Review of Insulated Rail Joints
Review of Insulated Rail Joints

Synopsis: The insulated rail joint (IRJ) is a safety critical component of the rail track infrastructure. The IRJ provides the dual function of electrical isolation and structural stability to the track. Unfortunately, IRJs possess the shortest mean service life amongst all railway track components and their service life is found to be highly variable. The Australian heavy-haul rail track system is experiencing increased operational throughput—both in terms of increased magnitude of axle loading and higher frequency of wheel passages across the joints. Consequently, predicting the service life of IRJs to avoid any potential accelerated, undetected, premature failures—and to approach the problem of management of in-service IRJs rationally—is more pressing than ever before. Project R3.100-BT17 represents a timely response by the CRC for Rail Innovation to the needs of the Australian heavy-haul track industry. The fundamental objective of the project is to develop a longer-life IRJ technology in the context of maintaining structural integrity, safety, and the operational efficiency of railway systems. Similar collaborative research amongst the rail industry and suppliers is ongoing in various heavy-haul industries around the world, with research reports on modification to the existing conventional designs and testing of innovative products regularly reported in industry forums, conferences, magazines and academic journals. This report presents current state-of-the-art research outcomes on IRJs with particular attention to heavy-haul track applications.

Established and supported under the Australian Government’s cooperative Research Centres Programme
# Table of Contents

Executive Summary ........................................................................................................ ii

List of Figures and Tables ............................................................................................. iii

Abbreviations and Acronyms ....................................................................................... iv

Introduction ..................................................................................................................... 1

1. Designs of IRJs .......................................................................................................... 3
   1.1. International IRJ Designs .................................................................................. 3
    1.1.1. North America: USA .................................................................................... 3
    1.1.2. North America: Canada .............................................................................. 4
    1.1.3. South Africa ............................................................................................... 6
   1.2. Australian IRJ Design ...................................................................................... 6

2. Loading ..................................................................................................................... 9
   2.1. Failure Modes ................................................................................................. 10

3. Modelling and Analysis ............................................................................................ 12
   3.1. Finite Element Model ...................................................................................... 12
    3.1.1. 3-D FE Models ......................................................................................... 12
    3.1.2. 2-D FE Models ......................................................................................... 13
   3.2. Mechanistic Models ....................................................................................... 14

4. Laboratory Tests ...................................................................................................... 15
   4.1. Loading Rigs ................................................................................................. 15

5. Field Tests ............................................................................................................... 17

References .................................................................................................................... 19
Executive Summary

In this report, the state-of-the-art in research reported on bonded insulated rail joints (IRJs) is summarised. The following conclusions can be drawn based on the review:

- Under heavy-haul railway traffic load, bonded IRJs fail at a greater rate when compared to any other railway track component.

- Design and manufacture of IRJs to date are controlled by fewer technologies. IRJs are usually factory-manufactured under high quality control as evidenced by testing to standards and codes of practice. New technologies that do not require factory manufacturing are emerging in the market.

- Recent Australian research (Rail CRC Project 75) has advocated reducing the thickness of endposts from 8.5mm to 5mm. The industry has adopted this recommendation.

- Design solutions for increasing the service life of IRJs vary between countries. For instance, the United States’ design is mainly focused on increasing the stiffness of the IRJs assemblies by increasing the dimensions of joint bars, whilst other nations are primarily focused on material innovation (e.g. steel with a higher yield point, or composites) without modifying the conventional IRJ design parameters.

- There is no agreement on best practice when installing, maintaining, and repairing IRJs. The US practice advocates directly supporting the joint section of the IRJ on a sleeper, whilst the Australian and other comparable heavy-haul national systems recommend that the joint sections be suspended symmetric to two sleeper supports.

- Although the US practice is to embed geogrid within the ballast layer in the vicinity of IRJs to improve lateral stiffness, little research has been conducted into the effect of ballast and subgrade stiffness on the impact loading of IRJs and how these variables might correlate with IRJ service life. This PhD study is the first of its kind to examine the effect of variation in ballast stiffness on the performance of IRJs.

- There is no universal agreement regarding the common modes of failure of bonded IRJs. For instance, the North American heavy-haul railway tracks report adhesive debonding followed by joint bar cracking, whilst the Australian heavy-haul railway tracks report railhead metal flow in the vicinity of the endposts as the most frequent mode of IRJ failure.

- Field visit visual observation reports indicate that there is significant statistical variability and deficiency with regard to IRJ installation, maintenance, and repair practices.

- There is a paucity of literature regarding the availability of efficient numerical modelling tools for IRJs that can be used for accurate prediction of railhead material accumulated plastic deformation failure and subsequent fatigue fracture problems under cyclic wheel loads.

- There is a renewed interest in IRJ research around the world, especially in regard to their service in heavy-haul applications.
List of Figures and Tables

Figure 1. A Typical IRJ

Figure 2. High Modulus IRJs [11–12]: 1.2m long joint bars on test with TTCI, 275mm wide Ties and insulated three-Tie plate (left); 1.2m long Joint with Center Liner (Right)

Figure 3. Miter-cut/long-angle cut insulated rail joint (right); lap joint detail design components (left) [11–12]

Figure 4. “Hercules” series insulated rail joints from NorFast Inc. [13]

Figure 5. 4-bolt mechanical TENCONI insulated rail joint in Canada [15]

Figure 6. Fourbolted IRJ wth square cut (left); “IVG joint” with angular cut (right) [16]

Figure 7. Australian Bonded IRJ – AS1085.12 (2002)

Figure 8. Typical support conditions of IRJs observed on railway track: symmetric support (left); asymmetrical support (middle); and center support (right)

Figure 9. Behaviour of suspended (top) and supported (bottom) IRJs to wheel loading

Figure 10. “Step” mechanism of wheel-rail impact.

Figure 11. Measuring the differential settlement around IRJ using a string (left); poor support condition of IRJs (right)

Figure 12. The most common failure modes of the IRJs reported in the literature: (a)–(j)

Figure 13. Typical 3-D models of IRJs: 3-D solid wheel-rail FE model (left) [18]; 3-D beam FE model of railway track [24]

Figure 14. Typical 2-D FE models of bonded IRJs: 2-D wheel & rail FE models (left) [32]; 2-D FE model (rail) and 2-D Hertzian contact pressure (wheel) (QUT Research team)

Figure 15. Typical mechanistic models of bonded IRJs: simple analytical static model (left) [33] more complex analytical dynamic model (right) [34]

Figure 16. Laboratory wheel-rail test rig used for RCF testing [38]

Figure 17. Laboratory loading rig currently under construction at CRE-CQU for IRJs testing

Figure 18. Test setup for the IRJs field testing conducted by CRE-QR [18]
### Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAR</td>
<td>Association of American Railroads</td>
</tr>
<tr>
<td>ARTC</td>
<td>Australian Rail Track Corporation Ltd</td>
</tr>
<tr>
<td>CQU</td>
<td>Central Queensland University</td>
</tr>
<tr>
<td>CRE</td>
<td>Centre for Railway Engineering</td>
</tr>
<tr>
<td>CWR</td>
<td>Continuous welded rail</td>
</tr>
<tr>
<td>FAST</td>
<td>Facility for Accelerated Service Testing</td>
</tr>
<tr>
<td>FE</td>
<td>Finite element</td>
</tr>
<tr>
<td>FRA</td>
<td>Federal Railroad Administration</td>
</tr>
<tr>
<td>HAL</td>
<td>Heavy axle load</td>
</tr>
<tr>
<td>IRJ</td>
<td>Insulated rail joint</td>
</tr>
<tr>
<td>MGT</td>
<td>Million gross tonnes</td>
</tr>
<tr>
<td>NS</td>
<td>Norfolk Southern</td>
</tr>
<tr>
<td>QR</td>
<td>Queensland Rail</td>
</tr>
<tr>
<td>QUT</td>
<td>Queensland University of Technology</td>
</tr>
<tr>
<td>RCF</td>
<td>Rolling-contact fatigue</td>
</tr>
<tr>
<td>TTCI</td>
<td>Transportation Technology Center, Inc.</td>
</tr>
<tr>
<td>UOW</td>
<td>University of Wollongong</td>
</tr>
<tr>
<td>UP</td>
<td>Union Pacific</td>
</tr>
</tbody>
</table>
Introduction

Bonded insulated rail joints (IRJs) are integral parts of the railway track system. Their design is similar to traditional butt joints, but with due care for maintaining electrical insulation between all surfaces of contact between various parts. A typical IRJ is shown in Figure 1; IRJs electrically isolate track into discrete sections to facilitate signal control. IRJs are also required to possess adequate structural strength to enable safe passage of wheels across the joint. As such, bonded IRJs are safety critical components that must satisfy the requirement for structural integrity as well as the isolation function for the railway signalling system.

![Figure 1. A Typical IRJ.](image)

As the result of the weak link nature of the bonded IRJs (lower stiffness at the joint section compared to the surrounding rail) and axle load dynamic load amplification at the joints (as a result of spatial discontinuity & possible geometric dipping at the joints), bonded IRJs are susceptible to accelerated mechanical failure. This is particularly so in heavy-haul corridors where axle load and annual gross haulage are on the rise. Consequently, IRJs routinely fail after carrying as little as 50 million gross tonnes of freight traffic (approximately 1-2 years), resulting in significant maintenance costs for the rail industry and service interruptions due to accidents around the world. [1–4] The common mechanical failures include plastic flow and fatigue damage near railheads close to the endposts, joint bar cracking, adhesive debonding, and degradation of track stiffness in the vicinity of the joints.

Research indicates that the mean service life of IRJs is only about 20% that of non-insulated joints including continuous welded rail (CWR). In addition, the number of IRJ replacements is estimated to be 20–50% of the sum total replacements of all rail track components. [5–7] On heavy-haul railway tracks in particular, the relatively short service life of IRJs when compared to all other running surface track system components has become a
significant economic concern. [8] The statistical variability in the service life of these IRJs is another major concern affecting the rail industry’s ability to confidently calculate the predicted life of IRJs and formulate maintenance strategies. This variability also increases the potential for premature failure.

As a safety critical component of the railway track infrastructure, IRJs should ideally possess greater mean strength with less variability. This advancement is vital to maintaining the structural integrity, safety, and operational efficiency of the rail system. This development will also improve decision making regarding IRJ maintenance and replacement, thereby reducing the risk of train collision due to the undetected failure of an IRJ. Ongoing international research projects in collaboration with the rail industry are focussed on the development of a new IRJ design which will provide an extended service life. The researchers’ approach has been to modify existing designs and test the effectiveness of these modifications in the field. This trial-and-error methodology is expensive, and thus far inconclusive.

The aim of this report is to review the state-of-the-art in IRJ technologies, with particular reference to the heavy-haul rail sector, through a comprehensive literature search. Only papers on rail joints and IRJs are taken into account. No reference is made to the greater body of extensive information reported on rail itself. The scope of the report embraces factors identified within the literature that are recognised as affecting the performance of IRJs, including design, loading environment, installation, and maintenance processes. Failure mechanisms of IRJs reported in the literature and based on limited field surveys are also included. The report is only focussed on design issues related to materials and structural aspects of IRJs, and not on electrical isolation aspects, as insulation effectiveness is assumed to have been satisfied in all designs a priori.
1. Designs of IRJs

The design options for bonded IRJs reported in the literature are presently limited. Both “conventional” and new IRJ designs have been tested on heavy-haul railway tracks with unsatisfactory results. Current research and design efforts toward improving IRJs are targeted at two main areas:

- Structural innovation, which may include improving the support systems (current options are suspended, continuously supported, and discretely supported systems), geometrical shape and size of joint bars, sleeper sizes and spacing, insulation material thickness, and geometry of cut joints, among others.

- Material innovation, where the improvement of joint bar strength, insulating materials, or adhesives is the main objective.

The design of IRJs generally involves some degree of both structural and material innovation; the extent of each is largely dependent on the particular expertise of each research institution.

1.1. International IRJ Designs

1.1.1. North America: USA

The Colorado-based Transportation Technology Centre, Inc. (TTCI) has been testing several IRJ prototypes in collaboration with the Association of American Railroads (AAR), the Federal Railroad Administration (FRA) and various rail industry organisations. These prototypes comprise new designs as well as modified versions of existing conventional IRJs. The focus of this collaborative design project is to develop stiffer and stronger IRJs that can withstand heavy axle loads without exhibiting any of the frequently observed failure mechanisms (i.e. adhesive debonding followed by joint bar cracking). [8–12]

Other changes to the design of IRJs have been explored by researchers with a view to extending their service life. Trials reported in the literature include increasing the length and cross-sectional dimensions of joint bars, increasing the width of sleepers, providing multiple supports and/or continuous supports underneath the IRJs, using stronger and tougher insulating materials or adhesives, and introducing special stiffening materials for centre liner insulators. Examples of two recent design improvements are shown in Figures 2 and 3. Several series of field tests to evaluate the performance of various IRJ designs installed at the TTCI’s mainline and Facility for Accelerated Service Testing (FAST) test tracks have been reported by the TTCI since 2004. [8–12] These trials have focussed on increasing the ‘strength’ of IRJs using the principle of structures as static systems; the relative
increase in track support stiffness and its effect on increased dynamic load appear to have been disregarded in the approach followed by the TTCI researchers.

Figure 2 depicts some of the IRJ designs provided by Protec Rail Products Inc. that have been installed on various railway tracks for performance testing by the TTCI. The target service life for these IRJs is approximately 2000 million gross tonnes (mgt). Field test reports indicate that, as of 2008, none of the above IRJs had been subjected to more than 850 mgt.

![Figure 2: High modulus IRJs (11–12): 1.2m long joint bars on test with TTCI, 275mm wide ties and insulated three-tie plate (left); 1.2m long joint with centre liner (right).](image)

A newly introduced advanced design of IRJs, known as the Mitre Cut Insulated Joint (Figure 3) is a long-angle cut/lap joint. This joint performed poorly during field testing on the mainline track, mainly as a result of railhead material failure. [11–12]

![Figure 3: Lap joint detail design components (left); mitre-cut/long-angle cut insulated rail joint (right); (11–12).](image)

The poor performance of the long “Mitre-Cut” lap IRJ is not a big surprise, as the design involves both a vertical and angled cut along the railhead and rail foot as well as a long shallow-angle inclined cut along the rail web. At the railhead and rail foot, the cut geometry exhibits sharp corners that are potential stress concentration...
locations. A section of the railhead almost turns into the nose section of a turnout that in itself is a weak spot for impact.

1.1.2. North America: Canada

Recently, Canadian companies have introduced new IRJ designs. The “Hercules” IRJ developed by NorFast Inc. (Figure 4) offers a longer service life, improved signal reliability, and faster, more economical field installation in comparison to existing conventional IRJs. However, the performance of such IRJs in heavy-haul railway applications has not yet been reported. The significant difference between the “Hercules” IRJ and the TTCI designs is that the “Hercules” is mechanically designed to withstand higher wheel loads without the use of glued bonds. A further advantage is that the “Hercules” joint can be entirely assembled in the field without any need for field welding. [13–14] The field assembly process appears both straightforward and versatile; joints can be formed either on tangent track or at turnouts/corners as shown in Figure 4.

Figure 4. “Hercules” series insulated rail joints from NorFast Inc. [13].

Unlike the TTCI’s “mitre-cut” IRJ, the “Hercules” IRJ is shown suspended between sleepers. It therefore appears that the “Hercules” designers have relied on more than static structural principles to achieve joint strength.

The Canadian distributor NedCan Products, Inc provides the North American rail industry with a non-bonded IRJ manufactured by the Swiss company Tenconi SA. Like the NorFast “Hercules” this IRJ does not rely on an adhesive bond to acquire the necessary strength to withstand heavy-axle traffic loads (Figure 5).
Figure 5. Tenconi 4-bolt mechanical IRJ (transition joint) (left); another Tenconi mechanical IRJ variant (right). [15] These IRJs feature high tensile steel encapsulated with a special blend of Polyamide 12 to attain their electromechanical characteristics. The joint is currently undergoing testing at the TTCI’s FAST track, and initial reports regarding its performance in comparison to conventional bonded joints are encouraging. [15]

1.1.3. South Africa

Both square- and inclined-cut bonded IRJs similar to conventional glued IRJs are being used in heavy-haul railway tracks in South Africa. [16] According to the supplier, VAE South Africa, both square- and inclined-cut IRJs can be provided as pre-fabricated joints glued into short rail pieces even though the bonded IRJs with a square cut can be made in the track. A new IRJ development reported to be currently under test, the “IVG joint”, is shown in Figure 6. This variant features an oblique design in head of rail with a simultaneously obtuse design in the web.

Figure 6. 4-bolt IRJ with square cut (left); “IVG joint” with angular cut manufactured by VAE gmbh (right). [16]

1.2. Australian IRJ Design

The design, manufacture and testing of IRJs in Australia is largely based Australian Standard AS 1085.12–2002 [17] (Figure 7). The typical Australian IRJ assembly is a bonded, double butt-strap joint consisting of two steel joint bars fixed to the rails with an epoxy adhesive (that may contain a fibreglass reinforced insulation material), an insulating endpost, high-tensile bolts, and other assorted components. Both 4-bolt and 6-bolt bonded IRJs are currently in service on various Australian railway tracks. Manufacturers can supply both square- and inclined-cut insulated joints factory pre-assembled. These joints can also be field-assembled in accordance with AS 1085.12 provisions.

Prior to 2007 Australian IRJs were manufactured with a minimum 8.5mm insulating endpost thickness to minimise the risk of joint metal flow bridging the endpost (‘closure’). Rail CRC Project 75 has recommended that insulating
endpost thickness be reduced to 5mm to minimise impact loading. Current IRJs are manufactured with endpost thicknesses of 5mm (in some cases 4.5mm) based on the Project 75 recommendation.

Figure 7. Exploded view of an Australian bonded IRJ as depicted in Australian Standard AS 1085.12–2002.

The support system for IRJs on Australian railway track is primarily the “suspended” type, with the centre-to-centre span between the two sleeper supports variable depending on whether a 4-bolt or 6-bolt IRJ is used. However, visual inspections conducted during field visits have identified significant inconsistencies with regard to the support conditions of glued IRJs on Australian railway tracks. Examples of all of the following support conditions can currently be found on Australian railway track: symmetrically-suspended, asymmetrically-suspended, single sleeper support underneath the IRJ close to endposts, and single support underneath the joint bar ends. Additional variations may also be in use. Figure 8 shows typical support conditions of bonded IRJs in Australian railway tracks.

Figure 8. Examples of typical support conditions for IRJs observed in Australian railway track: symmetric support (left); asymmetrical support (middle); and center support (right).
Currently, there is little information available with regard to the availability of any new Australian IRJ designs which are being installed and tested on heavy-haul railway tracks. The exception to this is field testing presently being conducted by the Australian Rail Track Corporation (ARTC) of existing IRJs modified with a laser weld to the railhead in the vicinity of endpost. On Australian railway track, railhead metal flow is the most common cause of failure of bonded IRJs. The cyclic accumulation of railhead material deformation under repeated wheel impact load (or ratcheting) ultimately leads to railhead fatigue failure and possible closure contact between the two rail ends separated by the insulating end post (resulting in signalling failure). Queensland Rail (QR) is currently trialling high yield strength material innovations for IRJs.
2. Loading

IRJs are subjected to a number of loading scenarios in the field. Their ability to withstand these loads will determine their service life.

At any given instance, only one wheel can be located within the span of a sleeper as the sleeper spacing is kept smaller than the wheelset spacing in the bogie structure. Therefore, an examination of the behaviour of IRJs (either suspended between sleepers or supported on a sleeper) is essential to understanding of their performance. Figure 9 illustrates the deformation of a suspended and a supported IRJ when subjected to wheel loading. It is clear that edge of a rail end (point of stress concentration zones/ singularities) on a supported joint is more vulnerable to direct impact from the running wheels. Limited finite element (FE) studies by Pang [18] confirm that supported joints exhibit higher impact than their suspended counterparts.

![Figure 9. Behaviour of suspended (top) and supported (bottom) IRJs in response to wheel loading.](image)

Notwithstanding the method of support, the railhead ends in IRJs are subjected to wheel impact due to the ‘step’ mechanism schematically illustrated in Dhanasekar et al (2007) – (Figure 10).
The ‘step’ forms due to difference in the elastic behaviour (predicted by Young’s Modulus) of the railhead steel and the endpost material (generally nylon), and the type of contact between the two materials. To minimise the ‘step’, one should ideally use a material that is as stiff as that of steel. The ARTC conducted an unsuccessful field trial of a ceramic (zirconia) endpost in a heavy-haul corridor. Although zirconia and railhead steel exhibit similar E-values [between 190 and 240 gigapascals (GPa)], the zirconia ultimately proved too brittle in this application.

In addition to wheel loading, IRJs are also subjected to loading due to permanent differential settlement of adjacent supporting sleepers (Figure 11).

IRJs may also be subject to other loading, including:

- diurnal variation of temperature (inducing tension/compression in joints – especially on the endpost)
- earthquake
- bush fire/flooding and other environmental loading

The behaviour of IRJs under these types of loading is not reported in the literature, and hence is not considered in the scope of this report.
2.1. Failure Modes

As highlighted in this report, IRJs fail due to a range of mechanisms. Each component that forms the IRJ (including interfaces between these components) fail under severe wheel-rail contact impact loading. Examples of some of the major failure modes of IRJs reported in the literature are shown in Figure 12.

(a) Rail end battering                      (b) Rail end shelling

(c) Rail end metal flow                    (d) Endpost battering/ delamination

(e) Cracked joint bar                      (f) Railhead spalling

(g) Chipping at rail end and gage corner   (h) Railhead crushing [12]
3. Modelling and Analysis

3.1. Finite Element Model

Numerical simulation studies of bonded IRJs are often carried out using various modelling methods—including finite element (FE) models as well as mechanistic analytical models. Both three-dimensional (3-D) and on a limited number of cases, two-dimensional (2-D) FE modelling techniques have been used as the main tool for analysis and design of bonded IRJs. Parametric 3-D solid FE modelling of IRJs to study variation in load cases (design parameters, mesh density) and cyclic plasticity (which requires multiple wheel passage) is very demanding on the computational time.

3.1.1. 3-D FE Models
Most of the 3-D solid FE modelling studies reported in the literature have been employed for wheel-rail contact impact load characterisation in the vicinity of endposts using nonlinear explicit FE dynamic analysis. [7, 18–23] These 3-D FE models are capable of predicting the dynamic amplification factors near the endpost that may occur due to rail geometric discontinuity as well as sudden changes in the rail track stiffness in the vicinity of the bonded IRJs. On the other hand, limited literature is available with regard to the use of nonlinear 3-D solid FE modelling for numerical prediction of the mechanical deterioration/plastic deformation and fatigue damage of insulated rail joints under repeated wheel loads. [24] Peltier and Barkan with other research group at the University of Illinois at Urbana-Champaign employed 3-D solid FE modelling to investigate the role of thermal stresses and longitudinal loads on the adhesive delamination of bonded IRJs, and developed a means of detecting epoxy debonding using strain measurement techniques. [25–27] Recently, 3-D solid linear FE analysis has been employed for parametric design investigations which explored the impact of varying joint bar dimensions, varying tie width, and introducing long-angle cut lap joints on the performance of IRJs. [9–11]

A hybrid FE modelling approach in which 3-D beam FE models were used along with 3-D solid FE models in order to reduce the computational time required for 3-D solid FE model nonlinear analysis was also reported in the literature. [6,18, 21]

3-D beam FE modelling was employed for modelling global train-track interaction in the vicinity of bonded IRJs and subsequent investigation of localised railhead material deterioration near the insulating endpost. [28] Koro et al. [29] employed 3-D beam FE modelling for their investigation of impulsive contact forces generated by vehicle-track interaction in the vicinity of rail joints due to discontinuity and joint dips. Figure 13 demonstrates typical 3-D solid and beam FE models reported in the literature for wheel-rail interface at IRJ locations in the railway track.

![Figure 13. Typical 3-D models of IRJs: 3-D solid FE model (left) [18]; 3-D beam FE model of railway track (right) [24].](image)

### 3.1.2. 2-D FE Models
2-D FE modelling & semi-analytical approaches are considered more efficient, and their application in IRJ design is the focus of this research project. Few 2-D FE modelling studies of bonded IRJs have been reported in the literature (typical 2-D FE models of IRJs are shown in Figure 14). Some researchers have employed 2-D FE modelling for characterisation of the effects of IRJs on wheel-rail contact stresses in the vicinity of the endpost. [30–32] However, to the knowledge of the authors, none of the 2-D FE models reported have been used to characterise IRJ failure mechanisms in the vicinity of the endposts. This is despite the fact that railhead failure is one of the most important failure modes in general—and the most frequent failure mode on Australian railway tracks in particular.

Therefore, the current modelling effort includes elastic and elastic-plastic rolling contact stress analysis of IRJs using a simplified 2-D FE model that employs both plane strain and plane stress modelling assumptions. Such models are useful for characterisations of contact stresses as well as for the investigation of localised railhead failure mechanisms in the vicinity of endposts under repeated wheel loading.

![Figure 14. Typical 2-D FE models of IRJs: 2-D wheel & rail FE models (left) [32]; 2-D FE model (rail) using 2-D Hertzian contact pressure (wheel load) (ongoing Research at QUT) (right).](image)

### 3.2. Mechanistic Models

Kerr and Cox [33] implemented analytical models for wheel-rail interaction at bonded IRJs that are primarily applicable to scenarios characterised by a slow-moving railway traffic load and simplified boundary conditions—such as a simply supported IRJ in a laboratory setup. Suzuki et al. [34] presented more complex mechanistic track dynamic models that can be used for characterisation of dynamic excitation and ballast settlement near IRJs. Similar mechanistic dynamic models have been developed for investigation of vehicle-track interaction in the vicinity of rail joints due to rail discontinuity as well as dipping at the rail joints. [29, 35–37] However, the use of such a mechanistic modelling approach does not seem to be conducive to investigating localised railhead material failure mechanisms in the vicinity of IRJ endposts, and such a study has not been reported in the literature. Figure 15 depicts typical mechanistic models of bonded IRJs reported in the literature.
Figure 15. Typical mechanistic models of bonded IRJs: simple analytical static model (left) [33]; more complex analytical dynamic model (right). [34]
4. Laboratory Tests

Limited information is available regarding laboratory testing of bonded IRJs. Kerr and Cox [33] conducted a standard laboratory test of bonded IRJs in order to investigate the fundamental mechanics of insulated rail joints and to validate simplified analytical models; however, the results are not necessarily applicable to IRJ problems with complex field boundary conditions.

Similar laboratory static testing of bonded IRJs was conducted at the Central Queensland University Centre for Railway Engineering (CRE-CQU). [18] The test results were used for validating numerical 3-D FE models and proof-testing the reliability of the bonded IRJs that were subsequently installed on heavy-haul railway track for field testing.

Further research is required toward the development of a comprehensive laboratory IRJ test setup that is capable of addressing not only static design issues but also railhead material failure mechanisms that occur in a dynamic wheel-rail contact load environment. The results obtained from such test setups can also be used for calibration of various numerical models that are useful for prediction of dynamic wheel-rail contact impact loads from measurements, IRJ failure mechanisms, among others.

4.1. Loading Rig

Figure 16 shows one of the few wheel-rail laboratory test rig setups reported in the literature that have been designed and employed for rolling-contact fatigue (RCF) testing. [38]
Even though the test rig was able to simulate rolling/sliding contact at the wheel/rail interface using full-size wheel rolling on a rail for limited level of vertical and creepage loads, the test setup was not specifically designed to investigate bonded IRJ failure problems through initiating railhead failure in the vicinity of the endpost. Therefore, characterisation of railhead failure due to ratchetting and/or fatigue failure in the vicinity of the endpost has not been addressed by the existing and complicated test rig shown in Figure 16.

A simplified and yet efficient loading rig for comprehensive laboratory testing is being designed at CRE-CQU as a part of this Rail CRC project. This test rig will be capable of exerting both normal and tangential wheel-rail contact pressure on bonded IRJ test samples. The system will be used to apply asymmetric cyclic loading so that normal and tangential contact stress distributions, cyclic plastic deformations, accelerated damage accumulation, and fatigue failure test data can be obtained. Figure 17 shows the main components for the loading rig currently under design and construction.
The test rig components consists of vertical and horizontal 500kN Servo-hydraulic actuators mounted to the CRE loading portals with pin joints at one end and the other end connected via load cells to yokes connected to a modified rail wheel sitting on an test IRJ mounted on the strong floor. The wheel is proposed to be a modified rail wheel with a hard and cylindrical rolling surface mounted on a shaft with bearings and connected to the yokes. The vertical actuator provides the vertical rail forces and is proposed to be operated under load control. The horizontal actuator provides the ability to move the wheel axis horizontally providing rolling wheel/rail contact and be operated under displacement control. The rail is mounted vertically and connected to the floor with rail supports that can be moved to change the rail support locations. The motion of both actuators will be controlled by the laboratory control system to provide the test cycle.

5. Field Tests

Currently, there are limited field test data available on railway track systems incorporating bonded IRJs. The TTCI has been the major player in field testing —amassing a significant number of continuous data measurements over many years, and also conducting accelerated field testing at FAST. The AAR and FRA have jointly funded an extensive field testing program conducted by the TTCI in cooperation with Norfolk Southern (NS) and Union Pacific (UP). These “Heavy Axle Load Revenue Service Experiments” commenced in 2004 and continued until the results of these tests were reported in December 2008. The objectives of these field tests included the evaluation of eight bonded IRJ test joints installed and instrumented at four different locations under various support conditions. The field test data indicate that suspended IRJs failed at 330 mgt. On the other hand, IRJs supported on three-tie support plates continued to provide service without failure after accumulated traffic of 810 mgt has been already recorded. Detailed information about the ongoing TTCI field tests can be found in the literature reference provided with this report. [1, 5, 11-12]
The CRE-QR has also conducted approximately 9 months of field testing of IRJs on QR’s heavy-haul railway track, from June 2006 to March 2007 (see Figure 18). The primary objective of these experiments was to identify the dynamic contact-impact forces at the wheel-railhead interface in the vicinity of endposts, and to assess the long-term performance of the instrumented IRJs located in a heavy-haul railway network by using continuous strain response measurements. Experimental field testing was conducted on two instrumented IRJs simultaneously, using multiple strain gauge channels attached to the rails in the vicinity of the rail ends. The critical locations used for the installation of the measurement sensors for long-term strain data acquisition were first identified using 3-D FE simulation studies. Consequently, multiple strain gauge rosettes were attached in the vicinity of the identified hot spots on both sides of the rail webs and at the bottom of the rail bases. Detailed information about these tests can be found in the references which accompany this report. [18, 21–23]

![Figure 18. Test setup for the IRJs field testing conducted by CRE-QR. [18]](image)

To the authors’ knowledge, the literature currently contains no record of field testing that has tackled the difficulties associate with characterisation of IRJ railhead material failure problems. However, researchers at QUT, UoW and CQU—in collaboration with QR and the ARTC under this rail CRC research project (i.e. longer-life insulated rail joints)—have formalised plans for ongoing field testing which aims to capture comprehensive IRJ damage mechanisms in the service conditions on heavy-haul railway track. These failure mechanisms will include railhead damage in the vicinity of rail joints, joint bar cracking, differential settlement of sleepers and joint dipping, railhead material characterisation, and structural and material innovation testing, among others. Subsequently, the test data obtained from field testing, laboratory testing, and numerical modelling studies will be employed to address the problem of premature IRJ failure currently vexing the rail industry.
References


