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Numerical Analysis of Rolling Contact Fatigue in Common Turnouts of Iran Railway Track

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ABSTRACT: The highest amount of reported failures in railway tracks are due to turnout problems. The main causes of these breakdowns are: high wheel-rail contact forces, creep in the switchblade due to changes in the rail profile, and inconsistency in the rail profile during wheel passage over wing rail and crossing nose causing collision forces. In this paper, a new method for crossing nose fatigue life prediction is presented using the finite element approach. Firstly, a dynamic model containing a complete turnout (switch and crossing panels) is simulated. For a closer look at the crossing, the results of the forces generated by the dynamic model are transmitted to a more detailed static model at specific sections, because of the criticality of this point in track. Then the stress and strain results are extracted to perform the fatigue analysis on the crossing nose in order to calculate fatigue crack initiation life and critical planes. Regarding the importance of fatigue and the necessity of investigating the effect of different variables on fatigue life, a parametric study is conducted considering variables such as velocity, wagon weight, and turnout type. The results indicate that the predicted fatigue life in UIC60 crossings is less than U33. Also, by increasing the wagon weight and speed or the curve radius fatigue crack initiation life have increased.ntrol the lock-in regime.

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1- Introduction

Turnouts are important parts of the railway tracks as they provide guidance to the rail traffic. Wear, Plastic deformation and rolling contact fatigue are severe problems that can happen in turnouts due to high impact forces that are generated in the crossing because of rail discontinuity (between the crossing nose and the wing rail).

In Iran, high Rolling Contact Fatigue (RCF) and wear rate in the crossing nose is a severe problem that causes operation disturbance in a new turnout within two months [1]. Therefore, solutions for the RCF problem in the turnout crossings are highly demanded, and many scientists in the recent decade are investigating RFC related problems in turnouts.

Wear, accumulated plastic deformation and RCF have been introduced by researchers like Pletz et al. [2] and Wan et al. [3] as dominant damage mechanism in turnout's crossing nose. Wiest et al. [4] has investigated the low cycle fatigue in crossings made of two different materials under consecutive wheel passages using Finite Element Method (FEM).

Mandal [5] has studied cyclic behavior of rails by applying a dynamic wheel load through a contact patch, the distribution of contact pressure was considered using a non-Hertzian formulation. Johansson et al. [6] simulated the degradation of rail profiles in switches & crossings, a methodology was presented for simulating (predicting) all damage mechanisms for a mixed traffic situation in a switch. Xiao et al. [7] developed a three dimensional model to put on the simulation of stress, plastic strain and vertical displacement in the crossing under dynamic wheel load at the different wheel-crossing contact positions. Elastic-plastic finite element simulation of wheel-crossing-ties was considered.

Xin et al. [8] has studied the rolling contact fatigue crack initiation and fatigue life prediction for the railway turnout crossing, a 3D explicit Finite Element (FE) model of a wheelset passing a turnout crossing was used to obtain the dynamic responses of the system. Contact forces, displacements, and accelerations, as well as the stresses and strain in the crossing nose, were reported along with crossing's crack initiation life.

In this paper, a multi-body dynamic and a FEM model have been developed in order to investigate the RCF crack initiation life and RCF crack initiation and in two highly used turnouts, U33 and UIC60, in Iran. A multi-body dynamic model was used to calculate vertical and lateral contact forces when a train passed a full length railway turnout. Then the results were imported in the FEM model to investigate the strain- stress response of crossing nose. The stress-strain outputs were used to calculate crossing's RCF crack initiation life. Rigorous parametric studies have been conducted to investigate the effect of axle load, train speed and friction coefficient on crossing's RCF crack initiation life.

2- Methodology

Multi-body dynamic calculations have been performed using Universal Mechanism to measure vertical and lateral contacts forces when the freight wagon passes through a full

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length turnout. For simplification in model's geometry, a V-shaped imperfection, based on [9], has been added to rail, where the wheel gets in the first contact with the crossing nose, to reproduce the impact that occurs due to the change in the inclination of the rolling planes. Fig. 1 illustrates this simplification.

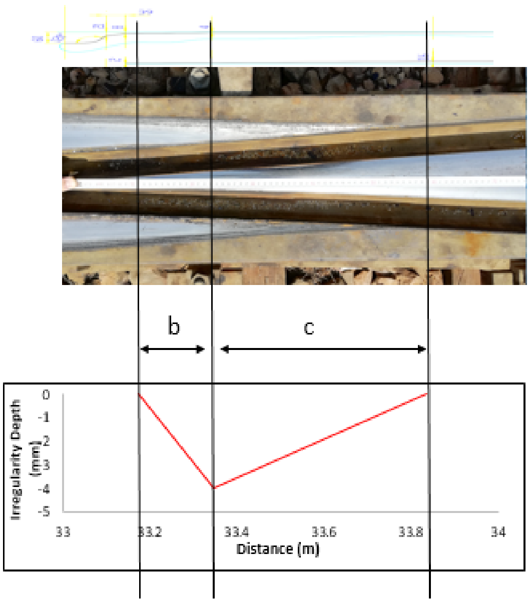

Fig. 1. Simplification of multi-body dynamic model

For detailed studies on stresses and strains as well as hardening quasi-static sub-model of crossing panel of each turnout has been developed using the implicit code ABAQUS/Standard [10]. The FEM sub-model includes a section of 5m in length of the wheel and the crossing nose, and isotropic and kinematic hardening [11, 12] is introduced to model as constitutive behavior of crossing. The meshed model is shown in Fig. 2.

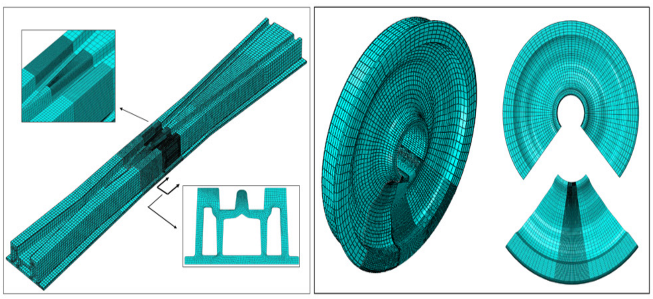

Fig. 2. Meshed quasi-static FEM model

Jiang and Sehitoglu [13] criterion are used to predict the fatigue life and critical plane of the crossing. This criterion combines two approach based on the energy density and critical plane for low cycle fatigue problems, and it is strongly dependent on the stress state, loading histories and material type. It is considered that both normal and shear components of stress and strain on the critical plane contribute to the damage of the material. The fatigue parameter *FP* is defined as

$$FP = \langle \sigma_{max} \rangle \frac{\Delta\varepsilon}{2} + J\Delta\gamma\Delta\tau$$

By surveying all the possible planes at a material point, the maximum FP and the critical plane are determined. The energy density is computed as FP on every material plane and for every increment of loading. The critical plane is defined as the plane with the maximum FP.

3- Results & Discussion

An example of the Von Mises stress states, in UIC60 turnout with axle load and train speed of 25 ton and 130 km/h, respectively, have been shown Fig. 3 when the rolling the wheel is situated and comes into contact with the crossing at each position. The criteria to estimate the most critical contact position has been chosen to be the Von Mises stress. In this case, the position with the highest Von Mises stress value of 747 MPa is at the distance of 527 mm on the crossing from its nose.

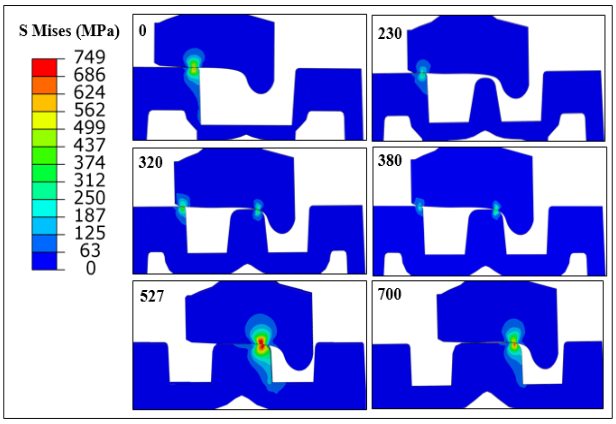

Fig. 3. Von Mises stress in different cross sections of UIC60 turnout.

Rolling contact fatigue crack initiation life cycles in the lateral distance is plotted in Fig. 4. One point at the surface and four other points beneath the contact point have been chosen for the fatigue life calculation. The distances from the rail surface are 1.35 mm, 3.83 mm, 5.96 mm and 10.19 mm respectively. It can be seen in this Figure that as the vertical distance from the rail surface increases, the fatigue crack initiation life increase, and if the rolling contact fatigue crack initiates, it will be at the surface of the rail.

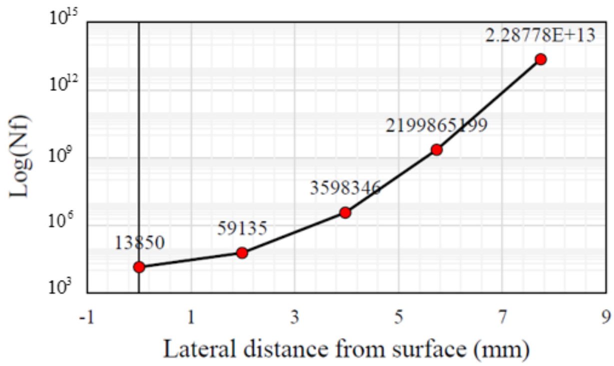

Fig. 4. The number of cycles to fatigue in the lateral direction.

The rolling contact fatigue crack initiation life results of the parametric study in UIC60 turnout with different wagon weight and speed has been plotted in Fig. 5.

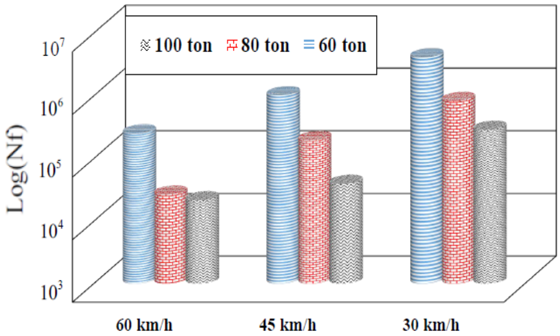

Fig. 5. Parametric study results.

4- Conclusion

The results indicate that the predicted fatigue life in UIC60 crossings is less than U33. Also, by increasing the wagon weight and speed or the curve radius fatigue crack initiation life have increased in different parametric study cases. Also, results show that rolling contact fatigue crack initiates at the surface of the rail and wheels contact region.

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