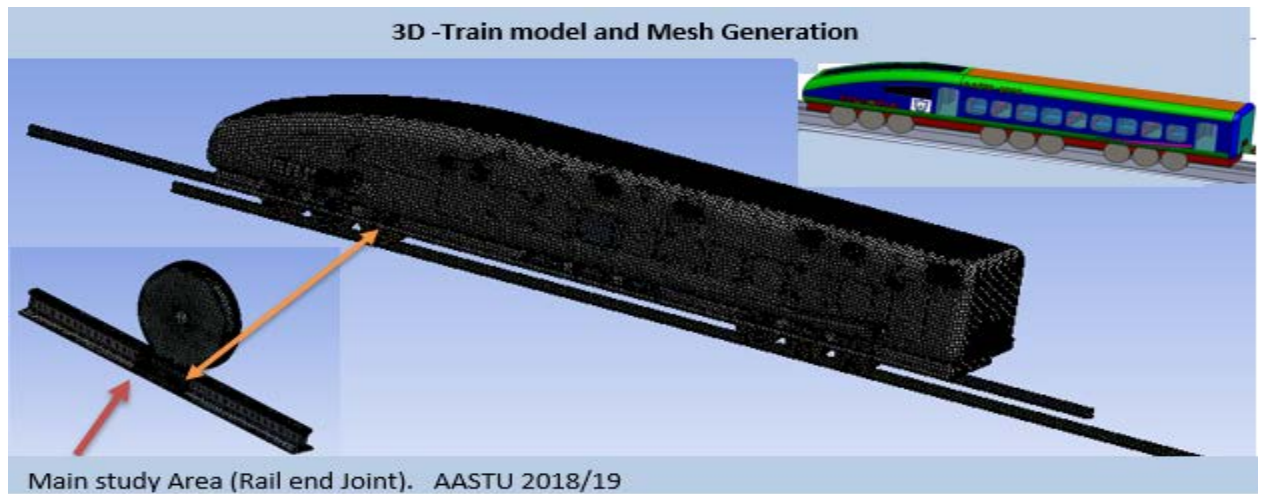


Figure 4. Model and mesh generation specific to the joint (main study area).

Part	Part Type	Element Type	Number of Element	Moment of Inertia
Rail	3D-	Linear tetrahedron	49076	4.77e6 kg.mm <sup>2</sup>
Joint bar	Deformable	Linear tetrahedron	21567	1.05e5 kg.mm <sup>2</sup>
S bolt and nut	Solids	Linear tetrahedron	7379	1992.9 kg.mm <sup>2</sup>
Wheel		Linear tetrahedron	73669	5.89 e6 kg.mm <sup>2</sup>

Table 4. Mesh results when relevance center and span angle is set to fine.

**ANSYS work bench procedure for analysis:** - File of the wheel and track is saved in IGS format on solid work 18. >>3D model of assembly is inserted in ANSYS work bench. >> Simulation is selected for analysis of wheel and track. >> Connection is made between wheel and rail as per contact set. >>Frictional and Rough Contact between rail joints is selected. >> Tetrahedral element is selected mesh is generated. >>Track is fixed in all 3 DOF by fixture option. >> Design load is applied on wheel. >> Result is obtained by showing the final result option.

## 6. RESULTS AND DISCUSSION

### I. When Load acting at center of joint response of the rail end joint as follows

- **Center Supported Joint.**

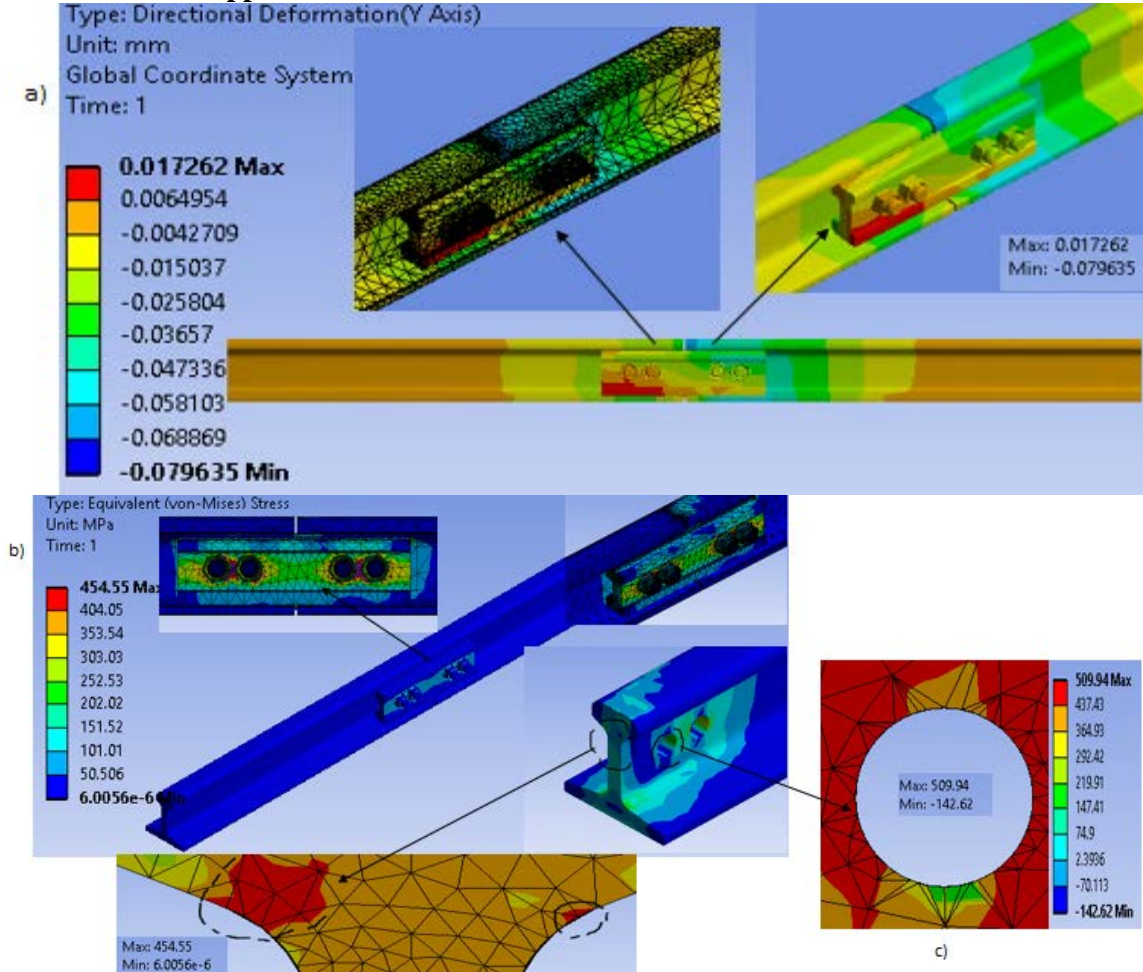
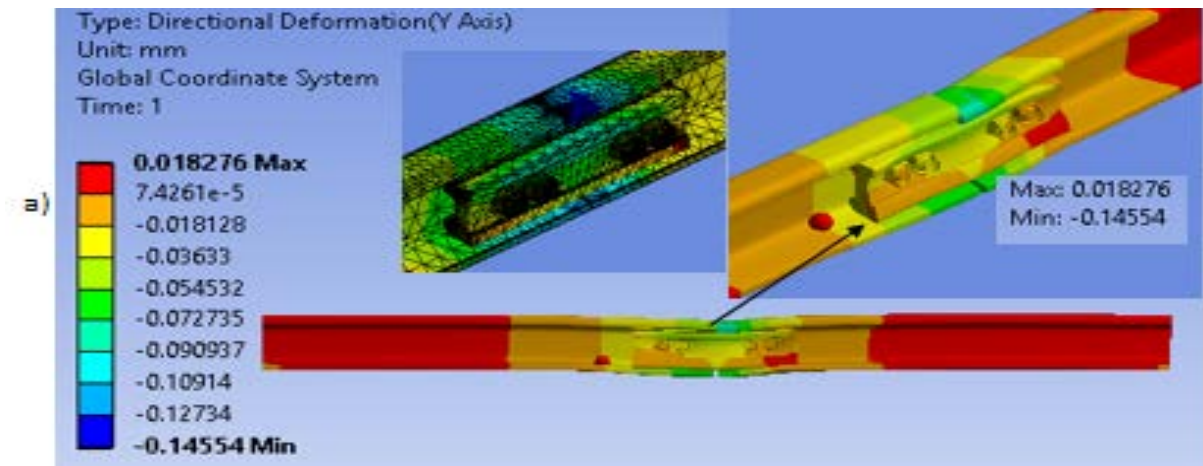


Figure 5. a) Vertical displacement along rail with a bolted joint (mm). b) von Mises stress at rail end upper fillet (MPa). c). Principal stress around first bolt hole (MPa)

- **Near To Support Condition**



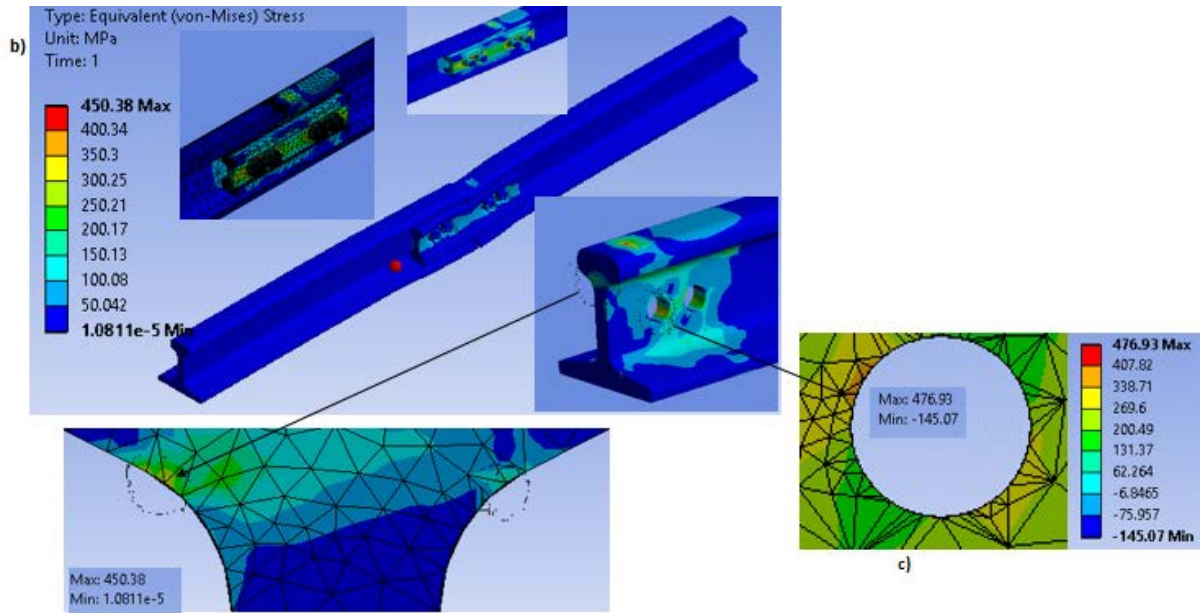


Figure 6. a) Vertical displacement along rail with a bolted joint (mm). b) von Mises stress at rail end upper fillet (MPa). c). Principal stress around first bolt hole (MPa).

• **Suspended Joint**

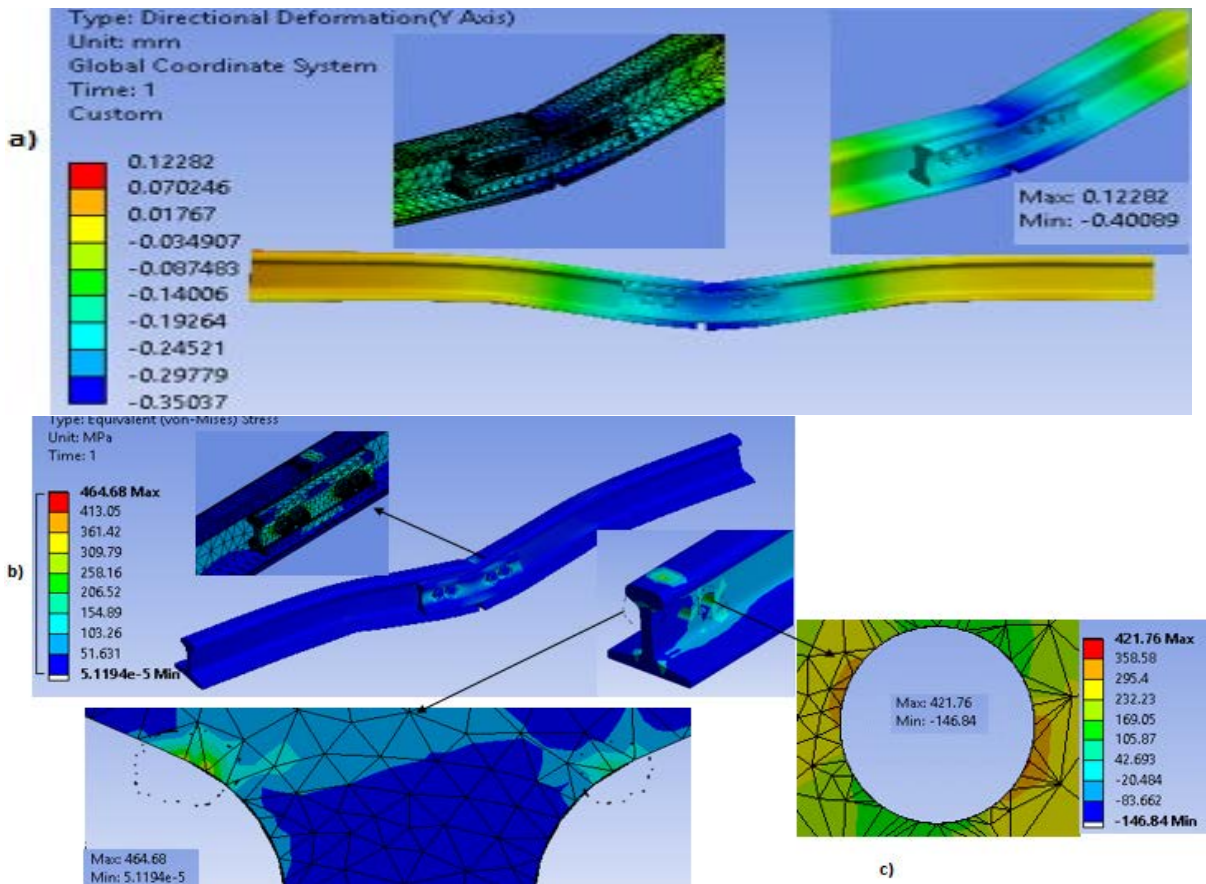


Figure 7. a) Vertical displacement along rail with a bolted joint (mm). b) von Mises stress at rail end upper fillet (MPa). c). Principal stress around first bolt hole (MPa)

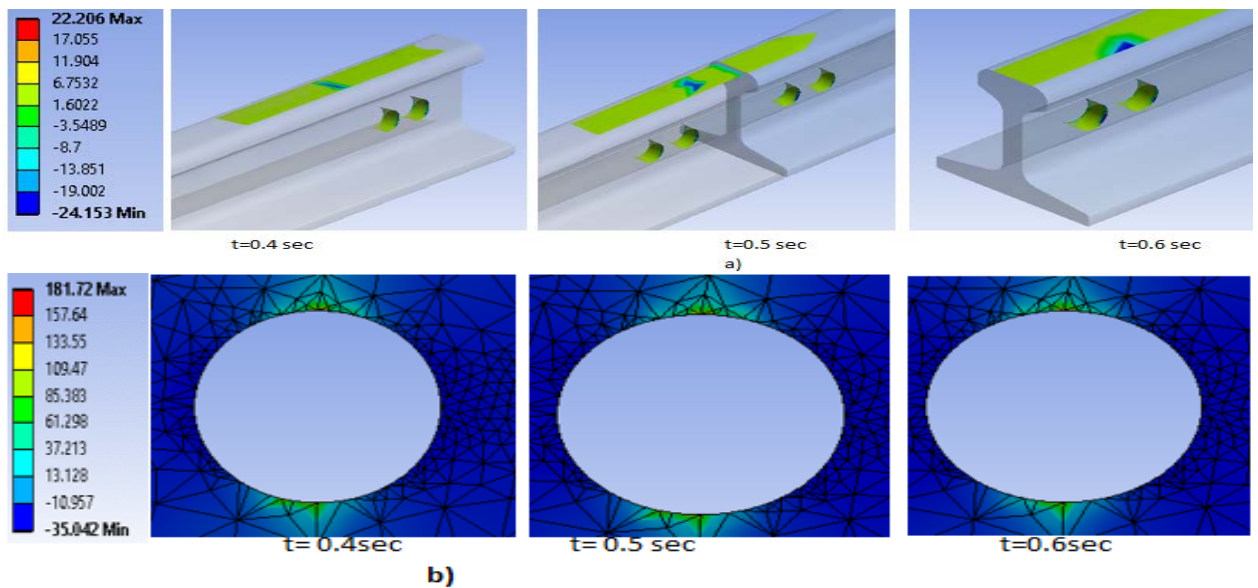
Summer on results and discussion obtained when static wheel load is acting at center of the rail end joint for three different support conditions as follows

Rail End Joint Support Configuration	Studied parameters	Results
Center Supported	Rail end vertical Displacement	0.017mm
	Rail end bolt hole Tensile Stresses	509.94MPa
	Rail end upper fillet von Mises Stresses	454.55MPa
Near to Support	Rail end vertical Displacement	0.0183mm
	Rail end bolt hole Tensile Stresses	476.38MPa
	Rail end upper fillet von Mises Stresses	450.38MPa
Suspended Joint	Rail end vertical Displacement	<b>0.123mm</b>
	Rail end bolt hole Tensile Stresses	<b>421.76</b>
	Rail end upper fillet von Mises Stresses	<b>464.68</b>

Table 5 Summary of response of different support configuration for load acting at center of rail end joint.

The increase in the vertical displacement was relatively high when suspended joint is used; this result may be attributable to consider closer spacing of the two centre crosssties bolted joint. The reduction of the bolt hole tensile stress is attributable to the release of the bolt load. The magnitude of the upper fillet stress was relatively high, which might have been caused by the limited contact area and the excessive relative movement around that area.

## II. When Train Moving At Maximum Operating Speed (70km/Hr.) The Response Of The Rail Joint





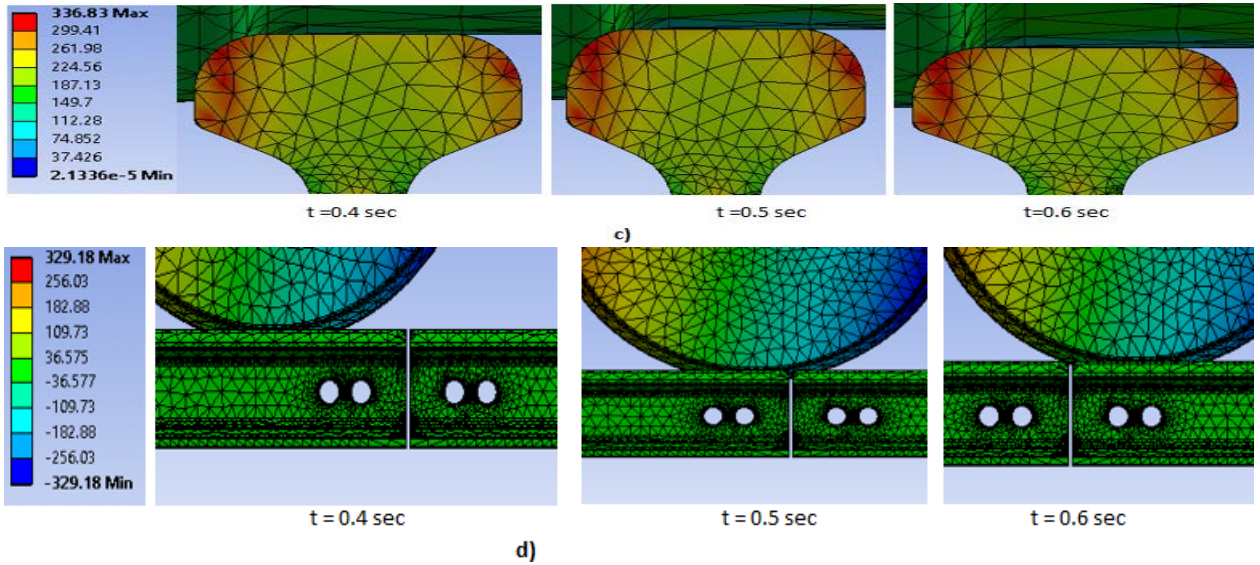


Figure 8. The simulation results at train speed of 70 km/hr: (a) Wheel-rail contact patch in (MPa). (b) Bolt-hole stress around rail-end in (MPa). (c) von Mises stress at rail-end upper fillet in (MPa). (d) Vertical displacement at rail-end in (mm).

The loading history of the vertical contact force at the wheel-rail interface when the wheel was moving at a speed of 70km/hr

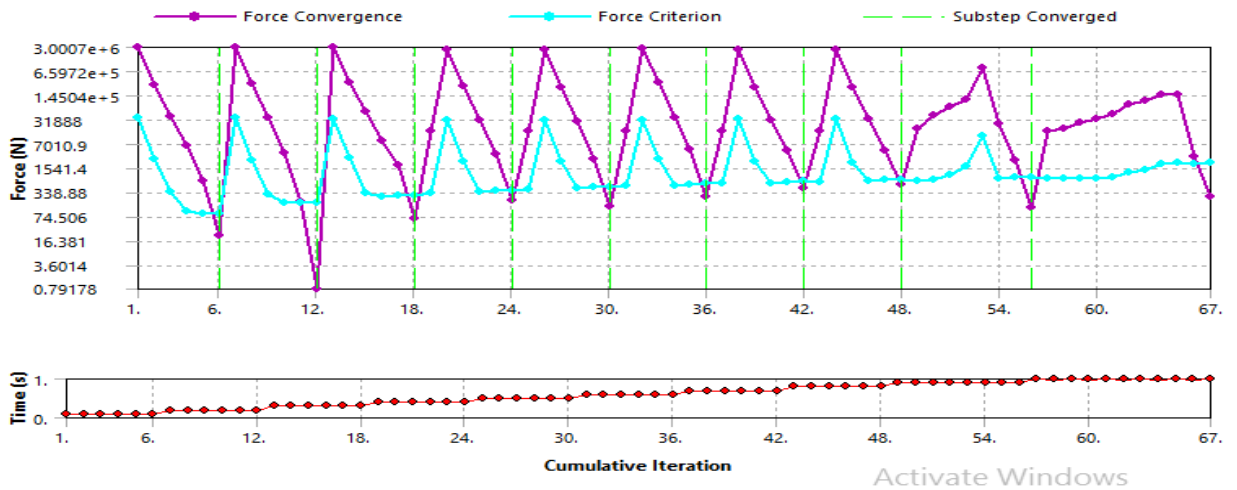
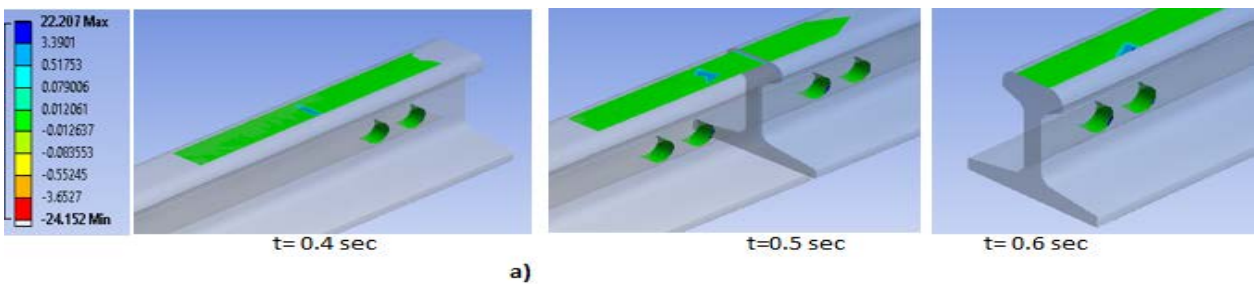


Figure 9. Loading history when vertical contact force at the wheel-rail interface at a speed of 70km/hr

### III. When Train Moving At Maximum Operating Speed (12km/Hr.) The Response Of The Rail Joint.



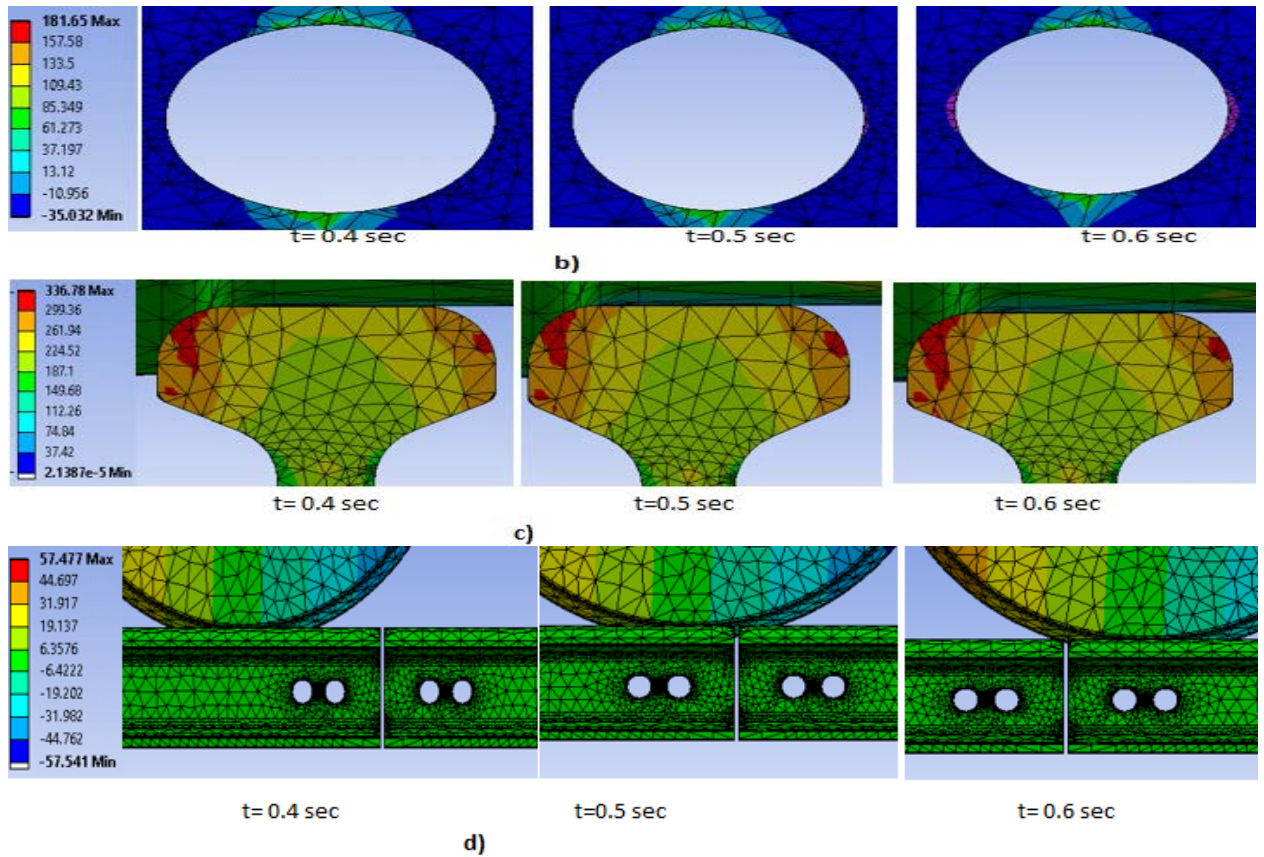


Figure 10. The simulation results at train speed of 12 *km/hr*: (a) Wheel-rail contact patch in (MPa). (b) Bolt-hole stress around rail-end in (MPa). (c) von Mises stress at rail-end upper fillet in (MPa). (d) Vertical displacement at rail-end in (mm).

The loading history of the vertical contact force at the wheel-rail interface when the wheel was moving at a speed of 12*km/hr*

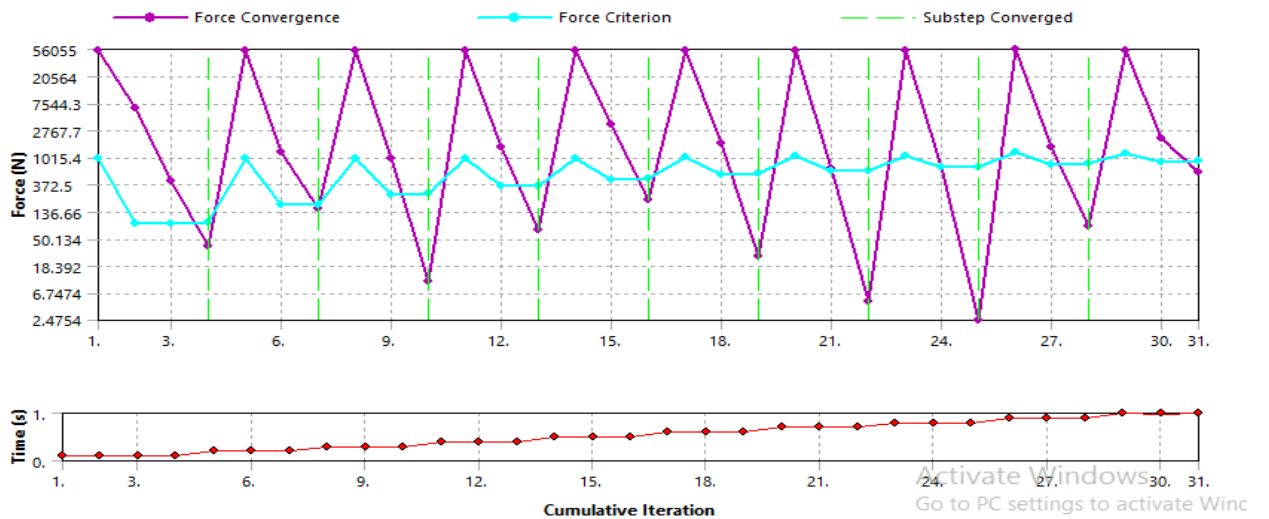


Figure 11. Loading history when vertical contact force at the wheel-rail interface at a speed of 12*km/hr*

**Summary of result and discussion of moving load**

Operating Speed	Studied Parameter	Values
70km/hr maximum operating speed	wheel-rail contact patch (MPa)	<b>22.207</b>
	stress around rail-end bolt-hole (MPa)	181.72
	von Mises stress at rail-end upper fillet (MPa)	336.83
	vertical displacement at rail-end (mm)	329.18
12km/hr minimum operating speed	wheel-rail contact patch (MPa)	<b>22.207</b>
	stress around rail-end bolt-hole (MPa)	181.65
	von Mises stress at rail-end upper fillet (MPa)	336.78
	vertical displacement at rail-end (mm)	57.44

Table 6. Effect of speed on rail joint

As shown on the above summary Table 6 on the effect of bolt loading and speed on rail end joint, variation of speed will not affect the wheel rail contact patch which is strongly agreed with the formulation of contact mechanics, but bolt loading were strongly affect the wheel rail contact patch. As general the results shows for same bolt loading cases variation of speed strongly affect the rail end vertical displacement only which is agree with the formulation of contact mechanics formulation for the relation between varying speed and vertical displacement which was done by[9,10].

**7. CONCLUSION**

In this study, the responses of a bolted rail joint component are determined under static and dynamic loads, the results are assumed to be significant. The analysis can include rail end vertical displacement, rail end bolt hole tensile stress, and upper fillet von Mises stress responses of bolted rail joint caused by vertical wheel load. The analysis is taking into account by using various position of bolted rail joint on the support and effect of maximum and minimum operating speed. When load was acting at the centre of rail end, the joint gets its maximum upper fillet stress which is more risk for life of the rail super structure when the joint support is suspended.

This part of rail track needed more attention than other parts, to reduce the problem related to the rail joint. This paper recommends using the sleeper support at the rail joint position and bolt around the end gap need to have more strength than part of the joint due to the exposure of the vertical load and it should be center supported, then it will have less deflection and high stiffness. Generally, the rail end joint needs a special treatment to reduce the rail super structure failure.

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