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Computational Static Analysis of Rail-Wheel Model of Indian Railways

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Abstract: *In this paper, 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 along with the conventional approaches. 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 according to the Indian Railway Standard. Finally, the effects of the results have been studied for the essence of analysis.*

Keywords: *Rail-wheel, contact shear stress in rail-wheel contact region, freight wagon*

1. INTRODUCTION

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. Indian Railways gains around 70% of its income 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.

2. ELEMENTS OF MODELLING

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. 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 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 [1].

2.1 STANDARD 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 [2]. The most used standards of rail sections of Indian railways are given in Table 1.

TABLE 1: Standard Rail Sections [2]

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

2.2 MATERIAL COMPOSITION AND PROPERTIES OF RAILS

On the Indian railway tracks most used rails are of 60-kg UIC section. It is being designed for speeds upto 160 kmph and can sustain a traffic density of 35 GMT (gross million tonnes per km/annum) [2]. 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.

2.3 MODELLING OF UIC 60 KG RAIL

The geometry of UIC 60-kg rail has 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 necessary 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. The rail model is prepared in the following steps:-

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.

Part Modelling - Then, extrude the closed region of sketch, up to a considerable length of 1500 mm so as to model the sketch into solid body.

Drafting - This feature gives the different views (top, side, front, back) of the part modeled and that data accounts a lot for the manufacturing firm for production of products.

TABLE 2: Chemical composition [2]

Grade	Carbon C	Manganese Mn	Silicon Si	Sulphur S (max.)	Phosphorous P (max.)	Aluminium Al (max.)	Liquid 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: Mechanical properties [2]

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

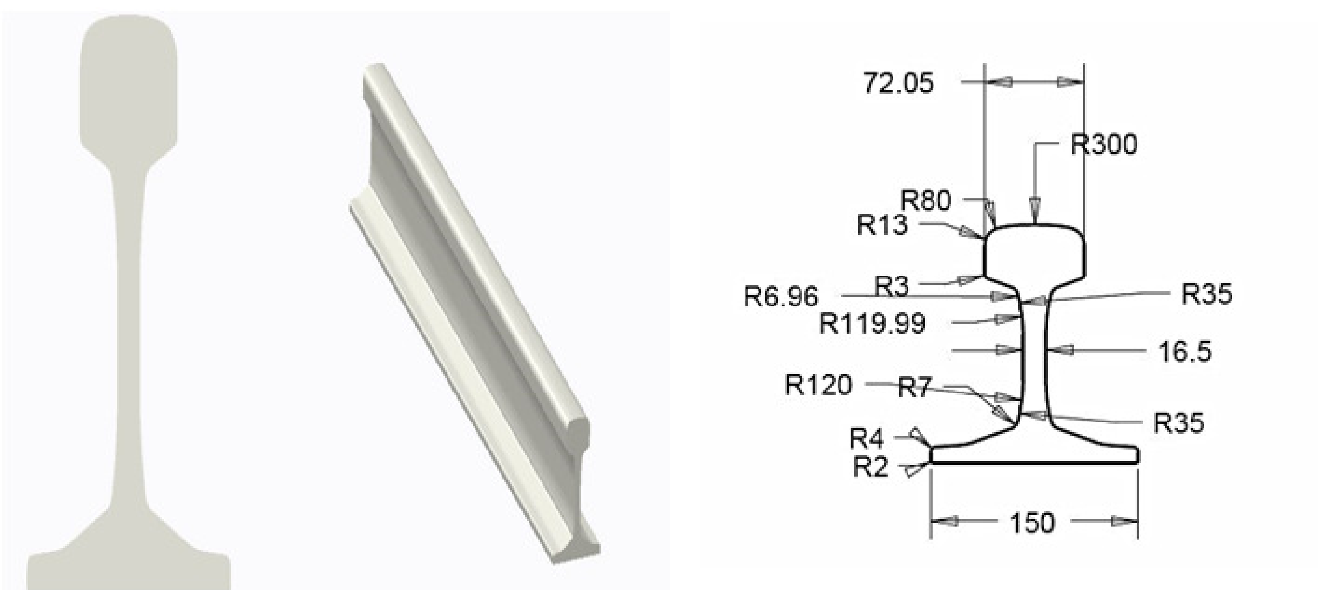


Fig. 1. Modelled view of Rail a) Front view b) Isometric view c) UIC Rail in Creo parametric 2.0

2.4 STANDARDS FOR RAILWAY WHEELS

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). 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%. [1]. The material used for wheel is also Cast steel.

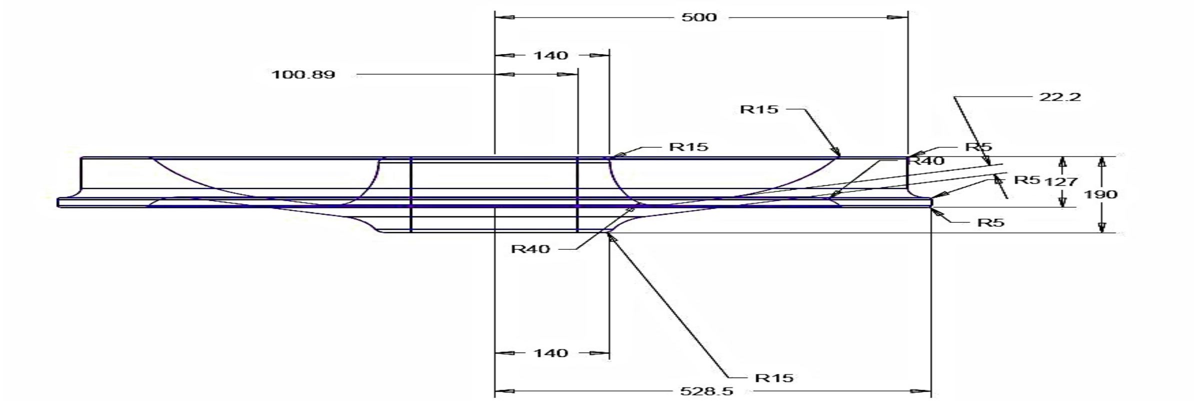


Fig. 2. BOXN Wheel in Creoparametric 2.0

TABLE 4. Chemical Composition of wheel [1]

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	

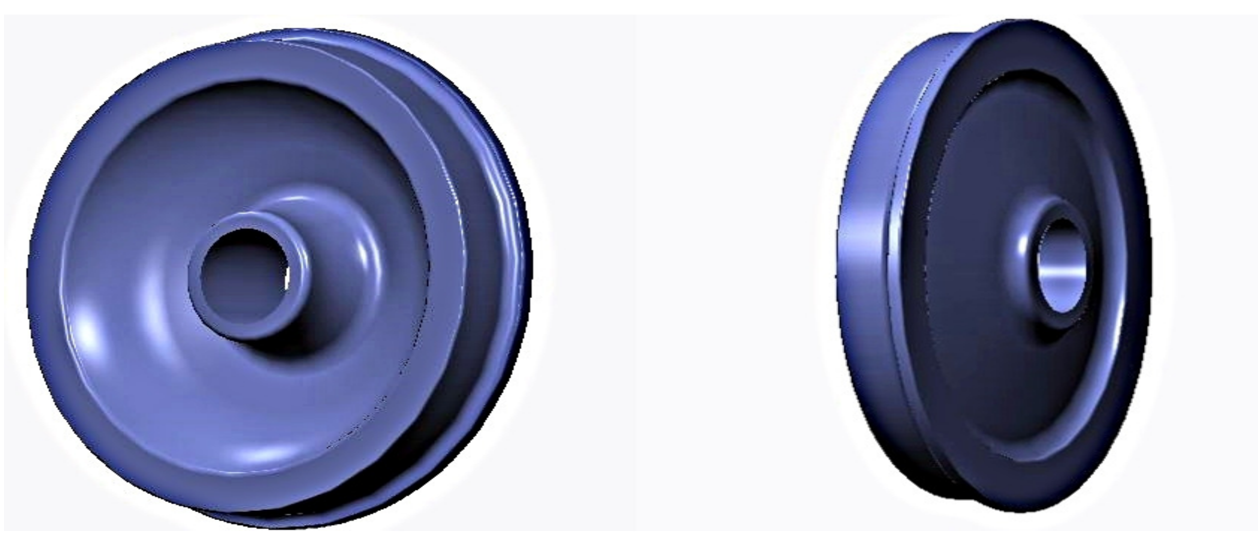


Fig. 3. Model of BOXN wheel in Creo parametric 2.0

2.5 RAIL-WHEEL ASSEMBLY & CURVE PROJECTION ON RAIL

The half made sketch of BOXN wheel has been revolved about the geometric center line created at the lateral axis of the wheel in creo parametric 2.0. 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. The relationship status between the rail and wheel was set to the tangent. 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 4.

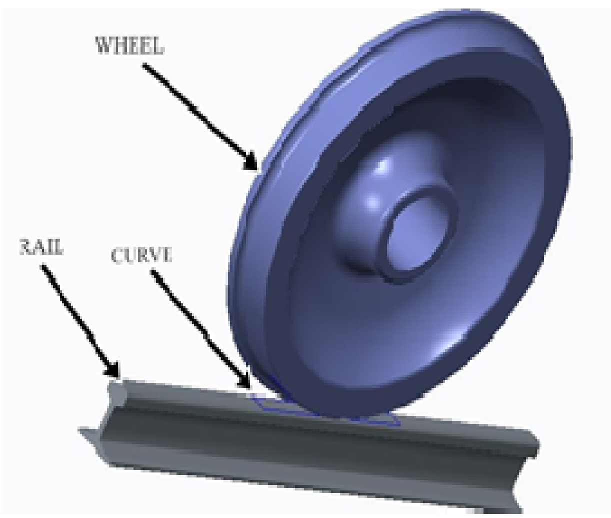


Fig. 4. Assembly of Rail-Wheel in Creo parametric 2.0

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 width 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 4. The design of the model of rail is according to International Union of Railways (UIC) and also according to weight per unit length used in India. The rail material is grade 880 (90 UTS section).

3. STATIC ANALYSIS OF MAXIMUM CONTACT SHEAR STRESS

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.

3.1 MATERIAL SELECTION & TANGENT MODULUS

Cast steel of grade 880 is used as the material for the rail and wheel. 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. Tangent modulus 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 behaviour tangent modulus need to be included to know the value of change in strain for a specified range of stress [3].

3.2 DESIGN MODELER & MECHANICAL SOLVER

Those lines have been suppressed which were not required. 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. 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. 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.

3.3 MESHING

The meshing used here is triangular surface meshing, and the size for meshing has been set up to the fine so that the 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 accurately. Total elements used in the meshing are 40,162 and the number of nodes generated are 93431.

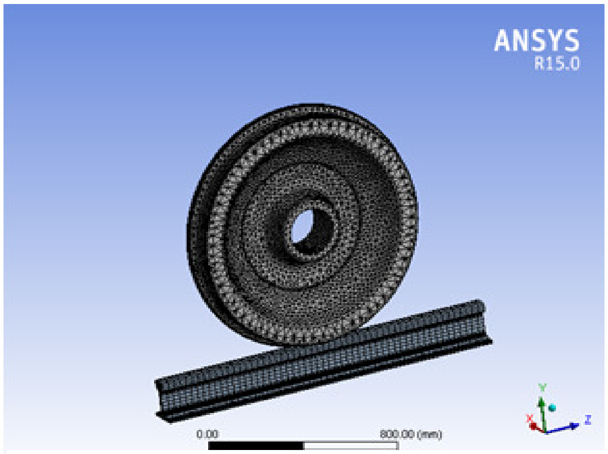


Fig. 5. Triangular surface meshing in fine quality

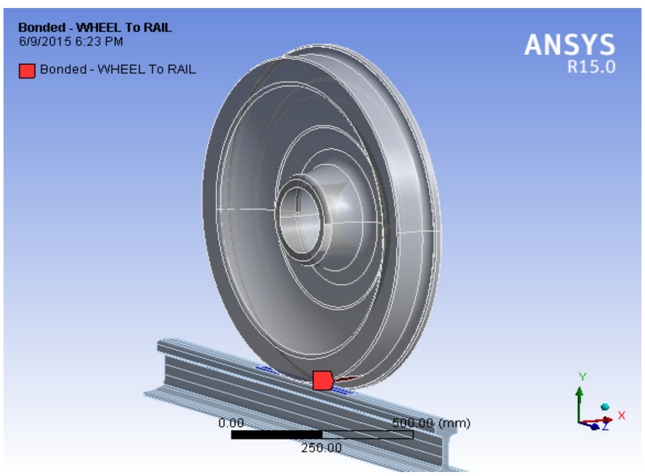


Fig. 6. Bonded contact

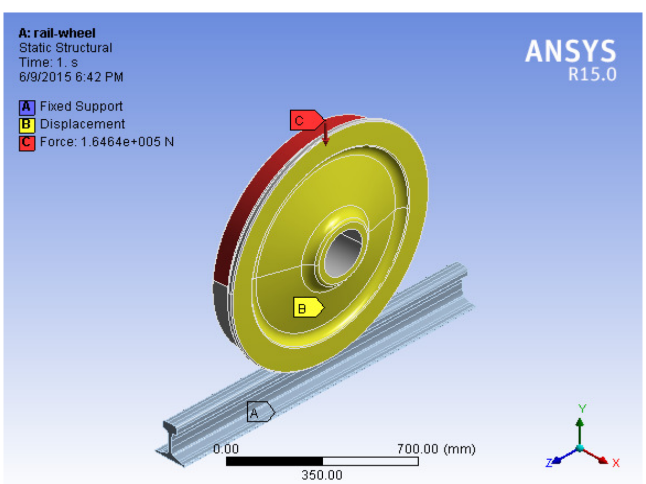


Fig. 7. Boundary Conditions

3.4 CONNECTIONS

By defining the proper contact between the two bodies, the contact region has been taken. In contact region, the contact type is bonded contact as it is static structural analysis, so there remains no scope for frictional contact or frictional value. The Interface treatment between the two bodies has been defined by adding offset with the ramped effect, means the load will be applied gradually.

3.5 BOUNDARY CONDITIONS

Fixed support

The analysis is of static structural type and requires *fixing of the 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.

Force applied

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 i.e. maximum load which a wheel can take on UIC 60 kg rails.

Displacement constraints

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. The boundary conditions has been shown in figure 7. In the further figures 8 (a) & (b) displacement and force is taken on y axis respectively and time of unit second on x axis.

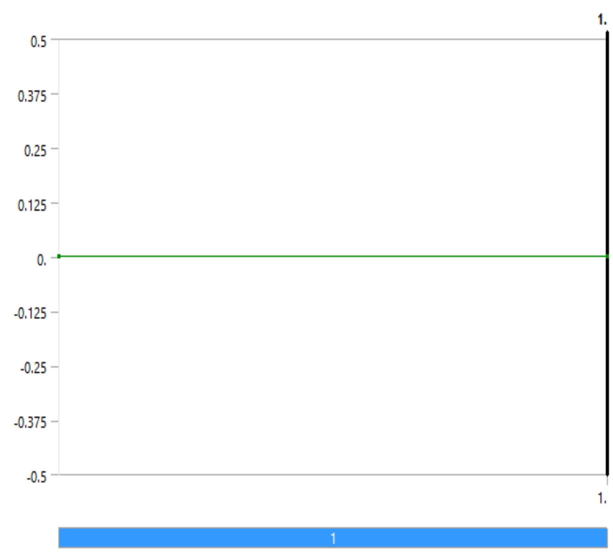


Fig. 8(a). Displacement (mm) Vs Time (s)

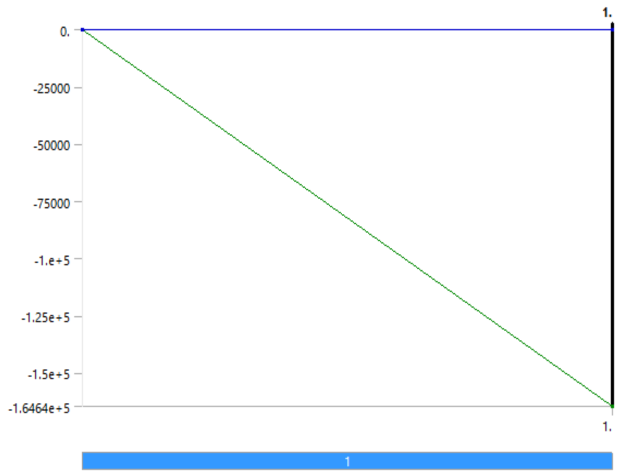


Fig. 8(b). Force (N) Vs Time (s)

3.6 CONTACT SHEAR STRESS – ANSYS 15.0 APPROACH

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 which 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-9(a) below and the graphical representation of the shear stress with respect to the time stepping is further shown in figure-9(b).

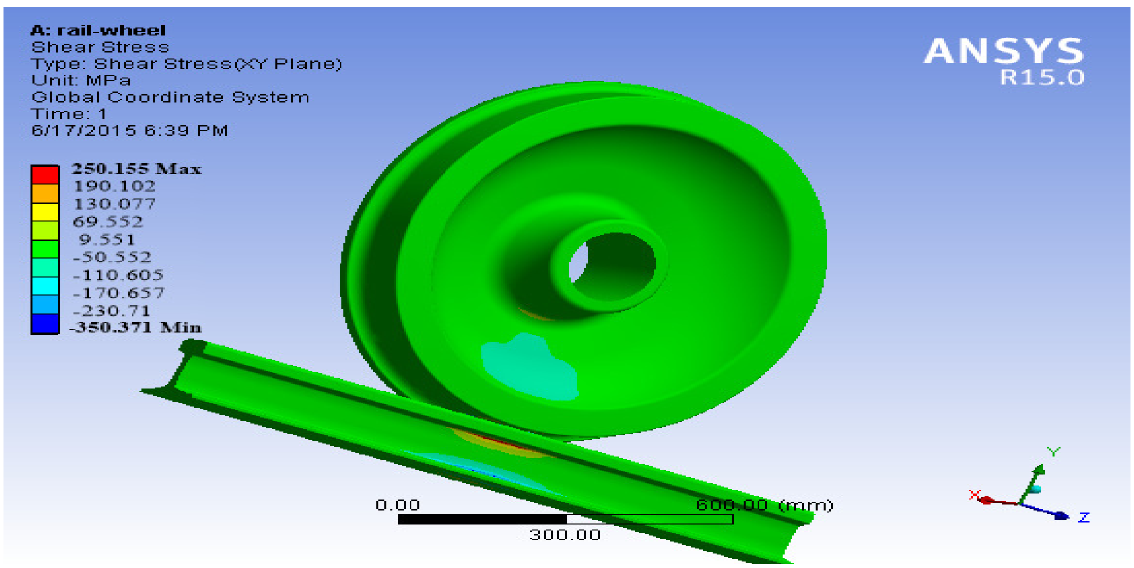


Fig. 9(a). Model analysis of Shear stress

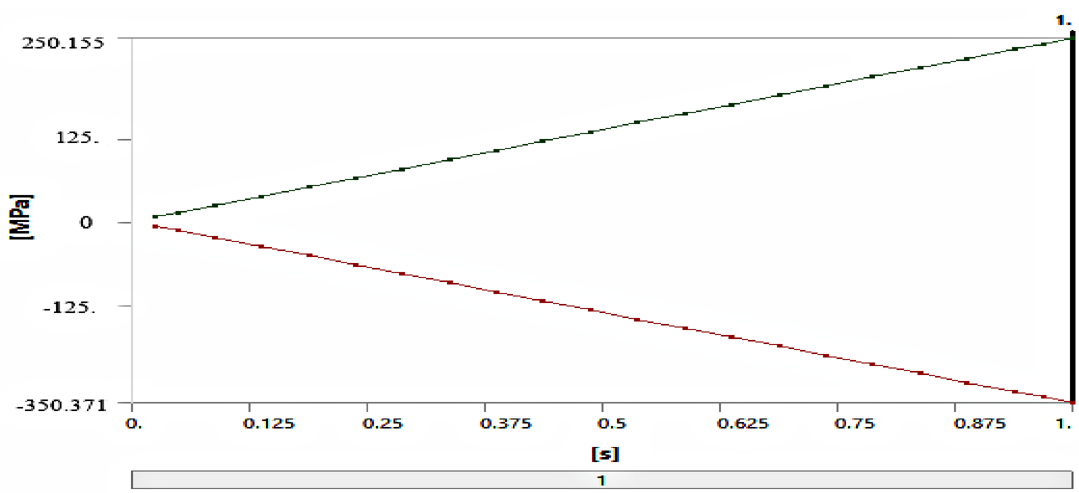


Fig. 9(b). Graphical Representation of Shear Stress

It can be observed 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.*

3.7 CONTACT SHEAR STRESS- HERTZIAN APPROACH

We know that, $T_{max} = 4.13\ (P/R)^{1/2}$

Where, T_{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) [2]. Maximum contact shear stress is present at a depth of 5-7 mm below the rail surface. The maximum value of contact stresses for broad Gauge is limited to 30% of the UTS value i.e.

For 72 UTS Rail the maximum contact stress value is 30 % of 72 UTS i.e. 21.6 kg/mm^2 and

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

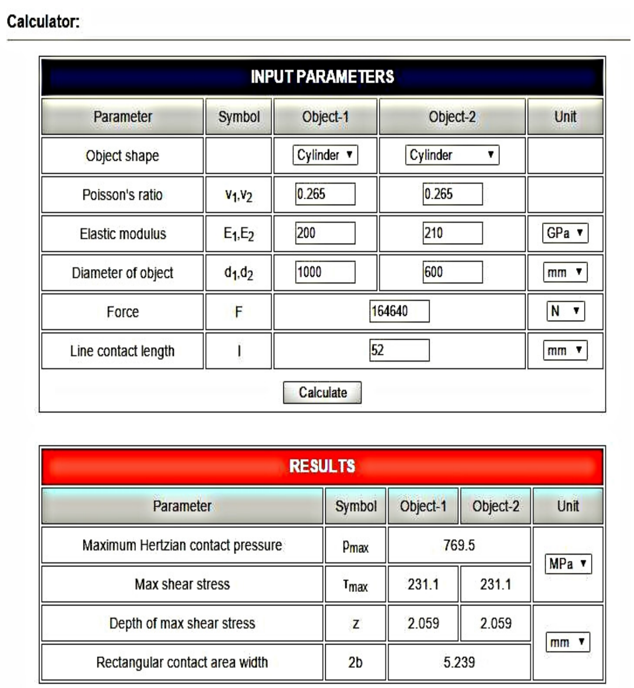
The input data is same as we used in Ansys 15.0 approach i.e.

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

Radius of Wheel (Tread Radius) R = 500 mm

Substituting these values in the hertzian contact stress formula we get T_{max} = 24.63 kg/mm^2

Now, we can write that the *Maximum Contact shear stress is 24.63 kg/mm^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	MPa
Depth of max shear stress	z	2.059	2.059	mm
Rectangular contact area width	2b	5.239		mm

Fig. 10. Hertzian Stress Calculator [4]

3.8 CONTACT SHEAR STRESS- HERTZIAN STRESS CALCULATOR

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 the contact stresses and contact pressure for cylindrical 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 [4].

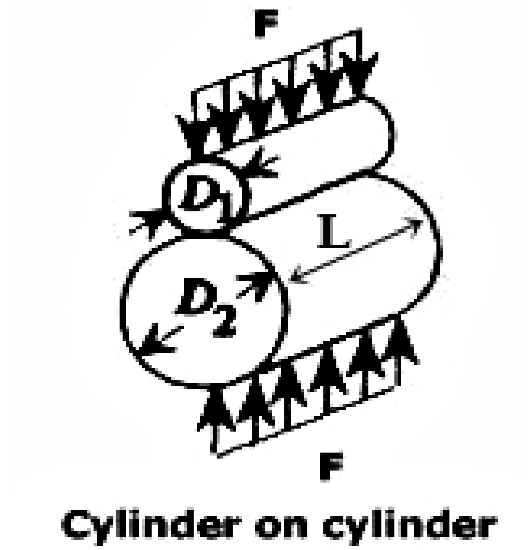


Fig. 11. Wheel-Rail contact similar to two cylinder contact [4]

From the Hertzian stress calculator shown in figure-10, 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-12.

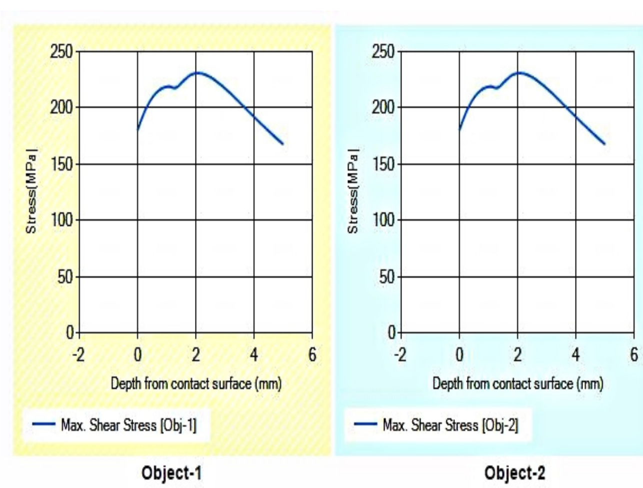


Fig. 12. Maximum Contact shear stresses Vs Depth from Contact Surface for object 1 & 2

4. RESULTS FOR MAXIMUM CONTACT SHEAR STRESS

The 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.

TABLE 5: 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

5. CONCLUSIONS

The maximum contact shear stress found to be less than 27.0 kg/mm^2 which is actually 30% of 90 UTS (90 kg/mm^2) rail. 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 corresponding to Ansys 15.0 approach, Hertzian theory and Hertzian stress calculator respectively for 90 UTS rail of UIC 60 kg section and all are less than the permissible value of contact stress which is 27.0 kg/mm^2 for 90 UTS rails and it was the prime objective of this paper. The freight train wagons on the tracks of P-way of Indian railways, carries 25 tonnes of axle load 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 technical paper. 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 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, Axle load of 30 tonnes can be safely used on 90 UTS Rails. The scope for the future recommendations always remains, if it carries a deep and analytical research for the benefit and development of the nation.

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