A Major Project Report

on

COMPUTATIONAL STRESS ANALYSIS OF RAIL-WHEEL MODEL OF INDIAN RAILWAYS

Submitted in partial fulfillment of the requirements
for the award of the degree of

MASTER OF TECHNOLOGY

in

MECHANICAL ENGINEERING

(COMPUTATIONAL DESIGN)

Submitted by

DEVENDRA SINGH

(ROLL NO. 2K13/CDN/08)

Under the Guidance of

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DECLARATION

I, **Devendra Singh**, hereby declare that the major project report entitled "**Computational stress analysis of Rail-wheel Model of Indian Railways**" in the partial fulfillment for the award of degree of Master of Technology in Mechanical Engineering (Computational Design) is an authentic work carried out by me at Delhi Technological University under the guidance of **Dr. R.C. Singh**, Assistant Professor and **Mr. Roop Lal**, Assistant Professor of Mechanical Engineering Department.

I have not submitted the work in this dissertation for the award of any other degree or diploma to any other university/institution.

Devendra Singh

(2K13/CDN/08)

CERTIFICATE

This is to certify that the major project report entitled **"Computational stress analysis of Rail-wheel Model of Indian Railways"** submitted by **Mr. Devendra Singh Roll No. 2K13/CDN/08** in partial fulfillment for the award of **Master of Technology in Mechanical Engineering (Computational Design)** from the Delhi Technological University, is a record of authentic work carried out by him under our supervision and guidance.

The declaration made by **Mr. Devendra Singh Roll No. 2K13/CDN/08** is correct to the best of our knowledge and belief.

DR. R.C. SINGH
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Devendra Singh

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ABSTRACT

Wheel-rail contact analysis is one of the most standout problems in the modeling and analysis of railway vehicles. The wheel-rail interaction is an exceptional part of rail-vehicle progress as it accounts for the capacity of freight wagon and is being considered the most critical parameter for the freight traffic wagons on the railway tracks. In this thesis, the static response of the wheel on a rail is analyzed by modelling and analyzing the geometries of standard section of Rail and wheel through the softwares Creo parametric 2.0 and Ansys 15.0 for calculating the stresses between the Rail-wheel contact region. An analytical approach for calculating the tangent modulus has been drafted during the selection of material and its properties using the Ramberg Osgood Equation. The Hertzian contact theory gives the expression for the maximum contact shear stress value at the point of contact between the rail and the wheel. To validate the value of contact shear stresses founded in this thesis, responses of the assembled model using Ansys 15.0 are compared with the Hertzian approach as well as with the Hertzian stress calculator. Then it has been found that all the three maximum contact shear stresses achieved by different methods are less than the standard limiting values of maximum contact shear stresses in accordance to the Indian Railway Standard. Finally the effects of the results have been studied for the essence of analysis.

Maximum contact shear stress between Rail-wheel is found to be 25.5 kg/mm^2, 24.63 kg/mm^2, 23.55 kg/mm^2 by Ansys 15.0, Hertzian theory and Hertzian stress calculator respectively for 90 UTS rail of UIC 60 kg section and all are less than the limiting value of contact stress which is 27.0 kg/mm^2 for 90 UTS rails and it was the prime objective of thesis.

The thesis is divided into six chapters. The first chapter describes the introductory part of Indian Railways and importance of Freight traffic, followed by the scope and domain of the freight traffic. The next chapter gives an insight regarding the Railway track, rails and wheels, apart from this the chapter also focuses on theory of contact stresses as well as bending stresses. Chapter three, describes the processing of modelling of Rail UIC 60 kg (90 UTS) and wheel of BOXN standard, followed by the fourth chapter which accounts for the computational static analysis of the assembled model of rail and wheel. Chapter five, represents the result validation of contact shear stress and compares it with the limiting values in accordance to Indian Railway Standard. Chapter six delineates the conclusion.

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LIST OF ABBREVIATIONS

BOX	High sided bogie open wagon
BOXN	High sided bogie open with pneumatic brakes
BHN	Brinell hardness number
BG	Broad gauge
MG	Meter gauge
NG	Narrow gauge
CAD	Computer aided design
CAE	Computer aided Engineering
C.P. 2.0	Creo parametric 2.0
FPS	Foot pound second
GMT	Gross million tonne per km/annum
IR	Indian Railway
IRS	Indian Railway Standard
RDSO	Research, Design and standards organization
RBS	Revised British Standard
UIC	International Union of Railways
UTS	Ultimate tensile strength

CHAPTER 1

INTRODUCTION

1-1 Brief Introduction to Indian Railways

Indian railways is the 4th largest railway network throughout the world having the route length of about 65,436 km after the US, China and Russia which are having 224,792 km, 103,144 km and 128,000 km of route length respectively. India has 115,000 km of track length over a route length of 65,436 km across 7,172 railway stations. The first train from Mumbai to Thane travelled the distance of 34 km in 1853 during British regime. With respect to Rolling stock, Indian Railways holds more than 239,281 Freight Wagons, 62,924 Passenger Coaches and 9,013 Locomotives (43 steam, 5,345 diesel and 4,568 electric locomotives). The trains have a 5 digit numbering framework and runs 12,617 passenger trains and 7421 freight trains daily. As of 31 March 2013, 20,884 km (12,977 mi) (31.9%) of the aggregate 65,436 km (40,660 mi) course length was electrified. Since 1960, all electrified sections on Indian Railways use 25,000 Volt AC traction via overhead catenary delivery.

Now a days in most parts of India, Indian railways has become one of the means of transport which is quite cheaper and convenient. Indian railways has three types of track gauges namely Broad gauge (1676 mm), meter gauge (1000 mm) and narrow gauge (762 mm and 610 mm) having the length of their tracks, 89 771 km; 15 684 km and 3,350 km respectively. There are two main sections of the Indian Railways - freight / cargo vehicle and passengers ride. *Freight segment* generates approximately two-thirds of revenues, while the rest comes from passenger traffic.

1-2 Research, Design and Standards Organization (RDSO)

Indian Railways has a sound association known as Research Designs and Standards Organization (RDSO), situated at Lucknow for all research & design and outlines of standardization tasks. In August 2013, Indian Railways went into an association with Indian Institute of Technology (Madras) to create innovation to tap solar energy for lighting and air conditioning in coaches.

This would significantly decrease the fossil fuel reliance of Indian Railways. The technical department of Indian Railways is administered by RDSO and its R&D division. The RDSO headquarter is certified for its quality and management system by ISO 9001:2000. It concerns for rail manufacturing and design consultancy for Indian railway. Centre for Railway Information System (CRIS) works for all the computerization projects of Indian Railways.

1-3 Production units of Indian Railways

Indian Railways manufactures most of its rolling stock and heavy engineering parts at its six manufacturing units, called Production Units, which are controlled directly by the Ministry. There are six production units of Indian railways which are engaged in the manufacturing of rolling stock, wheels, axles and other ancillary components of the rail. The six production units of Indian railways are Chittaranjan Loco Works; Diesel engine factory modernization; Diesel Engine Factory; Integrated Coach Factory; Rail Coach Factory; And Rail Wheel Factory. The brief information about their location and functioning is given in the following table.

Table 1-1: Production and Manufacturing Units

Unit	Headquarters	Production
Chittaranjan Locomotive Works	Chittaranjan	Electric Locomotives
Diesel Locomotive Works	Varanasi	Diesel Locomotives
Integral Coach Factory	Chennai	Coaches
Diesel Components Works	Patiala	Diesel Components
Rail Coach Factory	Kapurthala	Coaches
Wheel and Axle Plant	Bangalore	Wheels and axles

1- 4 Railway zones

Indian Railways is composed of certain zones throughout the country, which are again sub-divided into divisions. The quantity of zones in Indian Railways expanded from six to eight in 1951, nine in 1952 and seventeen in 2003. Each zonal railway is comprised of a specific number of divisions, every having a divisional office. There are total sixty-eight divisions.

Table 1-2: Railway Zones [23]

Name	Route (km)	Divisions
Southern	5098	Chennai, , Madurai & Salem, Thiruvananthapuram, Tiruchirappalli, and Palakkad
Central	3905	Mumbai CST, Pune, Solapur, Bhusawal, and Nagpur
Western	6182	Mumbai Central, Ratlam, Rajkot, Ahmedabad, Vadodara and Bhavnagar
Eastern	2414	Howrah, Asansol, Malda and Sealdah
Northern	6968	Delhi, Firozpur, Lucknow, Moradabad Udhampur and Ambala
North Eastern	3667	Izzatnagar, Varanasi and Lucknow
South Eastern	2631	Adra, Kharagpur, Chakradharpur and Ranchi
Northeast Frontier	3907	Alipurduar, Rangia, Lumding Katihar and Tinsukia
South Central	5951	Vijayawada, Guntakal, Guntur, Secundrabad, Hyderabad and Nanded
Kolkata Metro	25	NA

Name	Route (km)	Divisions
East Central	3628	Danapur, Mughalsarai, Dhanbad, Sonpur and Samastipur
North Western	5459	Jaipur, Ajmer, Jodhpur and Bikaner
East Coast	2677	Khurda Road, Visakhapatnam and Sambalpur
North Central	3151	Allahabad, Jhansi and Agra
South East Central	2447	Bilaspur, Nagpur and Raipur
South Western	3177	Hubli, Mysore and Sambalpur
West Central	2965	Jabalpur, Kota and Bhopal

1-5 Modernization of Railways

To modernize, strengthen and expand such a network, the government and private capital have to work on the various sections of railways e.g. Gauge conversion, connecting remote / backward areas, adding new lines, these are the challenges in front of Indian railways. In addition, the Government of Delhi, Mumbai, Chennai, Bangalore, Hyderabad and Kolkata have introduced rail-based mass rapid transit system in metropolitan cities. The goal of the project is to make cities safe and pollution-free travel for passengers in an authentic manner. This ensures the fastest means of transportation, saving time and lowers the accident. The project has made significant progress. Delhi Metro Rail project performance is particularly memorable.

1-6 Railway Track Gauges of Indian Railways

In India, the track gauges used are as Narrow Gauge, Meter Gauge, Standard Gauge and Broad Gauge. Indian railways uses Broad gauge (1676 mm), meter gauge (1000 mm), narrow gauge (762 mm and 610 mm). Indian railways is dependent on Broad gauge and approximately 108,000 km of track length and about 60, 000 km of route length has been covered by the broad Gauge. Meter gauge is present only for historical reasons and covers about 4,000 km of Route length. It was about 20,000 km in the 1970's. Narrow gauges are present on hilly terrains routes due to the cost considerations and covers less than 2,000 km on route length.

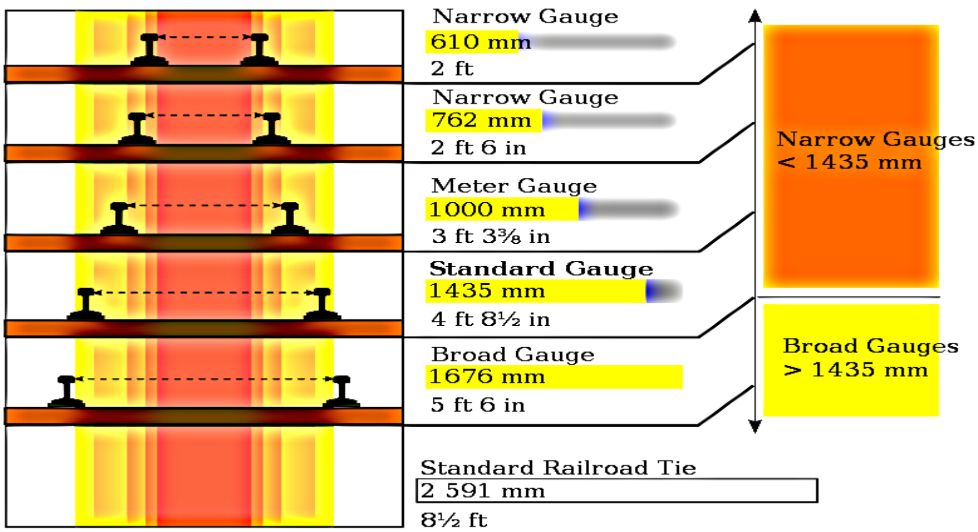


Figure 1-1: Railway Track Gauges [23]

1-7 Freight Traffic in India

Indian Railways gains around 70% of its incomes from freight/cargo traffic (₹686.2 billion from cargo and ₹304.6 billion from travelers in 2011–12). The majority of its benefits originates from transporting cargo, and this makes up for losses on passenger traffic. This intentionally helps in keeping low fares for passengers and cross-finances the losses making in passenger traffic with the benefit making of freight traffic. The commodity prices and other things prices are affected by the freight traffic. If the fare of freight traffic gets increased the prices of the loaded commodities of the wagon gets automatically rises. The Rapid development of industrial and agricultural sectors depends on the rail transport as these things have to be transported from one place to another for the proper equitable distribution among the distributors for selling. Particularly core sectors like ores, coal, petroleum products, and iron & steel, along with essential commodities such as food grains, sugar, salt, fertilizers, edible oils, cement, etc. are the important. The revenue of freight traffic was 73.2 million tonnes during the year of 1950-51 and with respect to time it gets increased and reached up to 793.89 million tonnes during the year 2007-08. Transport effort is generally measured in terms of Net tonnes Kilometers (NTkm). It was 38 billion during 1950-51 and reached up to 581 billion during the session of 2007-2008. The data can be tabulated as follows

Table 1-3: Freight traffic on Indian Railways

Item	Unit	1950-51	2003-04
Revenue traffic	Million tonnes	73.2	557.4
Net tonnes kilometers	Million	37,565	381,241

1-8 Domain and Scope of Freight traffic

Freight traffic is the main revenue source of Indian railways, hence it needs to be focused more. The inflation of commodities depends on the freight traffic hence if the load carrying capacity of the wagon could be increased then it would definitely result in the price reduction of the commodities as well as it would increase the revenue for Indian Railways. The Rail Section used in India on most part of the railway track is UIC 60 Kg rail that means the 60 kg rail per meter according to the International Union of Railways. So the contact analysis between the rail and wheel becomes the critical parameter in order to increase the load per wagon in tonnes. The increased axle load would lead to the reduction of the railway fares for the freight traffic and decreasing the price of commodities. This would lead to the development of Indian Railways.

CHAPTER 2

LITERATURE REVIEW

2-1 Components of the track

Satish Chandra & M.M. Aggarwal [1] described that the permanent way or track is the railroad on that trains run. It comprises of two parallel rails secured to sleepers with a predetermined separation between them. The sleepers are implanted in a layer of ballast of indicated thickness spread over level ground known as formation. The ballast gives a uniform level surface and drainage, and passes the load to a bigger territory of the arrangement. The rails are joined in arrangement of series by fish plates and screws and these are affixed to the sleepers with different sorts of fittings. The sleepers are separated at a predefined separation and are held in position by the counterweight of ballast. Every segment of the track has a particular function to perform. The rails acts as the member which transmit the wheel load of trains to the sleepers. The sleepers hold the rails in their legitimate (proper) positions, give a right gauge with the assistance of fittings and fastenings, and transfer the load to the ballast. The arrangement takes the total load of the track and of the trains proceeding onward it. The detailed figure 2-1 shown below shows the various components of the track.

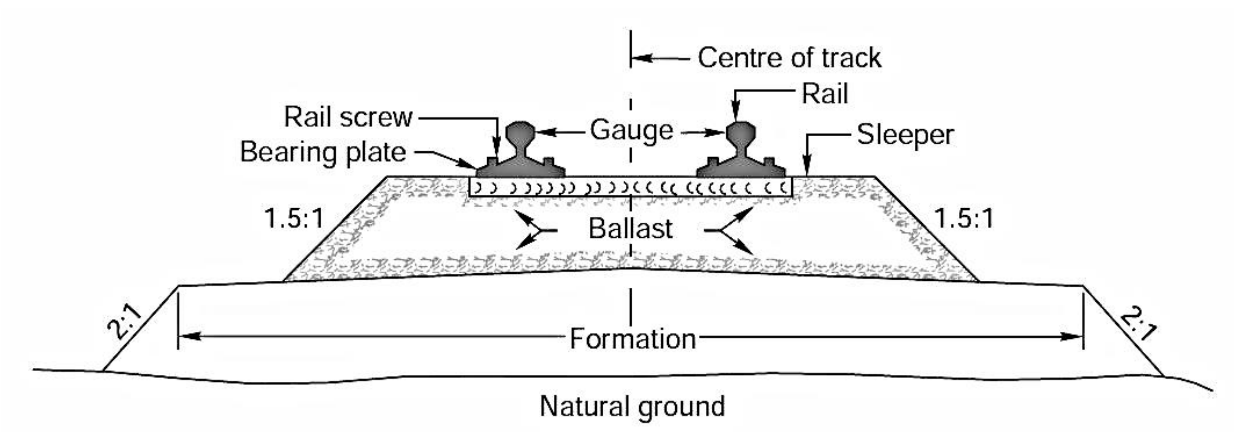


Figure 2-1: Components of the track [1]

2-2 Prerequisites of a Good Track

A track ought to give an agreeable and safe ride at the greatest allowable velocity with least support cost. To accomplish these objectives, a sound perpetual way ought to have the accompanying qualities.

(a) The gauge should be right and uniform.

(b) The rails should have impeccable cross levels. In curves, the external rail have a proper super elevation to consider the centrifugal force

(c) The arrangement should be straight and free of crimps. On account of bends, a proper transition should be given between curve and the straight track.

(d) The inclination should be uniform.

(e) The track should be flexible and versatile keeping in mind the absorption of shocks and vibrations of running trains.

(f) The track should have a decent seepage (drainage) framework so that the stability of the track is not influenced by waterlogging.

(g) The track should have great sidelong quality with the objective that it can keep up its stability despite of varieties in temperature and other such elements.

(h) There should be procurements for simple substitution and renewal of the different track parts.

(i) The track should have such a structure, to the point that is its beginning cost low, as well as its upkeep expense is least.

2-3 Specification of the Indian Railway track

The majority of the railway lines on Indian Railways are single lines, by and large with its formation 6.10 m (20 feet) wide for Broad Gauge (BG) and 4.8 m (16 feet) wide for meter gauge. The development is for the most part is stable aside except the zones where clayey soil or other sorts of shrinkable soils are found. The majority of the track is straight with the exception of 16% of the track on BG and MG and 20% of the track on NG, which is on curves. The most extreme level of curve allowed is 10° on the Broad gauge, 16° on the meter gage, and 40° on the Narrow gauge. The ballast utilized is broken stone counterbalance, however in a few ranges, sand and coal ash have additionally been utilized. Around a 20 cm to 30 cm (8" to 12") cushion of ballast is typically given underneath the sleepers to transfer the load equitably and to give the essential flexibility to the track. The diverse materials used to build sleepers are wood (31%), cast iron (42%), and steel (27%). Experience has demonstrated that cast iron sleepers are not capable for high-density routes. Solid concrete sleepers have been created by Indian Railways and are proposed to be continuously laid on gathering on group A and B routes which are high speed lines of 160 km/h and 130 km/h on broad gauge routes.

Sleepers are laid to different sleeper densities differing from (M + 7) to (M + 4) or 1540 for each km to 1310 for each km relying on the weight and volume of movement. Here M stands for length of rail in meters. (M + 7) means 20 sleepers for every rail length for BG and 19 sleepers for every rail length for MG. The standards of rails for Indian Railways are 60 kg and 52 kg for BG and 90 R, 75 R and 60 R, for MG (in 90 R, 75 R, and so on.., R remains for reconsidered British specifications). Rails typically come in 13 m (42 feet) lengths for BG lines and 12 m (39 feet) lengths for MG lines.

The rails are welded together to frame longer rails also, are laid logically on the track so as to decrease maintenance costs and noise levels and subsequently give more comfortable travel. The rails are welded in three rail boards, regularly by the glimmer butt welding system, to frame short welded rails (SWRs). But long welded rails (LWRs) are also being dynamically presented on different routes of Indian Railways. Thermit welding is ordinarily done at the site to convert the short welded rails into the long welded rails. The fastenings utilized are generally screw and rail spikes, keys, and so on. Rail is to be more focused as the analysis is based on the rail and wheel. So, rail is described as follows.

2-4 Functions of Rails

Rails are like steel supports. These are given to perform the accompanying capacities in a track.

(a) Rails give a persistent and level surface for the displacement of trains.

(b) Rails give a pathway which is smooth and has very small value of friction. The friction between the steel wheel and steel rail is about one-fifth of the friction between the pneumatic tire and metalled road.

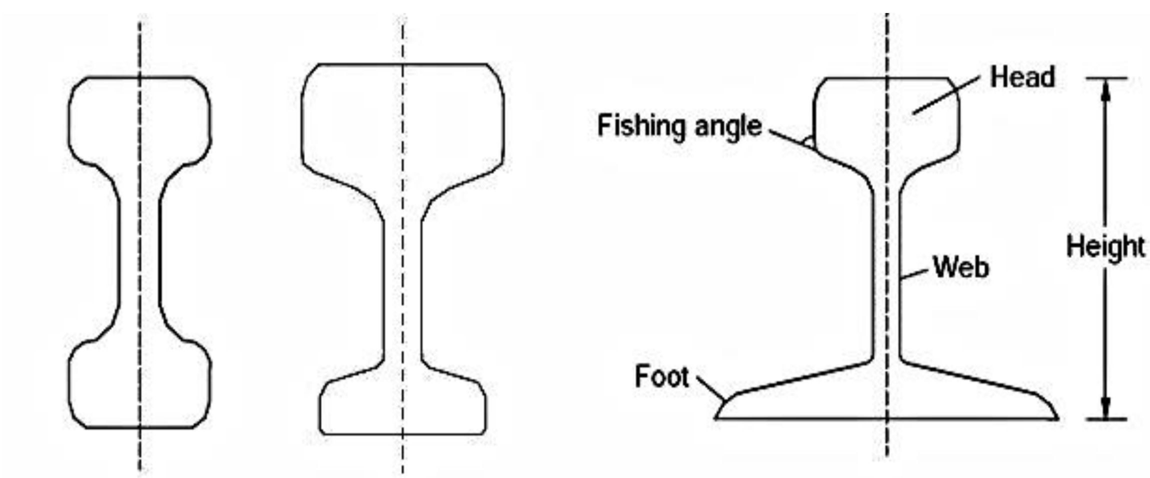
(c) Rails serve as a guide for the wheels in a lateral manner.

(d) Rails bear stresses grew because of vertical burdens transmitted to them through axles and wheels of moving stock and also because of braking and heating effects of thermal forces.

(e) Rails transmits the load to a vast region of the arrangement through sleepers and the ballast.

2-5 Types of Rails

The main rails utilized were *Double headed (DH)* and made of an I or dumb bell segment (Figure 2-2a). The thought was that once the head gets destroyed during the time of service then the rail could be inverted and can be reused again. Experience, in any case, demonstrated that while the time of service base table of the rail was dented to such a degree due to long and persistent contact with the seats of ballast and sleepers that it was impractical to reuse it. This prompted the advancement of the *Bull-headed (BH) rail*, which had a practically comparative shape yet with additional metal in the head to better withstand wear and tear (Figure 2-2b). This rail segment had the significant disadvantage that chairs were needed for fixing it to the sleepers.
A *flat-footed rail* (FF) (Figure 2-2c), with a rearranged inverted T-type of cross section was, accordingly, created, which could be settled straightforwardly to the sleepers with the assistance of spikes. Another point of advantage of the flat footed rail is that it is a more conservative and economical design outline, giving more noteworthy quality and sidelong security to the track when contrasted with a BH rail for a given cross-sectional area. The flatfooted (FF) rail has been adopted for selection on Indian Railways.



(a) Double Headed Rail (DH) (b) Bull Headed Rail (BH) (c) Flat-Footed Rail (FF)

Figure 2-2: Types of Rails [1]

2-6 Prerequisites of Rail Section

The necessities for a perfect rail area are as per the following.

(a) The rail should have strength, stiffness, most economical section and long lasting durability.

(b) The center of gravity of the rail should lie at the mid-stature of the rail so that the compressive stresses may remain equal to the tensile stresses

(c) A rail fundamentally comprises of a head, a web, and a foot, and there should be an appropriation of metal in its different parts so that each of them can satisfy its necessities appropriately.

2-7 Rail Standards

The rail is assigned by its weight per unit length. In FPS units, it is the weight in lbs per yard and in metric units it is in kg per meter. A 52 kg/m rail means that it has a weight of 52 kg for every meter. The heaviness of a rail and its section is chosen after the following considerations,

(a) Heaviest axle load

(b) Maximum allowable speed

(c) Depth of counterbalance cushion of ballast

(d) Type and distance between sleepers

(e) Other incidental variables

The standard rail sections being used on Indian Railways are 60 kg, 52 kg, 90 R, 75 R, 60 R and 50 R. The two heavier rail areas, 60 kg and 52 kg, were as of late presented and are assigned in metric units. Other rails are outlined according to the revised British Standard and are assigned in FPS units however their measurements and weight are presently in metric units. In the classification 90 R, 75 R etc. here R stands for amended or Revised British specifications. Each rail rolled has a brand on its web, which gets repeated at a particular intervals. According to IRS–T–12–88, the brand imprints are as per the following:

IRS-52 kg – 710 – TISCO – II 1991 →OB

The definitions for the above mentioned abbreviations are as per the following:

(a) IRS-52-kg: Number of IRS rail segment, i.e., 52 kg

(b) 710: Grade of rail section, i.e., 710 or 880

(c) TISCO: Manufacturer's name, e.g., Tata Iron and Steel Co.

(d) II 1991: Month and year of production (February 1991)

(e) → : A bolt demonstrating the direction the highest point of the ingot

(f) OB : Process of steel making, e.g., open hearth essential (OB)

The brand stamps on the rails are to be come in letters no less than 20 mm in size and 1.5 mm in tallness at interims of 1.5 to 3.0 m

2-8 Maximum Load on Rails

In spite of the fact that the weights of a rail and its section relies on different considerations, the heaviest axle load that the rail can carry, is the important parameter in freight traffic. The below written relationship gives the maximum axle load by creating the relating the maximum axle load to the rail section.

Maximum axle load = 560 × Sectional weight of rail in lbs per yard or Kg per meter

→For rails of 90 lbs/yard

Maximum axle load = 560 × 90 lbs = 50,400 lbs or 22.5 tonnes

→For rails of 52 kg/m

Maximum axle load = 560 × 52 kg = 29,120 kg = 29.12 tonnes

→For rails of 60 kg/m

Maximum axle load = 560 × 60 kg = 33,600 kg = 33.6 tonnes

2-9 Length of Rails

Hypothetically, the more extended the rail, the lesser the quantity of joints and fittings needed, the lesser the expense of development and support. Longer rails are temperate, give smooth and agreeable rides. The length of a rail is limited because of the following reasons.

(a) Lack of mode for transport of longer rails, especially on curves.

(b) Difficulties in manufacturing of long rails.

(c) Difficulties in getting greater expansion joints for long rails.

(d) Inner thermal stresses in heavy long rails.

Thinking seriously about the above variables, Indian Railways has approved a Rail length of 13 m for Broad Gauge (BG) and 12 m for Meter Gauge (MG) and Narrow Gauge (NG) tracks. Indian Railways is planning to utilize 26 m, and even longer, rails in its track framework.

2-10 90 UTS (Ultimate Tensile Strength) Rails

Indian Railways has basically been utilizing medium manganese rails having an Ultimate tensile Strength (UTS) of 72 kg/mm^2 & 90 kg/mm^2 for 52 kg/m rails and 90 kg/mm^2 for 60 kg/m rails, produced by the Bhilai steel plant. The service life of 52 kg (72 UTS) rails is just about 350 GMT (gross million tonnes per km/annum). These rails have the accompanying primary preferences because of the following reasons.

1).The service life of 90 UTS rails is around 50% more than that of customary medium manganese 72 UTS rails.

2).The aggregate GMT that 72 and 90 UTS rails can convey during their essential Service life is as per the following

Table 2-1: GMT limits for Rail Sections along with UTS

Section with UTS	Aggregate GMT
52 kg (72 UTS)	350 GMT
52 kg (90 UTS)	525 GMT
60 kg (90 UTS)	900 GMT

3) 90 UTS rails are stronger against wear and have a hardness of about 270 BHN (Brinell hardness number) as against that of 220 BHN of medium manganese rails with 72 UTS.

4) The permissible shear stress of 90 UTS rails is much higher, as can be seen from the table given below.

Table 2-2: Allowable Shear Stress

Rails	Allowable shear stress
Medium Manganese Rails (72 UTS)	18.0 kg/mm^2
Wear Resistant Rails (90 UTS)	22.5 kg/mm^2

Studies have demonstrated that the maximum shear stress because of BOXN wagons (Appendix I) could be of order of 20.0 kg/mm^2, which is in overabundance of the admissible shear stress for medium manganese 72 UTS rails. Subsequently, for routes on which BOXN wagons are running, it is the need to have 90 UTS rail.

2-11 Standard Section of Rails

As the 60 kg UIC rails are more common in use on the Indian railway track, that's why here in this chapter 60 kg rail is being used as a model geometry. The detailed dimensions of various standard rail sections are shown in Figure 2-3 & Table 2-3.

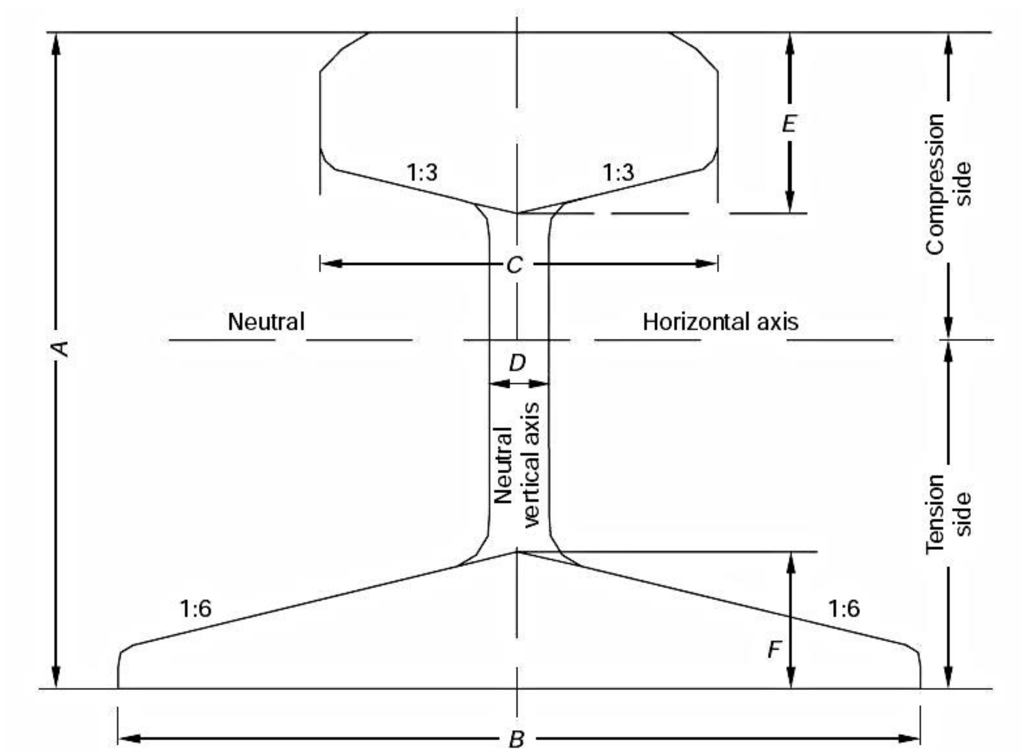


Figure 2-3: Standard flat foot Rail Section [1]

Table 2-3: Details of standard sections of Rails

Rail Section	Wt/metre (kg)	Area of section (mm2)	Dimensions (mm)					
			A	B	C	D	E	F
50 RBS	24.80	3168	104.8	100.0	52.4	909	32.9	15.1
60 RBS	29.76	3800	114.3	109.5	57.2	11.1	35.7	16.7
75 RBS	37.13	4737	128.6	122.2	61.9	13.1	39.7	18.7
90 RBS	44.61	5895	142.9	136.5	66.7	13.9	43.7	20.6
52 IRS	51.89	6615	156.0	136.0	67.0	15.5	51.0	29.0
60 UIC	60.34	7686	172.0	150.0	74.3	16.5	51.0	31.5

Rails are largely manufactured by Bhilai steel plant, Sail, Tata steel and Jindal steel & power. UIC 60 kg rail is most common manufactured by all of the industries, apart from this fact this particular section of rail is heavily dependent section of Indian railway. The following geometry of 60 kg rail has been adopted from UIC and is as per the strict dimensions.

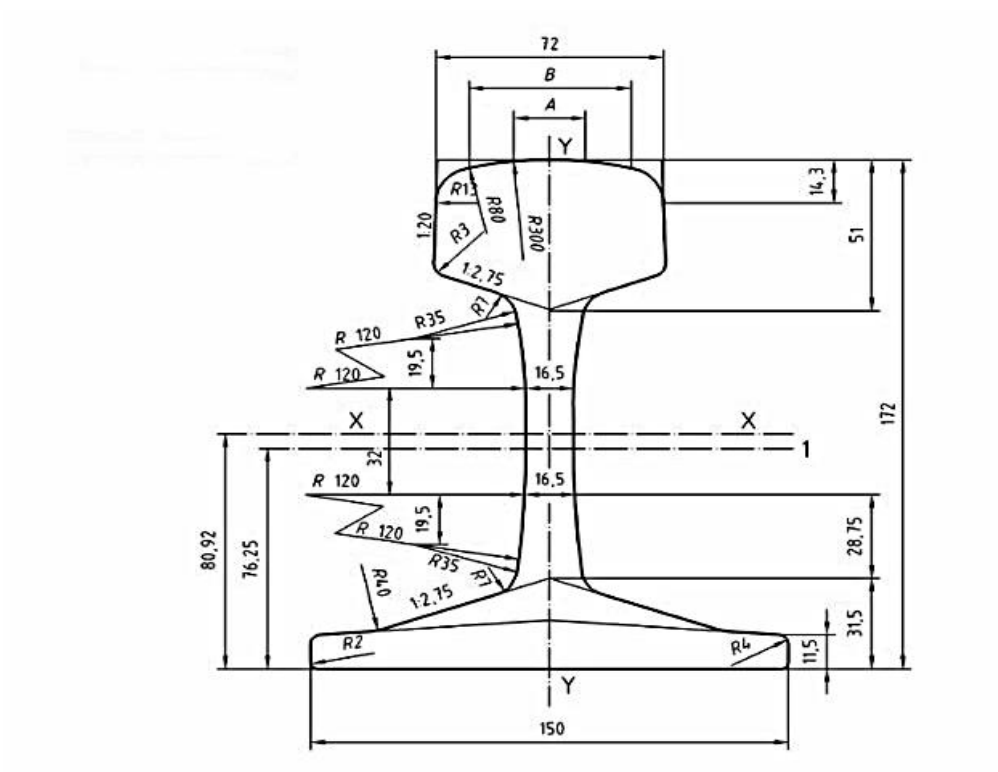


Figure 2-4: UIC 60 kg Rail {A=20.456 mm, B=52.053 mm}; [2]

1 is the Centre line of branding in Figure 2-4 and all the dimensions are in mm. Following are the details of above shown Figure 2-4

Cross-sectional area : 76.70 cm^2

Mass per meter : 60.21 kg/m

Moment of inertia x-x axis : 3038.3 cm^4

Sectional modulus - Head : 333.6 cm^3

Sectional modulus - Base : 375.5 cm^3

Moment of inertia y-y axis : 512.3 cm^4

Sectional modulus y-y axis : 68.3 cm^3

The UIC 60 kg rail consists head, fishing, web and base. It transfers the wheel load to the sleepers by acting as a girders. The dimensions of various parts of the rail cross section along with the values are present in Figure 2-5 & Table 2-4.

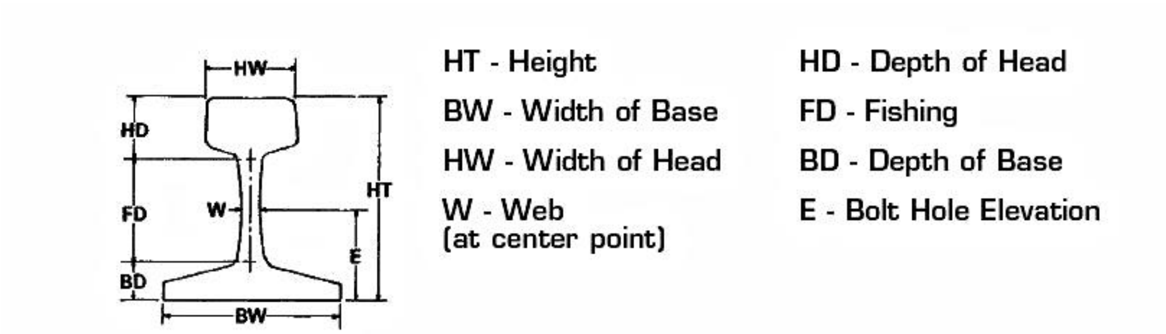


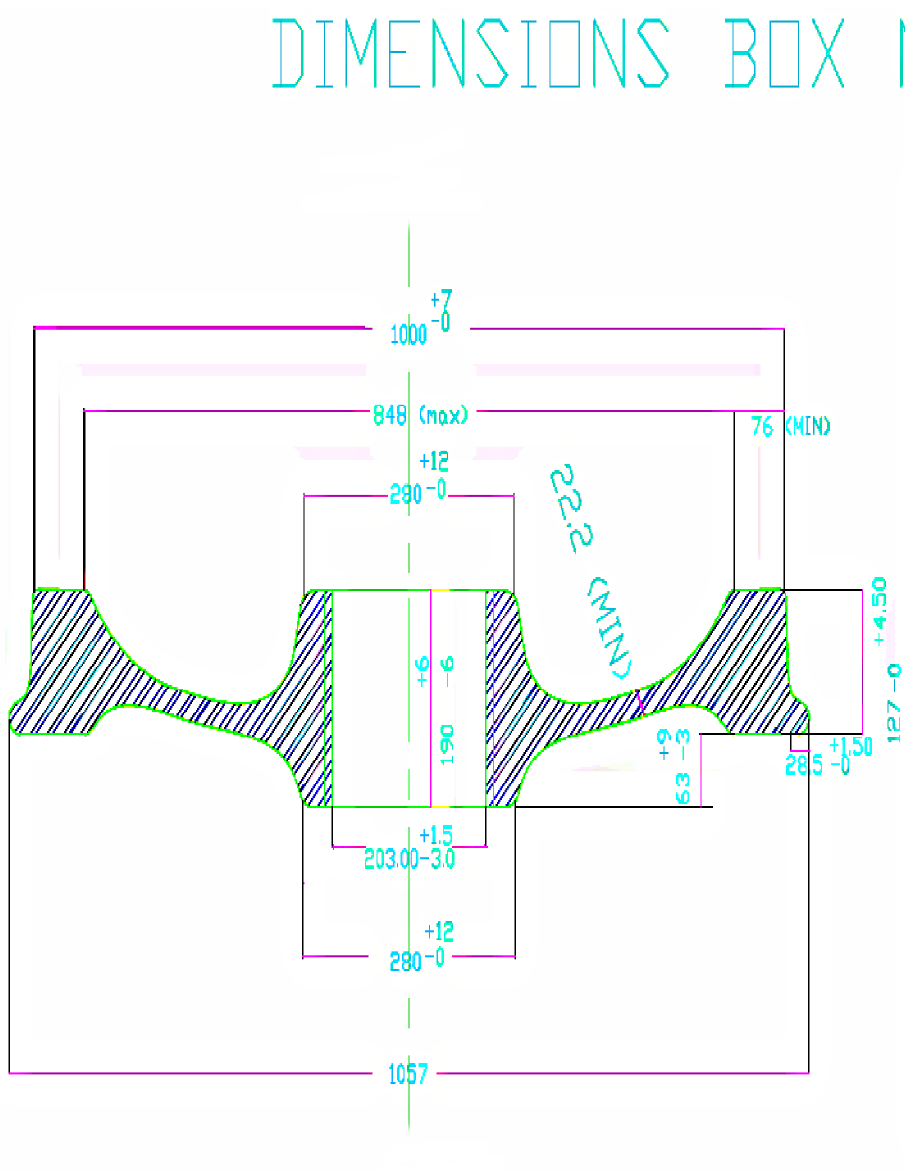
Figure 2-5: Nomenclature of UIC 60 kg Rail [11]

Table 2-4: Dimensions of UIC 60 kg Rail

Part names	Designations	Dimensions (mm)
Height	HT	172
Depth of head	HD	51
Width of base	BW	150
Fishing	FD	89.5
Width of head	HW	72
Depth of base	BD	31.5
Web	W	16.5
Bolt hole elevation	E	80.92

2-12 Standard section of Railway wheel

Below Standards for the wheel of train has been adopted from Rail Wheel factory, located at yelahanka, Bangalore (one of the production unit of Indian Railways). The wheel is of BOXN type, used primarily for transporting iron ore. These are open top wagons and is being used for the wagon having tare weight of 25 tonnes and axle load of 22 tonnes.



DIMENSIONAL LIMIT OF CASTWHEEL(BOX-N)		
S.No	DESCRIPTION	DIMENSIONAL LIMIT
1	TREAD DIA	1000 +7 -0
2	RIM INSIDE DIA	848 (MAX)
3	FRONT HUB DIA	280 +12 -0
4	BACK HUB DIA	280 +12 -0
5	HUB BORE(ROUGH)DIA	203 +1.5 -3
6	FLANGE HEIGHT	28.5 +1.5 -0
7	RIM WIDTH	127 +4.5 -0
8	HUB LENGTH	190 +6 -6
9	BACK HUB PROJECTION	63 +9 -3
10	OVER ALL DIA	1057
11	RIM HICKNESS	76 (MIN)
12	PLATE THICKNESS	22.2 (MIN)

Figure 2-6: Sketch of BOXN standard wheel [3]

Tread diameter is the second outermost diameter of the wheel which is about 1000 mm with positive tolerance of 7 mm. Maximum diameter of the rim at inside is about 848 mm. Front hub & Back hub diameters are of 280 mm with the positive tolerance of 12 mm. Bore diameter is of 203 mm with positive tolerance of 1.5 mm and negative tolerance of 3 mm. Flange height is of 28.5 mm with the positive tolerance of 1.5 mm. Rim width is 127 mm with positive tolerance of 4.5 mm. Hub length in which axle shaft has to be inserted is of 190 mm with ± 6 mm tolerance. Plate thickness at the mid of the wheel has to be maintained at least 22.2 mm. Overall diameter of the wheel is about 1057 mm. The wheel shown below in Figure 2-7 has been captured at Sahibabad Railway Station, Uttar Pradesh. The wheel is of open top wagon and is having the appropriate dimensions

Figure 2-7: BOXN standard wheel (Image captured at SBB Railway station)

2-13 Contact stresses Between Rail and Wheel

Hertz [4] defined a hypothesis to calculate the area of contact and the pressure distribution at the contact region between the rail and the wheel. According to this hypothesis, the rail and wheel contact is like that of two cylinders (the round wheel and the curved head of the rail) with their axes at right angle to one another. The territory of contact between the two surfaces is bound by an elliptical shape as demonstrated in Figure 2-8.

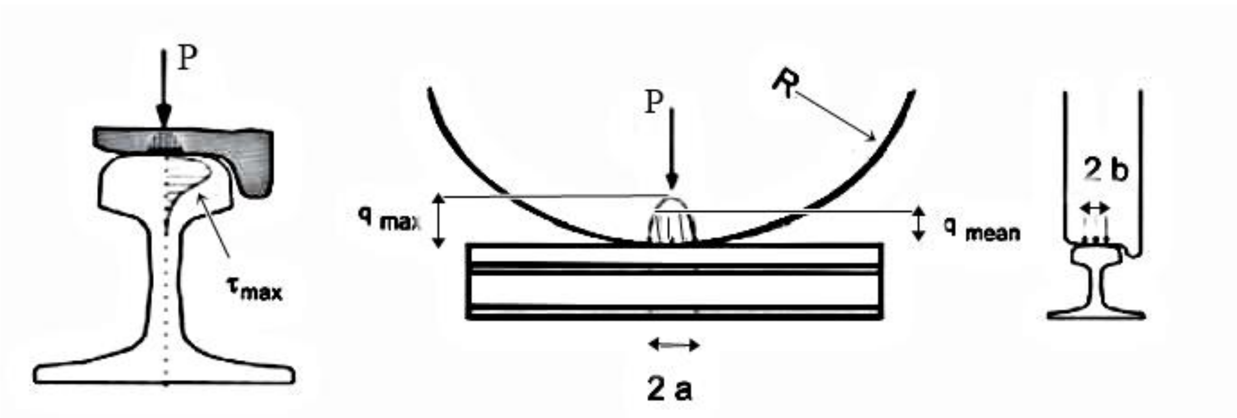


Figure 2-8: Shear Stress Distribution at Railhead [5]

Eisenmann [6] did the experiment and given expression for the maximum contact shear stress value at the point of contact between the rail and the wheel as

$$\tau_{max} = 4.13(P/R)^{1/2}$$

Where, τ_{max} is the maximum shear stress in kg/mm^2, R is the radius of the wheel in mm, and P is the (static wheel load in kg + 1000 kg due to curve loading). Maximum Contact shear stress presents at a depth of 5-7 mm below the rail surface.

NOTE: The maximum value of contact stresses for BG is limited to 30% of the UTS value i.e.

For 72 UTS Rail the maximum contact stresses value will be 30 % of 72 i.e. 21.6 kg/mm^2.

For 90 UTS Rail the maximum contact stresses value will be 30 % of 90 i.e. 27 kg/mm^2.

2-14 Bending stresses in Rails

Satish Chandra & M.M. Aggarwal [1] explained the general hypothesis (theory) of bending of rails by taking into account the suspicion that the rail is a long bar constantly bolstered by a flexible establishment of elastic foundation. The rail is subjected to flexural or bending stresses due to the vertical load on it. The bending stresses that a rail is subjected to as an aftereffect of vertical burdens is outlined in figure 2-4. The hypothesis of stresses in rails considers the elastic nature of supports. Based on this theory the outcome for the bending stresses is as follows.

$$M = 0.25pe^{-(x/l)}\,[\sin x/l - \cos x/l]$$

where, M is the bending moment, p is the segregated vertical load, $l=(EI/\mu)^{1/4}$ is the characteristic length, EI is the flexural stiffness of rail, μ is track modulus, and x is the distance of the point from the load.

As indicated by the bending moment equation the bending moment is zero at the points where $x= \pi l/4$, $3\pi l/4$ and maximum where $x = 0$, $\pi l/2$, $3\pi l/2$, and so on.

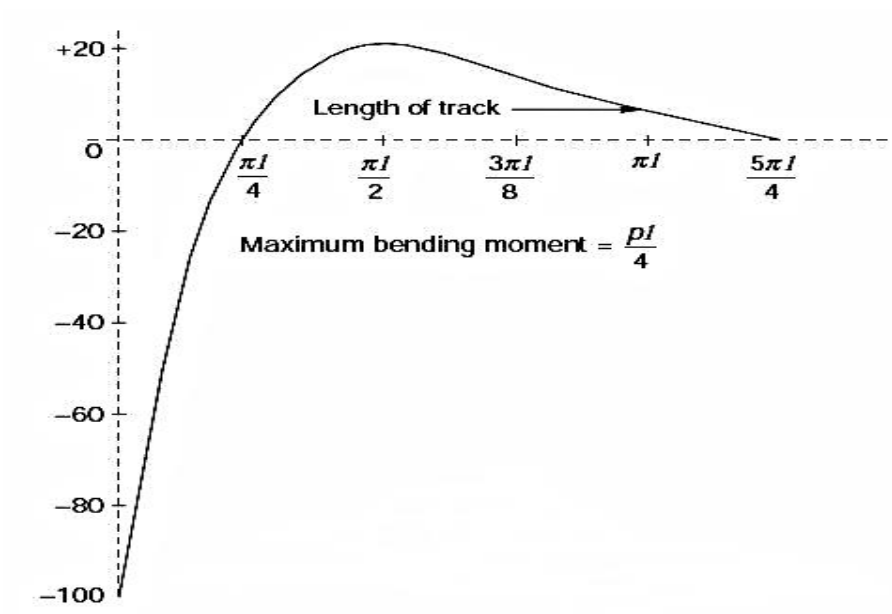


Figure 2-9: Variation of bending stress with the distance from the contact [1]

For ascertaining the stresses following up on the rail, first the maximum bending moment needs to be calculated due to the series of loads. Then bending stress can be easily calculated by dividing the bending moment by the section modulus (z =I/y) of the rail.

2-15 Limiting Values of Stresses on Broad Gauge for 90 UTS Rail

Table 2-5: Limiting value of stresses on BG for 90 UTS

Parameter	Permissible value (kg/mm^2)
Bending stresses on the Rail	36.0
Contact stress between Rail and wheel	21.6
Fish Bolt Stresses	30
Bolt hole Stresses	27

2-16 Research gap

The literature review indicates that the axle load on freight wagon is about 25 tonnes in India including the tare weight of wagon on 90 UTS rail of 60 kg section. The maximum contact stress for 90 UTS Rails is 30% of the ultimate tensile strength i.e. 27 kg/mm^2, that means the axle load can be increased in such a way so that the maximum contact stresses remains less that the permissible limit of maximum contact stress and load capacity of freight wagon could be increased up to 130 tonnes.

CHAPTER 3

COMPUTATIONAL MODELLING

3-1 Elements of the model

As the analysis is based on the geometry of rail & wheel so the main elements of the modelling are the rail and wheel used in Indian railways on permanent way. It seems very simple task to model these two geometries but it isn't. In fact when smaller thing gets modeled it becomes very difficult task to maintain accuracy while modelling. The main elements of the modelling are

1. Rail
2. Wheel

While modelling it is the necessity to maintain the accuracy, design and dimensions of the elements. To model the Rail, it was important to follow the international standards of rails as provided by UIC (International Union of Railways) whereas to model the wheel, Indian standards has been kept in attention provided by the Rail Wheel factory, located at yelahanka, Bangalore. It is one of the production unit of Indian Railways.

3-2 Units and Standards of the geometry for the Models

Unit selection plays an important role in order to maintain the accuracy, so units must be declared to move further for modelling. The units used in the modelling are presented in the Table 3-1

Table 3-1: Units

Dimensions	Units	Symbols
Length	Milimeter	[mm]
Force	Newton	[N]
Mass	Tonne	[ton]

3-3 Standards for Rails

Rails are the members used in track of permanent way in two parallel lines so as to provide a continuous surface for the movement of wheels of train over it. It is designated by its weight per unit length. For an example – A 60 kg/m rail denotes that it has a weight of 60 kg per meter. The most used standards of rail sections of Indian railways are given in Table 3-2.

Table 3-2: Standard Rail Sections

Gauge	Rail Section	Type of Section	Rail length
Broad Gauge	60 kg/m	UIC	13 m
Broad Gauge	52 kg/m	IRS	12 m

UIC - International Union of Railways, IRS - Indian Railway Standard, RBS - Revised British Standard

Material Composition and Properties of Rails

On the Railway tracks of Indian railway most used rail is 60-kg UIC section rail. It is being designed for speeds upto 160 kmph and can sustain a traffic density of 35 GMT (gross million tonnes per km/annum). Rails are made up of High carbon steel so as to sustain the high stresses without undergoing any deformation or failures. The Cast steel used for the manufacturing of rails should have the following chemical and mechanical compositions given in the following tables.

Table 3-3: Chemical composition

Grade	Carbon C	Manganese Mn	Silicon Si	Sulphur S (max.)	Phosphorous P (max.)	Aluminium Al (max.)	Liquid hydrogen H_2
880	0.6-0.8	0.8-1.3	1.3-0.5	0.04	0.04	0.02	3.0

Table 3-4: Mechanical properties

UTS (Mpa)	Young's Modulus, E (Mpa)	Running Surface Hardness	Density (Tonnes/mm^{3})	Yield Strength (Mpa)	Poisson's ratio	Tangent Modulus (Mpa)
880	2.1×10^5	260	7.85×10^{-9}	460	0.265	34,000

3-4 Modelling of UIC 60 kg Rail

The geometry of UIC 60-kg rail consists a complex dimension system with lots of arc & radius at the corners. Multiple arcs and radii are the main complexity of this geometry. While modelling this geometry, it is very necessary to plot the major dimensions first then to move other dimensions. Maintaining the dimensions while creating the radii over one another is quite a difficult job to perform in modelling, hence it becomes necessity to lock some major dimensions in order to perform the complex command operations. If the model gets over constraint while modeling then unlock some dimensions to make the model constraint free. Creo parametric 2.0 has provided the ease to manipulate the dimensions according to the need and requirement of the user, with the full ease provided to the user. The rail model prepared in the following steps

1. Sketching - The sketching is the root to generate a part model. While sketching the attention need to be focused on dimensions & making the sketch a closed region as the sketch has a lot of dimensions and radii.
2. Part Modelling - After sketching, extrude the closed region of sketch up to a considerable length of 1500 mm so as to model the sketch into solid body.
3. Drafting - This feature gives the different views (top, side, front, back) of the part modeled and that data matters a lot for the manufacturing firm for production of products.

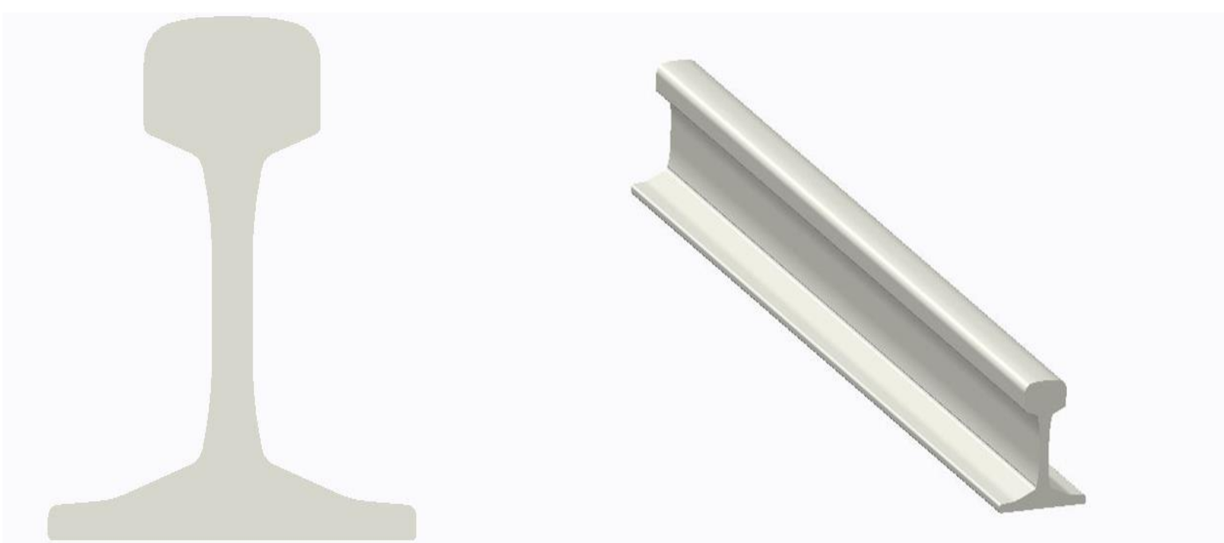


Figure 3-1: Modelled view of Rail a) Front view b) Isometric view

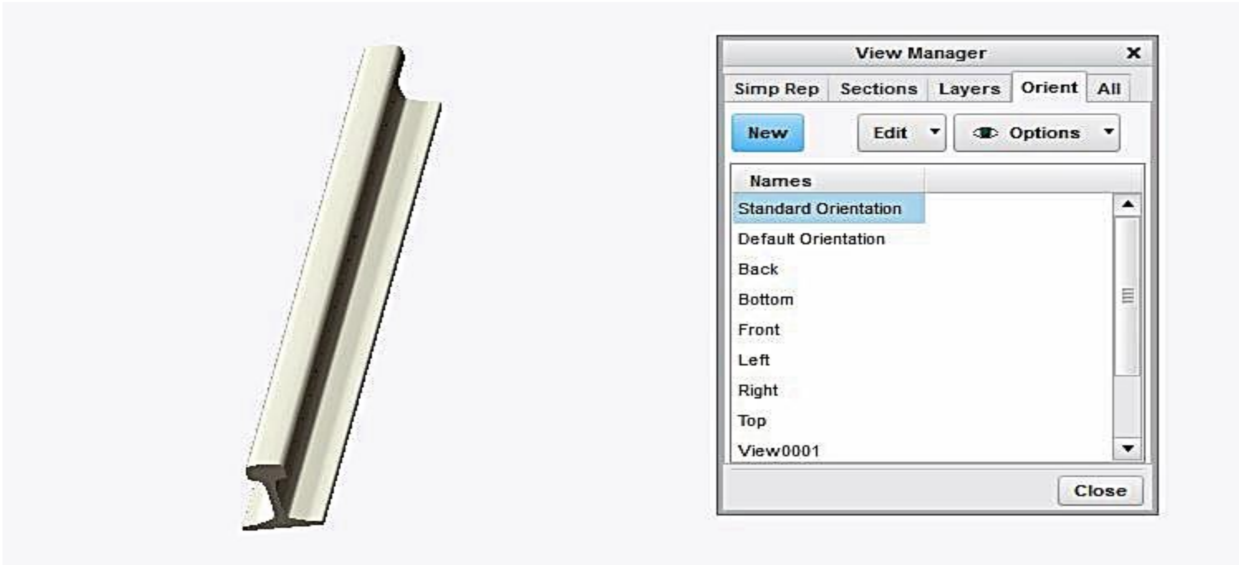


Figure 3-2: Standard orientation of UIC 60 Rail in Creo parametric 2.0

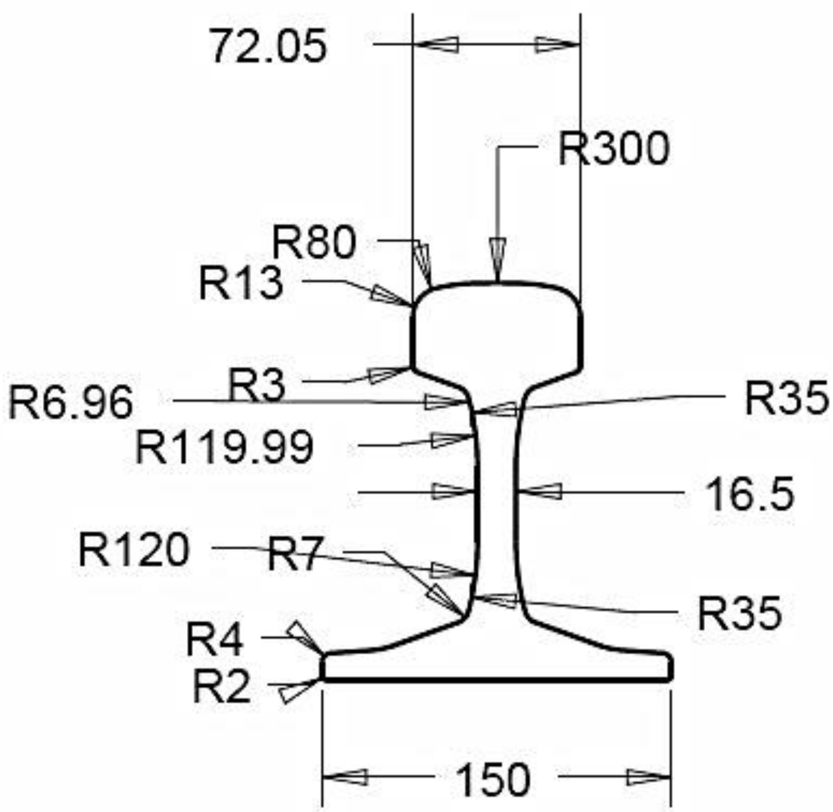


Figure 3-3: Front view of UIC 60 Rail with drafting dimensions in Creo parametric 2.0

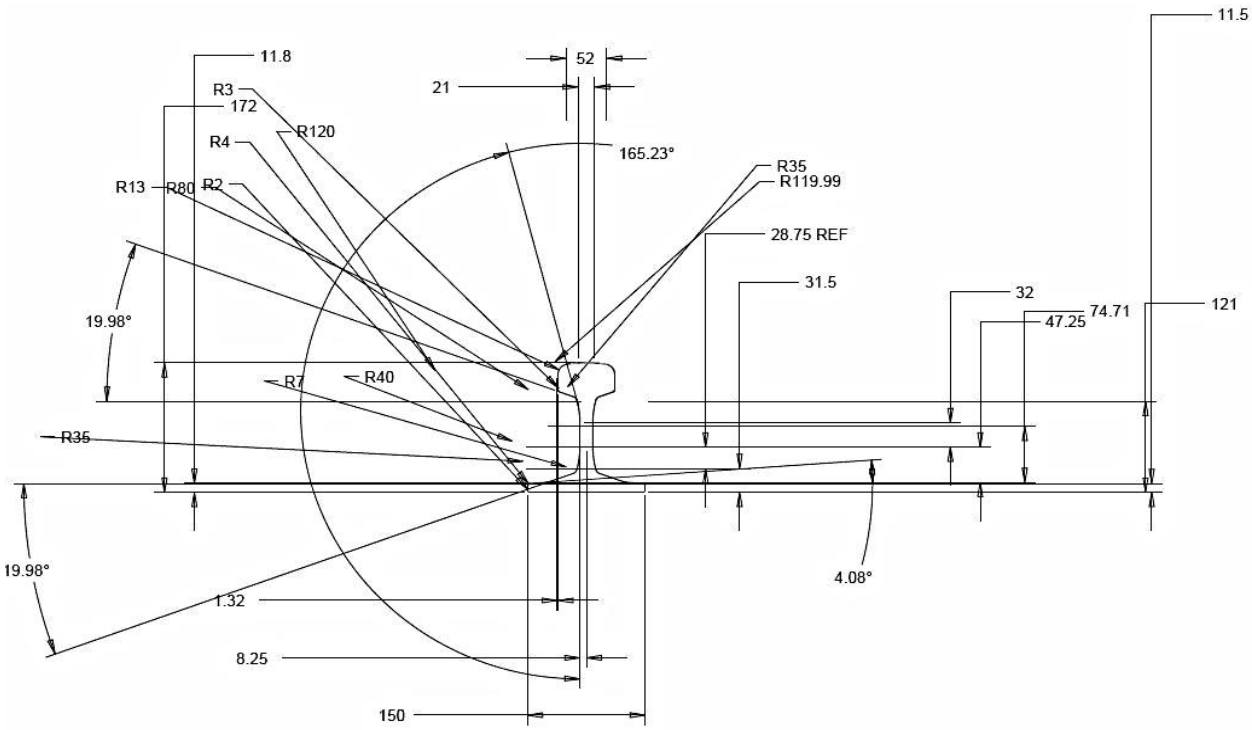


Figure 3-4(a): Front view of UIC 60 Rail with Complex drafting dimensions in Creo parametric 2.0

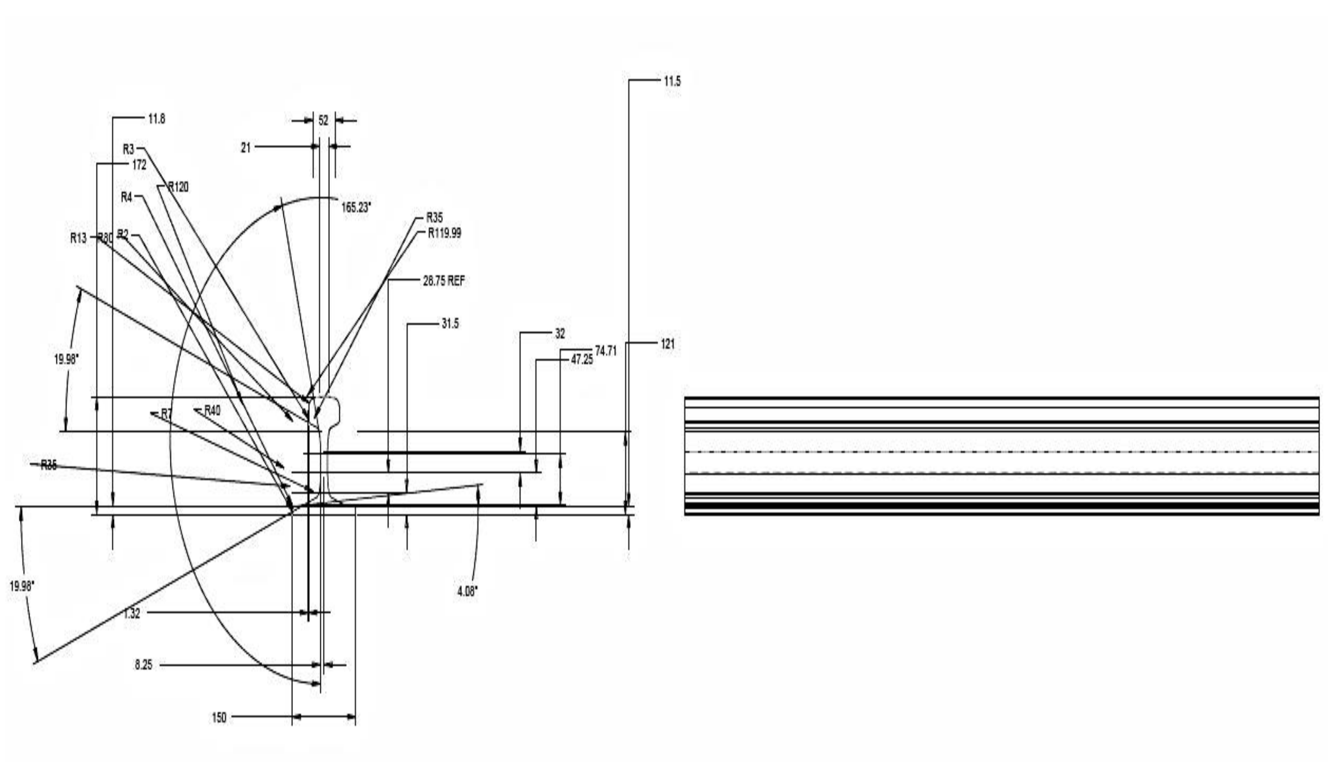


Figure 3-4(b): Front & Side view of UIC 60 Rail with Complex drafting dimensions in Creo parametric 2.0

3-5 Tolerances for Rails

On determining the weight of the rails, it should come 0.5% below and 1.5% above than its calculated weight. It is the condition on which the tolerances are subjected, so we should take care of weight along with the dimensions.

Table 3-5: Allowable variations in dimensions of rails

Item	Tolerances
Overall height	+0.8 mm to -0.4 mm
Width of head	± 0.5 mm
Width of flange	+1.2 mm to -1.0 mm
Thickness of web	+1.0 mm to -0.5mm
Vertical flange	± 1.2 mm
Length of rails	+2.0 mm to -10 mm

3-6 Standards for Railway Wheels

Wheels are the driven rolling elements of the train which take care of the entire wagon load on it. In this chapter, Standards for the wheel of train has been adopted from Rail Wheel factory, located at yelahanka, Bangalore (one of the production unit of Indian Railways).

Material composition of Railway wheel

Chemical composition of the wheel consists of carbon, silicon, manganese, silicon, molybdenum, nickel, Sulphur, & phosphorus in considerable amounts. In addition to this gas content is also being added in form of nitrogen & hydrogen. On a combined level the amount of chromium, molybdenum & nickel should be less than or equal to 0.4%. The material used for wheel is also Cast steel.

Table 3-6: Chemical composition of Railway wheel

Materials		Contents (%)
Carbon (%C) (Class B)		0.55-0.70
Manganese(Mn)		0.57-0.83
Silicon (Si)		0.12-0.73
Chromium (Cr)	Combined 0.40 maximum	0.2 max
Molybdenum(Mo)		0.08 max
Nickel (Ni)		0.3 max
Sulphur (S)		0.035 max
Phosphorus (P)		0.035 max
Gas content		
Nitrogen (N_2)	70 ppm max	
Hydrogen (H_2)	03 ppm max	

3-7 Modelling of Railway wheel

The half made sketch of BOXN wheel has been revolved about the geometric centre line created at the lateral axis of the wheel in creo parametric 2.0.

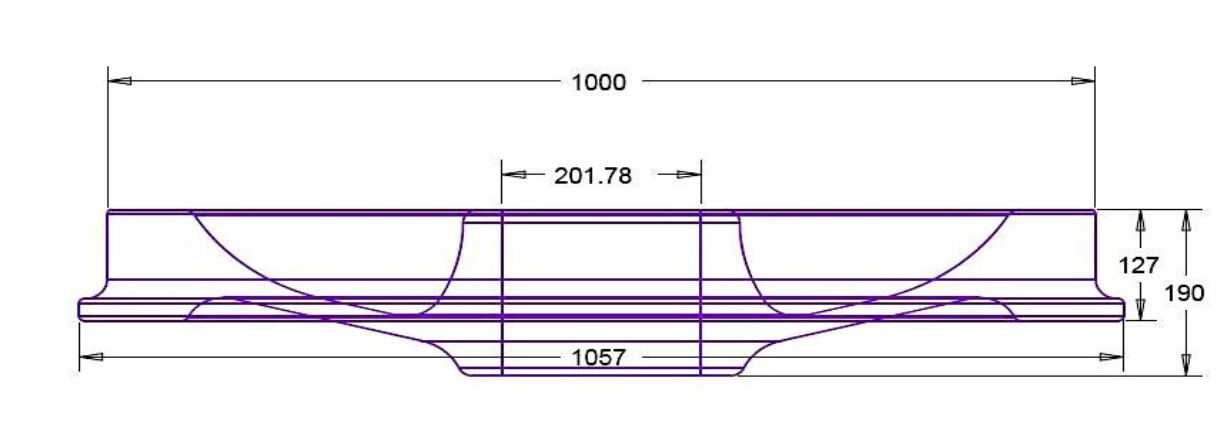


Figure 3-5: BOXN wheel drafting in Creo parametric 2.0

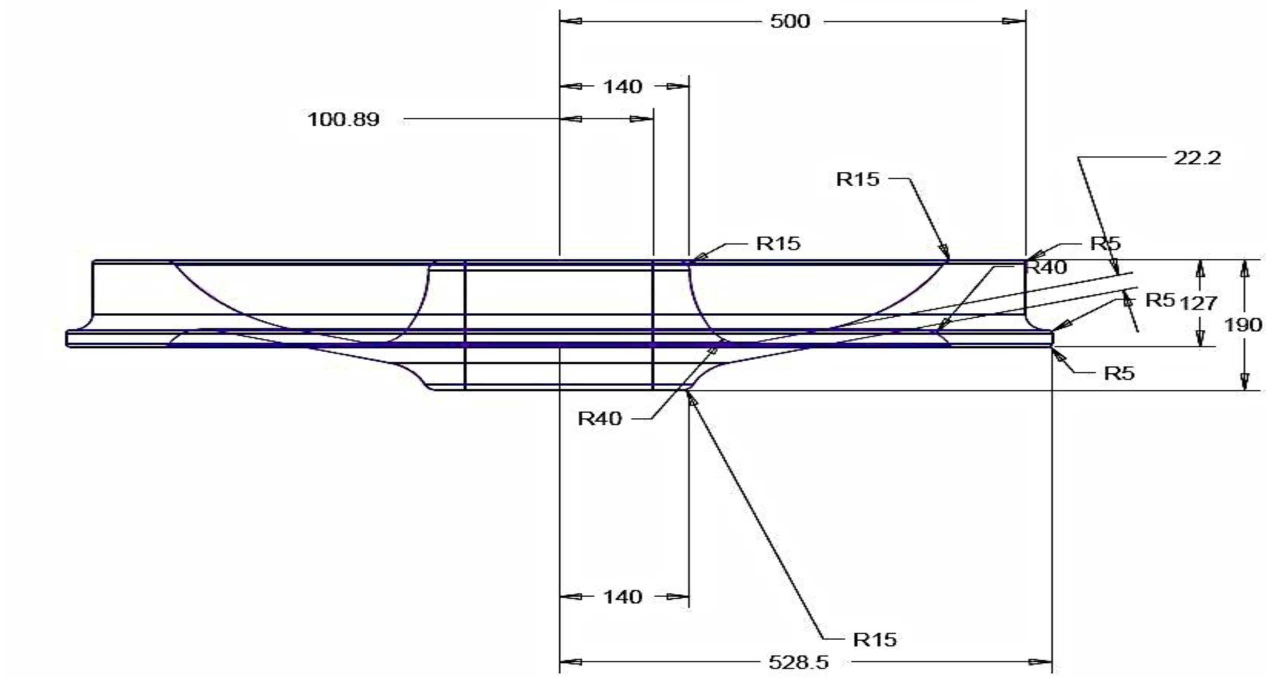


Figure 3-6(a): BOXN wheel complex drafting in Creo parametric 2.0

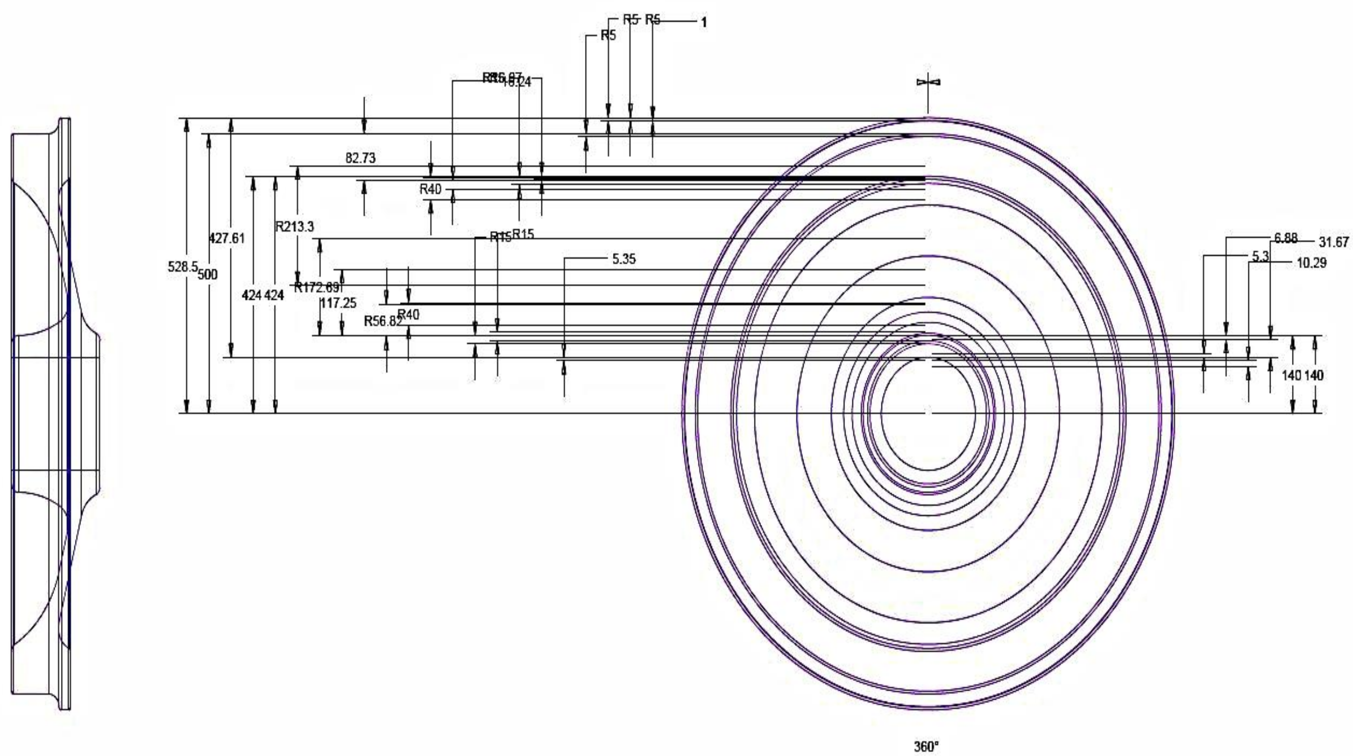


Figure 3-6(b): BOXN wheel drafting in front view & side view in Creo parametric 2.0

Figure 3-7: Side views of Model of BOXN wheel in Creo parametric 2.0

3-8 Rail-Wheel Assembly

The assembly of rail and wheel has been kept so simple and effortless as only two components needs to be assembled. Smooth and uncomplicated component designs allowed to assemble both the parts in an accessible manner. The first objective was to maintain the ease of assembly. During the assembly, firstly the rail was being fixed as it is the most stable component of the permanent way so, the relationship status of the rail was set to default according to the assembly. Then focus was on to create the relationship status between the rail and wheel & it was given the tangent status between rail and wheel.

The head radius of 300 mm of rail was set tangent to the tread of the wheel as the contact region for analysis will be in between the tread and head of the rail. The contact region was the essential and prime intent on which attention needs to emphasize while analysis. The assembly has been shown in the following Figure 3-8.

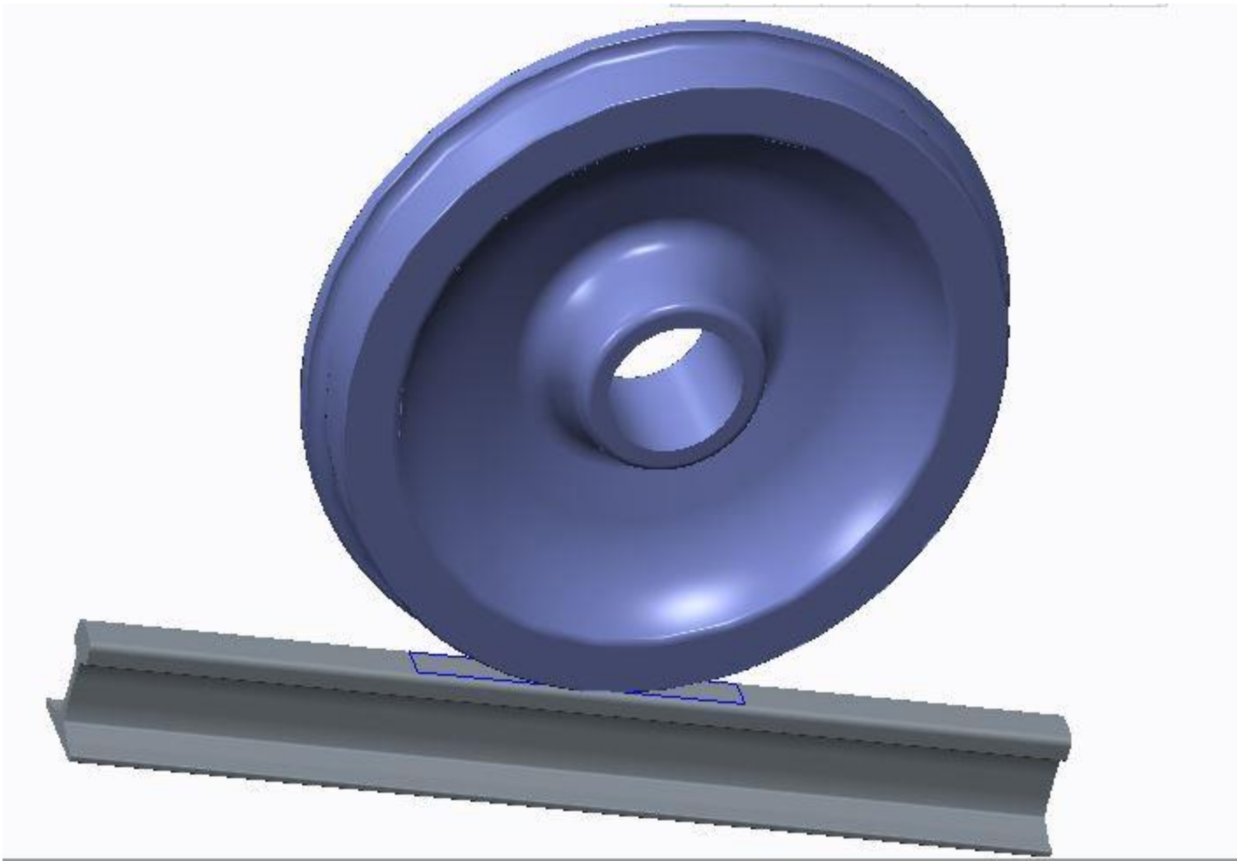


Figure 3-8: Assembly of Rail-Wheel in Creo parametric 2.0

3-9 Projection of Curves for Contact Region

The curve for the contact region has been projected on the surfaces where the contact is, which means around the contact interface by creating some of the curves so as to define the contact surface. The curve has been drawn on the rail head bounding the 80 mm & 300 mm radii on the rail, then it has been projected on the wheel using the projection command. It can be observed that the curves highlighted in blue colour is being used for the contact region for the rail and wheel. It’s a quite unusual projection as it is on the rail head which itself has a number of radius over it. So it is very rare to project the curve on to the curve which is actually a radius on the head of the rail. The curve has the dimension of 52 mm on the radius of 80 mm & 300 mm over the rail head and the lengthwise dimension of curve is 500 mm. The curve projection has been shown in blue colour in Figure 3-9.

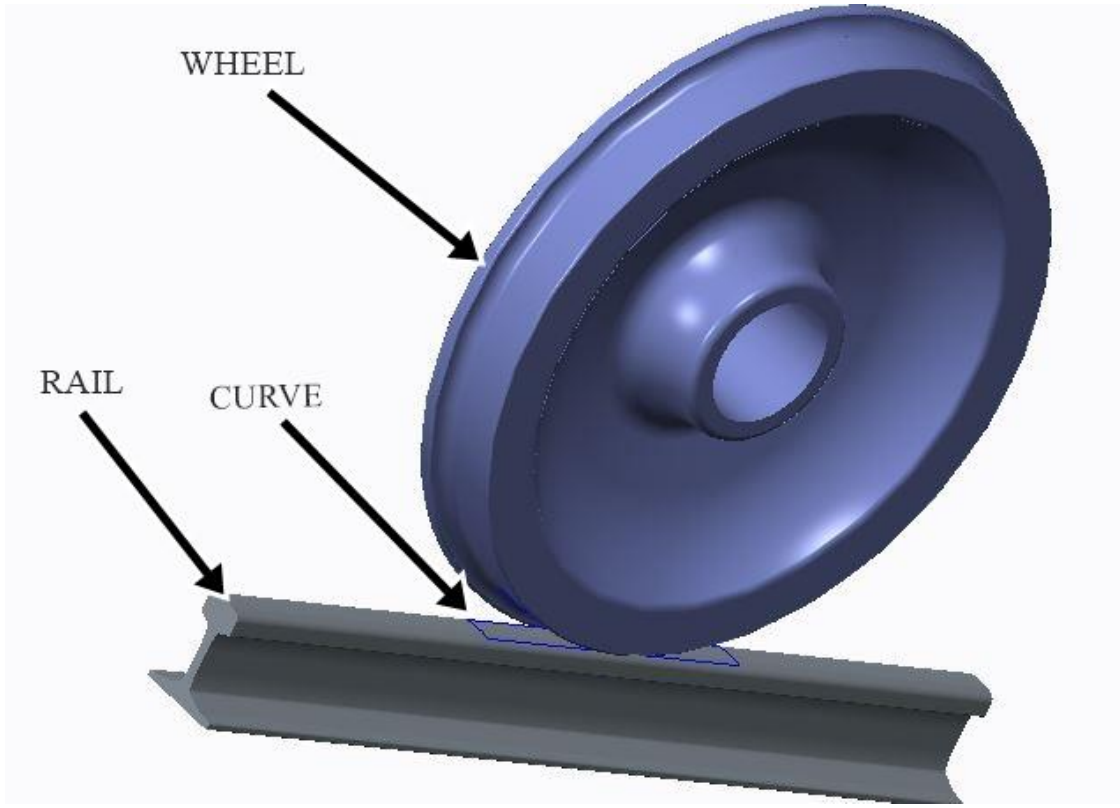


Figure 3-9: Projection of curve as contact region on Rail-Wheel in Creo parametric 2.0

CHAPTER 4

COMPUTATIONAL STATIC ANALYSIS

4-1 Analysis of Contact region of Rail-wheel

The contact region is between two bodies, both the bodies are made up of steel material. The parts are rail and wheel. They are having a point contact between them and these two bodies are meshed with suitable elements. The desired results like the stress and contact pressure are to be evaluated in this report.

Let us proceed with the analysis. Using the assembly of Rail-wheel cad model prepared in the last chapter, the analysis has been processed. The curve for the contact region has been projected on the surfaces where the contact is, which means around the contact interface by creating some of the curves so as to define the contact surface.

The curve has been drawn on the rail bounding the 80 mm & 300 mm radius on the rail, then it has been projected on the wheel using the projection command. It can be observed that the curves highlighted in blue colour is being used for the contact region for the rail and wheel. Once the modelling is done, the file has been exported to a neutral format like STEP so that it could open in ansys. Under the export STEP window, by selecting solid and shell, also selecting the datum curves which are required for splitting the surface in ansys design model the file has been exported to the Ansys.

4-1-1 Material selection

In ansys workbench, the static structural project has been used in order to carry the analysis. The file has been renamed as Rail-wheel. Cast steel of grade 880 is used as the material for the rail and wheel. Under the engineering data the values of material properties has been entered, before that units has been checked carefully and the metric activated units are done in millimeter and second, which are the desired units. The material used for the rail & wheel is structural steel which has been given the properties of cast steel by manipulating the default properties of the structural steel. Density is to be in tonne/mm^3, young's modulus to be in Mpa and the value of poisson ratio is 0.265, which is for cast steel grade 880.

4-1-2 Bilinear isotropic hardening

Bilinear isotropic hardening has been included. In isotropic hardening the yield surface expands uniformly in all the directions during the plastic flow. The term 'isotropic' in isotropic hardening refers to the uniform dilatation of the yield surface which is different from a general 'isotropic' yield criterion (i.e., material orientation).

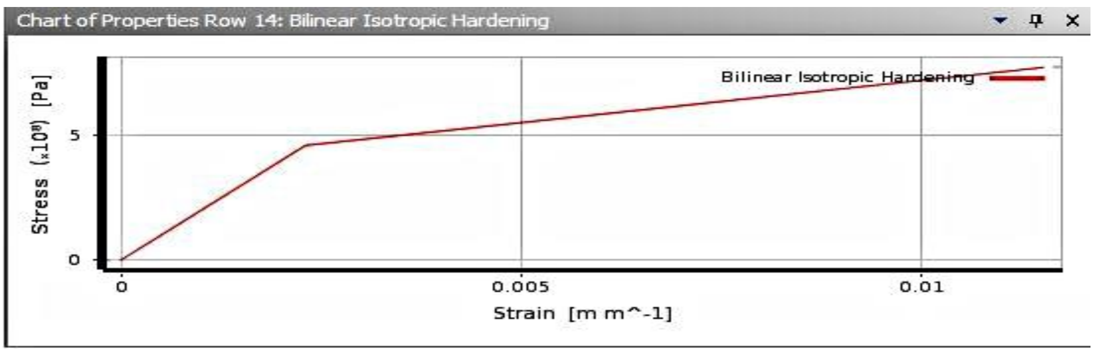


Figure 4-1: Bilinear isotropic hardening in Ansys 15.0 for cast steel grade 880

The slope of stress-strain curve is shown in figure 4-1 & the general representation of Isotropic hardening is shown in figure 4-2.

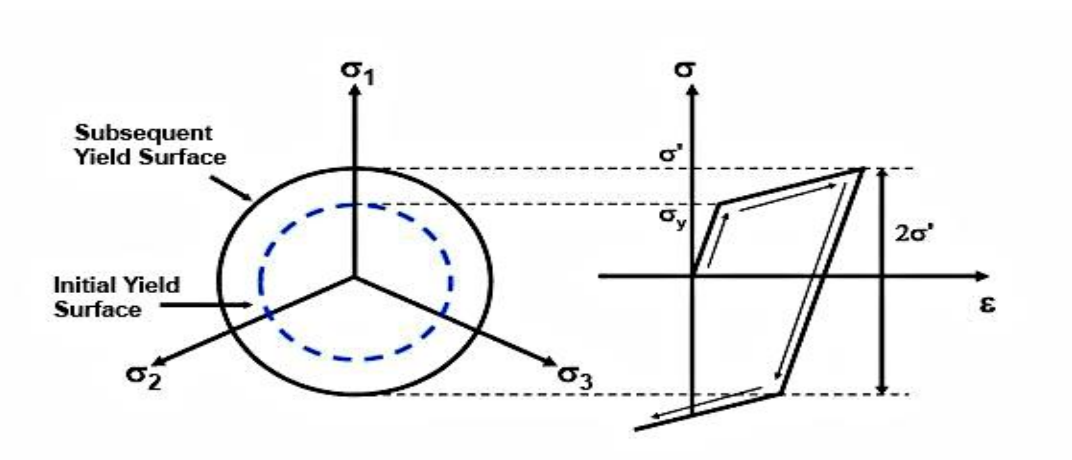


Figure 4-2: Isotropic hardening (Ansys Inc. proprietary) [7]

4-1-3 Tangent modulus

It is the slope of the stress strain curve at a particular value of stress or strain. The units of yield strength and tangent modulus to be in Mpa. Yield strength to be 460 Mpa and tangent modulus to be 34000 Mpa. It is 20000 Mpa for the structural steel. Tangent modulus is another interesting property of this structural steel, when the material shows the non linear elastic stress-strain behavior tangent modulus need to be included to know the value of change in strain for a specified range of stress. There is no particular value of tangent modulus and it varies with the strain and describes the type of hardening. The value of tangent modulus is given by the Ramberg-Osgood equation. It is the inverse of first derivative with respect to strain

$$E_t = \frac{E\sigma_{ys}}{\sigma_{ys} + 0.002\, n\, E\, (\sigma/\sigma_{ys})^{n-1}}$$

Where, E_t = Tangent modulus

E = Young's modulus

σ = stress

σ_{ys} = yield strength

n = Ramberg-Osgood parameter (strain hardening exponent), measure of non-linearity of the curve. Normally its value is 5 or more than 5.

Using this expression the value tangent modulus is 34 000 Mpa. Tangent modulus is used to find the value of slope in stress-strain curve beyond the yielding point. The term is little bit confusing as it doesn't give indication about stiffness, and elastic behaviour but estimates the hardening effect.

For structural steel the values are

E_t = 20000 Mpa,

$E = 2 \times 10^5$ Mpa

σ_{ys} = 250 Mpa

Inserting these values in the formula of tangent modulus, we get the following results

$$20000 = \frac{2 \times 10^5 \times 250}{250 + 0.002\, n \times 2 \times 10^5 (\sigma/\sigma_{ys})^{n-1}}$$

$$n(\sigma/\sigma_{ys})^{n-1} = 5.625$$

if , $((\sigma/\sigma_{ys})^{n-1})_{\text{structural steel}} = ((\sigma/\sigma_{ys})^{n-1})_{\text{cast steel Grade 880}}$ then,

<u>For Cast steel Grade 880</u> we have the following values

E_t = ?

E = 2.1×10^5 Mpa

σ_{ys} = 460 Mpa

$n(\sigma/\sigma_{ys})^{n-1} = 5.625$

Inserting these values in the formula of tangent modulus, we get the following results

$$E_t = \frac{2.1 \times 10^5 \times 460}{460 + (0.002 \times 2.1 \times 10^5 \times n\, (\sigma/\sigma_{ys})^{n-1})}$$

$$E_t = \frac{2.1 \times 10^5 \times 460}{460 + (0.002 \times 2.1 \times 10^5 \times 5.625)}$$

$$E_t = 34224.977 \text{ Mpa}$$

For the design purpose the value of tangent modulus for rail & wheel has been taken 34000 Mpa.

4-1-4 Material Data of Structural Steel GRADE 880

Table 4-1: Constants for structural steel

Density	7.85e-009 tonne mm^{-3}
Coefficient of thermal expansion	1.2e-005 C^{-1}
Specific heat	4.34e+008 mJ $tonne^{-1}$ C^{-1}
Thermal conductivity	6.05e-002 W mm^{-1} C^{-1}
Resistivity	1.7e-004 ohm mm

Table 4-2: Parameters of Strain life

Strength coefficient, Mpa	Strength exponent	Ductility coefficient	Cyclic hardening component	Cyclic strength coefficient, Mpa	Ductility Exponent
920	-0.106	0.213	0.2	1000	-0.47

Table 4-3: Isotropic Elasticity

Young's modulus, Mpa	Bulk Modulus MPa	Poisson's Ratio	Shear Modulus MPa
2.e+005	1.4184e+005	0.265	79051

Table 4-4 Bilinear isotropic Hardening

Tangent Modulus MPa	Yield Strength MPa
34000	460

4-2 Design Modeler

Once the material is completely defined with the proper units, then it needs to import the CAD geometry named rail-wheel.step which is an assembly file. The checkmark gets highlighted when the geometry gets imported in the ***design modeler***. The model has too many bodies including the lines which can be seen from the parts of the bodies. Actually the need is only for the roller and the rail, others are the lines which will be used to create the projection on the surface. Those lines have been ***suppressed*** which were not requiring. Now there it is only the curves which are required for splitting the surface.

Then with the help of ***face split*** in the dropdown of tools selecting the face to be split under the target face which is rail, the curve on the rail gets selected. Now it was the turn to apply the face split on wheel, by selecting the target face and then the required curve of contact region. The curve on the rail & wheel gets highlighted. Then the face split has been generated which means the surface has split on which the contact regions being imposed.

When both the face split gets done then suppress the bodies or line bodies which are not required. Then it has been observed that the split edges are not the curve bodies or line bodies, which earlier were before the face split. Now the model has fulfilled all the requirements which are required for the simulation and is ready to import in ***Mechanical solver***.

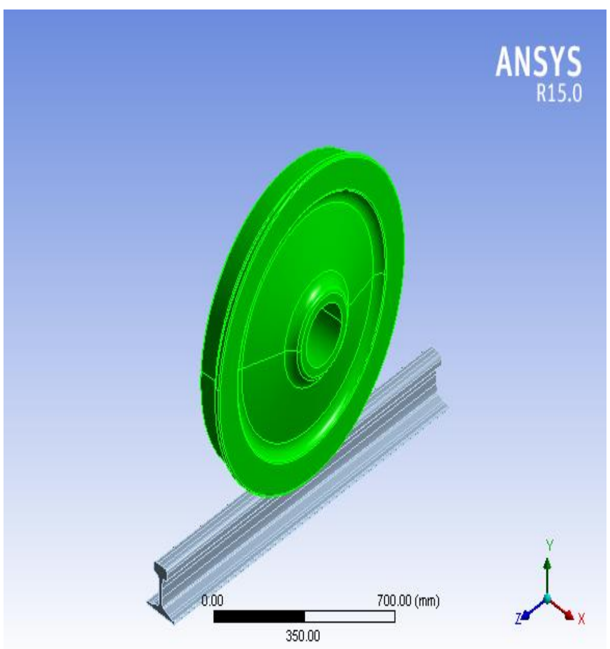


Figure 4-3 (a): Wheel in Ansys 15.0

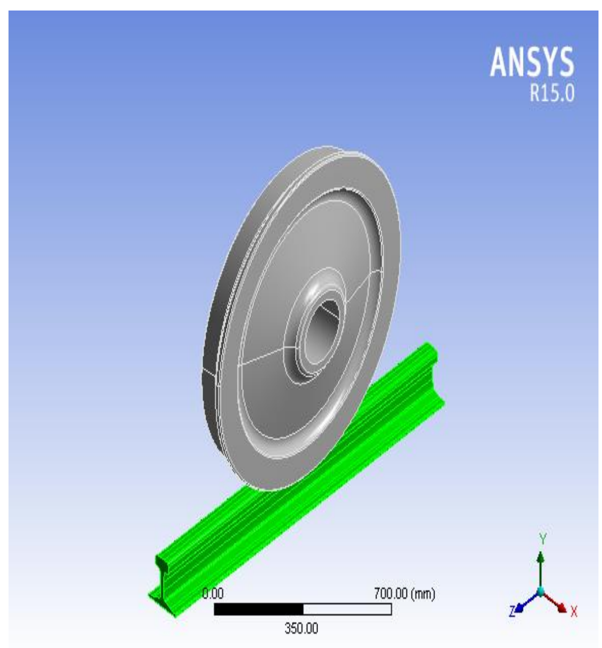


Figure 4-3 (b): Rail in Ansys 15.0

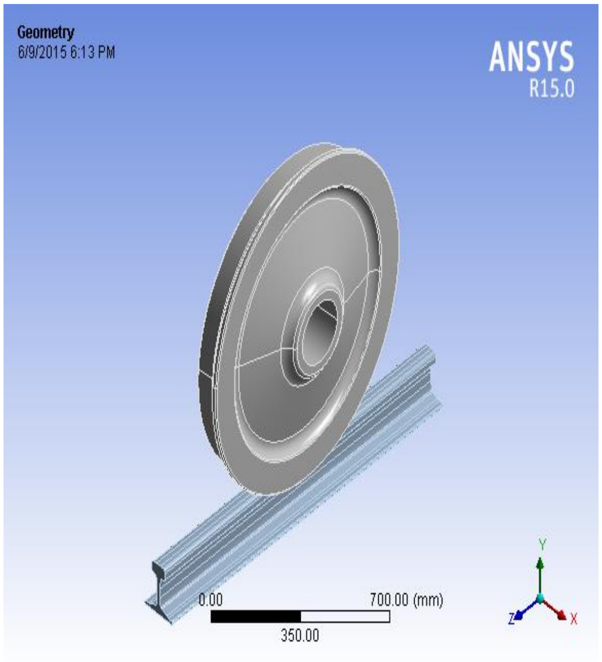


Figure 4-3 (c): Geometry in Ansys 15.0

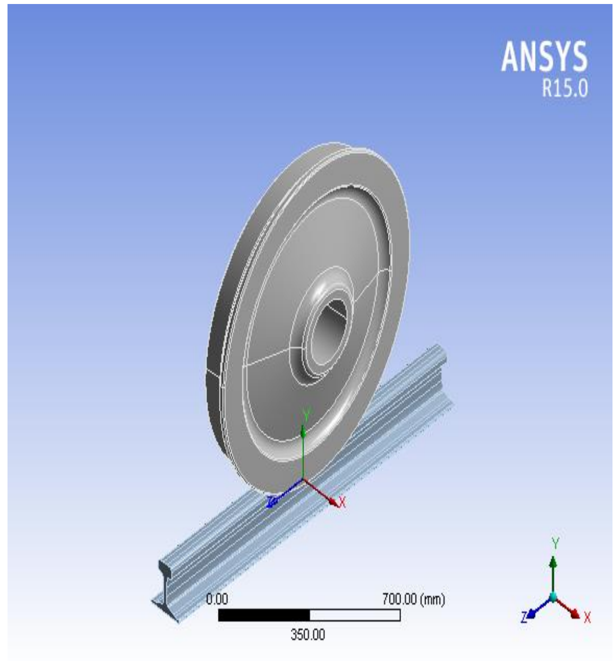


Figure 4-3 (d): Global coordinate system in Ansys 15.0

4-3 Mechanical solver

The simulation of these two bodies has been carried in this software Ansys 15.0. The geometry has been imported to the software and the coordinate systems and connections are default, which has been defined automatically. The main objective is to splitting the surface which surrounds the contact, which helps in reducing the number of contact elements, which means if the contact is defined between these whole two bodies then the computation time will be more. The curve bounded area is the enough area required to define the contact at interface.

4-3-1 Meshing

Meshing is the discrete representation of the geometry used in the analysis. It partitions the space of the geometry into elements so that equations can be approximated over those elements. The better the mesh quality, better will be its rate of convergence and solution accuracy. If the meshing quality is up to the mark, result achieved will be accurate. The meshing used here is ***triangular surface meshing***, and the size for meshing has been set up to the fine so that accurate result may be achieved. Triangular meshing is the simplest one and easy to create and is being used in the structured grids. ***Fine meshing*** is preferred than coarse meshing as fine meshing is more robust and efficient to get the solution accuracy. Total elements used in the meshing are 40,162 and the number of nodes generated are 93431. The meshing is shown in Figure 4-4.

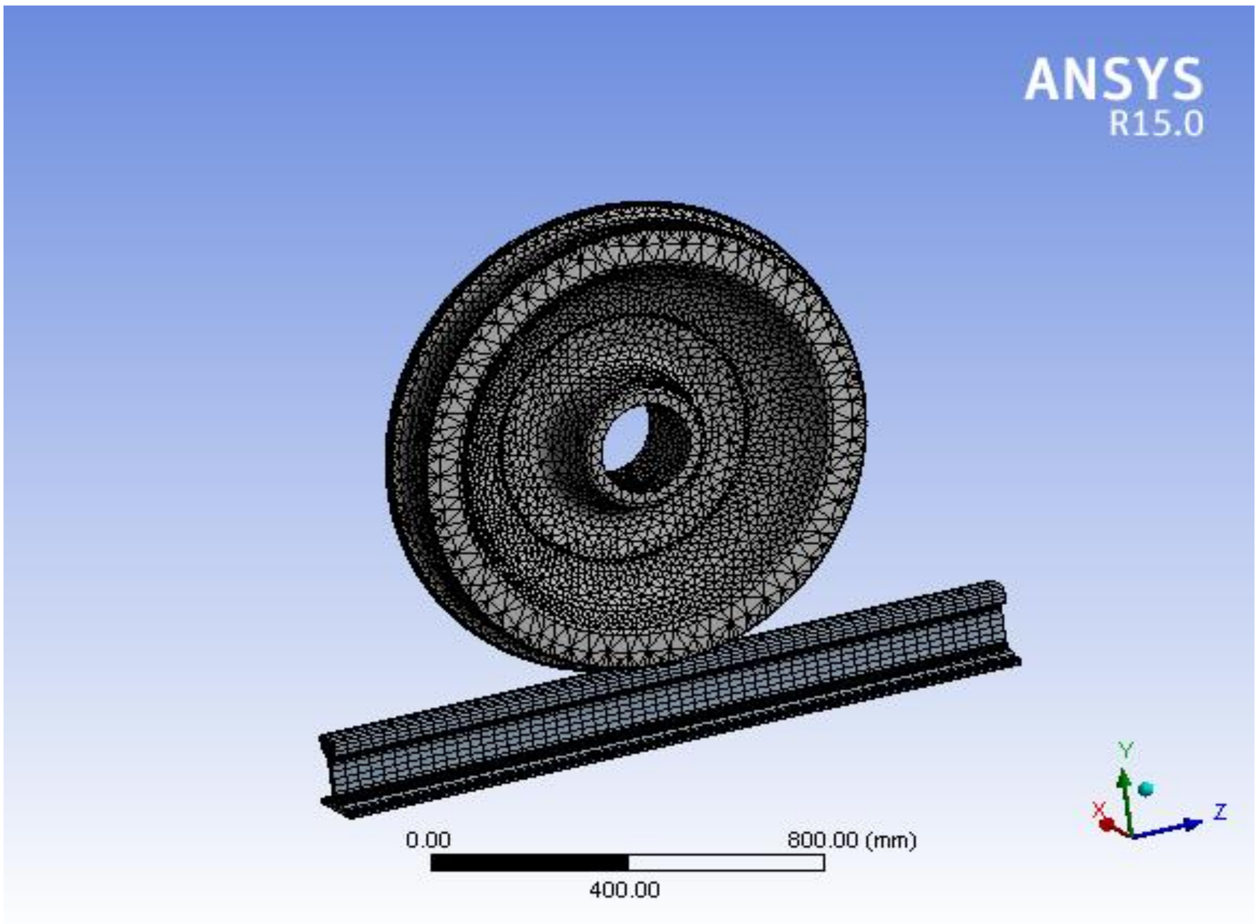


Figure 4-4: Triangular surface meshing in fine quality

4-3-2 Contact Connections

By defining the proper contact between the two bodies, the contact region has been taken. The contacting body is roller which is highlighted in red colour and the target body is the rail highlighted in the blue colour. In contact region window, the contact type is bonded contact as it is static structural analysis, so there remains no scope for frictional contact or frictional value. Augmented lagrange formulation has been followed and the detection method is program controlled. The Interface treatment between the two bodies has been defined by *adding offset with the ramped effect, means the load will be applied gradually*.

Here, face to face auto detection is only allowed whereas face to edge, edge to face and edge to edge auto detection is not allowed so as to create the proper contact between the mating surfaces.

Contact body is wheel and it has only one contact face, on the other hand the target body is rail which has three target faces.

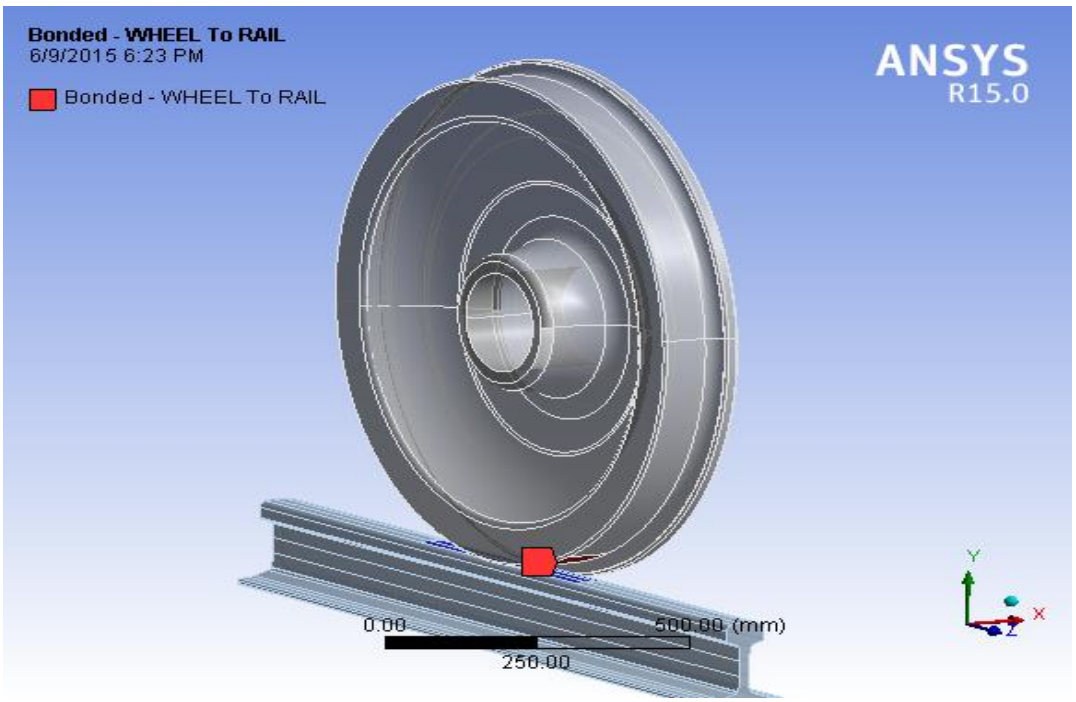


Figure 4-5: Bonded contact between Rail and wheel

4-3-3 Boundary Condition

<u>Fixed support</u>

The analysis is of static structural type and requires the *fixing of rail*. So the fixed_support has been provided to the rail by selecting the bottom face of the rail by enabling the face selection. This means that, fixed bottom face will not be translated or rotated in any of the directions.

<u>Force applied</u>

The force will be applied in the negative direction so it has been taken in the vertical downward direction *on the above face of wheel*. Hence, the force has been defined on the y component. The y component to be 164640 N force. This force is half of the axle load as the axle load is divided into two parts for the two wheels and also it is the maximum load which a wheel can take on UIC 60 kg rails.

Displacement constraints

To *constraint the wheel*, wheel side surfaces need to be constrained so displacement constraints has been applied to one of the side of the wheel by selecting multiple faces. The wheel has been constrained in such a way so that it can move only in y direction but not in x and z direction. So x and z direction displacement has been set up to zero. Now the model is ready for simulation and all the desired results need to be retrieved after simulation. The boundary conditions has been shown in the below Figure 4-6. In the further figures 4-7 (a) & (b) displacement and force is taken on y axis respectively and time of unit second on x axis.

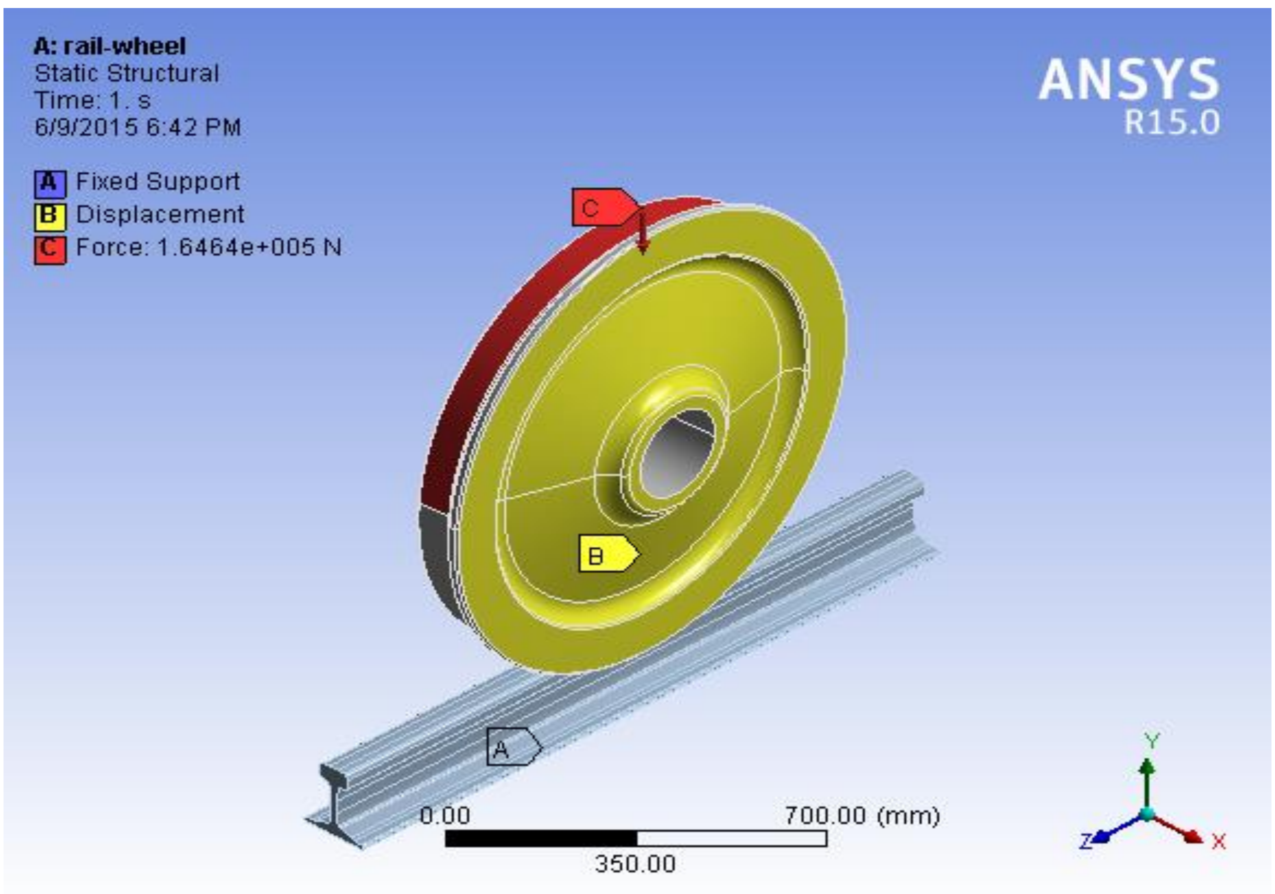


Figure 4-6: Boundary Conditions (fixed support, load applied, constraints)

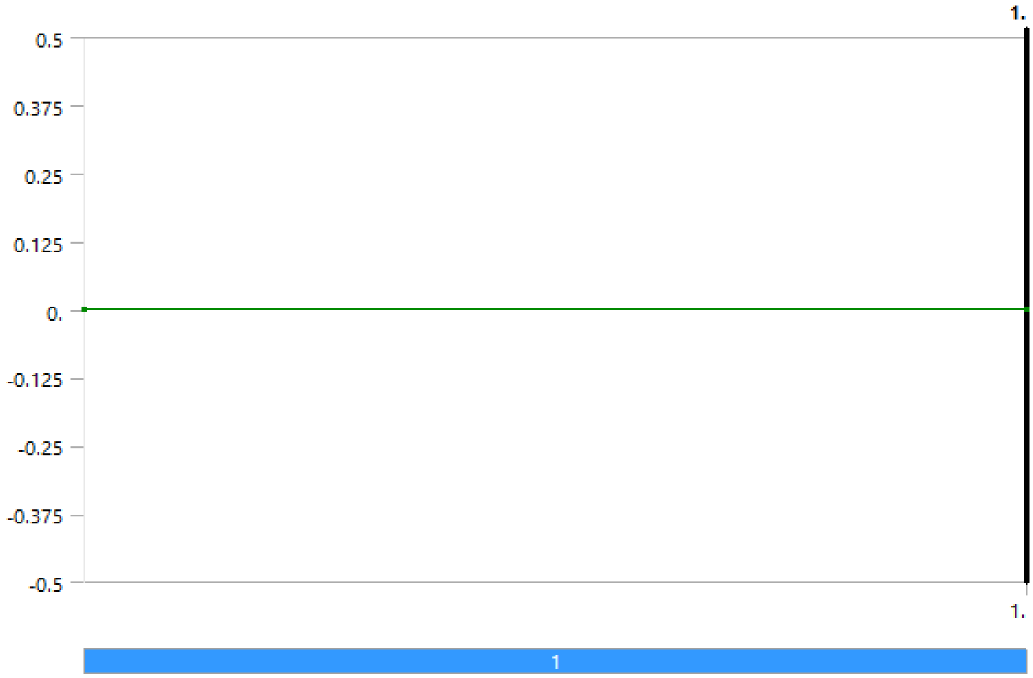


Figure 4-7(a): Displacement (mm) Vs Time (s) for Model

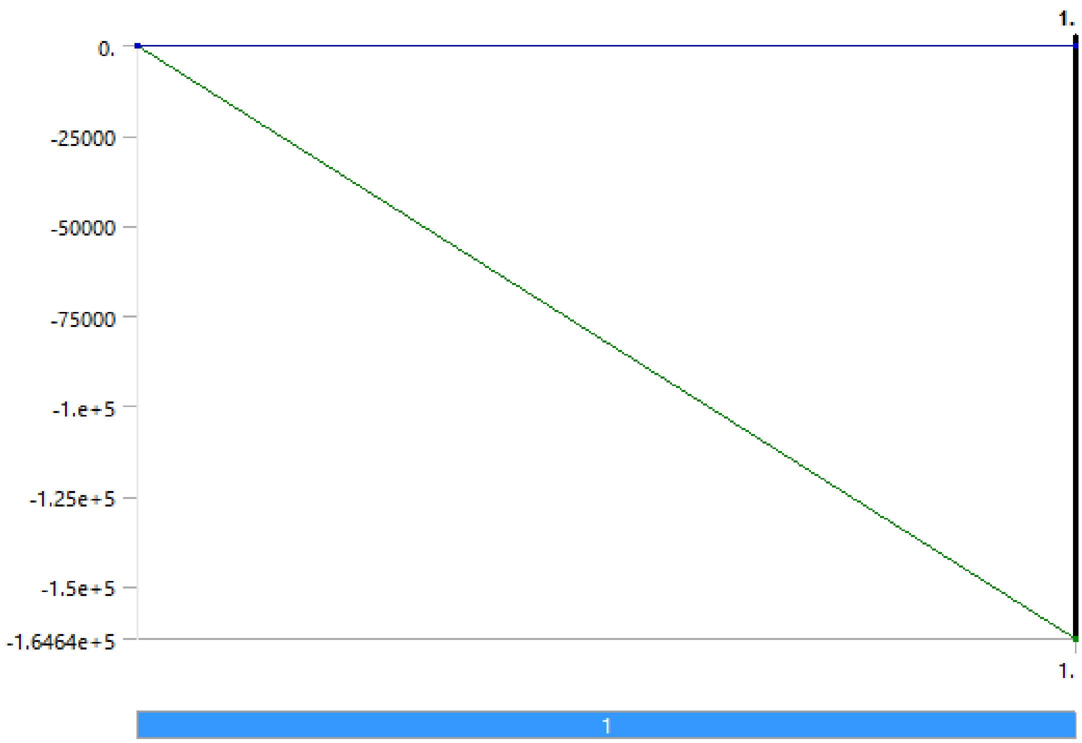


Figure 4-7(b): Force (N) Vs Time (s) for Model

4-4 Analysis settings for Simulations

As the load will be applied gradually, hence the *time stepping* has been defined. Initial substeps has been setup to 20, minimum substeps as 10 and the maximum substeps as 50. So that load will be divided into 20 equal number of parts and minimum steps will be 10 and maximum limit is 50. Newton Raphson method of non-linearity remains default selected.

4-5 Solutions for Static Analysis

The solutions has been achieved by evaluating all the results for different parameters i.e. Equivalent stresses, principal stresses, shear stresses, strain, factor of safety, contact pressure, contact penetrations etc. The solutions for different parameters are discussed along with its graphical, tabular and pictorial representation in this chapter. The analysis results for the different parameter are in the following order.

1. Equivalent stress(von-mises)
2. Maximum principal stress
3. Minimum principal stress
4. Stress Intensity
5. Shear stress
6. Total deformation
7. Strain energy
8. Safety factor
9. Contact status
10. Contact pressure

4-5-1 Equivalent Stresses (von-mises)

The contact region of rail and wheel is under the encumbrance of the load applied to the wheel. Maximum stress is at the contact region of rail and wheel is 53.274 Mpa highlighted in the red colour. Minimum stress is at the most part of the model and is equal to 8.87 x 10^{-6} Mpa which is highlighted in blue colour and is quite usual. The region below the contact region is under the critical load and showing most of the stressed zone of the whole assembled body. The region of the rail which is far away from the contact region is also having the least the stress zone. The variation of the stress value on the assembled model is shown in the Figure 4-8(a) below and the graphical & tabular representation of the stress with respect to the time steping is further shown in Figure 4-8(b) & Table 4-5 respectively.

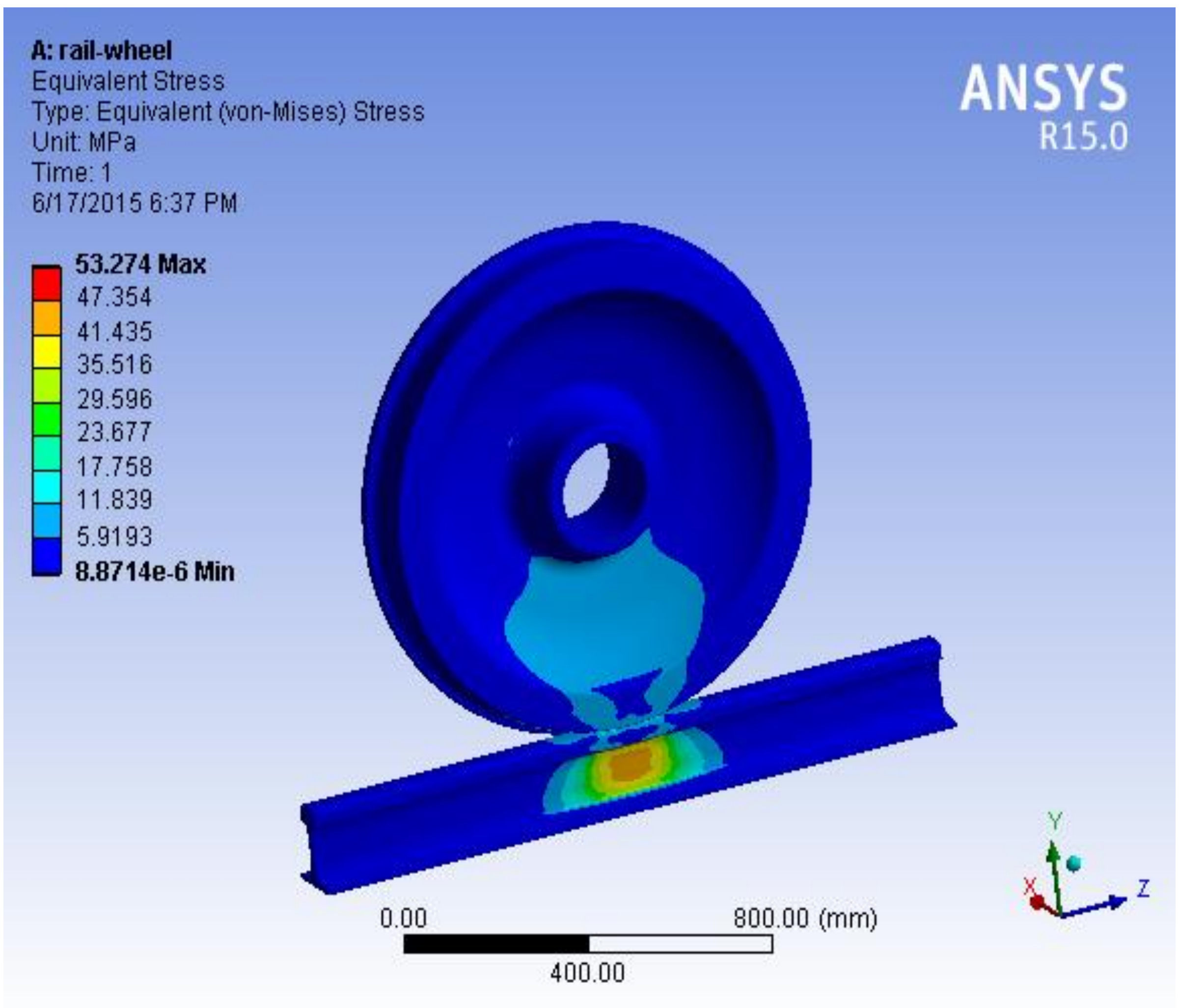


Figure 4-8 (a): Model analysis of Equivalent stress (von-mises)

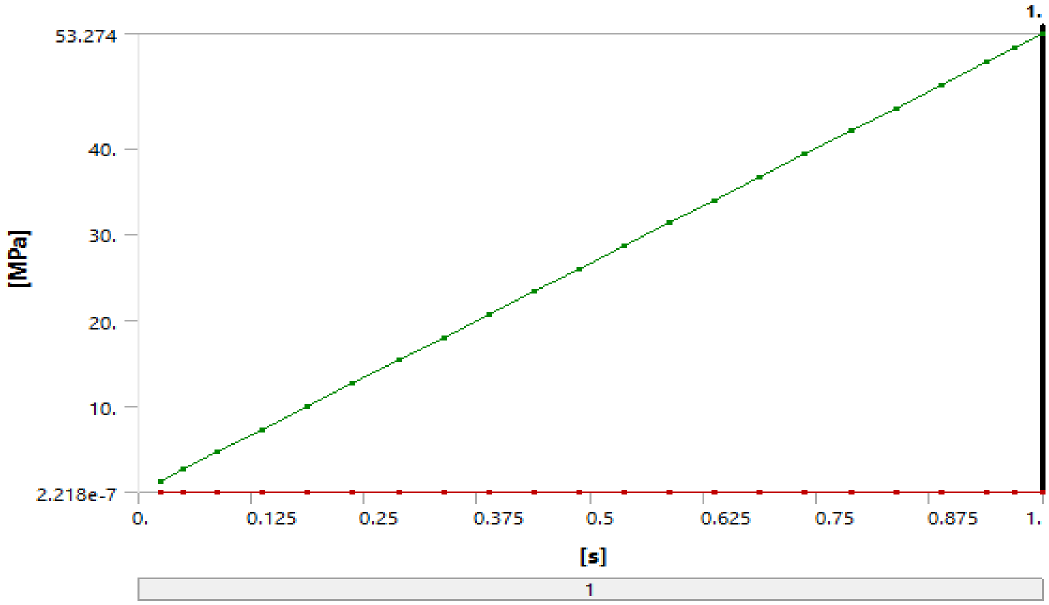


Figure 4-8(b): Graphical Representation of Equivalent stress (von-mises)

Table 4-5: Tabular Data of Equivalent stress (von-mises)

Steps	Time [s]	Minimum [MPa]	Maximum [MPa]
1	2.5e-002	2.218e-007	1.3318
2	5.e-002	4.4356e-007	2.6637
3	8.75e-002	7.7623e-007	4.6614
4	0.1375	1.2198e-006	7.3251
5	0.1875	1.6633e-006	9.9888
6	0.2375	2.1069e-006	12.652
7	0.2875	2.5505e-006	15.316
8	0.3375	2.994e-006	17.98
9	0.3875	3.4376e-006	20.643
10	0.4375	3.8812e-006	23.307
11	0.4875	4.3247e-006	25.971
12	0.5375	4.7683e-006	28.635
13	0.5875	5.2119e-006	31.298
14	0.6375	5.6554e-006	33.962
15	0.6875	6.099e-006	36.626
16	0.7375	6.5426e-006	39.289
17	0.7875	6.9862e-006	41.953
18	0.8375	7.4297e-006	44.617
19	0.8875	7.8733e-006	47.28
20	0.9375	8.3169e-006	49.944
21	0.96875	8.5941e-006	51.609
22	1.	8.8714e-006	53.274

4-5-2 Maximum Principal Stress

The maximum value of maximum principal stress is in the top layers of the rail at the contact region of rail and wheel, highlighted in the red colour and is equal to 18.375 Mpa and the minimum value of maximum principal stress is equal to –24.975 Mpa highlighted in blue colour but observing to figure we can say that there is no minimum value of maximum principal stress on the model. Observing to the model it can be identified that the most section of the model is having the average value of maximum principal stress equals to -5.7083 Mpa highlighted in the light green colour. The variation of the maximum principal stress value on the assembled model is shown in the Figure 4-9(a) below and the graphical & tabular representation of the maximum principal stress with respect to the time steping is further shown in Figure 4-9(b) & Table 4-6 respectively.

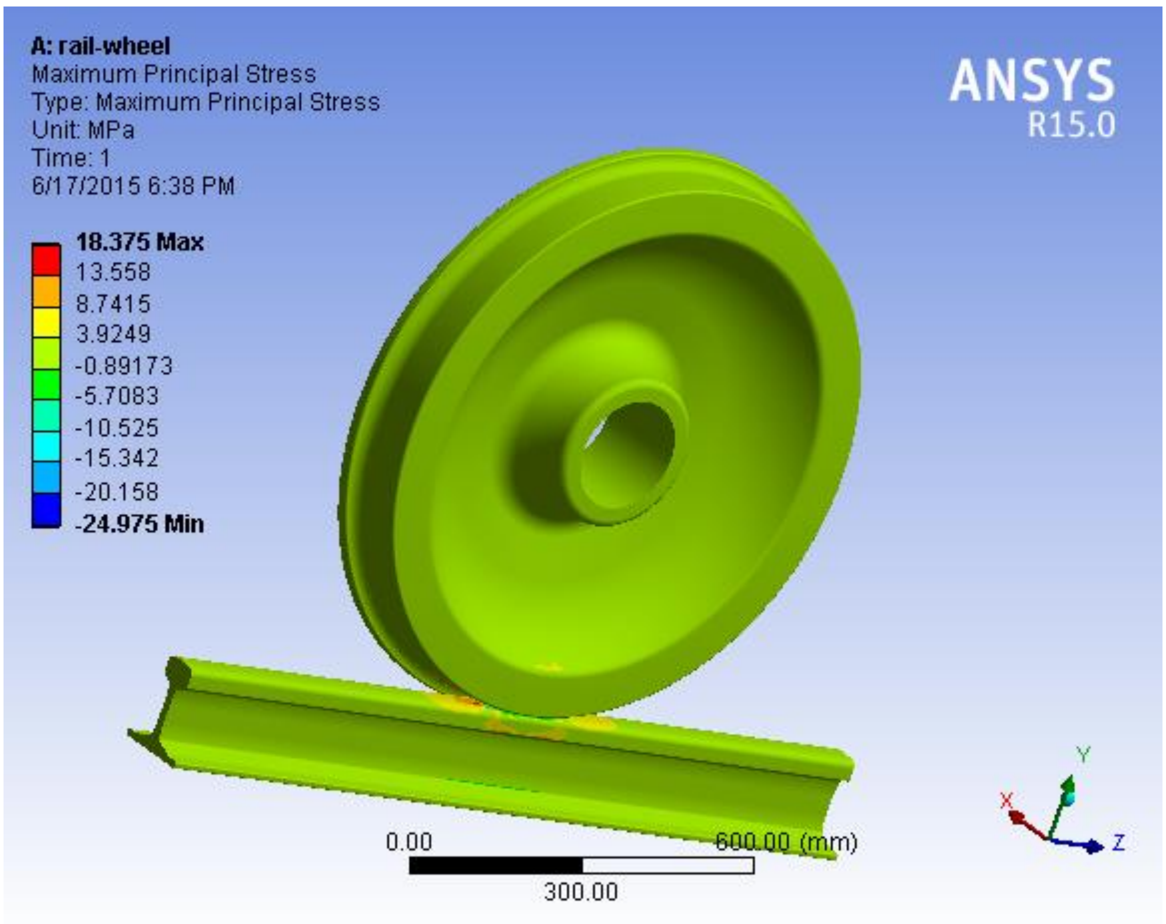


Figure 4-9 (a): Model analysis of Maximum principal stress

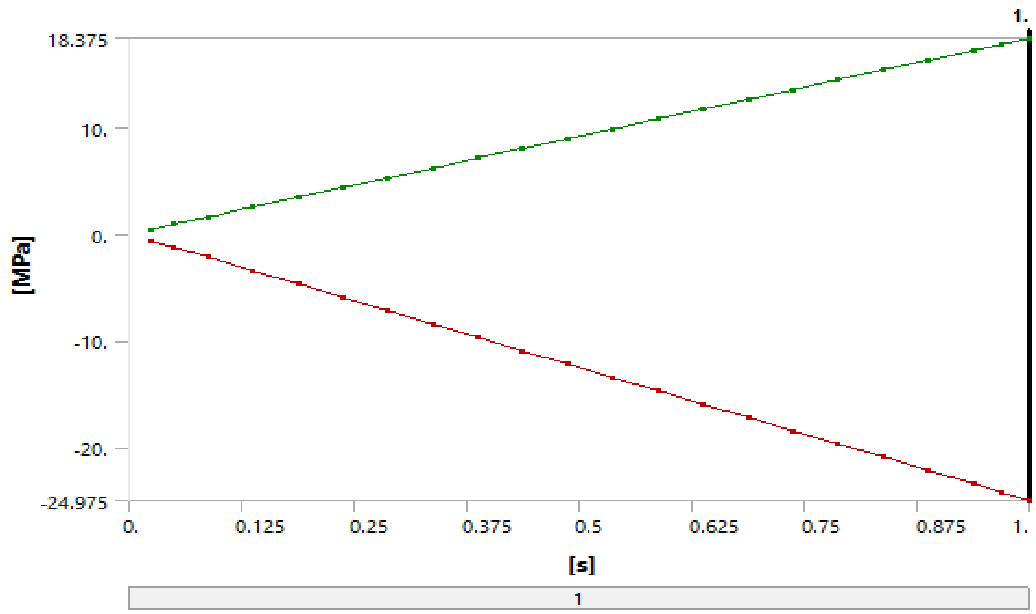


Figure 4-9(b): Graphical Representation of Maximum principal Stress

Table 4-6: Tabular Data of Maximum principal Stress

Steps	Time [s]	Minimum [MPa]	Maximum [MPa]
1	2.5e-002	-0.62439	0.45938
2	5.e-002	-1.2488	0.91876
3	8.75e-002	-2.1853	1.6078
4	0.1375	-3.4341	2.5266
5	0.1875	-4.6828	3.4453
6	0.2375	-5.9316	4.3641
7	0.2875	-7.1803	5.2828
8	0.3375	-8.429	6.2016
9	0.3875	-9.6778	7.1203
10	0.4375	-10.927	8.039
11	0.4875	-12.175	8.9578
12	0.5375	-13.424	9.8765
13	0.5875	-14.673	10.795
14	0.6375	-15.921	11.714
15	0.6875	-17.17	12.633
16	0.7375	-18.419	13.551
17	0.7875	-19.668	14.47
18	0.8375	-20.916	15.389
19	0.8875	-22.165	16.308
20	0.9375	-23.414	17.226
21	0.96875	-24.194	17.8
22	1.	-24.975	18.375

4-5-3 **Minimum Principal Stress**

The maximum value of minimum principal stress is at the most of the section of the model, highlighted in the red colour and is equal to 2.67 Mpa which means that this region will be less stress accentuated and the minimum value of minimum principal stress corresponds to -63.14 Mpa highlighted in blue colour but observing to the model we can say that this zone will be the exact contact patch of the wheel and rail. Observing to the model it can be identified that the rail under the contact zone is having the most of the minimum values of minimum principal stresses which means that this section of the model is highly stress accentuated. It is highlighted in the sky blue colour. The variation of the minimum principal stress value on the assembled model is shown in the Figure 4-10(a) below and the graphical & tabular representation of the minimum principal stress with respect to the time steping is further shown in Figure 4-10(b) & Table 4-7 respectively.

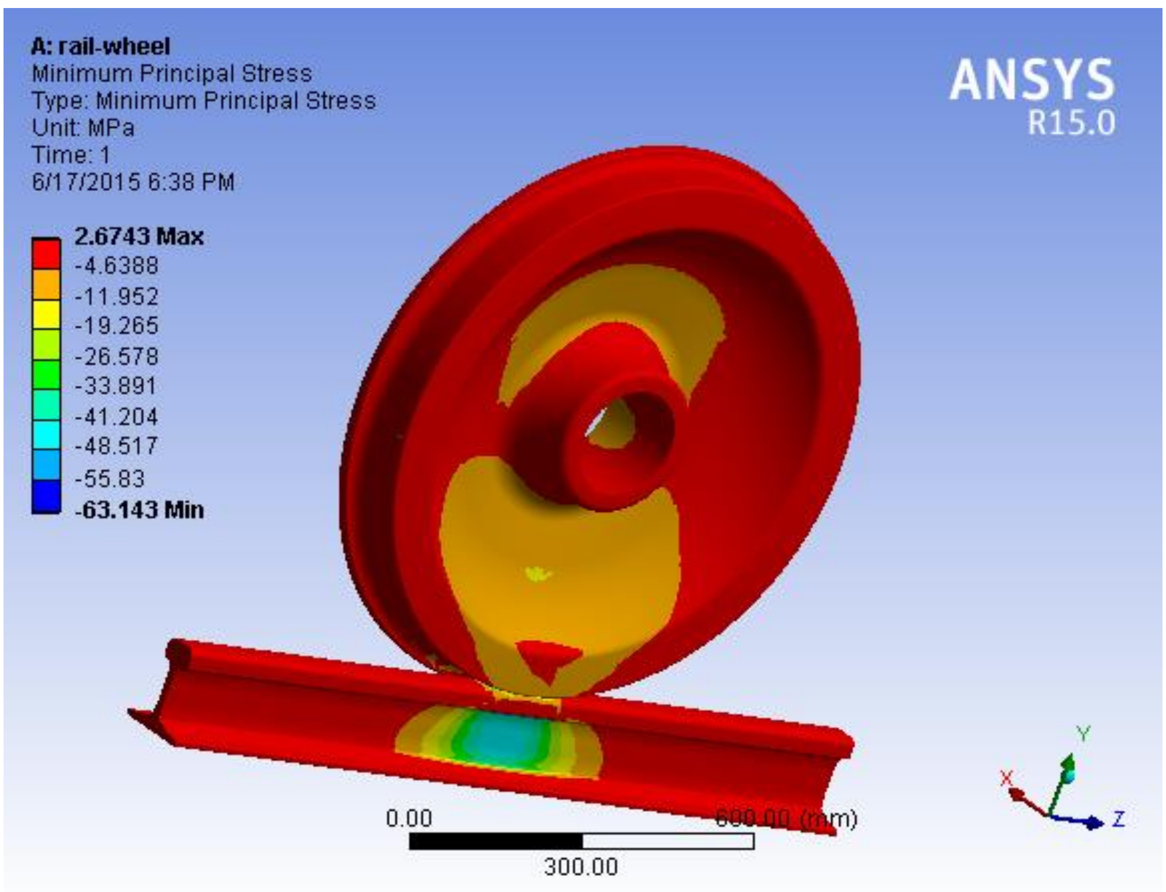


Figure 4-10 (a): Model analysis of Minimum principal stress

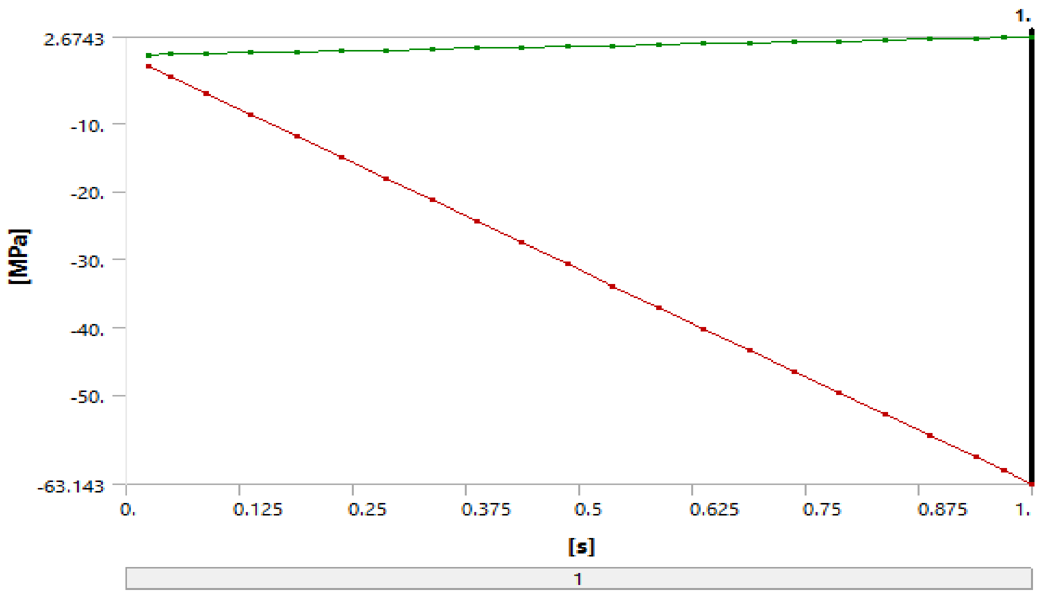


Figure 4-10(b): Graphical Representation of Minimum principal Stress

Table 4-7: Tabular Data of Minimum principal Stress

Steps	Time [s]	Minimum [MPa]	Maximum [MPa]
1	2.5e-002	-1.5787	6.6855e-002
2	5.e-002	-3.1572	0.13371
3	8.75e-002	-5.5251	0.234
4	0.1375	-8.6822	0.36771
5	0.1875	-11.839	0.50142
6	0.2375	-14.997	0.63513
7	0.2875	-18.154	0.76885
8	0.3375	-21.311	0.90256
9	0.3875	-24.468	1.0363
10	0.4375	-27.625	1.17
11	0.4875	-30.782	1.3037
12	0.5375	-33.94	1.4374
13	0.5875	-37.097	1.5711
14	0.6375	-40.254	1.7048
15	0.6875	-43.411	1.8385
16	0.7375	-46.568	1.9723
17	0.7875	-49.725	2.106
18	0.8375	-52.882	2.2397
19	0.8875	-56.04	2.3734
20	0.9375	-59.197	2.5071
21	0.96875	-61.17	2.5907
22	1.	-63.143	2.6743

4-5-4 **Stress Intensity**

The maximum value of stress intensity is at the junction of web and top flange or head of the model highlighted in the red colour and is equal to 53.899 Mpa which means that the head of the rail under the contact region is highly stress intensed section of the rail under the load and the minimum value of stress intensity corresponds to 1.004 x 10^{-5} Mpa highlighted in blue colour which means that most part of the model is almost unaffected by the stress intensity and remains very less stress intensed section of the model. Orange and yellow colour depicts the highly stress intensed in the web section, after the maximum value of stress intensity which is at the head under the contact region highlighted in red colour. The variation of the stress intensity value on the assembled model is shown in the Figure 4-11(a) below and the graphical & tabular representation of the stress intensity with respect to the time steping is further shown in Figure 4-11(b) & Table 4-8 respectively.

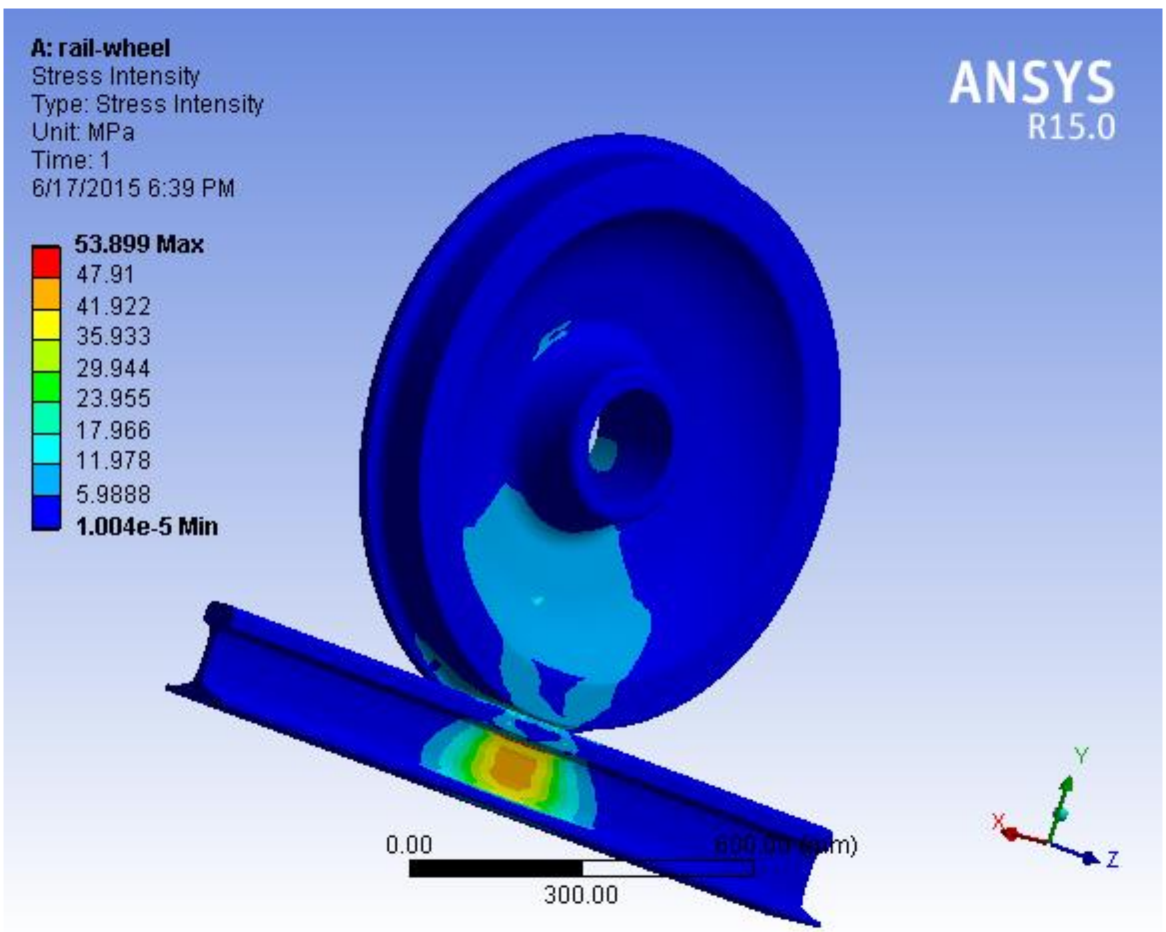


Figure 4-11(a): Model analysis of Stress Intensity

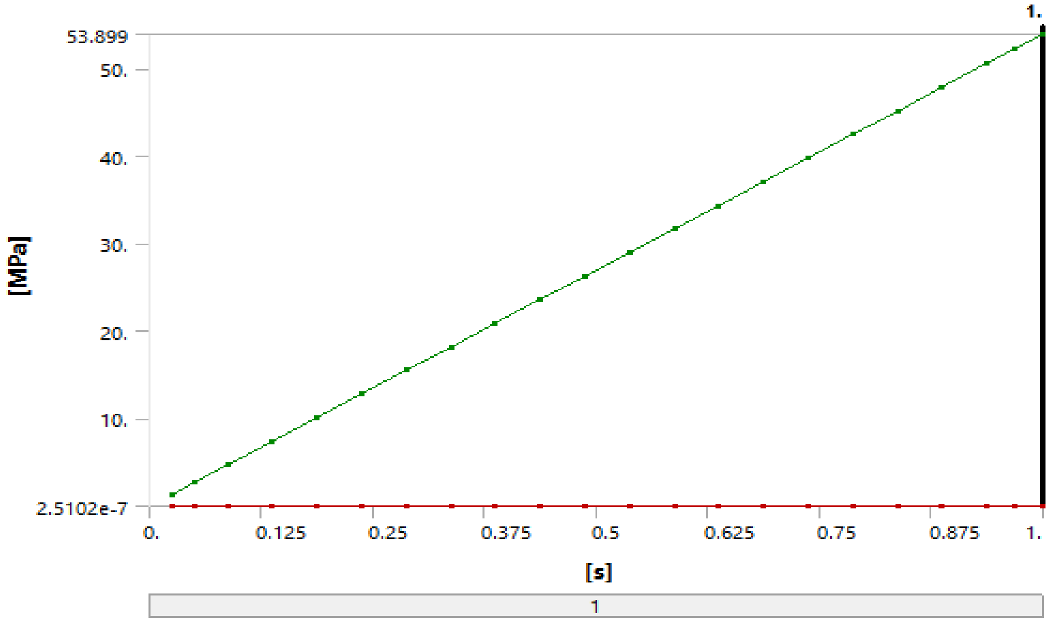


Figure 4-11(b): Graphical Representation of Stress Intensity

Table 4-8: Tabular Data of Stress Intensity

Steps	Time [s]	Minimum [MPa]	Maximum [MPa]
1	2.5e-002	2.5102e-007	1.3474
2	5.e-002	5.0201e-007	2.6949
3	8.75e-002	8.785e-007	4.7162
4	0.1375	1.3805e-006	7.4112
5	0.1875	1.8825e-006	10.106
6	0.2375	2.3845e-006	12.801
7	0.2875	2.8865e-006	15.496
8	0.3375	3.3885e-006	18.191
9	0.3875	3.8905e-006	20.886
10	0.4375	4.3925e-006	23.581
11	0.4875	4.8945e-006	26.276
12	0.5375	5.3965e-006	28.971
13	0.5875	5.8985e-006	31.666
14	0.6375	6.4005e-006	34.361
15	0.6875	6.9025e-006	37.056
16	0.7375	7.4045e-006	39.751
17	0.7875	7.9066e-006	42.446
18	0.8375	8.4086e-006	45.141
19	0.8875	8.9106e-006	47.836
20	0.9375	9.4126e-006	50.531
21	0.96875	9.7263e-006	52.215
22	1.	1.004e-005	53.899

4-5-5 Shear Stress

The maximum value of shear stress is at the junction of web and top flange of the model highlighted in the red colour and is equal to 250.15 Mpa which means that the junction of web and top flange of the rail below the contact region is the most affected section by shear stress under the load and the minimum value of shear stress corresponds to -350.37 Mpa highlighted in blue colour and is at the junction of web and the bottom flange. Important thing to be noticed is that the shear stress has only generated at the junction of web and flange (top and bottom). The variation of the shear stress value on the assembled model is shown in the Figure 4-12(a) below and the graphical & tabular representation of the shear stress with respect to the time steping is further shown in Figure 4-12(b) & Table 4-9 respectively.

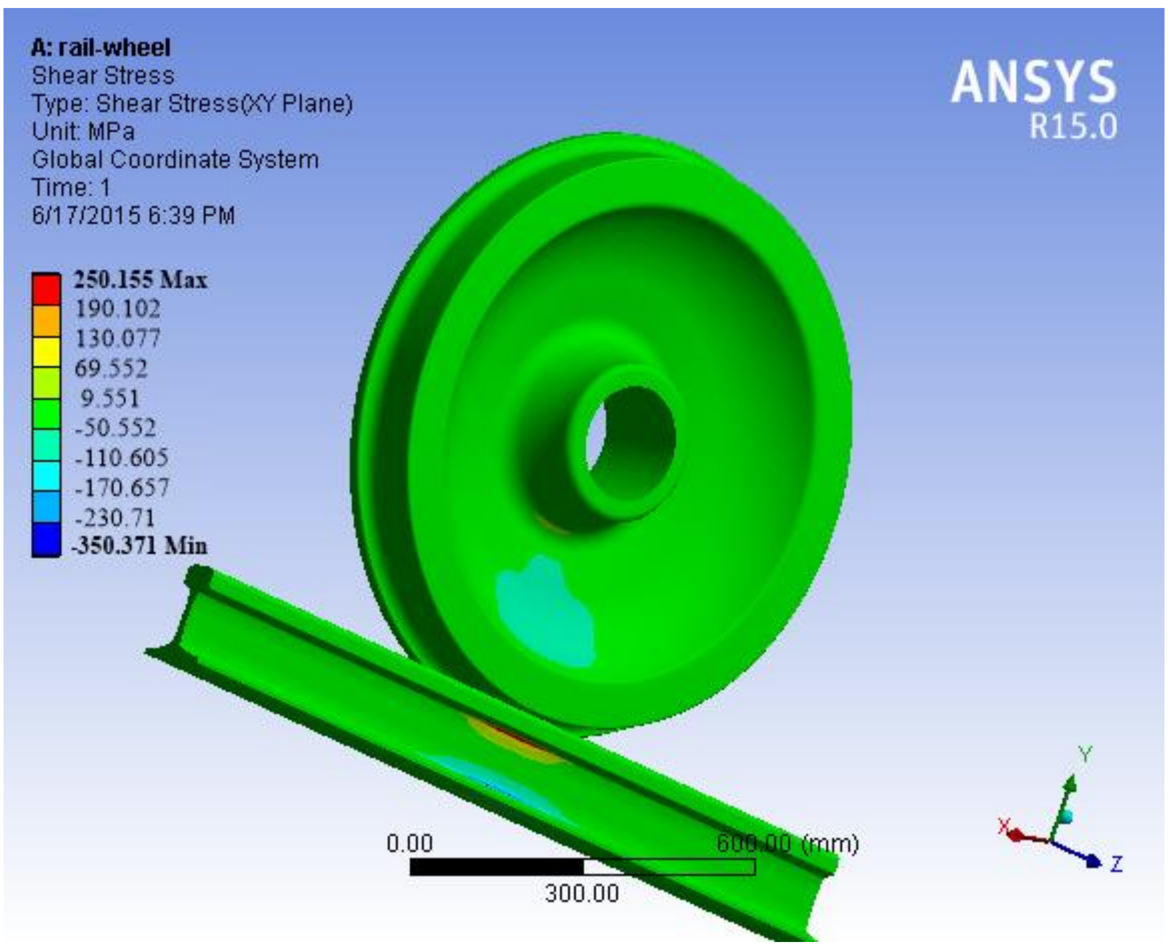


Figure 4-12(a): Model analysis of Shear stress

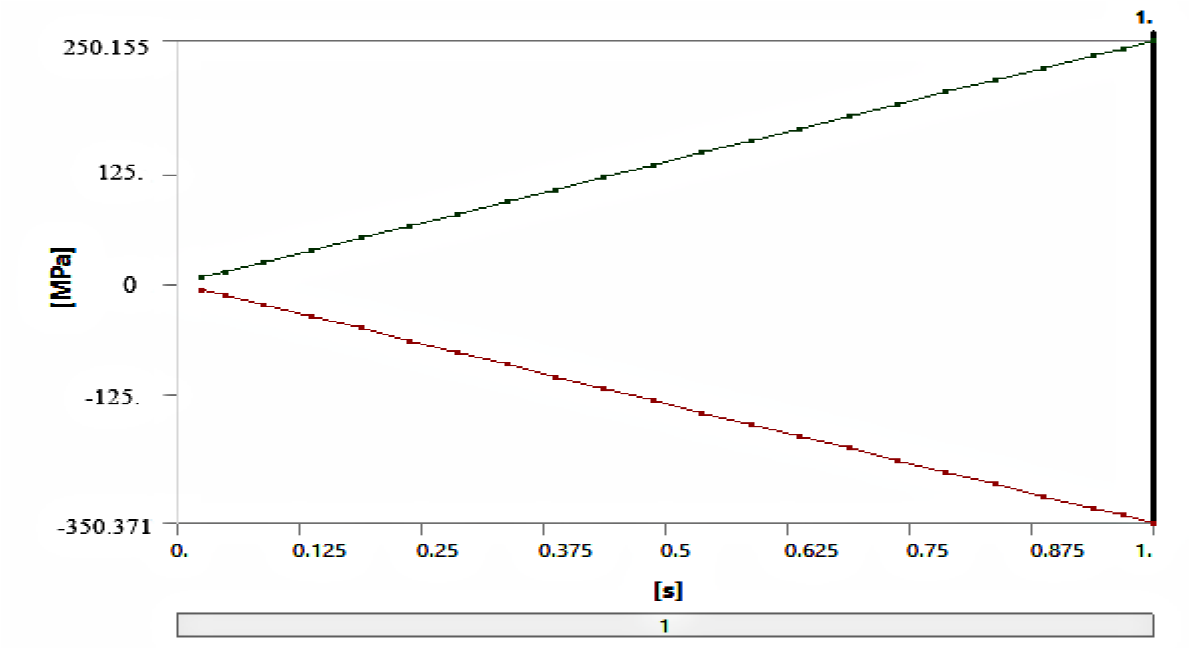


Figure 4-12(b): Graphical Representation of Shear Stress

Table 4-9: Tabular Data of Shear Stress

Steps	Time [s]	Minimum [MPa]	Maximum [MPa]
1	2.5e-002	-50.552	9.531
2	5.e-002	-64.822	20.989
3	8.75e-002	-79.092	32.439
4	0.1375	-93.362	43.889
5	0.1875	-107.632	55.339
6	0.2375	-121.902	66.789
7	0.2875	-136.172	78.239
8	0.3375	-150.442	89.689
9	0.3875	-164.712	101.139
10	0.4375	-178.982	112.589
11	0.4875	-193.252	124.03
12	0.5375	-207.522	135.489
13	0.5875	-221.792	146.939
14	0.6375	-236.062	158.389
15	0.6875	-250.332	169.839
16	0.7375	-264.602	181.289
17	0.7875	-278.872	192.739
18	0.8375	-293.142	204.189
19	0.8875	-307.412	215.639
20	0.9375	-321.682	227.089
21	0.96875	-335.952	238.539
22	1.	-350.371	250.155

4-5-6 Total Deformation

Total deformation is vector sum of all the directional displacement of the model. The minimum value of total deformation is 0 mm on that zone of the rail which is quite far away from the contacting region highlighted in the blue colour and it is very permissible aspect of the analysis. Maximum value of total deformation is 0.056 mm at the top of the wheel portion which is carrying the load highlighted in the red colour. Average deformation is near the contact zone between the rail and wheel highlighted in the green colour, it is carrying 0.024 mm. The variation of the total deformation value on the assembled model is shown in the Figure 4-13(a) below and the graphical & tabular representation of the total deformation with respect to the time steping is further shown in Figure 4-13(b) & Table 4-10 respectively.

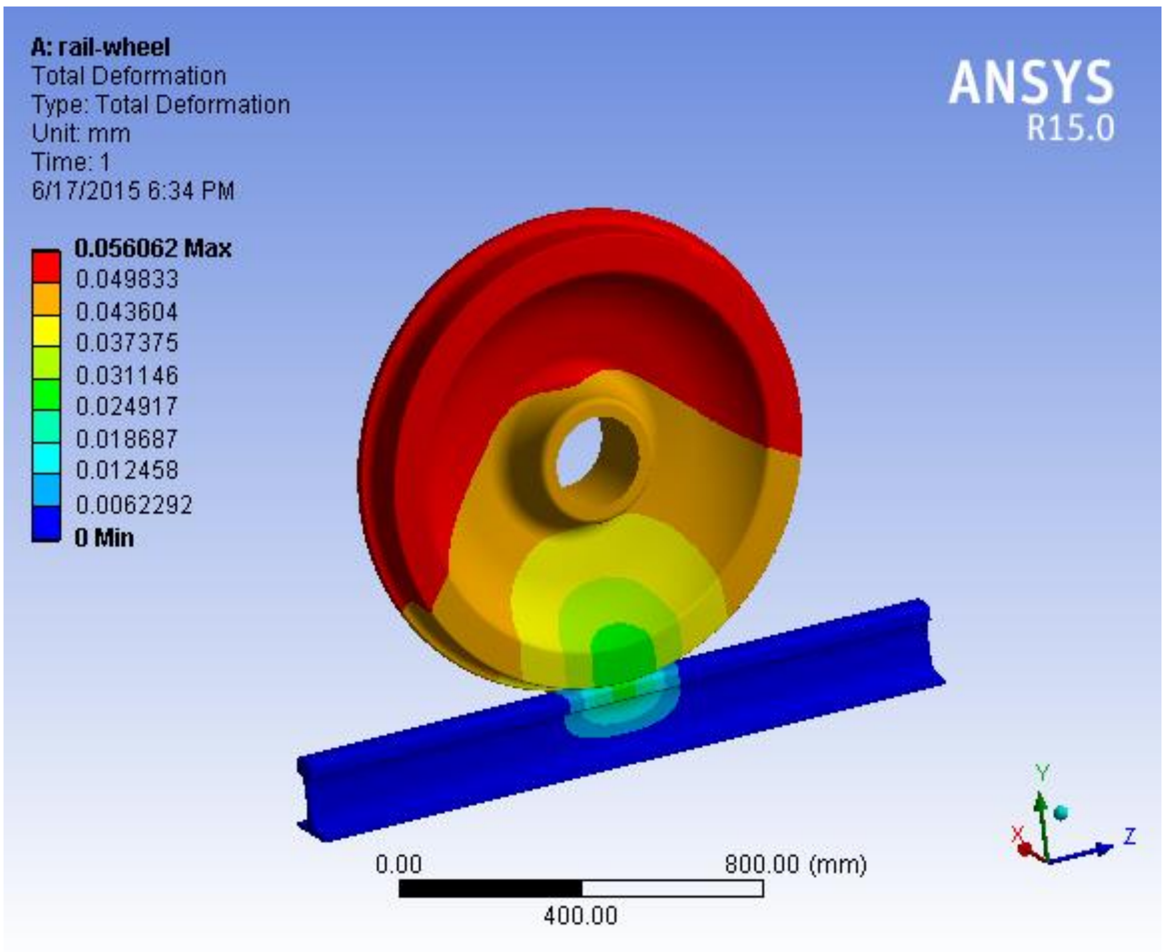


Figure 4-13(a): Model Analysis of Total Deformation

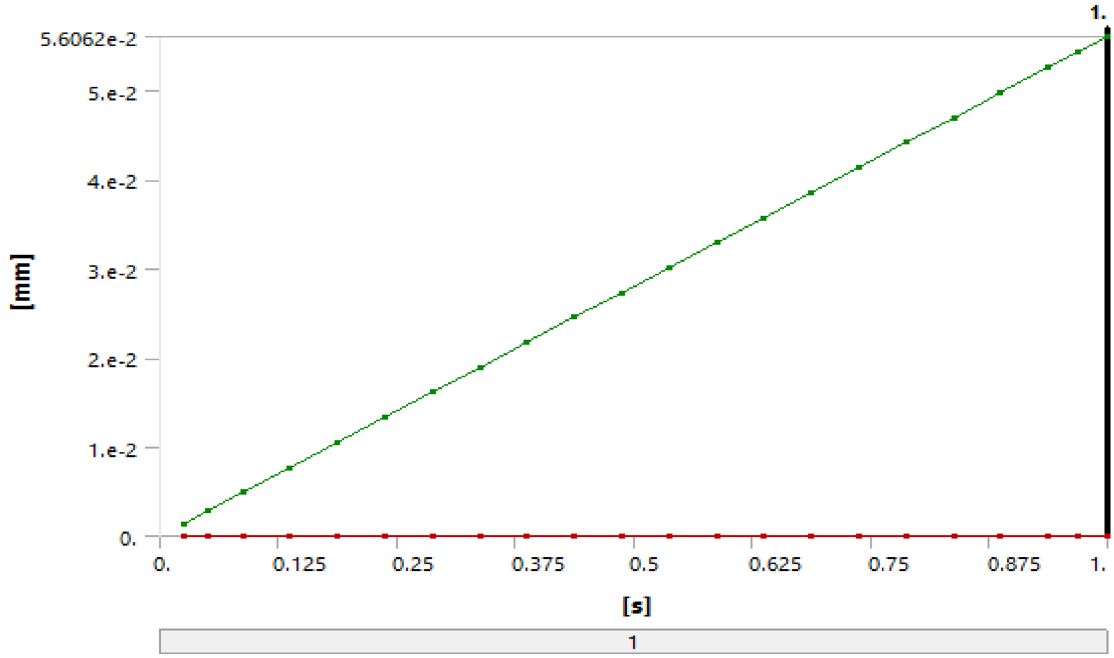


Figure 4-13(b): Graphical Representation of Total Deformation

Table 4-10: Tabular Data of Total Deformation

Steps	Time [s]	Minimum [mm]	Maximum [mm]
1	2.5e-002	0	1.4016e-003
2	5.e-002		2.8031e-003
3	8.75e-002		4.9055e-003
4	0.1375		7.7086e-003
5	0.1875		1.0512e-002
6	0.2375		1.3315e-002
7	0.2875		1.6118e-002
8	0.3375		1.8921e-002
9	0.3875		2.1724e-002
10	0.4375		2.4527e-002
11	0.4875		2.733e-002
12	0.5375		3.0134e-002
13	0.5875		3.2937e-002
14	0.6375		3.574e-002
15	0.6875		3.8543e-002
16	0.7375		4.1346e-002
17	0.7875		4.4149e-002
18	0.8375		4.6952e-002
19	0.8875		4.9755e-002
20	0.9375		5.2558e-002
21	0.96875		5.431e-002
22	1.		5.6062e-002

4-5-7 Strain Energy

As the cast steel of grade 880 is the strongest steel material which can take the high compressive load so the strain remains very less or negligible that's why strains are not discussed here although the strain energy has been discussed. The maximum value of strain energy is 21.36 mJ which is at the middle section of the web under the contact region highlighted in the red colour. The zone of the strain energy only lies at the middle section of web with diversified values. The minimum value of the strain energy is 2 x 10^{-13} mJ or almost negligible highlighted in blue colour. The variation of the strain energy on the assembled model is shown in the Figure 4-14(a) below and the graphical & tabular representation of the shear energy with respect to the time steping is further shown in Figure 4-14(b) & Table 4-11 respectively.

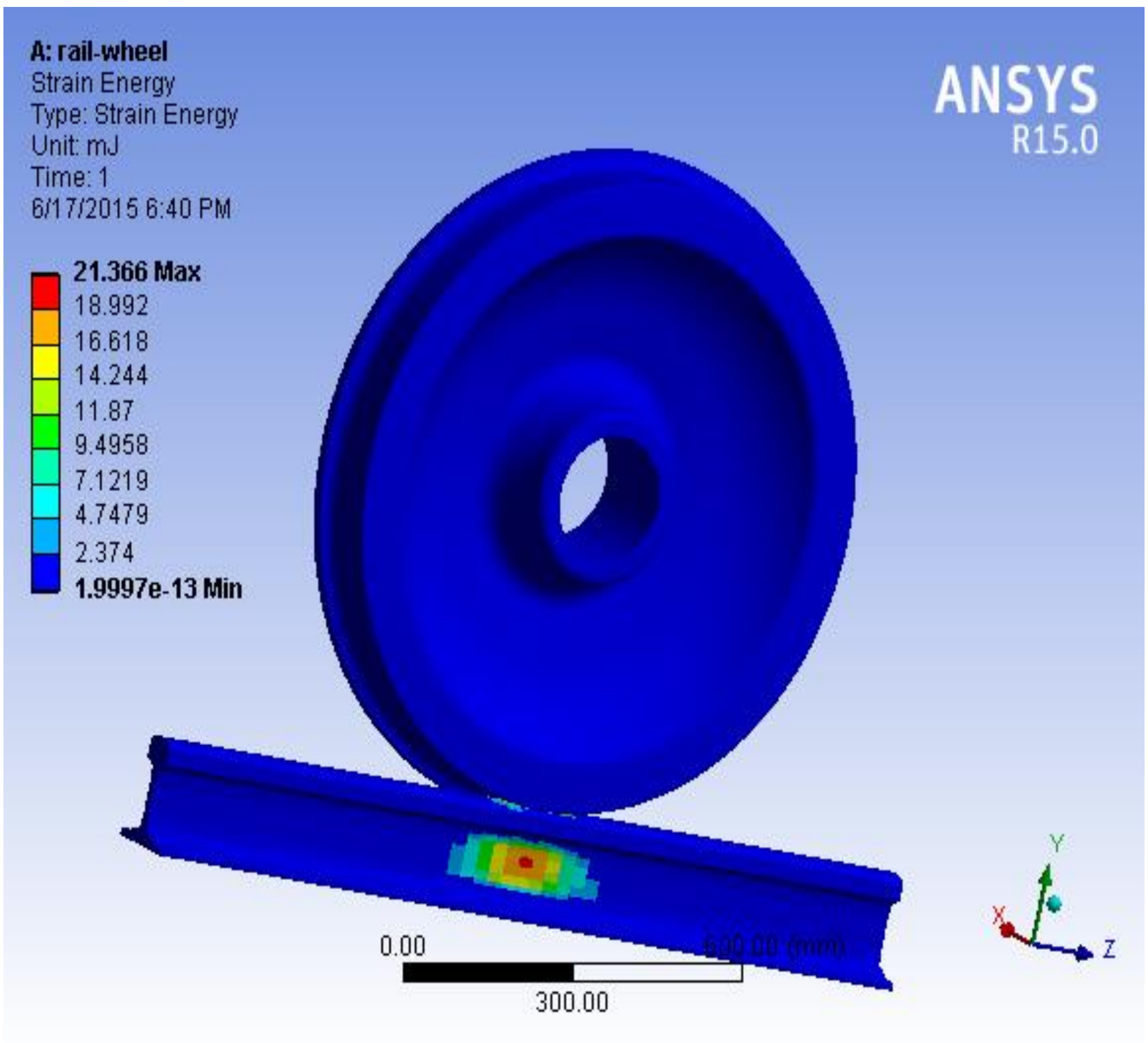


Figure 4-14(a): Model analysis of Strain Energy

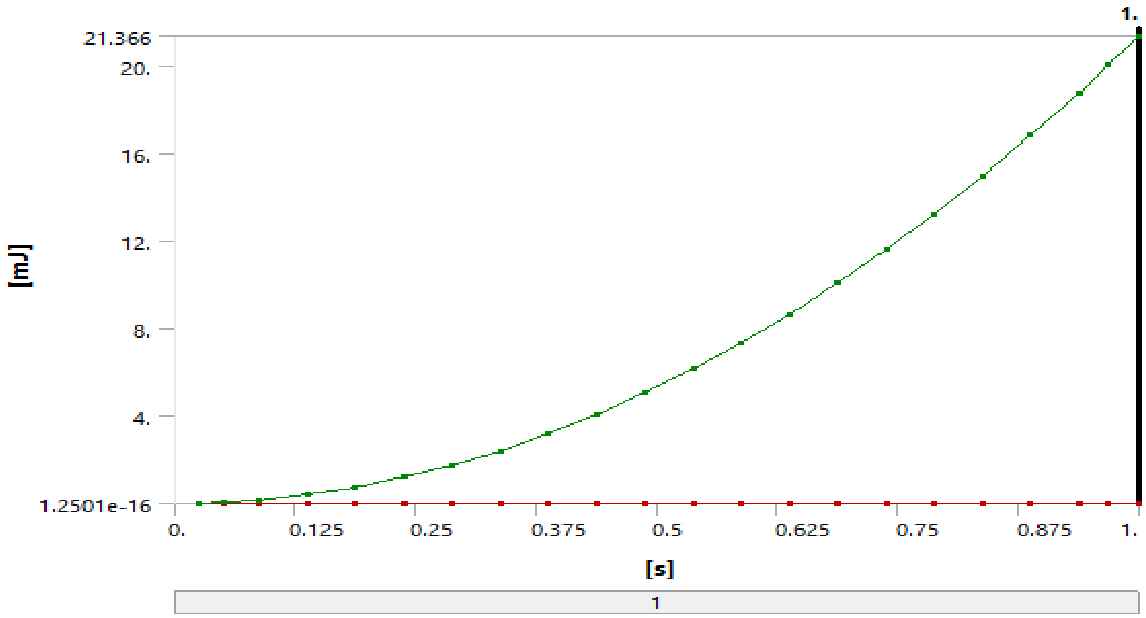


Figure 4-14(b): Graphical Representation of Strain Energy

Table 4-11: Tabular Data of Strain Energy

Steps	Time [s]	Minimum [mJ]	Maximum [mJ]
1	2.5e-002	1.2501e-016	1.3354e-002
2	5.e-002	4.9985e-016	5.3414e-002
3	8.75e-002	1.5309e-015	0.16358
4	0.1375	3.7803e-015	0.40394
5	0.1875	7.0296e-015	0.75113
6	0.2375	1.1279e-014	1.2052
7	0.2875	1.6527e-014	1.766
8	0.3375	2.2776e-014	2.4337
9	0.3875	3.0024e-014	3.2082
10	0.4375	3.8273e-014	4.0895
11	0.4875	4.7521e-014	5.0777
12	0.5375	5.7769e-014	6.1726
13	0.5875	6.9017e-014	7.3745
14	0.6375	8.1265e-014	8.6831
15	0.6875	9.4512e-014	10.099
16	0.7375	1.0876e-013	11.621
17	0.7875	1.2401e-013	13.25
18	0.8375	1.4025e-013	14.986
19	0.8875	1.575e-013	16.829
20	0.9375	1.7575e-013	18.778
21	0.96875	1.8766e-013	20.051
22	1.	1.9997e-013	21.366

4-5-8 <u>Safety Factor</u>

Safety factor is the critical parameter while designing as it accounts for the permissible stress on behalf of ultimate stress or yield stress. The maximum value of safety factor is 15 shown in blue colour at most part of the model. The moderate value of the safety factor is 10, at the whole web under the contacting region and the minimum value of safety factor corresponds to 4.69 which has to be maintained for designing the rail. The variation of the safety factor value on the assembled model is shown in the Figure 4-15(a) below and the graphical & tabular representation of the safety factor with respect to the time steping is further shown in Figure 4-15(b) & Table 4-12 respectively.

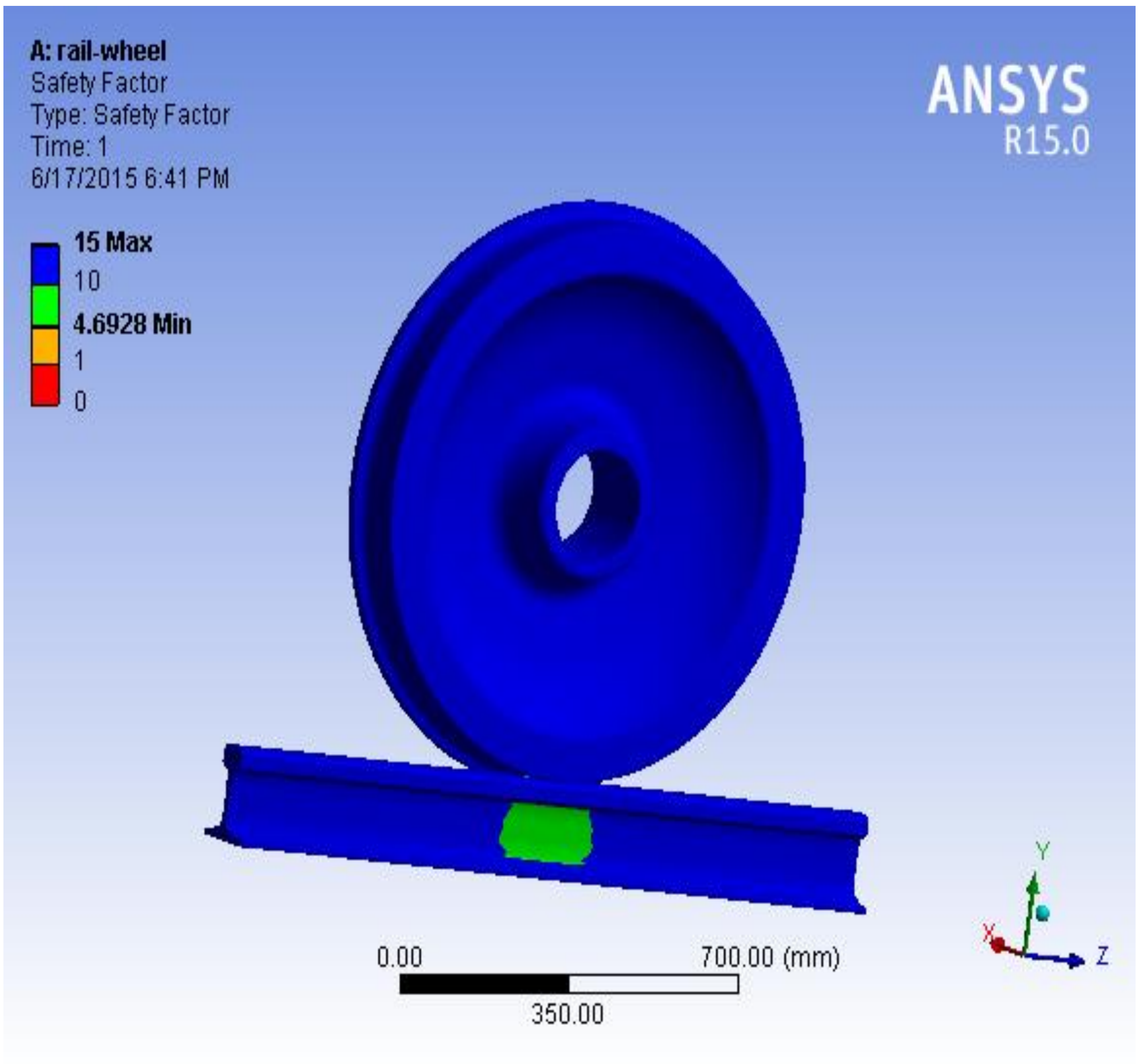


Figure 4-15(a): Model analysis of Safety factor

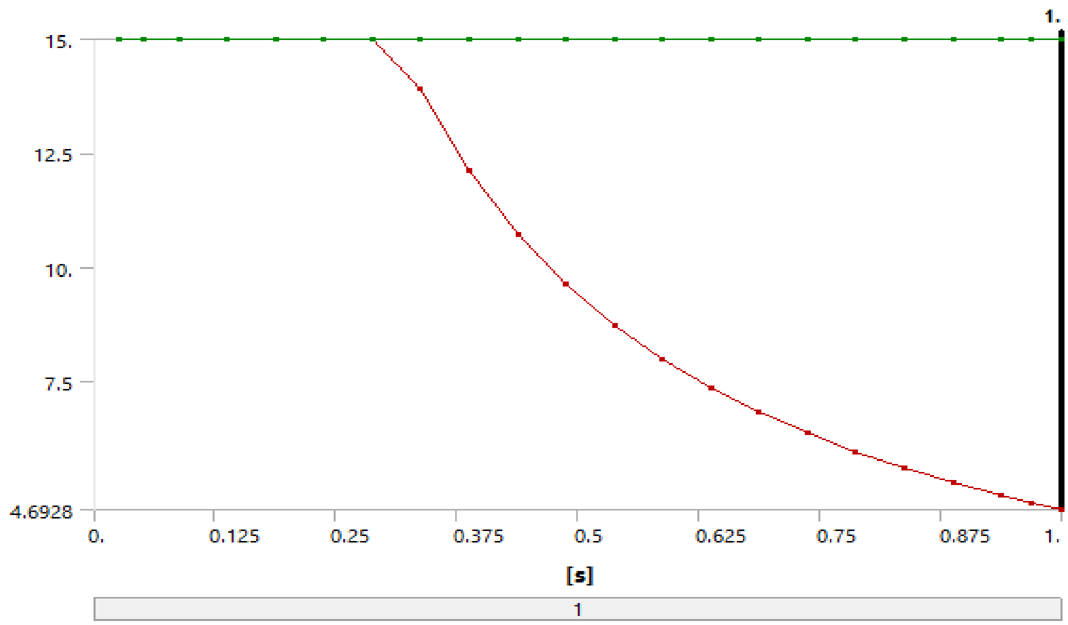


Figure 4-15(b): Graphical Representation of Safety Factor

Table 4-12: Tabular Data of Contact Safety factor

Steps	Time [s]	Minimum	Maximum
1	2.5e-002	15.	15
2	5.e-002		
3	8.75e-002		
4	0.1375		
5	0.1875		
6	0.2375		
7	0.2875		
8	0.3375	13.904	
9	0.3875	12.11	
10	0.4375	10.726	
11	0.4875	9.6262	
12	0.5375	8.7307	
13	0.5875	7.9877	
14	0.6375	7.3612	
15	0.6875	6.8258	
16	0.7375	6.3631	
17	0.7875	5.9591	
18	0.8375	5.6033	
19	0.8875	5.2876	
20	0.9375	5.0056	
21	0.96875	4.8441	
22	1.	4.6928	

4-5-9 Contact Status

The contact status shows the region of the rail which is in contact with wheel. The sticking region of wheel and rail has been highlighted in the dark orange colour. The sliding contact is highlighted by light orange colour. The yellow colour depicts that the rail and wheel are not in contact and the region in yellow colour is the nearby region of the contact region between rail and wheel. The blue colour has highlighted that the rail and wheel are not in contact and the region in blue colour is far away from contact region. The variation of the contact status between wheel and rail in different colour is shown in the Figure 4-16(a) below and the graphical & tabular representation of the contact status with respect to the time steping is further shown in Figure 4-16(b) & Table 4-13 respectively.

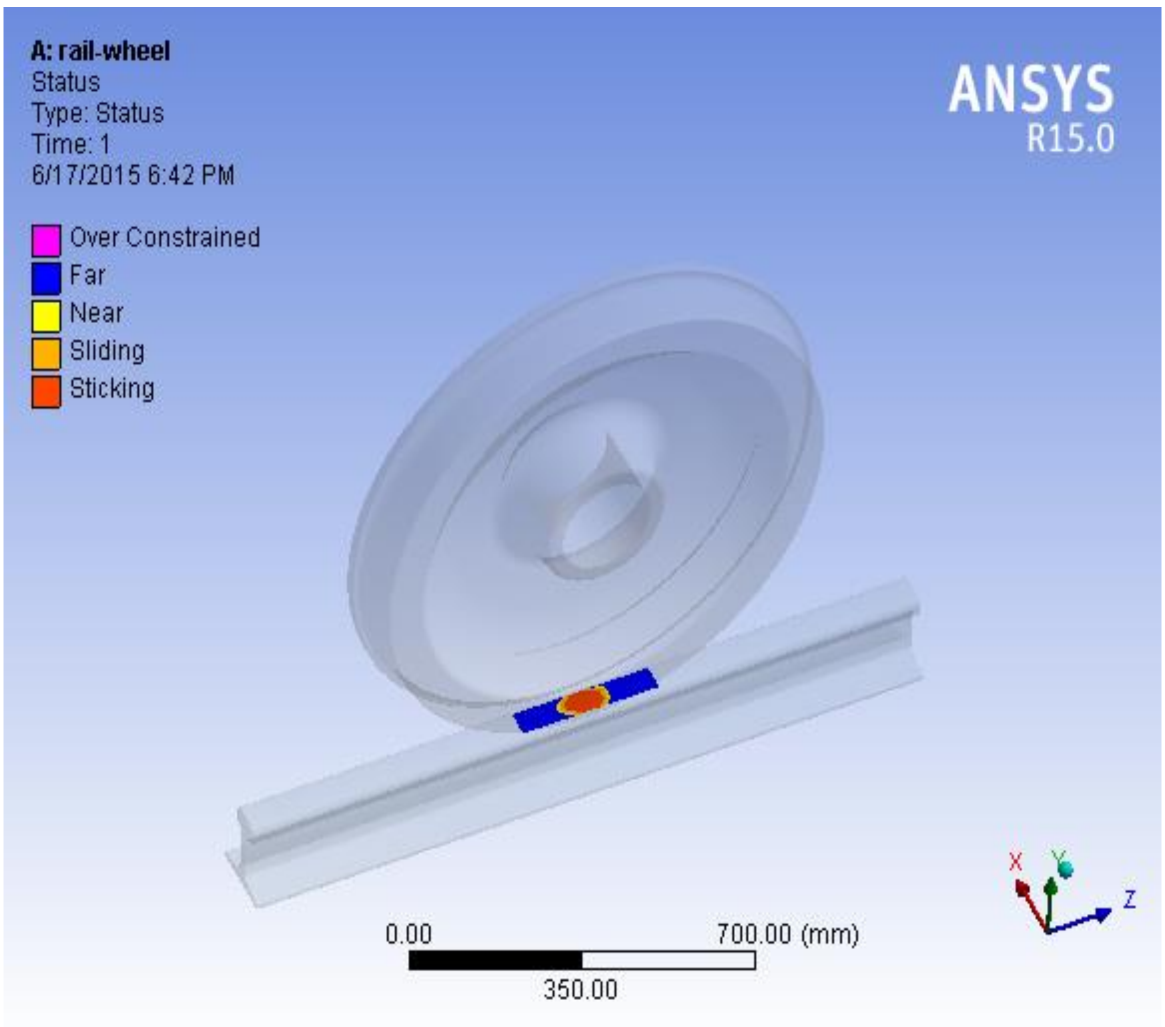


Figure 4-16(a): Model analysis of Contact Status

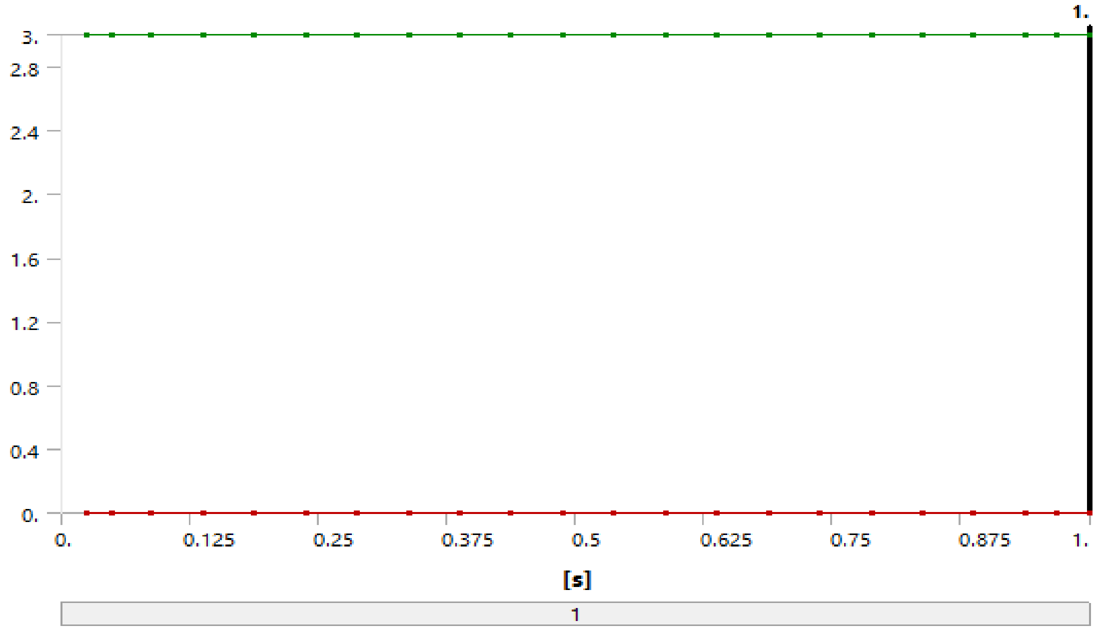


Figure 4-16(b): Graphical Representation of Contact Status

Table 4-13: Tabular Data of Contact Status

Steps	Time [s]	Minimum	Maximum
1	2.5e-002	0.	3.
2	5.e-002		
3	8.75e-002		
4	0.1375		
5	0.1875		
6	0.2375		
7	0.2875		
8	0.3375		
9	0.3875		
10	0.4375		
11	0.4875		
12	0.5375		
13	0.5875		
14	0.6375		
15	0.6875		
16	0.7375		
17	0.7875		
18	0.8375		
19	0.8875		
20	0.9375		
21	0.96875		
22	1.		

4-5-10 Contact Pressure

The orientation of the model has been changed in order to observe the contact pressure. The maximum value of contact pressure is 102.49 Mpa which is at the mating region of wheel and rail at the microscopic level, and this value is under the permissible value for maximum contact pressure. The minimum value of the contact pressure is 0 Mpa shown in blue colour. Observing to the contacting region, it can be identified that the most of the contacting region is in sky blue colour having the pressure of 34.16 Mpa. The variation of the contact pressure on the assembled model is shown in the Figure 4-17(a) below and the graphical & tabular representation of the contact pressure with respect to the time steping is further shown in Figure 4-17(b) & Table 4-14 respectively.

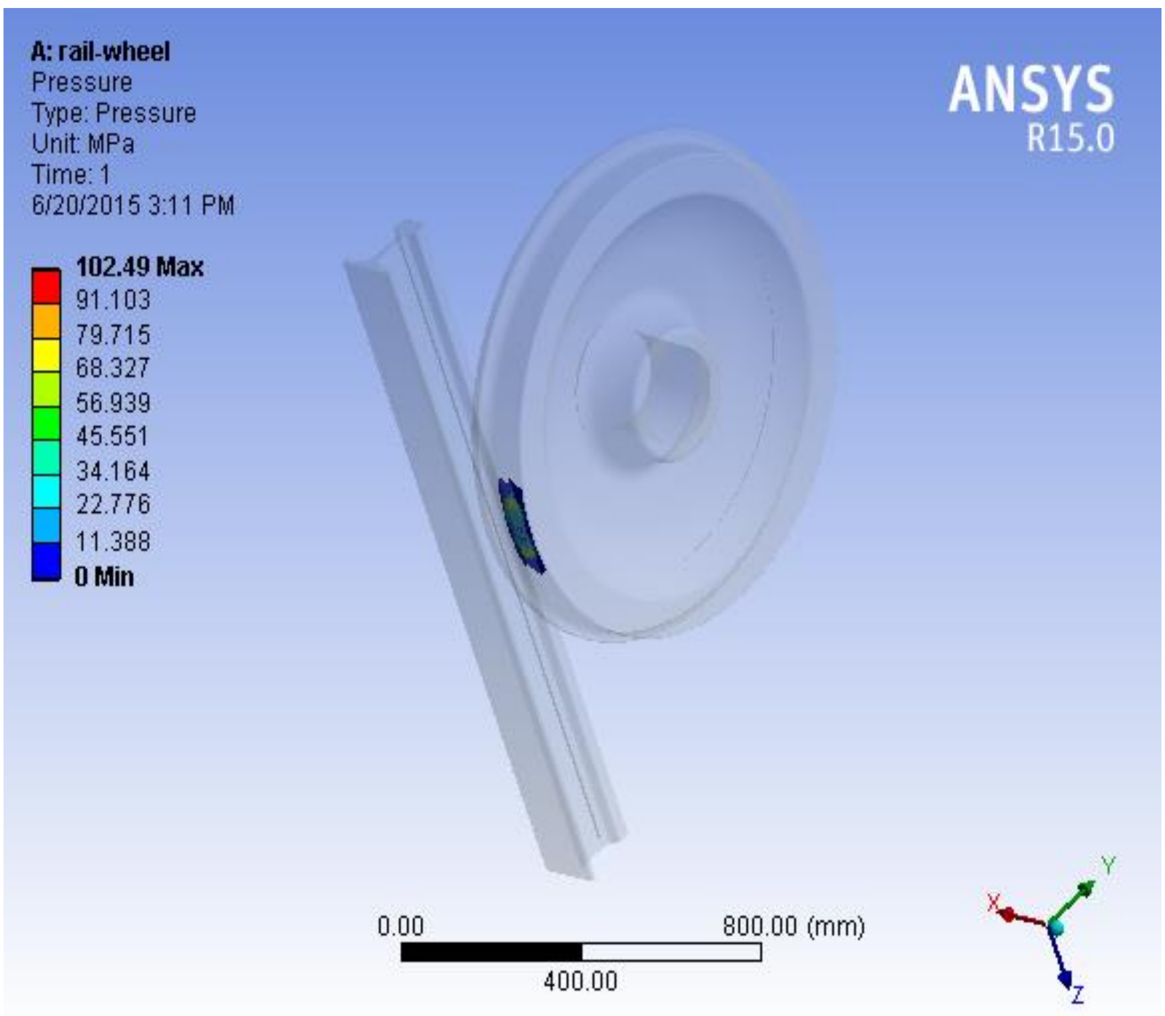


Figure 4-17(a): Model analysis of Contact pressure

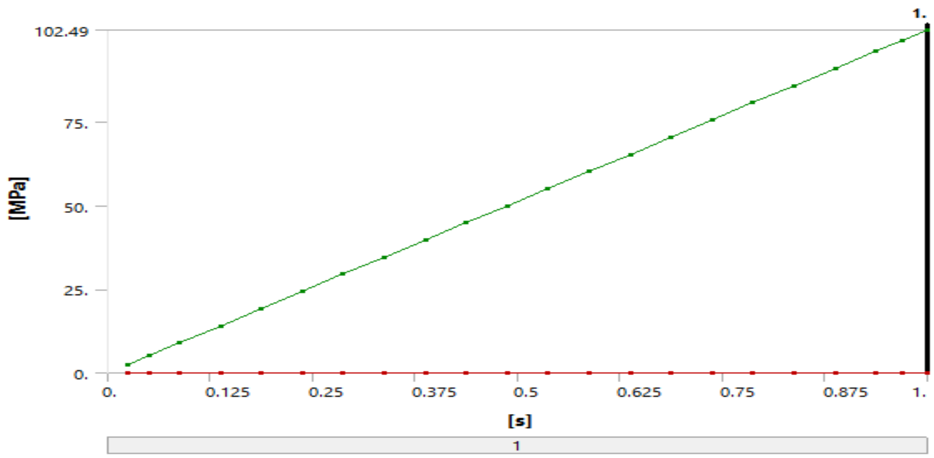


Figure 4-17(b): Graphical Representation of Contact pressure

Table 4-14: Tabular Data of Contact pressure

Steps	Time [s]	Minimum [MPa]	Maximum [MPa]
1	2.5e-002	0.	2.5626
2	5.e-002		5.1246
3	8.75e-002		8.9679
4	0.1375		14.092
5	0.1875		19.217
6	0.2375		24.341
7	0.2875		29.466
8	0.3375		34.591
9	0.3875		39.715
10	0.4375		44.84
11	0.4875		49.964
12	0.5375		55.089
13	0.5875		60.213
14	0.6375		65.338
15	0.6875		70.462
16	0.7375		75.587
17	0.7875		80.711
18	0.8375		85.836
19	0.8875		90.961
20	0.9375		96.085
21	0.96875		99.288
22	1.		102.49

CHAPTER 5

RESULTS AND DISCUSSIONS

5-1 Contact shear stress Results

The Results has been verified by comparing the Ansys 15.0 result with the Hertzian analytical approach as well as with Hertzian Contact stress Calculator.

5-2 Contact shear stress - Ansys 15.0 Approach

From the article 4-5-5 of last chapter it has been found that the *Maximum Contact shear stress is 250.155 Mpa or 250.155 N/mm^2 i.e. equal to 25.5 kg/mm^2*.

5-3 Contact shear stress – Hertzian Approach

From the article 2-13 of Chapter 2 we know that

$$\tau_{max} = 4.13(P/R)^{1/2}$$

Where, τ_{max} is the maximum shear stress in kg/mm^2, R is the radius of the wheel in mm, and P is the (static wheel load in kg + 1000 kg due to curve loading). Maximum Contact shear stress presents at a depth of 5-7 mm below the rail surface.

NOTE: The maximum value of contact stresses for BG is limited to 30% of the UTS value i.e.

For 72 UTS Rail the maximum contact stresses value will be 30 % of 72 i.e. 21.6 kg/mm^2.

For 90 UTS Rail the maximum contact stresses value will be 30 % of 90 i.e. 27.0 kg/mm^2.

From Article 4-3-3 of Chapter 4, we can write

Wheel Load, P = 164640 N = 16782.87 kg + 1000 kg due to curve loading = 17782.87 kg

Similarly, from Chapter 2, according to the article of standard section of railway wheel, we can write that Radius of Wheel (Tread Radius) R = 500 mm

Substituted all the values in the formula we get

$$\tau_{max} = 4.13(17782.87 / 500)^{1/2}$$

$$\tau_{max} = 24.63 \text{ kg/mm}^2$$

Now, we can write that the *Maximum Contact shear stress is 24.63 kg/mm²*

5-4 Contact shear stress – Hertzian stress calculator [27]

When the two bodies with curved surfaces are in contact under a force then the point or line contact between those bodies changes to area/region contact, and three dimensional stresses are developed. These stresses are called contact stresses. The contact stress calculator has been intended to compute contact stresses and contact pressure for cylinder and spherical shaped contact.

As per this concept, the rail and wheel contact is analogous to that of two cylinders (circular wheel and the curved head of rail) shown in figure below.

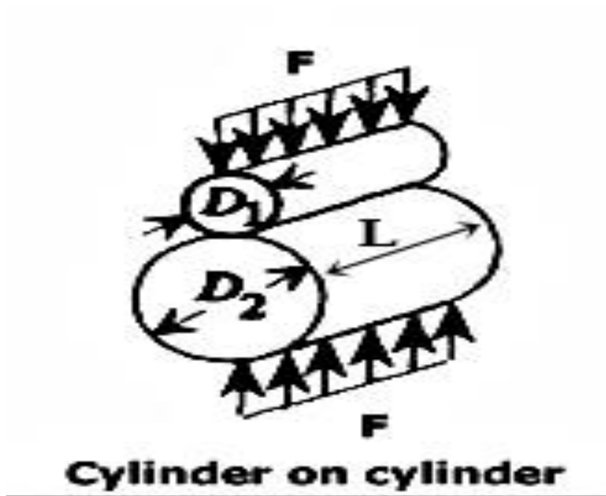


Figure 5-1: Wheel-Rail contact similar to two cylinder contact [27]

Hertzian stress calculator is shown below in figure 5-2. Input parameter are as per the data used in this thesis and can be seen in the figure 5-2 and the. The input parameter has been inserted in the Hertzian stress calculator and using Hertzian approach all the results has been calculated by this Hertzian stress calculator and the output results are also in the figure 5-2.

Calculator:

INPUT PARAMETERS				
Parameter	Symbol	Object-1	Object-2	Unit
Object shape		Cylinder ▼	Cylinder ▼	
Poisson's ratio	v_1, v_2	0.265	0.265	
Elastic modulus	E_1, E_2	200	210	GPa ▼
Diameter of object	d_1, d_2	1000	600	mm ▼
Force	F	164640		N ▼
Line contact length	l	52		mm ▼

Calculate

RESULTS				
Parameter	Symbol	Object-1	Object-2	Unit
Maximum Hertzian contact pressure	p_{max}	769.5		MPa ▼
Max shear stress	τ_{max}	231.1	231.1	
Depth of max shear stress	z	2.059	2.059	mm ▼
Rectangular contact area width	2b	5.239		

Figure 5-2: Hertzian Stress Calculator [27]

From the Hertzian stress calculator shown in figure 5-2, it can be easily observed that the *Maximum Contact shear stress is 231.1 Mpa or 231.1 N/mm^2 i.e. equal to 23.55 kg/mm^2*. Maximum shear stresses are drawn with respect to the depth from contact surface for Object-1 and Object-2 in the following figure 5-3.

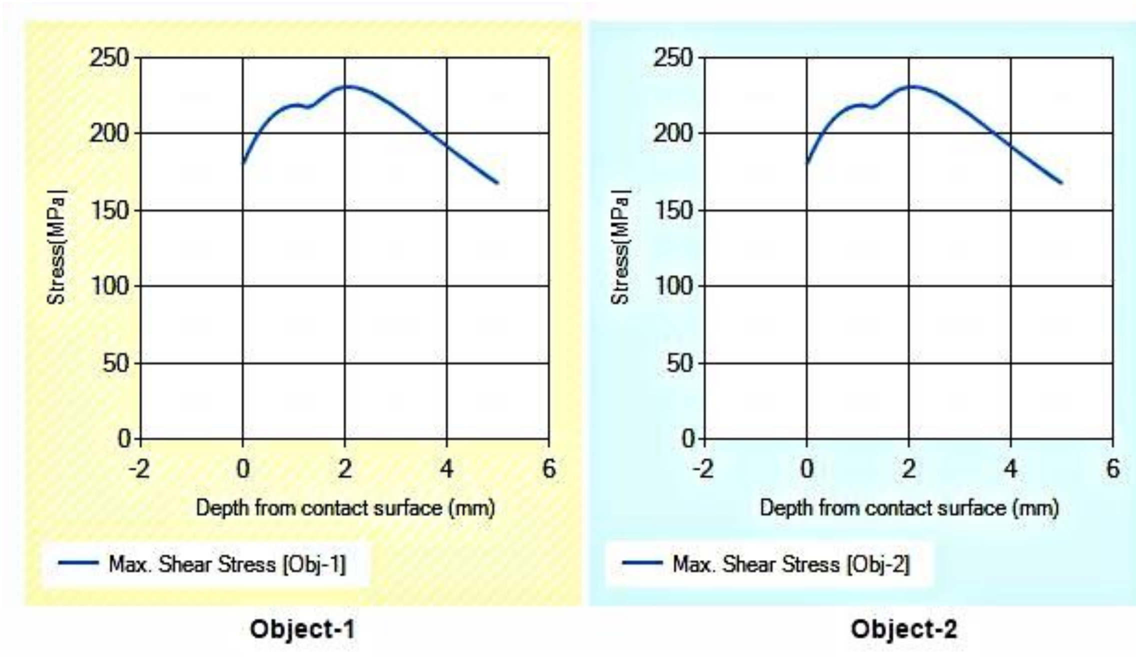


Figure 5-3: Maximum Contact shear stresses Vs Depth from Contact Surface for object 1 & 2

5-5 Result Validation for Maximum contact shear stress

When the two bodies with curved surfaces are in contact under a force then the point or line contact between these bodies changes to area/region contact, and three dimensional stresses are developed. These stresses are called contact stresses. The contact stresses has been calculated above with the three methods and the compiled results are as follows

Table 5-1: Results Comparison and validation of Maximum Contact shear stress

Mode of Analysis	**Maximum contact Shear stress (kg/mm^2)**
ANSYS 15.0	25.5
Hertzian Approach	24.63
Hertzian stress calculator	23.55

The above tabulated observation shows that, all the three maximum Contact shear stresses values are less than 27 kg/mm^2 , which is 30% of the 90 UTS Rail.

CHAPTER 6

CONCLUSIONS

Conclusions

In this thesis report, the Rail-wheel model of Indian railways has been analyzed computationally after modelling and analyzing on the software Creo-parametric 2.0 & Ansys 15.0. The design of the model of rail was according to International Union of Railways (UIC) and also according to weight per unit length used in India. The rail cross section is UIC 60 kg and the wheel standards was according to the Indians standards of BOXN Wagon manufactured by Rail wheel factory (production unit of Indian railways).

The results for the contact stress on the rail was found safe and in the permissible range as the values were lying below the permissible stresses. The maximum contact shear stress found to be less than 27.0 kg/mm^2 which is 30% of the 90 UTS rails. Maximum contact shear stress between Rail -wheel is found to be 25.5 kg/mm^2, 24.63 kg/mm^2, 23.55 kg/mm^2 for Ansys 15.0, Hertzian theory and for Hertzian stress calculator respectively for 90 UTS rail of UIC 60 kg section and all are less than the limiting value of contact stress which is 27.0 kg/mm^2 for 90 UTS rails and it was the prime objective of thesis.

1) The model was given the proper dimensions along with the desirable tolerances. Conditions for axle load was actual, which a UIC 60 kg rail can take over it. The maximum axle load for the UIC 60 kg rail is about 33.6 tonnes, which it can take according to the standards. But on the tracks of Indian railways about 25 tonnes of axle load of freight train including the tare weight of BOXN wagon are in operations. The analysis was static in nature so the contact between rail and wheel was not frictional but a bonded contact. As in general a BOXN wagon of freight train consists 4 axles having two wheels on each axle, so converting axle load to wheel load it becomes half of the axle load i.e. 16.8 tonnes. In fact it is equal to 164640 N i.e. (16.8 x 1000 x 9.81 N).

2) The rail was being fixed from the bottom surface as it remains on the track of P-way (permanent way) with the assistance of sleepers and ballasts by fish plate.

3) The analysis was static and the wheel load was acting in vertical downward direction so it was necessary to constraint the wheel in such a way so that it could move in vertical downward direction but not in other two directions.

4) Material used for the analysis is Cast steel of Grade 880 which has the desired properties and is being used by the leading industries (Tata Steels, Jindal steels, SAIL and Bhilai steel plant of India) for manufacturing of rails.

Essence of the Analysis / Recommendations

The essence of the analysis points towards that the generated contact pressure was under the limiting values of Indian railways. This is really interesting to know that for the freight train wagons on the tracks of P-way of Indian railways about 25 tonnes of axle load, is in application for UIC 60 kg rails, whereas maximum limit of UIC 60 kg is 33.6 tonnes.

The UIC 60 kg rails have been found safe for running higher axle load on behalf of the analysis done in this report. In the simulation and analysis of the model it was never found that the rail or wheel was getting abolished or wrecked. Apart from this all the other parameters found were also in the permissible range and on behalf of the analysis it can be concluded that wagon of at least 130 tonnes (25 tare weight + 105 carrying capacity) can be used on the UIC 60 kg rails, if all the other parameters are in the permissible range. Thus, the Axle load of 30 tonnes can be safely used on 90 UTS Rails. The scope for the future recommendations always remains, if carried a deep and analytical research for the benefit and development of the nation.

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APPENDIX I

CODES FOR FREIGHT WAGONS

The following codes are used now for classifying freight cars. The classification scheme is not entirely systematic. Older wagons especially have codes that are not easily explained in this way. But in general an optional gauge code is followed by a type code which is followed by an indication of the coupler and whether the wagon is air-braked.

- **Gauge code**
  - M : (prefix) MG
  - N : (prefix) NG
- **Wagon type code**
  - B : (prefix) Bogie wagon (sometimes omitted)
  - BV : Brake van
  - V : Brake/parcel van (see above for brake van codes)
  - O : Open wagon (gondola)
  - C : Covered wagon (boxcar)
  - F : Flat car
  - FK : Flat car for container transport
  - FU : Well wagon
  - LA : Low flat car with standard buffer height
  - LB : Low flat car with low buffer height
  - LAB : Low flat car, one end with low buffers, the other with high buffers
  - R : Rail-carrying wagon
  - T : Tanker (additional letters indicate material carried)
  - U : Well wagon
  - W : Well wagon

- K : Open wagon: ballast / material / refuse transport (older wagons)
- C : Centre discharge
- S : Side discharge
- R : Rapid (forced) discharge, bottom discharge
- X : Both center and side discharge
- X : (also) High sided
- Y : Low (medium) side walls
- L : Low sided
- H : Heavy load

The ‘B’ indication is sometimes omitted as all new wagons are bogie stock.

Following the type code in the classification code a letter may denote the type of coupler, nowadays optional, as all new freight cars are fitted with centre buffer couplers (CBC). An 'N' suffix is for 'pneumatic', or air-braked wagons. Most newer stock that is air-braked also has CBC couplers, so the 'C' is usually dropped. E.g., BOXN for air-braked BOX wagons, not BOXCN. Almost all the older stock is vacuum-braked.

- Coupler, brake, and other suffixes:
  - C = Centre buffer coupler (CBC)
  - R = Screw coupling only
  - T = Transition coupler (CBC with additional side buffers and screw coupling)
  - N = Air-braked
  - M = (suffix) Military

APPENDIX II

MODELLING SOFTWARE
CREO PARAMETRIC 2.0

Modelling software

Creo parametric is the CAD software used for 3D CAD parametric modelling of solids. It's a Design software used for product design and is being used by the leading manufacturers of the industry. The graphical user interface of creo parametric is shown in figure below.

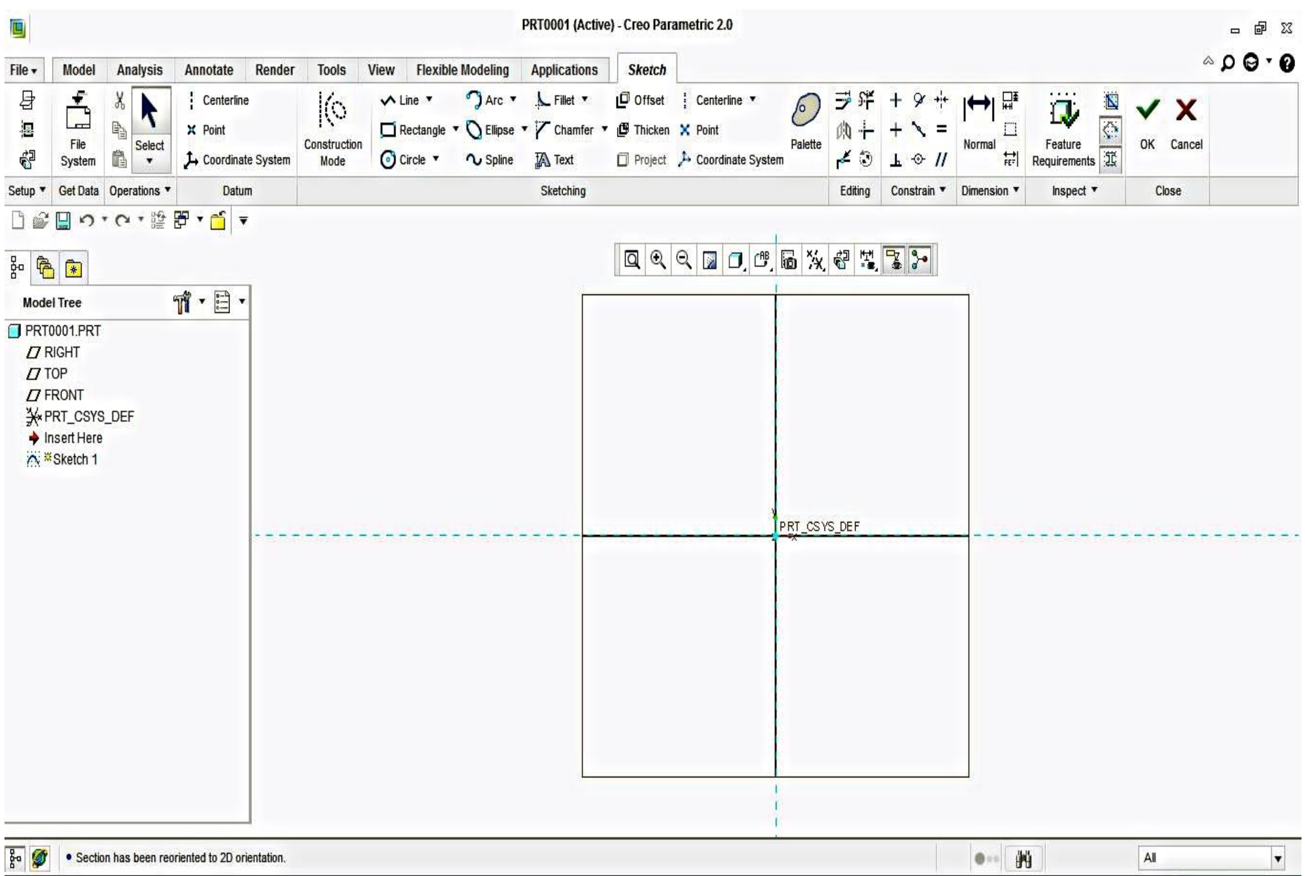

Figure 1: GUI of Creo parametric 2.0

The software provides a great strength of features that allows us to explore the technical illustrations of the modellings. In addition to this, it is also capable for creating simulations & finite element analysis. The software provides a greater visuals and effective visualizations so that one could get familiar with the geometry of the model. Schematic designs can be achieved through it so that all the views of the designed model may be created for the manufacturing. PTC (Parametric Technology Corporation) has developed this software. Till now, the software has been revised two times and the following versions of the software are given in the following table.

Table 1: Versions of Creo parametric

Name/Version	**Release Date**
Creo 1.0	6/1/2011
Creo 2.0	4/9/2012
Creo 3.0	6/17/2014

APPENDIX III

CAE SOFTWARE

ANSYS 15.0

Analysis software

Ansys is an engineering simulation software used for finite element analysis of mechanical components or systems and in analysis of mechanical design problems. The software administers a wide range of applications in diversified aspects of physics. It's a CAE (Computer aided Engineering) software which facilitates us with a full range of solutions for all type of problems whether it's a static/dynamic, linear/non-linear, structural, thermal, heat transfer, fluid, acoustic or electromagnetics problem. Material library along with its all mechanical properties is the effective feature of this software. It's a software used for product design & analysis and is being used by the leading industries and finest research & development tool used in automobile, structural, aerodynamics and in defence industry. ANSYS 15.0, the latest version of the software has been used here in this chapter for carrying the static structural analysis of the contact region between the rail-wheel for the stress analysis and other results.

The workbench of the Ansys is the essential window for Static structural stress analysis of the contact region of rail-wheel model. Static structural analysis is the imperative stress analysis to find out equivalent stress (von-mises), maximum principal stress, minimum principal stress, stress intensities and shear stresses. In addition to this other parameters like equivalent strain, maximum principal strain, minimum principal strain, maximum shear strain has also to be determined along with strain energy and safety factor. For the analysis the effective method has to be used for developing the correct boundary conditions and values for the stress analysis.

The graphical user interface of workbench of ANSYS 15.0 is shown in Figure 1.

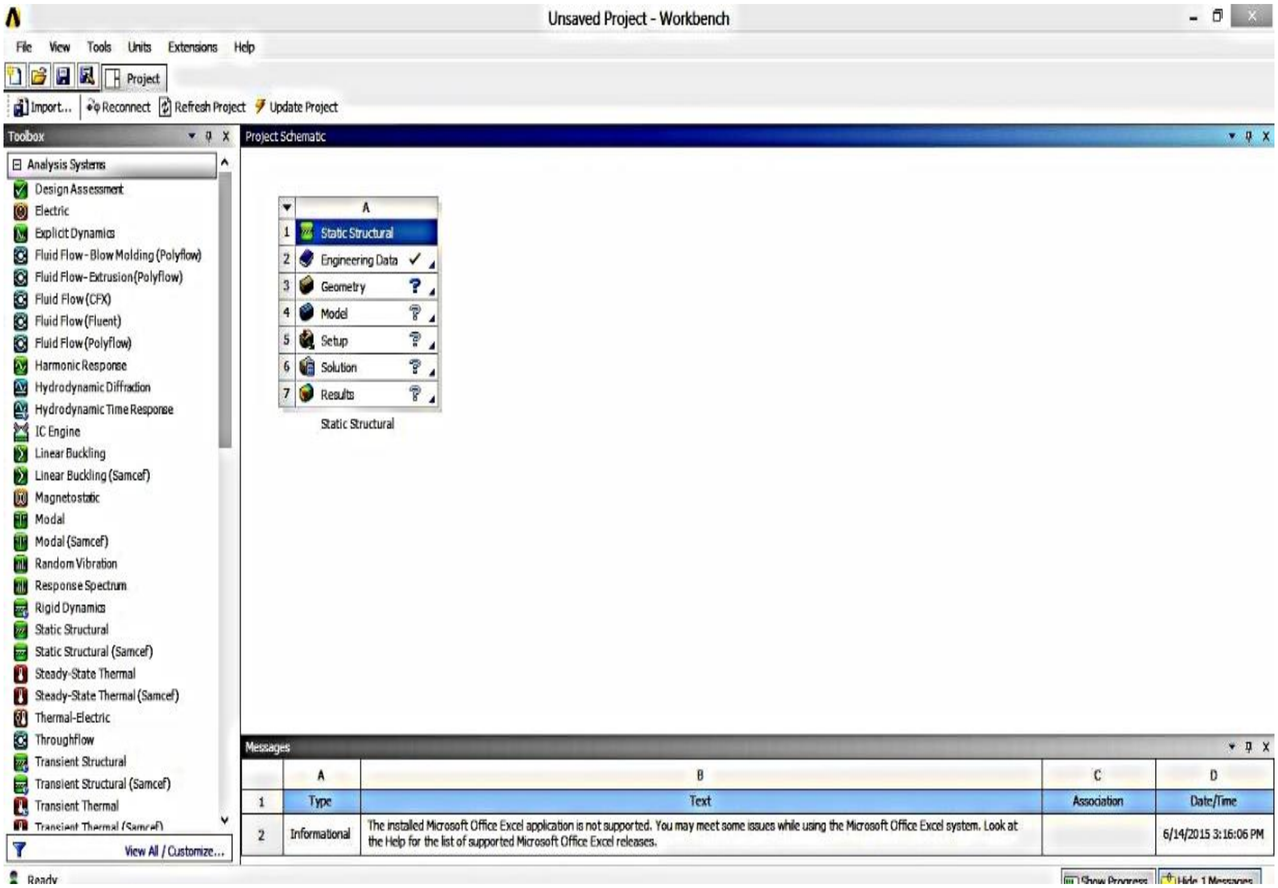

Figure 1: GUI of Ansys 15.0 Workbench