FATIGUE ANALYSIS OF RAIL JOINT USING FINITE ELEMENT METHOD

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Abstract

Fatigue life estimates can be used to guide the selection of inspection intervals for rail joint bars in service. A three-dimensional finite element model for rail joint bars is developed and dynamic load is applied to estimate the fatigue life of the joint bars. Different components of the rail joint bars are being created separately and assemble in Autodesk Inventor. The model consists of assembly of the rail, joint bars, bolts, nuts, washers, and wheel. A three-dimensional finite element analysis of rail joint bars is carried out in ANSYS after importing from Autodesk Inventor. The static and dynamic loads are being applied to estimate fatigue life and endurance strength at the section. The material properties of the rail and wheel are assumed to be same. The material properties of the wheel and rail are considered to be bilinear kinematic hardening in ANSYS. All the material properties and boundary conditions are being applied strictly as per the guidelines made available by the Indian Railways in their manual.

Key Words: *Rail Joint, Modeling, Finite Element Method*

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1. INTRODUCTION

A rail joint is the weakest link in the track. There is a break in the continuity of the rail in horizontal as well as in vertical plane at this location because of the expansion gap and Im perfection in the rail heads at joint. The fitting at the joint become loose, causing heavy wear and tear to the track materials. It is normally felt that a rail joint requires about 30% extra maintenance than the plain track.

A modern steel rail has a flat bottom and its cross section is derived from an I -profile. The upper flanges of the I-profile have been converted to form the railhead. In India, one commonly used rail profile is the UIC60 rail, where 60 refer to the mass of the rail in kg per meter. The rails provide continuous and level surface for movement of trains. The rails provide a pathway which is smooth and has very less friction. The friction between steel wheel and steel rail is about 1/5thof the friction between the pneumatic tire and metal led road. The rails serve as a lateral guide for the running of wheels. The rails bear the stresses developed due to vertical loads transmitted to it through axles and wheels of rolling stock as well as due to braking forces and thermal stresses. The rails carry out the function of transmitting the load to a large area of formulation through sleeper's ballast. The rails also act as electrical conductors for signaling system.

In a railway track with concrete sleepers protect the sleeper from wear and impact damage, and they provide electrical insulation of the rails. From a track dynamics point of view, the rail pads play an important role. They influence the overall track stiffness. When the track is loaded by the train, a soft rail pad permits a larger deflection of the rails and axle from the train is distributed over more sleepers. Also, soft rail pads isolate high-frequency vibrations. They suppress the transmission of high-frequency vibrations down into the ballast. A stiff rail pad, on the other hand, gives a more direct transmission of the axle load, including the high-frequency load variation down to the sleepers below the sleepers below the wheels. The sleepers provide support of the rails and preserve gauge, level and alignment of the track. The sleepers transmit vertical, lateral, and longitudinal forces from the rail down to the ballast bed. They should also provide electrical insulation between the two rails. The ballast layer supports the track (the rails and the sleepers) against vertical and lateral forces from the trains. It is tightly compacted or tamped around the sleepers to keep the track precisely leveled and aligned. From a physical point of view, the ballast materials and their interactions are complex. Constitutive laws of ballast materials are under development. The main functions of ballast are :

- To transfer and distribute the load from sleepers to a larger area of formation
- To provide elasticity and resilience to track for getting proper riding comfort
- To provide necessary resistance to track for longitudinal and lateral stability
- To provide effective drainage to track
- To provide effective means of maintaining evenness and alignment of the track

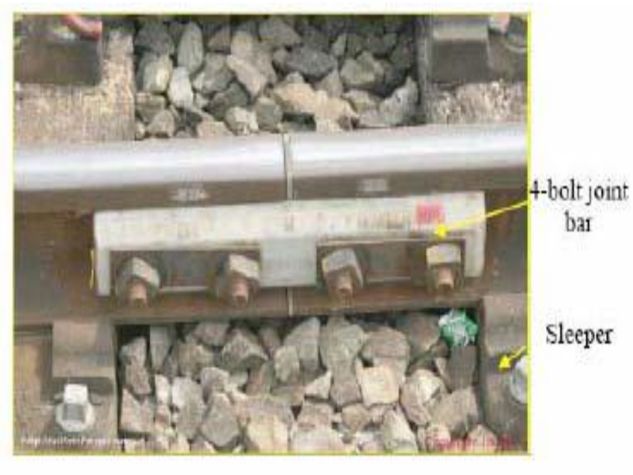

Fig.1 A typical 4 bolt insulated rail joint

The function of the fishplate is to hold the two rails together both in the horizontal and vertical planes. The fish plates are manufactured from a special type of steel having composition of Carbon, Manganese, Silicon, Sulphur and Phosphorous 0.30 to 0.42%, Not more than 0.8%, Not more than 0.15%, Not more than 0.06 % respectively. The fish plates are so designed that the fishing angles at the top and bottom surface coincide with those of the rail section so as to have a perfect contact with the rail. Elastic elements (springs) are components which return to their original dimensions when forces causing them to deflect are removed. Elastic elements used to: Equalize the vertical wheels (unloading of any wheel is dangerous because it causes a reduction/loss of guidance forces).Stabilize the motion of vehicles on track (self-excited lateral oscillations i.e., hunting of wheel sets is dangerous).Reduce the dynamic forces and accelerations due to track irregularities.

2. FINITE ELEMENT ESTIMATIONS OF STRESSES IN JOINT BAR

Rail joint is a critical component of rail infrastructure component of rail infrastructure. Rail joints are widely used in the rail network. It consists of two joint bars. The bolts, nuts and washers are used to tightly fastening the assembly.

The assembly of model is done in modeling package of Autodesk Inventor Software. Autodesk inventor is 3D mechanical design software for creating 3-D digital prototypes used in the design, visualization and simulation of products. Cross section of standard Rail joint bar is shown in Fig.-2. The standard rail sections and the standard rail length prescribed on Indian Railways are used.

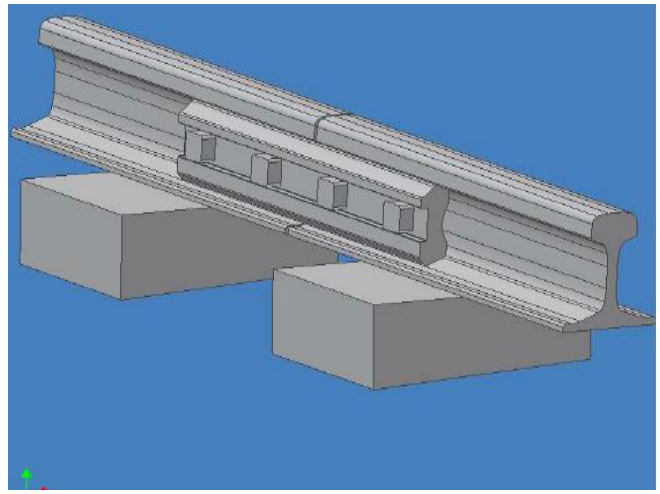

Fig.2 Standard Rail Joint

The model of assembly is being created in Autodesk Inventor after creating different components of the rail/wheel assembly separately. The model consists of assembly of the rail, joint bars, bolts, nuts, washers, and wheel.

A three dimensional finite element analysis of a rail/wheel contact is carried out on the rail joint section of track in ANSYS after importing from Autodesk Inventor. Fig.-3 shows model when wheel is on straight track. The static and dynamic loads are being applied to estimate stresses at the section.UIC 60 kg rail is used for analysis. The rail's length is a little more than the distance of two sleepers.

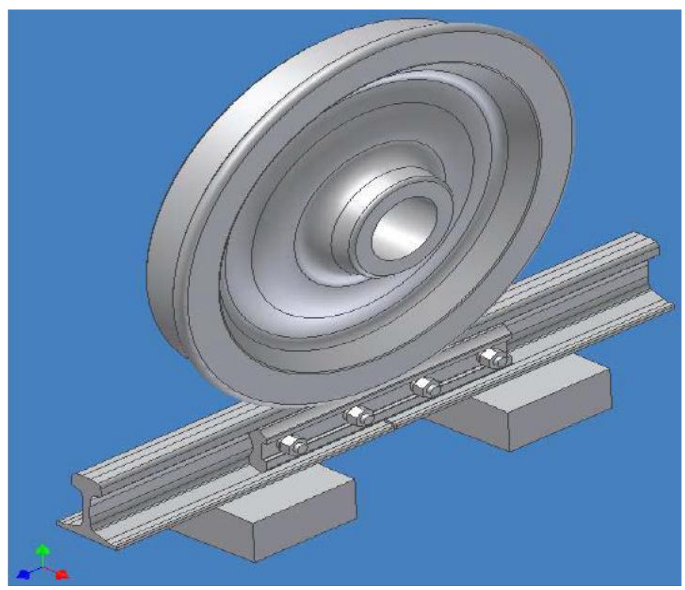

Fig.3 Autodesk generated assembly of wheel over rail joint

Once model is imported in ANSYS material properties were defined. All the material data is taken with reference to Indian Railways.

3. MATERIAL PROPERTIES

- Ultimate tensile strength : 880 MPa
- Tensile yield strength : 540 MPa
- Compressive yield strength : 540 MPa
- Endurance limit : 413 MPa
- Elastic support : 8.632 x 10-4 N/mm3
- Maximum Axle load : 159358.0625 N

4. BOUNDARY CONDITIONS

All the material properties and boundary conditions are being applied strictly as per the guidelines made available by the Indian Railways in their manual. The wheel runs at constant speed of 120 km/hr. UIC 60 rail is used for analysis. The initial temperature of wheel and rail is taken as 220C for analysis in ANSYS. The diameter of wheel is 915 mm. The axle load is 159.36 KN. Friction coefficient is 0.15. The material's density is 7800 kg/m3. Material properties of the rail and wheel are assumed to be same. The material properties of the wheel and rail are considered to be bilinear kinematic hardening in ANSYS. Fig.4 shows boundary conditions and load conditions on rail joint bar.

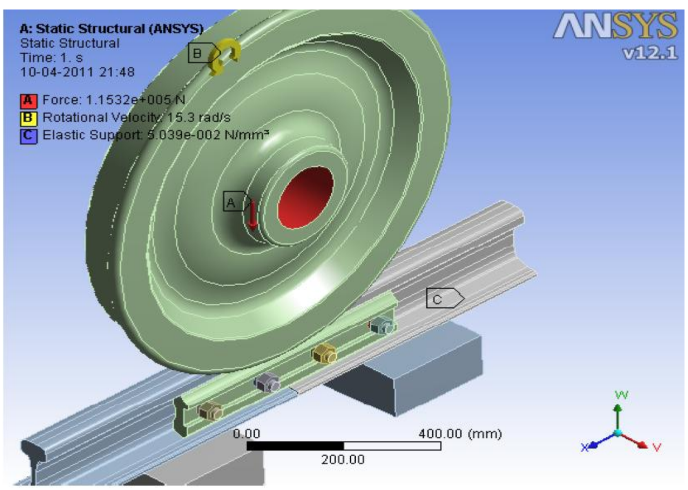

Fig.4 Boundary and load condition

5. RESULTS AND DISCUSSIONS

In this research, results obtained and observations made for the fatigue analysis of rail joint bars are analyzing following parameters :

- Fatigue factor of safety at a specified design life
- Fatigue life
- Von-Mises stresses
- Fatigue damage at a specified design life
- Stress biaxiality

Factor of safety in Rail joint bars with wheel is shown in Fig.5, the value of safety factor amounted to be 0.46295. Safety Factor from the lateral direction with wheel is shown in Fig.-6., the critical section is shown by red portion. Life in rail wheel joint bars with wheel is shown in Fig.7 and is amounted to be 33325 minimum. Contours of Von-Mises stress in rail joint is shown in Fig.8, the von-Mises stress is amounted to be 214.27 MPa. Whereas contours of Equivalent von-Mises stress in rail joint bars with wheel is shown in Fig.9. Equivalent von-Mises stress in rail joint bars is shown in Fig.10.

Fatigue Damage is a contour plot of the fatigue damage at a given design life. Fatigue damage is defined as the design life divided by the available life. The default design life may be set through the Control Panel. For Fatigue Damage, values greater than 1 indicate failure before the design life is reached. Fatigue Damage is shown in Fig.11.

Fatigue material properties are based on uniaxial stresses but real world stress states are usually multiaxial. This result gives the user some idea of the stress state over the model and how to interpret the results. Biaxiality indication is defined as the principal stress smaller in magnitude divided by the larger principal stress with the principal stress nearest zero ignored. A biaxiality of zero corresponds to uniaxial stress, a value of –1 corresponds to pure shear, and a value of 1 corresponds to a pure biaxial state. Biaxiality indication is shown in Fig.12,the majority of this model is under a pure uniaxial stress, with parts exhibiting both pure shear and nearly pure biaxiality.

In a Stress Life fatigue analysis, one always needs to query an SN curve to relate the fatigue life to the stress state. Thus in a fatigue analysis, the equivalent alternating stress can be thought of as the last calculated quantity before determining the fatigue life. The usefulness of this result is that in general it contains all of the fatigue related calculations independent of any fatigue material properties.

The main function of track is to guide the train. Another function of the track is to carry the load of the train and to distribute the load over an area of the sub grade that is as large as possible. The sleepers, supported by the ballast, transmit the load via the sleeper base area to the ballast, and the ballast disperses the load over a larger area of the sub ballast and sub grade. The rail was placed upon an elastic foundation with stiffness 0.05039N/mm2. Since this elastic foundation acts over an area, the units of stiffness are force/deflection/area. The stiffness value was divided by the area of the rail section. Hence, the elastic support is being considered between ballast and sleepers in the present work and value is taken with reference to Broad Gauge is 8.632*10-4 N/mm³.

The vertical load is assumed to be the maximum design load which is taken with reference to Technical Data of Coaching Stock of Indian Railways. Because of maximum availability of load using AC-3 Tier Sleeper load.

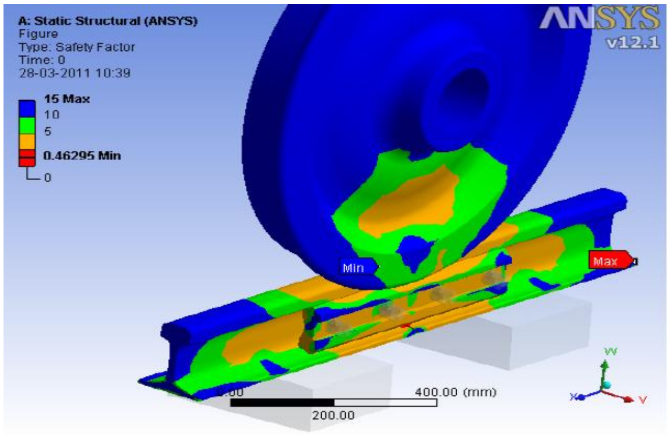

Fig.5 Safety Factor in Rail joint bars with wheel

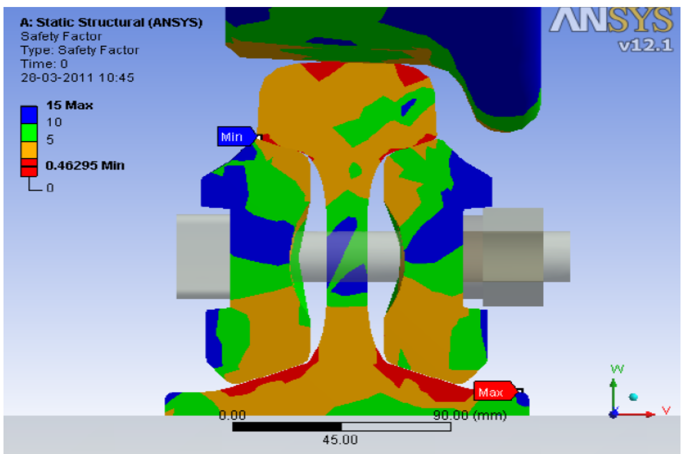

Fig.6 Safety Factor from the lateral direction with wheel

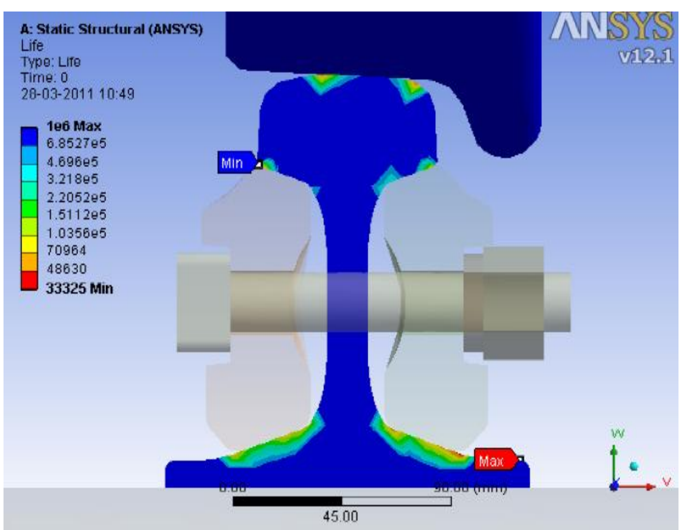

Fig. 7 Life in rail wheel joint bars with wheel

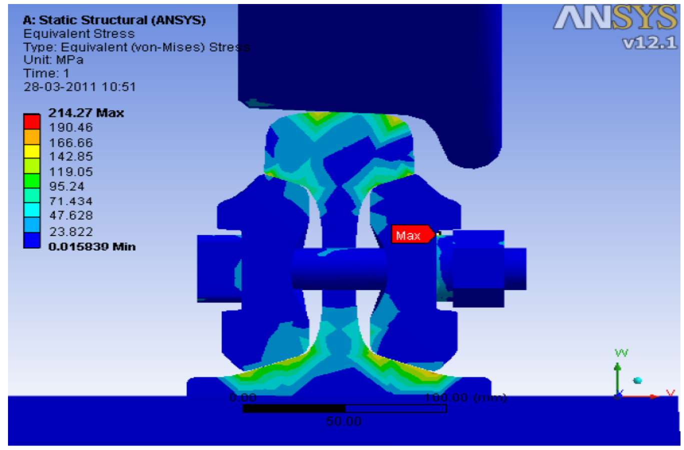

Fig.8 Contours of von-Mises stress with wheel

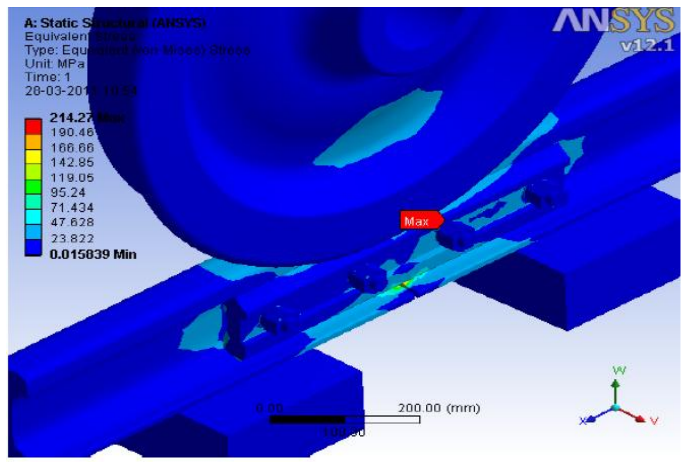

Fig.9 Equivalent von-Mises stress in rail joint bars with wheel

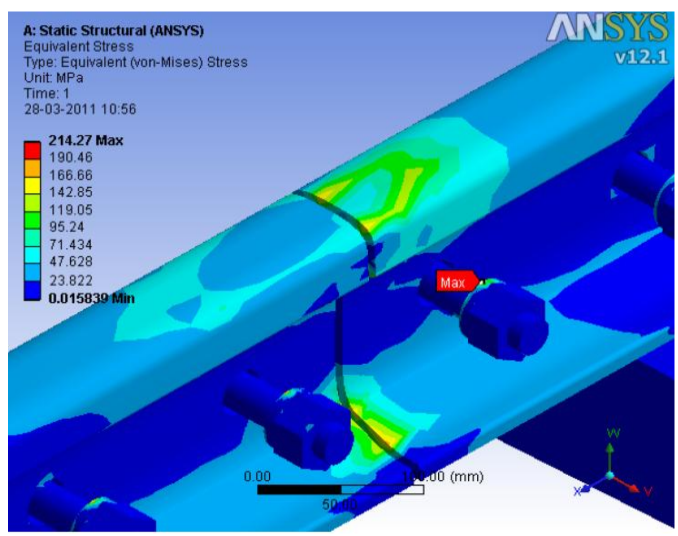

Fig.10 Equivalent von-Mises stress in rail joint bars

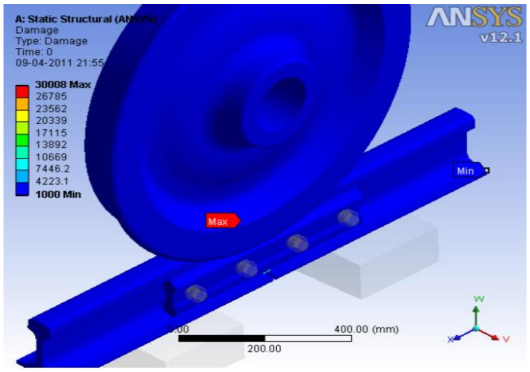

Fig. 11 Contour Plot of Fatigue Damage over the whole model

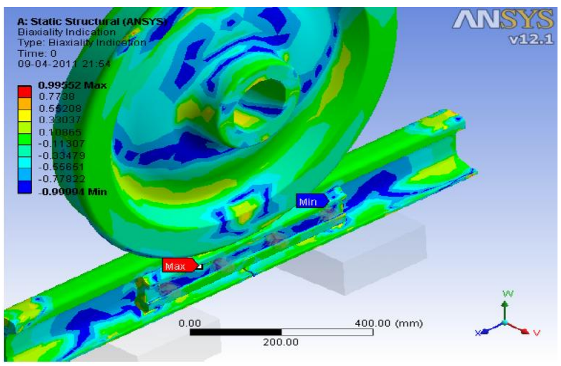

Fig.12 Contour Plot of Biaxiality Indication over the whole model

a. Tare weight = 515143.3245 N
b. Carrying Capacity = 50210.048 N
c. Gross load = 565353.3725 N
d. Maximum Axle load = 159358.0625 N

Vertically downward load is sum of Gross load and Maximum axle load. Normally wagons are comprised of eight wheels. A wheel set comprises two wheels rigidly connected by a common axle. Load is proportional on each wheel. Hence, gross load is divided by number of wheels in the wagon. Similarly, axle load is also divided by number of wheels on axle. Hence, distributing load proportionally in each wheel. Load is applied at the center of wheel on downward direction. Hence taking load proportionally with respect to wheels. Rotational velocity is taken as 15.3 rad/s for the wheel. After defining material properties and boundary conditions, results are being evaluated. The safety factor is being evaluated in fatigue.

CONCLUSIONS

The prescribed method in this research may be used to estimate the fatigue life of bolted rail joints in a variety of conditions. The finite element model for reverse bending calculates joint bar bending stresses that are comparable to the engineering estimates based on beam on elastic foundation theory. The engineering estimates are, therefore, an efficient method to estimate the tensile reverse bending stress at the top outer fiber of the joint bar, which is important for fatigue crack growth calculations. However, the finite element model for the wheel over the joint calculates stresses that are higher than the engineering approach. These results suggest that the engineering approach provides reasonable estimates for vertical bending only. Moreover, the finite element analysis captures the combined effect of vertical and lateral bending; i.e., two-axis bending; which is not included in the beam theory approximations.

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