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Stress Analysis of Embedded Rail Insert in Prestressed Concrete Sleeper

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Abstract

The combination of rails, fitted on sleepers with a suitable fastening system and resting on ballast and subgrade is called the railway track or permanent way. The most important function of fastening systems is to provide strong and flexible connection between rail and its supporting structure that can be sleeper or slab. Two types of fastening systems are used to secure the rails to the sleepers, indirect fixation and direct fixation. The "indirect fixation" fastening uses a steel tie plate beneath the rail and a tie pad between the plate and the tie. The "direct fixation" fastening eliminates the tie plate. Concrete shoulders cast into the sleeper provided lateral support to the clips.

The direct fixation fastening systems evolved over the years and now pre-stressed concrete sleepers use SGCI inserts together with Elastic Rail Clip and rubber/elastomeric pad to hold the rails. Stresses which effect the contact area between the rail insert & concrete sleeper by developing the Finite Element Model of rail insert embedded in sleeper. The worst condition of stresses has been found for the most effective hypothetical load case using ANSYS.

1. Introduction

In the early stages of railway history, the speeds of trains were quite moderate. The loads that were subjected to the track system could be regarded as static loads [3]. In recent times the locomotive design has evolved a great extent and the train speeds have increased substantially.

Future railway traffic will certainly be even faster than the trains of today, and at the same time the demanded load capacity of the trains will probably increase. This implies that the demands on the concrete sleeper will increase and the need for detailed, reliable analytical tools will be of greater importance in the near future.

The railway track was originally developed in order to exceed the load-carrying capacity of the roads. In the development of the railway track a component acting and looking like the sleeper of today was invented. Bonnett (1996) specifies the functions that are required of a modern sleeper used in railway tracks today [2]:

- Spread wheel loads to ballast
- Hold rails to gauge and inclination
- Transmit lateral and longitudinal forces
- Insulate rails electrically
- Provide a base for rail seats and fastenings

The functions described above show that the sleeper has an important role in the track system. It is thereby obvious that the sleeper has to be analyzed in an accurate way.

Several physical phenomena occur when dynamic (impact) loads are applied to concrete sleepers that do not occur under static conditions. For instance, the dynamic loads introduce stress waves in the sleeper, the acceleration of the sleeper introduces inertial forces, and the high strain rate changes the material properties of the concrete. Furthermore, the ballast pressure supporting the sleeper in the track will change with time in a dynamic load situation [1].

One reason for starting to use reinforced concrete sleepers was to get a great reduction in the overall cost of track maintenance [5].

A reference body of experiments with reinforced concrete sleepers arose as far back as 1880, and reinforced concrete sleepers were used quite extensively in the 1920s and 1930s in countries such as Italy and India [6].The use of reinforced concrete sleepers increased the structural stiffness and developed unique problems that are not associated with wooden sleepers, such as flexural cracks which could lead to deterioration of the sleepers [7].

It is important to identify the impact of various loads and stresses on the prestressed concrete sleeper. The concrete sleepers are cast with four rail inserts embedded in it. The rail inserts are used to fasten the rail with the help of rail clip as shown in Fig.1. The current work is focussed on finding out the stresses which effect the contact area between the rail insert & concrete sleeper. Finite element model of a concrete sleeper has been developed by use of existing element types and material models. The finite element model of the rail insert of SGCI type embedded in concrete sleeper has also been developed. Three effective load cases have been considered specific to Indian railways to carry out the stress analysis.

Fig.1. Rail Insert embedded in concrete sleeper

2. FE Modeling

2.1 Modeling of Concrete Sleeper

A mono block pre-stressed concrete sleeper used by RDSO(Research Division and Standards Organisation of Indian Railways) of type T-2495 has been designed in ANSYS 7. This sleeper has an overall length of 2750 mm and has a trapezoidal cross-section having width at top of 154mm, at bottom of 250 mm and height of 210 mm at the rail seat. A cant of 1 in 20 has been provided in the top surface of the sleeper for a distance of 175 mm on either side of the centerline of rail to cover the area of rail fittings.

For the stress analysis, a block of this sleeper has been modeled to arrive at a hypothetical condition of a single insert being embedded into the sleeper block. The length of this sleeper block is approximately taken as three times the width of the insert. The modeling of the sleeper block and the insert embedded into it is written in ANSYS MACRO.

2.2 Meshing Deatils of Sleeper Block

Once the insert is embedded into the sleeper block, the insert is first meshed considering the material properties of the SGCI (i.e. Young's Modulus E = 10.9E10 N/m^2, Poisson's Ratio PR = 0.23) in the meshing attributes. Similarly the sleeper block is meshed considering material properties of concrete (i.e. Young's Modulus of concrete EC = 3E10 N/m^2, Poisson's Ratio PR = 0.15) as the meshing attributes with Solid 45, 3-D structural solid element as element type as shown in Fig.2.

2.3 Modeling the shaft of the insert

Certain dimensions which are used for designing the insert in Ansys are taken as parameters. These geometric parameters are the independent quantities that are varied in order to achieve the optimum design.

The shaft of the insert is embedded in the concrete sleeper, its cross section is of an ellipse and its profile is designed as a curved surface to increase its contact area. As there is no command to create an ellipse in ANSYS 7, the ellipse is created through a set of key points satisfying the basic ellipse equation.

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

The key points are input in polar co-ordinate form i.e., (a cosθ, b sinθ). These key points are joined through a smooth curve (spline). Using the symmetry these smooth curves are reflected about Y-Z and X-Y planes to complete the ellipse. Similarly the guiding smaller ellipse is also created and line arc guiding the profile of the shaft through the specific key points of the larger and smaller ellipses is created. Now areas and volumes are created through the splines and arcs using modeling commands.

2.4 Modeling the shoulder and centre leg of the insert

The shoulder lies on the surface of the sleeper on which the elastic rail clip rests. The shoulder is modeled by tapered lines and its length is taken a geometric parameter. The centre leg of the insert is a half cylinder and is modeled as a semicircle extruded through out the length of the shoulder. The diameter of the hole (22mm) depends on the cross-section of the elastic rail clip and is a fixed parameter.

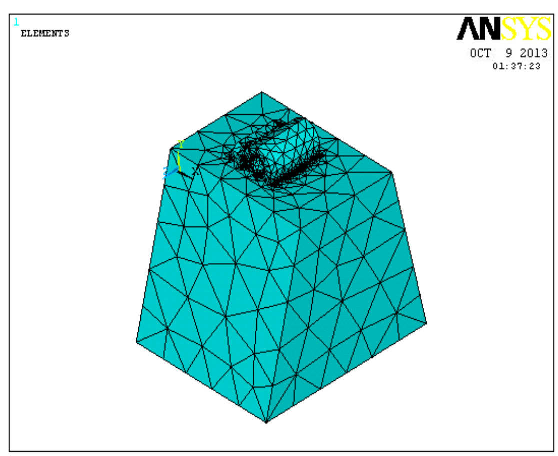

Fig.2. FE Model of Rail Insert embedded in a sleeper block

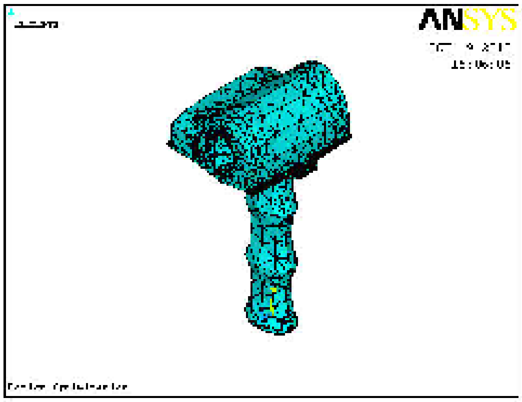

Fig.3. FE Model of the Rail Insert

3. Force and Stress analysis of insert in sleeper

The elastic rail clip (Pandrol clip) contacts the insert at locations I and C as shown in figure 4.1. The forces F_I and F_C will be acting at these locations, in addition to these forces a horizontal force F_h ($F_h = F_y - \mu \times F_z$) also acts on the insert coefficient of friction μ between rail and rubber pad or between rubber pad and concrete may be assumed as 0.4 (a conservative estimate). The force F_h can be safely assumed to be equally distributed along the length of the insert as shown in the fig.4. For analysis of stresses on the insert six different load cases have been considered as per the RDSO specifications and are explained below [8].

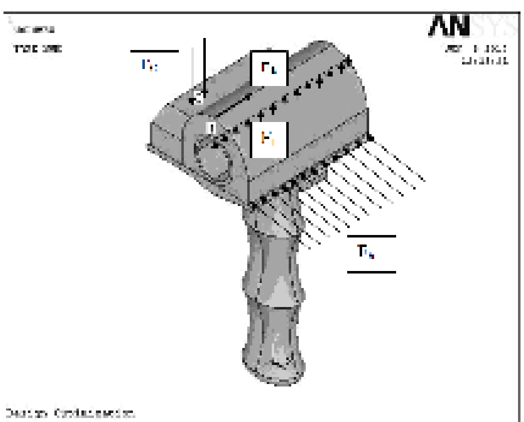

Fig.5. Different Forces acting on the Rail Insert

Case 1:
Only vertical load of 15000 kg acts on the rail in this case. According to RDSO specifications it gives the force analysis on the insert in this case gives the loads as
F_I = 28760 N,
F_C = 17980 N,
F_h = 0.

Case 2:
The rail is subjected to 13000 kg vertical load and 7000 kg horizontal force in this case. Force analysis on the insert gives the following forces.
F_I = 29550 N,
F_C = 18470 N,
F_h = 17640 N.

Case 3:
When the rubber or elastomeric pad is missing, the friction between rail and concrete is assumed to be absent, resulting in transfer of total horizontal force to the insert in this case. The force analysis gives
F_I = 29550 N,
F_C = 18470 N,
F_h = 68600 N.

Case 4:
The toe load is proposed to be increased to 1300 – 1500 kg. For the purpose of analysis the toe load is taken as 1500 kg. The force analysis gives
F_I = 39200 N,
F_C = 24500 N,
F_h = 17640 N.

Case 5:
The toe load has been increased to 1500 kg, in addition the elastomeric pad is missing (μ = 0), force analysis on the insert gives
F_I = 39200 N,
F_C = 24500 N,
F_h = 68600 N.

Case 6:
It is also proposed to evaluate stresses in the insert, when the workman strikes the rail clip with a hammer for checking its effectiveness [8]. The workman normally uses a hammer of 1.5 kg and it is assumed that he will raise it to a height of 1m before striking. Assuming freefall of the hammer, the striking velocity ≈ 9.8 m/ses.
Momentum at the time of strike = mV = $1.5 \times 9.8 = 14.7 kgm/\sec$
Assuming duration of strike ≈ 0.01 s.
The force applied on the insert is rate of change of momentum, i.e.

$$\approx 14.7 \times \frac{9.8}{0.01} \approx 14700 \text{ N.}$$

This force (F_a acts in the axial direction of the 22 mm hole in the insert at the centre leg part along with forces F_I = 39200 N , F_C = 24500 N, F_h = 0.

3.1 Load Cases for Stress Analysis of the Insert

The above six load cases are further simplified into three effective load cases to arrive at the worst state of stress conditions. The insert in different stages of the optimization procedure is subjected to forces from these three load cases.

Load case 1:

Only vertical load of 15000 kg acts on the rail in this case. According to RDSO specifications it gives the force analysis on the insert in this case gives the loads as

$F_I = 28760$ N, $F_C = 17980$ N, $F_h = 0$.

The force F_I acts at the inside upper surface in the insert hole and has been taken as uniformly distributed. The force F_C acts on a small elliptical area made due to contact between ERC (Elastic Rail Clip) and face of the insert shoulder at point C.

The principal stresses in different parts of the insert vary from 2.09E7 N/m^2(compressive) to 11.3E7 N/m^2(tensile).The Vonmises (S-Equivalent) stresses in the insert vary from 11.133E3 N/m^2 (tensile) to 17.3E7 N/m^2 (tensile).

When embedded in the sleeper block the principal stresses vary from 1.93E7 N/m^2(compressive) to 9.09E7N/m^2 (tensile). The principal stresses in the concrete block vary from 18.5576E4 N/m^2 (tensile) to 2.17E7 N/m^2 (tensile).

Load case 2:

The toe load has been increased to 1500 kg in addition the elastomeric pad is missing (μ = 0), force analysis on the insert gives

$F_I = 39200$ N, $F_C = 24500$ N, $F_h = 68600$ N.

The lateral load F_h acts just above the projected part of the insert on which the rail rests through the elastic liner.

The principal stresses in different parts of the insert vary from 58.6E7 N/m^2 (compressive) to 609.8E7 N/m^2 (tensile). Vonmises (S-Equivalent) stresses in the insert vary from 42.091E3 N/m^2 (tensile) to 604.0E7 N/m^2 (tensile).

When embedded in the sleeper block the principal stresses vary from 8.63E7 N/m^2 (compressive) to 48.9E 7 N/m^2 (tensile). The principal stresses in the concrete block vary from 0.124E 7 N/m^2 (compressive) to 10.5E 7 N/m^2 (tensile).

Load case 3:

The force acting in the axial direction of the 22 mm hole in the insert at the centre leg part to account for the hammer striking force, along with forces

$F_I = 39200$ N, $F_C = 24500$ N, $F_h = 0$.

The axial force accounting for the hammer force (F_a) = 14700 N is assumed to be acting at the top most node of the centre-leg part of the insert as shown in Fig.5.

The principal stresses in different parts of the insert vary from 26.1E7 N/m^2(compressive) to 195.0E7 N/m^2(tensile). Vonmises (S-Equivalent) stresses in insert vary from 15.638E3 N/m^2 (tensile) to 183.0E7 N/m^2 (tensile).

When embedded in the sleeper block the principal stresses vary from 4E 7 N/m^2 (compressive) to 20E 7 N/m^2 (tensile). The principal stresses in the concrete block vary from 45.8620E 4 N/m^2 (compressive) to 4.92E 7 N/m^2 (tensile).

Stress plots of the insert subjected to the three effective load conditions are shown from Fig.6. to Fig.34.

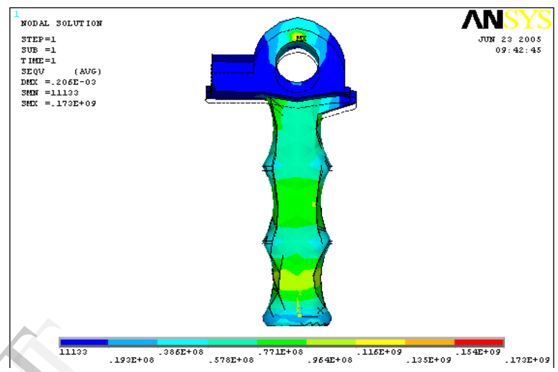

Fig.6. Plot of Vonmises stress(S-Eq) in the insert for Load case1, Front View

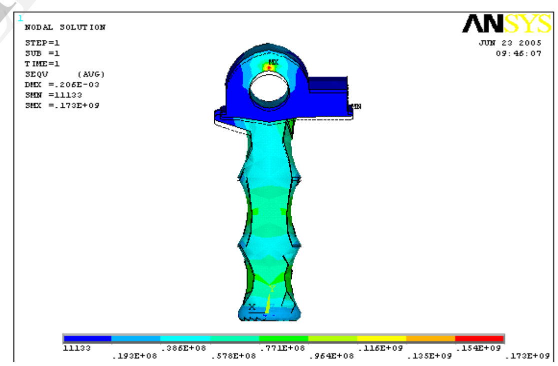

Fig.7. Plot of Vonmises stress(S-Eq) in the insert for Load case1, Rear View

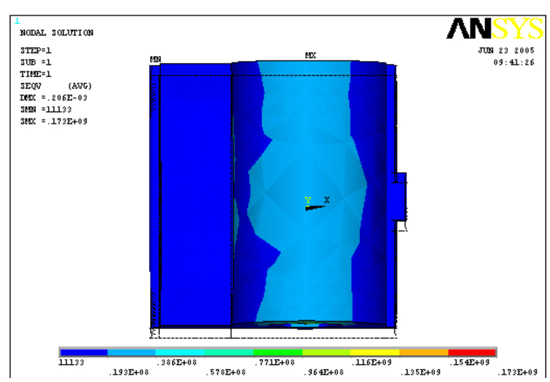

Fig.8. Plot of Vonmises stress(S-Eq) in the insert for Load case1, Top View

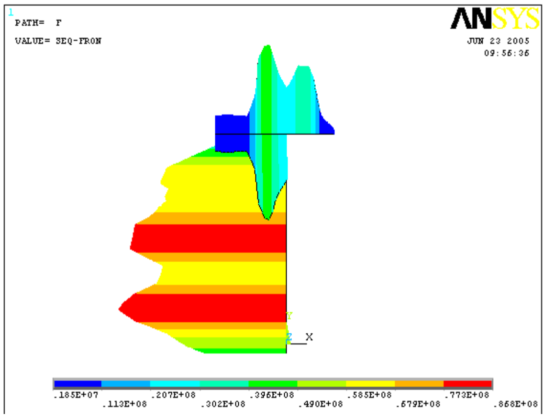

Fig.9. Plot of Vonmises stress(S-Eq) in the insert for Load case1, Cross sectional (Front) View

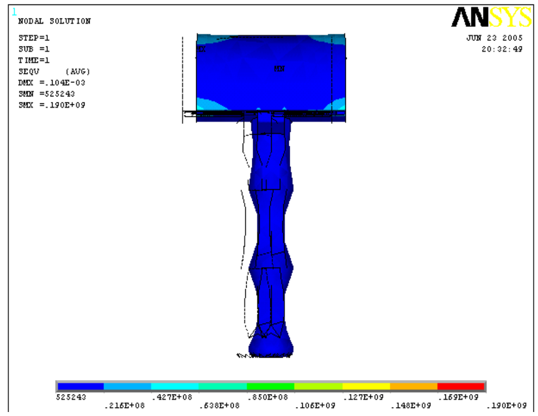

Fig.12. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case1, Right side View

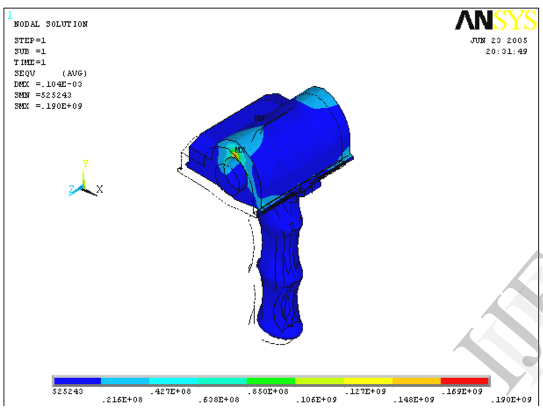

Fig.10. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case1, Isometric View

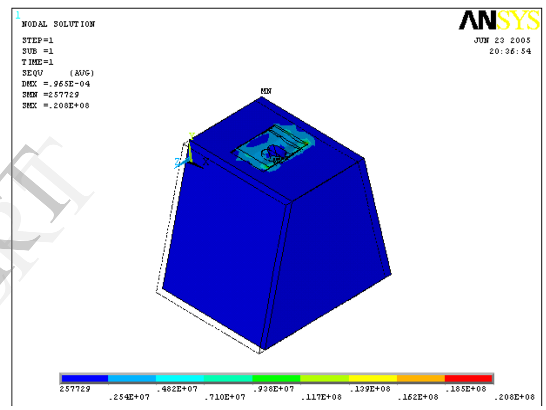

Fig.13. Plot of Vonmises stress(S-Eq) in the sleeper block, when insert is embedded in sleeper block for Load case1, Isometric View

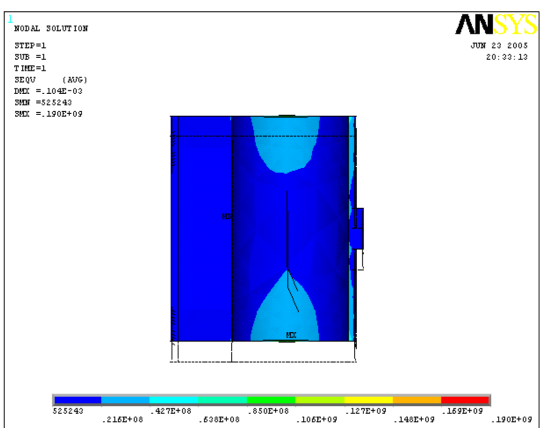

Fig.11. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case1, Top View

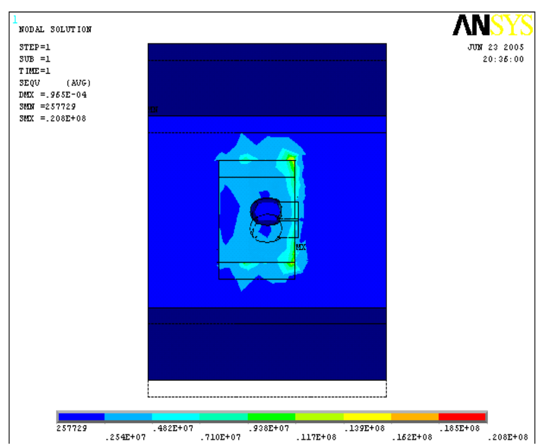

Fig.14. Plot of Vonmises stress(S-Eq) in the sleeper block, when insert is embedded in sleeper block for Load case1, Top View

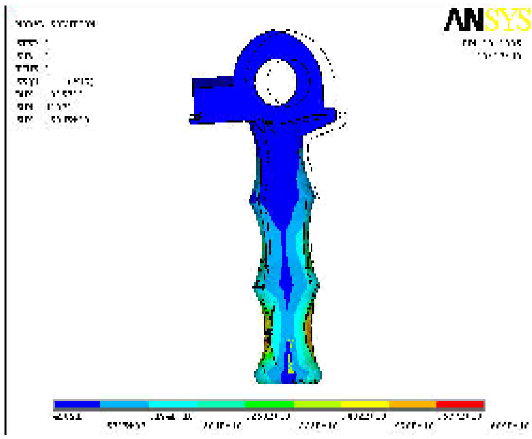

Fig.15. Plot of Vonmises stress(S-Eq) in the insert for Load case 2, Front View

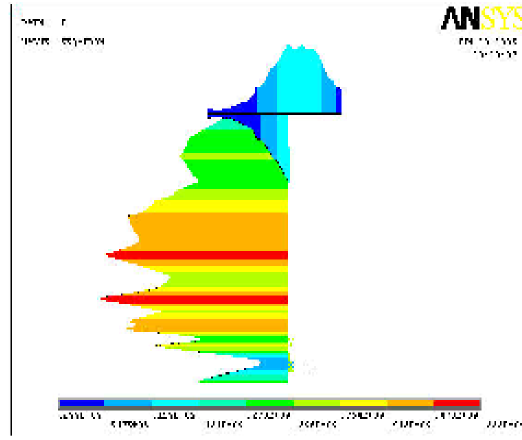

Fig.18. Plot of Vonmises stress(S-Eq) in the insert for Load case2, Cross sectional Front View

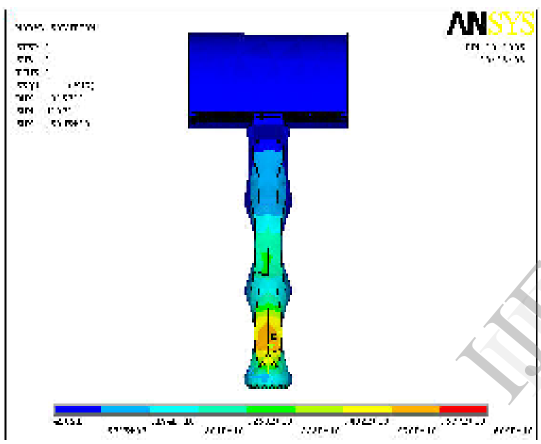

Fig.16. Plot of Vonmises stress(S-Eq) in the insert for Load case 2, Right side View

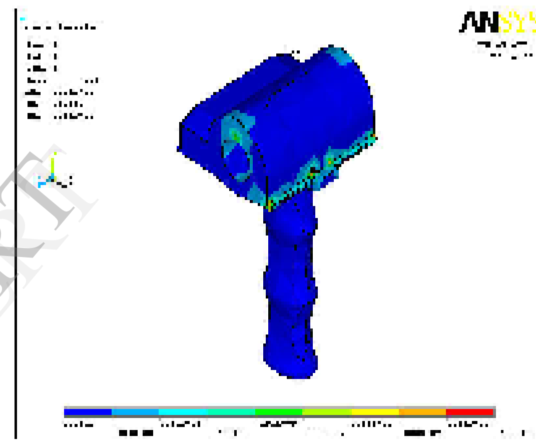

Fig.19. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case2, Isometric View

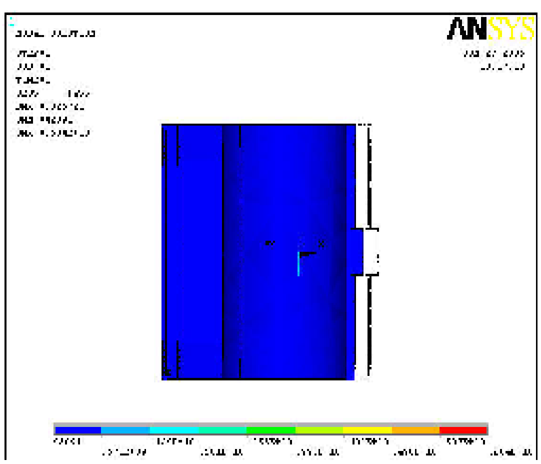

Fig.17. Plot of Vonmises stress(S-Eq) in the insert for Load case 2, Top View

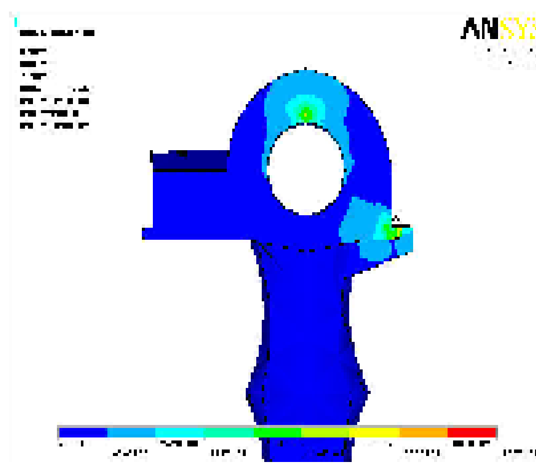

Fig.20. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case2, Front View

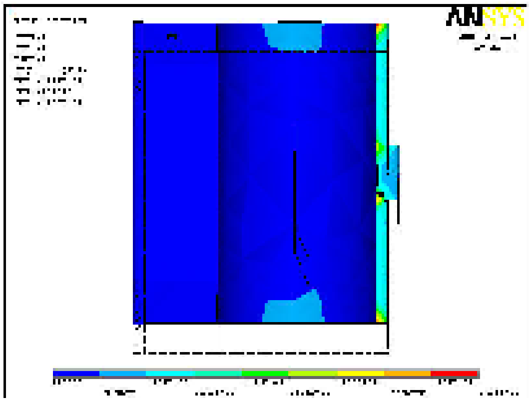

Fig.21. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case2, Top View

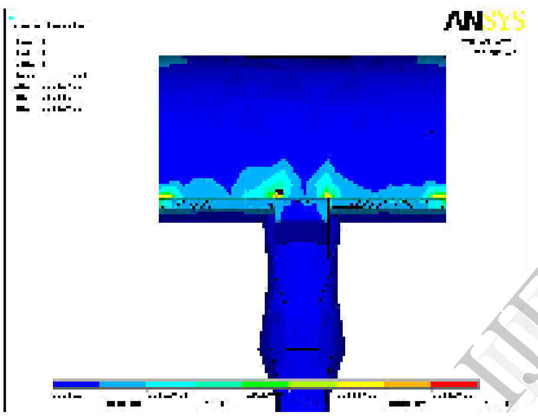

Fig.22. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case2, Right side View

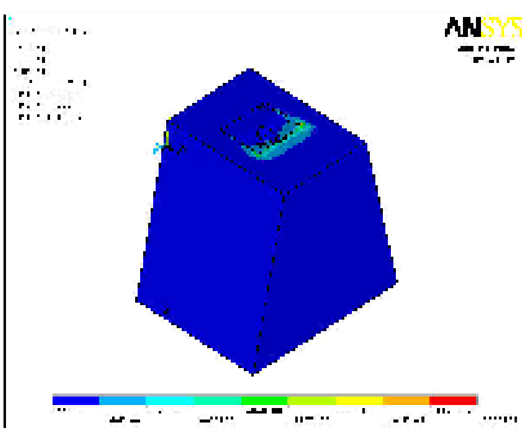

Fig.23. Plot of Vonmises stress(S-Eq) in the sleeper block, when insert is embedded in sleeper block for Load case 2, Isometric View

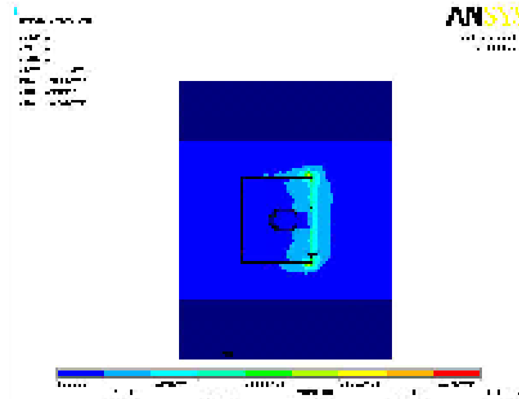

Fig.24. Plot of Vonmises stress(S-Eq) in the sleeper block, when insert is embedded in sleeper block for Load case 2, Top View

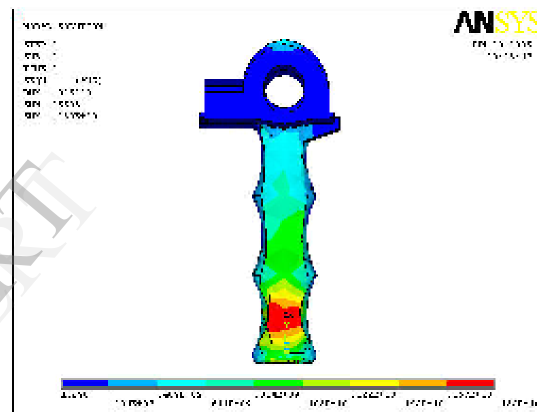

Fig.25. Plot of Vonmises stress(S-Eq) in the insert for Load case 3, Front View

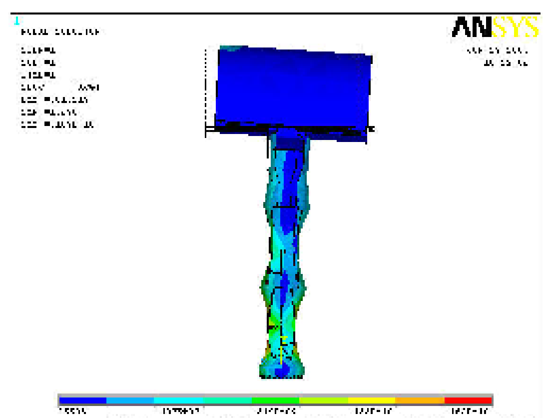

Fig.26. Plot of Vonmises stress(S-Eq) in the insert for Load case 3, Right side View

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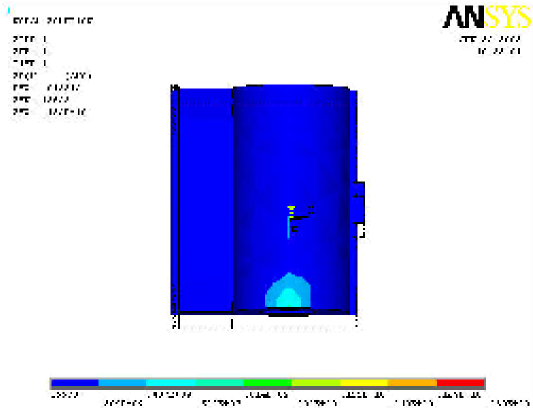

Fig.27. Plot of Vonmises stress(S-Eq) in the insert for Load case 3, Top View

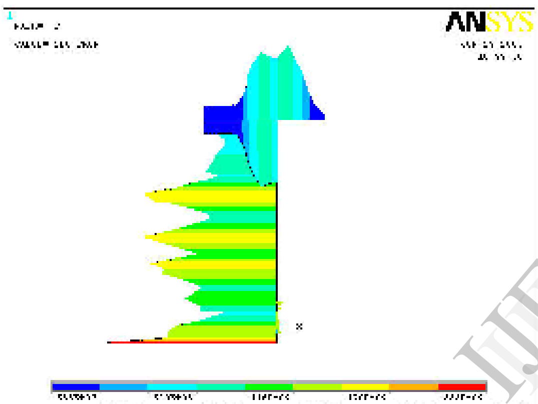

Fig.28. Plot of Vonmises stress(S-Eq) in the insert for Load case 3, Cross sectional Front View

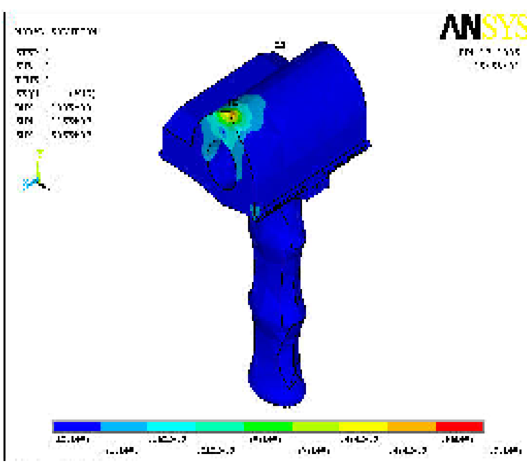

Fig.29. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case 3, Isometric View

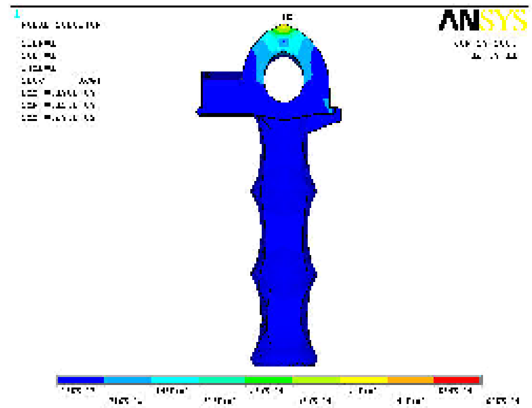

Fig.30. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case 3, Front View

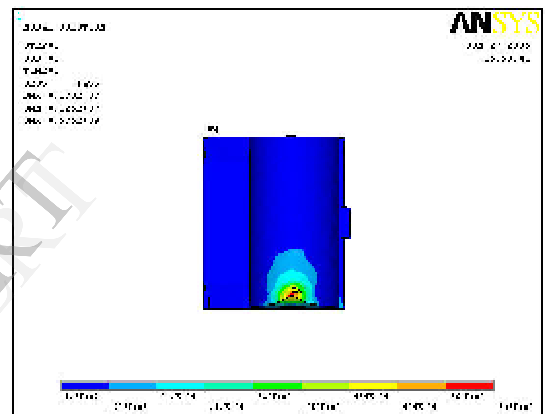

Fig.31. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case 3, Top View

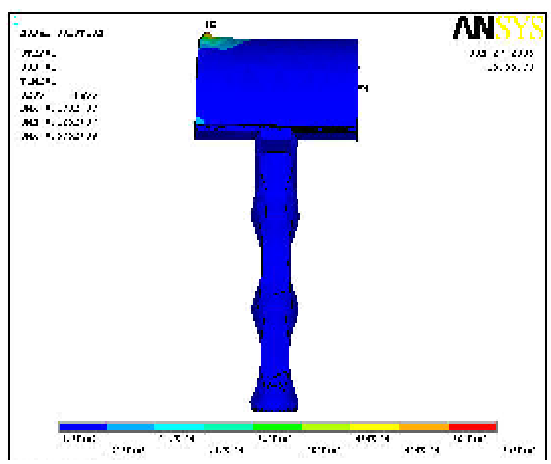

Fig.32. Plot of Vonmises stress(S-Eq) in the insert when embedded in sleeper block for Load case 3, Right side View

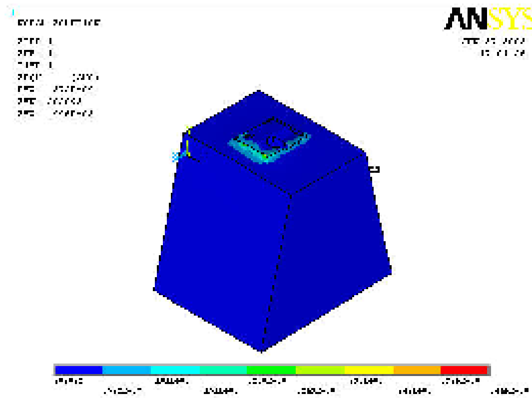

Fig.33. Plot of Vonmises stress(S-Eq) in the sleeper block, when insert is embedded in sleeper block for Load case 3, Isometric View

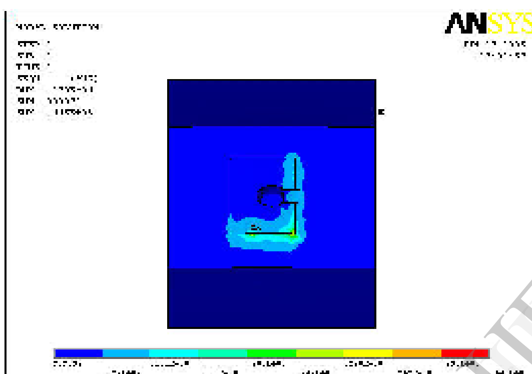

Fig.34. Plot of Vonmises stress(S-Eq) in the sleeper block, when insert is embedded in sleeper block for Load case 3, Top View

4. Results Obtained in stress Analysis of Insert before and after optimization for the three Load cases.

1. For the first load case the maximum Vonmises (S-Equivalent) stress in the insert has been found as 17.3E 7 N/m^2 (tensile).
2. For the second load case the maximum Vonmises (S-Equivalent) stress in the insert has been found as 604.0E 7 N/m^2 (tensile).
3. For the first load case the maximum Vonmises (S-Equivalent) stress in the insert has been found as 183.0E 7 N/m^2 (tensile).

4.1 Comparison of Stress Analysis Results

A comparison of stresses has been shown in the following tables from Table 1 to Table 3 for the insert model embedded in the sleeper model considering all the three effective load cases.

Table 1. For Load Case 1

Maximum Principal stress (N/m^2)	Minimum Principal stress (N/m^2)	Maximum Vonmises stress (N/m^2)	Minimum Vonmises stress (N/m^2)
11.3E 7 (T)	2.09E 7 (C)	17.3E 7 (T)	11.133E 3(T)

Table 2. For Load Case 2

Maximum Principal stress (N/m^2)	Minimum Principal stress (N/m^2)	Maximum Vonmises stress (N/m^2)	Minimum Vonmises stress (N/m^2)
609.8E 7 (T)	58.6E 7(C)	604E 7 (T)	42.091E 3(T)

Table 3. For Load Case 3

Maximum Principal stress (N/m^2)	Minimum Principal stress (N/m^2)	Maximum Vonmises stress (N/m^2)	Minimum Vonmises stress (N/m^2)
195.0E 7(T)	26.1E 7 (C)	183.0 E 7 (T)	15.638E (T)

(T)- Tensile, (C) - Compressive

5. Conclusions:

Design evaluation of SGCI rail insert used in concrete sleepers by the Indian Railways has been carried out. The stress analysis of the insert under its operating conditions for different effective load cases has been carried out.

Of the three load cases it can be observed that in Load Case 2, the rail insert is subjected to maximum amount of stresses compared to the other two effective load cases. Hence, Load Case 2 can be used as the worst state of stress condition for improvement in the design of the rail insert. This Load Case can also be considered for the Design Optimization of the rail insert.

6. References

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