1. Introduction

Insulated rail joints (IRJs) are safety critical sections in the signalling system of the rail network. To realise the electrical isolation function, insulation materials are inserted between rail ends secured by the joint bars and bolts. IRJs are also regarded as weak spots of the track structure and posses short service life. This situation stimulates high demand from the rail companies to improve the performance of IRJs; the study on the failure of IRJs has also became a recent focus in the international railway engineering research community.

To improve the performance of IRJs, understanding its failure mechanism is a priority. There are various failure modes corresponding to different designs of IRJs. In Australia, the railhead metal flow/material fatigue in the vicinity of the end post is regarded as the most common failure mode. As the wheels pass over the IRJs, severe wheel/rail contact impact loads are excited. Under such high level cyclic impact loads of wheel passages, the metal flow/material fatigue is initiated. With a view to fully understand the failure mechanism of the IRJs, study on the contact impact force between the running surfaces of the wheel and the rail is essential. As a part of an overall research project which aims to investigate the failure mechanism of the IRJ, this thesis studies the wheel/rail contact impact force using finite element analysis (FEA) and strain gauged laboratory and field experiments. The study on the material failure issue is conducted in another PhD thesis in which the impact loads and the associated contact results from this thesis are used as the input data.

1.1. Aims and Objectives

The aim of this research is to examine the wheel/rail contact-impact forces at IRJs. This aim is achieved through the following research procedures:

- Review the existing methods/models for determining wheel/rail contact-impact forces.
- Develop a 3D wheel rail contact impact FE model of an IRJ
- Examine the effect of several selected design and operational parameters on the contact-impact force excitation.
- Validate the FE model with experimental field data where possible.

1.2. Scope and Limitations

The scope of this research is to investigate the contact-impact force excited by a new wheel and a new IRJ; in other words, the stiffness discontinuity of IRJs rather than other running surface defects excites the impact forces that are of interest to this research. The vertical contact-impact force is examined in detail as it provides the major contribution to the damage. The associated contact responses are also examined for further study of the failure mechanism of IRJs. A sensitivity study of several key design and operational parameters is also included.

Due to the complexity of the modelling involved in the investigation of the wheel/rail contact-impact on the railhead in the vicinity of the end post, the following aspects are considered as out of the scope of this research:

- The wear and defects on either the railhead or the wheel tread
- Railway track misalignments

- Curved track
- Longitudinal stress resulting from temperature fluctuations
- Looseness of bolts
- Wagon/bogie/wheelset dynamics

1.3. Thesis Structure

This thesis contains eight chapters presenting the reviews of IRJ designs, literature reviews of wheel rail contact, contact-impact theories, FE modelling, numerical examples, strain gauged experiment as well as the FE model validation.

To improve the service life, various IRJs designs are employed in different countries; the major design parameters in those cases are reviewed in Chapter 2. The failure mechanisms of a typical IRJ are presented and a hypothesis for the common failure mode within the Australian heavy haul network, namely, the mechanical fatigue and/or metal plastic flow at the railhead in the vicinity of the end post under high level wheel/rail impact forces is presented. The models of wheel/rail contact impact reported in the literature are also reviewed in detail.

Chapter 3 reports the mechanics of contact and the theory of the finite element method. Both the classical and the computational theories of contact mechanics are reviewed. The solution methods for FEM are also briefly introduced. The explicit method employed in this research is introduced. The algorithms of FE modelling of contact impact are also presented.

The modelling of wheel/rail contact impact at IRJs is fairly complex; hence it needs some model idealisations to reduce the model size. In Chapter 4, the IRJs and the wheel geometry, material and boundary conditions are reviewed and then simplified. The wheel/rail contact establishment is presented. The details of loading, boundary conditions and contact definitions are reported. The meshing strategy that affects the model accuracy and efficiency is also presented in detail.

Chapter 5 presents numerical examples of wheel/rail contact impact at IRJs. Both static and dynamic analysis results are reported in detail and attention is also paid to compare the numerical results with the HCT. This chapter also provides results that prove the model is capable of providing both plausible and logical results. Sensitivity of some major design parameters is investigated for better understanding of the cause of impact as well as to achieve the future design improvement. The IRJ with optimised design parameters shows that the impact force can be effectively reduced to an insignificant level.

Chapter 6 briefly reports lab tests and field tests conducted as part of an ongoing research at the Centre for Railway Engineering (CRE) with the support from QR. The data collected from both tests are processed and compared to the numerical results. In the lab test, the IRJ is simply supported and subjected to a static load and investigated with several different loading positions along the length of the IRJ. In the field test, a continuous welded rail segment in the field is replaced by the strain gauged IRJ. A field installed data recording system has captured the dynamic response of the IRJ due to wheel passages. The signature of the strain data from the field test is also presented and discussed.

Chapter 7 reports the validation of the FE model. Both the static and the dynamic FE models are validated using the experimental data and reasonable agreements are achieved. Two traffic conditions in the field test, namely loaded and unloaded coal wagon traffic, are selected to validate the dynamic analysis.

The summary, conclusions and recommendations of this thesis are reported in Chapter 8.