NUMERICAL ANALYSIS OF ROLLING CONTACT FATIGUE CRACK GROWTH ON CURVED RAILWAY TRACKS

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Abstract

In this study, numerical analyses were conducted to investigate the non-proportional mixed-mode RCF crack growth behaviour in the presence of severe longitudinal, lateral and spin creepages. The whole procedure combined multi-body dynamic simulation (MBDS) and the extended finite element method (XFEM) in an indirectly coupled way. Attempts were also made to modify the FaStrip theory to obtain traction distributions based on elastoplastic contact pressures which were then applied in an XFEM model to predict surface crack growth directions. Parametric studies were also conducted to further quantify the influence of different creepage combinations on both crack growth directions at rail surface and crack growth rate at crack tips. It is concluded that the increase of either of the three creepages can significantly influence the phase and magnitude of stress intensity factor histories, albeit to different extents.

1. Introduction

Rolling contact fatigue is a common failure mode due to cyclic stresses caused by repeated wheel-rail contact. It can produce both surface or sub-surface cracks in the rail head, depending on the locations of existing defects and loading conditions. In order to reduce the cost of RCF damages, rail engineers have made tremendous efforts in developing reliable tools for RCF crack growth prediction, among which, the fracture mechanics method shows promising potential of providing higher accuracy and flexiblity. Despite its advantages, the fracture mechanics method still has several main challenges including the definition of crack geometry and characteristics of crack growth behaviour under large compressive loading as well as plastic deformation. Some researchers have successfully implemented numerical models to investigate the influences of residual stress, crack face friction, entraped fluid, rail bending, etc., on both RCF crack growth direction and rate. However, many of the studies were carried out with simplified pressure and traction distributions at the wheel-rail interface and their results often lack supports from field observations. In this study, complex tractions in curved tracks due to longitudinal, lateral and spin creepages were calculated based on modified FaStrip theory and pressure distributions from static FEA. After that, the loadings were applied in a quasi-static XFEM model to quantify the stress intensity factor (SIF) histories during one complete wheel passage. Crack growth direction predictions at rail surface were also attempted and compared with field observations.

2. Methodology & Results

The proposed numerical method for RCF crack growth prediction is shown as a flow chart in Fig. 1(a).

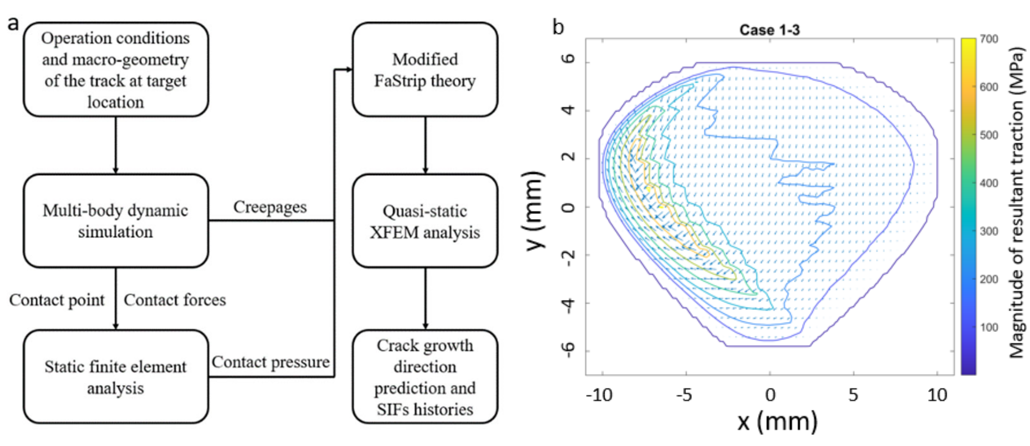

Figure 1. (a) Flow chart of the proposed numerical method. (b) An example of traction distribution.

The multi-body dynamic simulation (MBDS) was conducted using Universal Mechanism 8.5 with CONTACT add-on. As illustrated in the figure 1(a), field data related to track geometry and operating conditions were adopted in MBDS as input. After the steady-state was reached, the contact point, total vertical force and creepages on the high rail of the leading wheelset of the leading bogie of the wagon were recorded as this was considered as the worst scenario out of all the contact pairs from the same wagon. Then, static finite element analysis (FEA) were conducted using the information from MBDS to give accurate pressure distribution. After that, traction distributions, as shown in Fig. 1(b), were calculated based on the modified FaStrip theory and applied in quasi-static FEA to obtain crack tip displacements at rail surface and stress intensity factors (SIF) histories at the deepest crack front. The crack growth direction was predicted based on vector crack-tip displacement criterion.

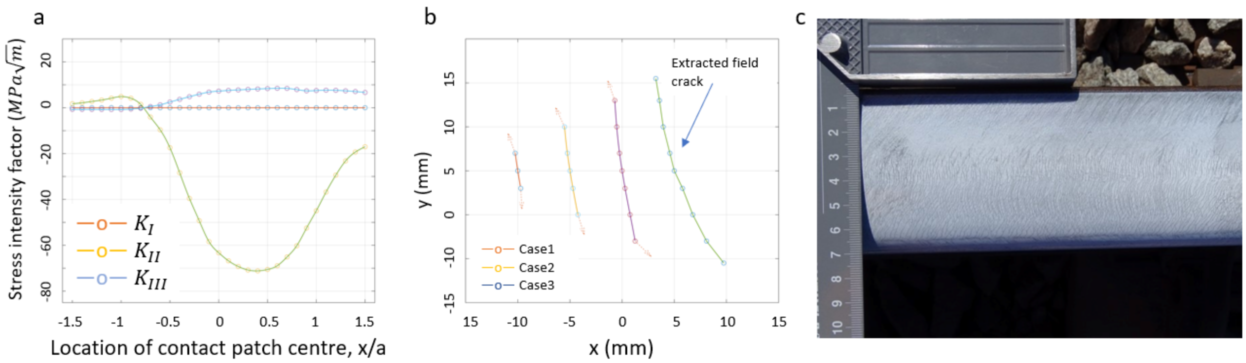

Figure 2. (a) an example of SIFs histories of one complete wheel passage. (b) An example of crack growth direction prediction at rail surface. (c) An example of rail surface cracks on curved tracks.

Some examples of the numerical results are shown in Figure 2. The surface crack growth is proved to be mode II and III driven as the mode I stress intensity factor is close to zero at most of the time as shown in Figure 2(a). The surface crack growth direction predictions of case 1, 2 and 3 are marked using dashed arrows in Figure 2(b) and the solid curves represent the simulated initial crack geometries at rail surface. Comparing with the extracted average crack geometry obtained from Figrue 2(c), the crack growth predictions using proposed numerical method show a good agreement with field observations.

3. Conclusions

An improved numerical method of RCF crack simulation was proposed by modifying FaStrip theory to extend its use for traction distribution estimation under elastoplastic contact conditions. The stress intensity factors (SIFs) histories during one complete wheel passage were quantified. Crack growth direction predictions at rail surface were also achieved and compared with field observations. The results demonstrated the capability of the proposed numerical method in predicting rolling contact fatigue surface crack growth behavior on curved tracks.

Acknowledgements

The present work has been supported by an Australian Research Council ITRH Project (IH150100006) and an Australian Research Council Linkage Project (LP200100110). The computation part of this research was accomplished with the assistance of resources and services from the National Computational Infrastructure (NCI), which is supported by the Australian Commonwealth Government.