Proceedings of the Seventh International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 15, Paper 12.2
Civil-Comp Press, Edinburgh, United Kingdom, 2026
ISSN: 2753-3239, doi: 10.4203/ccc.15.12.2

Enhancements to Rail Defect Management within the UIC IRS Framework

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Abstract

The International Union of Railways (UIC) develops and publishes International Railway Solutions (IRS), which are consensus-based technical documents produced through collaborative work among railway undertakings and infrastructure managers. These documents support the harmonisation of railway systems by providing practical, industry-driven guidelines and best practices. IRSs contribute to the railway sector's overarching objectives of safety, sustainability, and economic efficiency.

Within railway track engineering, the rail is a critical structural component, ensuring safe vehicle guidance, stable running behaviour, and overall system integrity. To support consistent and up-to-date rail maintenance practices, UIC publishes several IRS documents focusing on rail-related topics, notably IRS 70712 (*Rail Defects*) and IRS 71725 (*Treatment of Rail Defects*).

In recent years, these IRSs have undergone major revisions to address evolving operational requirements, including advances in inspection technologies and the growing adoption of risk-based maintenance strategies. This paper provides an overview of these rail-maintenance-related IRS documents and explains how they can be applied to strategic rail maintenance. Particular emphasis is placed on the technical rationale and expected operational benefits, following the life cycle of a rail defect—from initiation and detection to risk assessment, maintenance decision-making, and post-treatment evaluation.

Keywords: rail defects, rail maintenance strategy, IRS 70712, IRS 71725, rail inspection, risk-based maintenance

1 Introduction

Rail defect maintenance plays a crucial role in ensuring railway safety and stable service operation. A strategic approach to rail maintenance requires a clear understanding of the technical framework governing defect identification, classification, inspection, and mitigation.

Rail maintenance is challenging due to the wide variety of defect types that may occur. Each defect type has distinct characteristics in terms of detection method, crack-propagation behaviour, and appropriate mitigation strategy. Consequently, selecting the optimal inspection and maintenance approach requires a structured and standardized methodology.

In practical railway operations, IRS 70712 and IRS 71725 provide comprehensive guidance on these aspects. IRS 70712 establishes a scientific framework for identifying and categorizing rail defects, while IRS 71725 defines inspection strategies, monitoring principles, and maintenance actions. Together, these documents support harmonized and risk-based rail defect management.

This paper summarises the contents of both IRS documents and provides a practical, field-oriented example illustrating how inspection teams and infrastructure managers can apply these standards in daily rail maintenance activities.

2 IRS 70712 – Rail Defects

2.1 Introduction

IRS 70712 establishes a standardized scientific framework for the identification, classification, and assessment of rail defects across international railway networks. It replaces UIC Leaflet 712 (2002) and significantly enhances the reliability of defect detection, maintenance planning, and comparative statistical analysis.

Effective rail defect management is essential for infrastructure integrity, as it reduces the risk of catastrophic failures caused by mechanical fatigue, corrosion mechanisms, or metallurgical imperfections.

2.2 Methodological Foundations

The standard defines rail defects based on measurable physical and mechanical indicators and distinguishes three fundamental rail conditions:

1. **Damaged rails**, showing superficial deterioration;
2. **Cracked rails**, exhibiting surface-initiated or subsurface cracks with propagation potential;
3. **Broken rails**, where structural continuity is lost.

For each condition, IRS 70712 provides operational recommendations ranging from monitoring to immediate removal. The methodology integrates both deterministic and probabilistic approaches to degradation and failure behaviour.

2.3 Classification Framework

IRS 70712 introduces a four-digit defect coding system enabling systematic and unambiguous classification. Defects are categorized according to:

- Location (rail end, plain rail, weld zone)
- Cross-sectional position (head, web, foot)
- Defect mechanism (fatigue, corrosion, rolling contact fatigue)
- Sub-classification based on morphology

This harmonized framework supports advanced asset-management systems and enables interoperability of defect data across railway networks.

2.4 Representative Defect Mechanisms(Figure 1)

Several defect families are particularly significant due to their mechanical behaviour and failure kinetics:

- **Rolling Contact Fatigue (RCF)** defects, such as head checking (2223), flaking (2221), and shelling (2222), caused by cyclic shear stresses at the wheel–rail interface.
- **Manufacturing-related defects**, including kidney-shaped cracks (211) and piping (233), originating from metallurgical inclusions or casting discontinuities.
- **Welding defects** (411, 421, 432), resulting from inadequate energy input, poor bonding, or metallurgical heterogeneity in the weld zone.

These defects significantly increase fracture risk if not detected and treated in time.

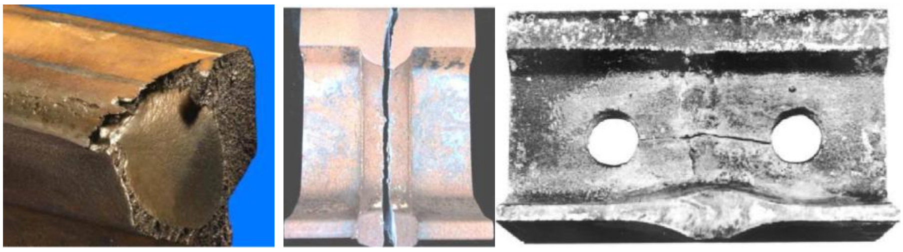

Figure 1: Examples of rail defects(2222, 421, 432)

2.5 Detection Technologies

IRS 70712 recommends a multi-modal inspection approach:

- **Ultrasonic testing** for internal defects and fatigue cracks
- **Eddy-current testing** for surface and near-surface RCF defects
- **Visual inspection** for surface damage and wear
- **Rail geometry measurements** to monitor corrugation and wear progression

The combination of these techniques improves detection reliability and defect characterization.

2.6 Maintenance and Mitigation Strategies

Preventive measures include rail grinding, milling, and reprofiling to remove early-stage surface cracks. Corrective actions involve selective rail replacement in cases of deep cracking, corrosion-related section loss, or structural discontinuity.

High-risk defects—such as squats (227), transverse weld cracks (421), and fillet-radius horizontal cracks (2321)—require urgent intervention to avoid unstable crack growth and sudden rail failure.

2.7 Scientific and Operational Implications

By standardizing defect terminology and classification, IRS 70712 enables comparative analyses across networks and long-term evaluations of rail steel performance, crack growth behaviour, and maintenance effectiveness. The coding system supports statistical modelling, predictive maintenance, and infrastructure optimisation.

3 IRS 71725 – Treatment of Rail Defects

3.1 Introduction

IRS 71725 provides a comprehensive technical framework for the identification, monitoring, and treatment of rail defects in heavy-rail infrastructure. It is based on decades of operational experience and scientific research into crack initiation, propagation, and mitigation.

3.2 Crack Growth Mechanisms

Rail cracks develop due to complex interactions among axle loads, dynamic forces, contact geometry, residual stresses, and temperature variations. Internal cracks exhibit detectable (P) and critical (F) sizes, defining the P–F interval during which preventive action is possible(Figure 2).

Surface-initiated defects such as head checking and squats evolve rapidly and require early intervention to prevent transverse fractures.

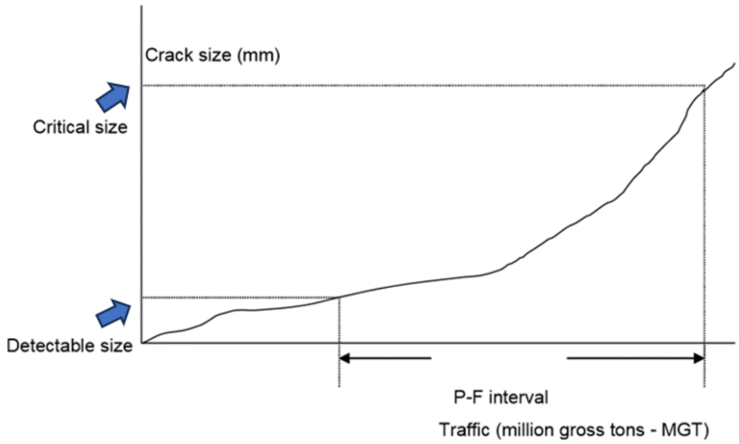

Figure 2: Definition of the P-F interval.

3.3 Maintenance Principles

Three maintenance approaches are defined:

- **Preventive maintenance**, aiming to avoid crack initiation through cyclic reprofiling;
- **Corrective maintenance**, applied after defect detection, including rail replacement and welding repairs;
- **Predictive maintenance**, using data analytics and historical trends to anticipate failures.

3.4 Planning Inspection Cycles

Inspection frequency depends on traffic load (MGT), line criticality, defect history, environmental conditions, and maintenance windows. IRS 71725 provides baseline inspection intervals according to UIC track classes and speed ranges, allowing adaptation to local conditions.

3.5 Defect Types

Five major defect families are distinguished:

- Transversal cracks

- Longitudinal horizontal cracks
- Longitudinal vertical cracks
- Surface-initiated defects (RCF)
- Oblique cracks (e.g. bolt-hole cracks)

Each defect type is linked to UIC codes and illustrated by representative examples.

3.6 Action Categories

Defect severity determines intervention urgency:

- **Category 0:** Immediate traffic prohibition and rail removal
- **Category I:** Immediate removal, maximum delay two weeks
- **Category II:** Removal within 12 months
- **Category III:** Monitoring only

Threshold dimensions define category assignment.

3.7 Detection Methods

Inspection relies on complementary techniques, including visual, ultrasonic, eddy-current, magnetic particle, and rail-geometry measurements. Each method has defined effectiveness ratings depending on defect type. Qualified NDT personnel are required.

3.8 Guidance on Defect Management

Risk-based inspection and maintenance planning consider defect statistics, rail characteristics, detection reliability, costs, and failure consequences. These models improve safety and reduce life-cycle costs.

4 Field Application of IRS-Based Rail Defect Management

4.1 Overview of the Operational Scenario

This section presents a practical application of IRS 70712 (*Rail Defects*) and IRS 71725 (*Treatment of Rail Defects*) through an illustrative field scenario. The objective is to demonstrate how the standardized defect taxonomy, inspection principles, and decision criteria defined in these IRS documents are applied in daily railway inspection and maintenance activities. The example follows an inspection team responsible for monitoring rail integrity on a mixed-traffic main line and highlights the integration of scientific defect characterization with operational decision-making.

4.2 Inspection Preparation and Mission Definition

The inspection campaign is conducted on a 40-km section of mixed-traffic main line, characterized by high axle loads and operational speeds exceeding 160 km/h. Recent data from an ultrasonic inspection vehicle indicated the presence of multiple internal anomalies. In accordance with IRS 71725, the inspection scope and priorities were defined based on line criticality, accumulated traffic load, historical defect density, and environmental conditions. The inspection strategy therefore emphasized early detection of transversal defects and rolling contact fatigue (RCF), which present the highest safety risk on high-speed infrastructure.

4.3 Infrastructure Context and Expected Defect Types

Prior to field deployment, the inspection team reviewed the defect taxonomy defined in IRS 70712 to anticipate likely defect mechanisms along the investigated section. Expected defect families included transverse cracks, longitudinal vertical cracks, surface-initiated RCF defects (head checking and squats), and weld-related discontinuities. IRS 71725 provided complementary guidance on defect thresholds, action categories, and permissible time intervals between detection and intervention. This combined scientific framework ensured consistency between field observations and engineering assessments.

4.4 Detection of Head Checking on Curved Track

During inspection of a curved segment with a radius of approximately 1,200 m, eddy-current measurements confirmed the presence of head-checking cracks on the high rail. According to IRS 71725, head checking typically initiates beneath the rail surface and propagates due to high shear stresses at the wheel–rail contact interface. Measured crack depths averaged 3.5 mm, placing the defects within Category III (monitoring only). Although immediate removal was not required, the findings indicated the need for preventive rail grinding during the next planned maintenance window to limit further crack propagation.

4.5 Identification of a Squat Defect

Further along the line, ultrasonic inspection revealed an asymmetric echo characteristic of a squat defect (UIC code 227). Squats exhibit variable growth rates influenced by steel grade, traffic intensity, and contact mechanics. Field measurements indicated an approximate defect length of 70 mm. In accordance with IRS 71725 classification thresholds, the defect was assigned to Category II, requiring rail replacement within a 12-month timeframe. The defect location was documented using GPS coordinates, photographic evidence, and ultrasonic signal records for subsequent engineering analysis.

4.6 Detection of a Longitudinal Vertical Crack

A critical finding occurred during the afternoon inspection, when a vertical ultrasonic probe detected a linear internal indication extending longitudinally within the rail head. This defect was identified as a longitudinal vertical crack (UIC code 213), which is considered particularly hazardous due to its potential for silent propagation over long distances. IRS 71725 describes a two-stage growth mechanism for such defects, consisting of a prolonged quasi-stable phase followed by rapid surface emergence and fracture. Given the elevated risk, the defect was immediately classified as Category I, necessitating urgent removal.

4.7 Technical Assessment and Decision-Making Process

Inspection results were transmitted in near real time to the central engineering office for technical assessment. Using the action categories defined in IRS 71725, maintenance priorities were established: immediate isolation and replacement for Category I defects, programmed intervention for Category II defects, and periodic monitoring for Category III defects. The integration of field measurements into the risk-based defect management system enabled optimized allocation of maintenance resources while preserving safety margins.

4.8 Influence of Track Condition on Defect Evolution

In parallel with defect detection activities, track geometry data were evaluated to assess their influence on crack initiation and growth. IRS 71725 highlights that degraded geometry, stiffness variations, and support defects can significantly increase dynamic wheel loads, thereby accelerating crack propagation. Any detected alignment irregularities or local stiffness anomalies were therefore recorded as contributing factors requiring corrective track maintenance to prevent future defect escalation.

4.9 Concluding Observations from Field Application

At the conclusion of the inspection mission, all collected data—including ultrasonic records, eddy-current measurements, visual documentation, and positional information—were uploaded to the infrastructure management system. This case study illustrates how the scientific principles codified in IRS 70712 and IRS 71725 enable a coherent link between defect detection, crack-growth understanding, and maintenance decision-making. The example demonstrates that standardized defect taxonomy and risk-based intervention rules are essential for ensuring that even early-stage rail defects are systematically assessed and mitigated before compromising railway safety and availability.

5 Conclusion

The recent updates of IRS 70712 and IRS 71725 address evolving operational challenges, including advanced inspection technologies and the transition toward risk-based maintenance strategies. This paper demonstrates how these IRS documents support strategic rail maintenance through a structured life-cycle approach—from defect initiation and detection to maintenance intervention and post-treatment evaluation. Their consistent application enhances railway safety, operational reliability, and cost efficiency.

References

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