Railway Accident Investigation Unit Ireland

INVESTIGATION REPORT

Chassis Plate Fracture on General Motors Class 201, Locomotive 224, 7th July 2020

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Report Description

Report publication

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Report structure

The report structure is taken from guidelines set out in “Commission Implementation Regulation (EU) 2020/572 of 24 April 2020 on the reporting structure to be followed for railway accident and incident investigation reports” having regard to “Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety”.

Reader guide

All dimensions and speeds in this report are given using the International System of Units (SI Units). Where the normal railway practice, in some railway organisations, is to use imperial dimensions; imperial dimensions are used, and the SI Unit is also given.

All abbreviations and technical terms (which appear in italics the first time they appear in the report) are explained in the glossary.

Descriptions and figures may be simplified in order to illustrate concepts to non-technical readers.

Preface

The RAIU is an independent investigation unit within the Department of Transport which conducts investigations into accidents and incidents on the national railway network, the Dublin Area Rapid Transit (DART) network, the LUAS light rail system, heritage and industrial railways in Ireland. Investigations are carried out in accordance with the Railway Safety Directive 2004/49/EC enshrined in the European Union (Railway Safety) (Reporting and Investigation of Serious Accidents, Accidents and Incidents) Regulations 2020.

The RAIU investigate all serious accidents. A serious accident means any train collision or derailment of trains, resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment, and any other similar accident with an obvious impact on railway or tramline safety regulation or the management of safety. During an investigation, if the RAIU make some early findings on safety issues that require immediate action, the RAIU will issue an Urgent Safety Advice Notice outlining the associated safety recommendation(s); other issues may require a Safety Advice Notice.

The RAIU may investigate and report on accidents and incidents which under slightly different conditions might have led to a serious accident.

The RAIU may also carry out trend investigations where the occurrence is part of a group of related occurrences that may or may not have warranted an investigation as individual occurrences, but the apparent trend warrants investigation.

The purpose of RAIU investigations is to make safety recommendations, based on the findings of investigations, in order to prevent accidents and incidents in the future and improve railway safety. It is not the purpose of an RAIU investigation to attribute blame or liability.

Summary

Iarnród Éireann (IÉ) 201 Class Locomotives were manufactured by General Motors (GM) in Canada and entered service in 1994. Locomotive 224 had its engine and generator removed in 2010 and 2019 for maintenance. When the engine and generator was removed cracks were identified in the *Bed Plate* (non-structural component) between the two *Chassis Plates* (structural component) of the Locomotive. IÉ carried out weld repairs to the Bed Plate but the weld repair did not conform to the EN15085 2007 standard series, entitled, "Railway applications - Welding of railway vehicles and components" or any IÉ approved written specification; and, on one occasion (in 2010 or 2019) the weld repair was unnecessarily continued from the Bed Plate into the Chassis Plate.

On 6th July 2020, the 14:25 hrs Cork Kent to Dublin Heuston passenger service operated with Locomotive 224 at the rear. Locomotive 224 experienced a coolant leak and electrical fault that caused the locomotive to shut down while approaching Limerick Junction. The train was deemed a failure and hauled to Heuston Station, Dublin.

On the 7th July 2020, while Locomotive 224 was at Heuston Station awaiting transfer to Inchicore Works, a driver observed the body of Locomotive 224 was sagging near the centre point and reported it to his supervisor who in turn alerted the relevant parties. On inspection, by the Chief Mechanical Engineer's (CME) Department's maintenance staff a main frame crack was identified. Locomotive 224 was then shunted to Inchicore Works for a more thorough examination.

At Inchicore Works, the Locomotive's engine and generator were removed to give a clear view of the damage. The crack was examined by IÉs Chief Chemist and Metallurgist, who was independently supervised by a metallurgist specialist, contracted by the RAIU. The metallurgical investigation identified that the failure occurred in the weld repair of the Bed Plate that was continued into the Chassis Plate.

In service, cyclic loading, particularly bending stress on the underside of the Chassis Plate (that had high residual tensile stresses generated from within the repair weld), resulted in multiple *fatigue* initiation sites developing and merging into a common crack that propagated through the Chassis Plate during the journey causing the Chassis Plate to fracture. The loss of integrity to the structure of Locomotive 224 resulted in a coolant pipe been disturbed and subsequent leak and the misalignment of the generator resulting in and electrical shut down fault.

The Chassis Plate of Locomotive 224 failed as a result of the following *causal factor* (CaF):

- CaF-01 – The flat Bed Plates were not replaced with cupped Bed Plates when Bed Plate cracks were identified as set out in the OEM Service Advisory SA 08-007;
- CaF-02 – During a weld repair of the Bed Plate, the Bed Plate was unnecessarily welded to the Chassis Plate.

Contributory factors (CoF) were identified as:

- CoF-01 – IÉ-RU had not adopted the EN 15085 standard series, entitled "Railway applications – Welding of railway vehicles and components" which were first published in 2007; although it is noted that this standard series is not mandatory;
- CoF-02 – While Service Advisory (SA 08-007) was available to the welder carrying out the repair through the CME Maintenance work stations, the implications of the modification were not discussed at IÉ management level prior to the incident and material for the modification was not procured.

A *systemic factor* (SF) was identified as:

- SF-01 – There was an over-reliance on the knowledge of the welder to develop and carry out a repair procedure without any formal instruction or supervision.

As a result, the RAIU made the following two safety recommendations:

- 2021004-01 – IÉ-RU CME should review all weld repairs carried out to structures of all rolling stock to assess the risk posed by such weld repairs and mitigate against the failure mode;
- 2021004-02 – IÉ-RU CME should develop a procedure for evaluating maintenance advice received from OEMs or other railway organisations to determine applicability to IÉ fleets and assess any associated risks.

Although not causal, contributing or systemic, the RAIU make the following additional observation (AO):

- AO-01 – The 201 Locomotive axle loads recorded by the acoustic bearing monitors indicate that the specified axle load may have been exceeded.

As a result, the RAIU made the following additional safety recommendation

- 2021004-03 – IÉ-RU CME and IÉ-Infrastructure Manager (IM) Chief Civil Engineer's (CCE) Department should carry out a risk assessment on the implications of the increased axle load of a 201 Locomotive.

Contents

RAIU Investigation

RAIU decision to investigate

1 In accordance with the Railway Safety Act 2005 and European Union (Railway Safety) (Reporting and investigation of Serious Accidents, Accidents and Incidents) Regulations 2020, the RAIU investigate *serious accidents*, the RAIU may also investigate and report on *accidents* and *incidents* which under slightly different conditions might have led to a serious accident.

2 On 9th July 2020, the RAIU received a notification of the structural failure of Locomotive 224 after IÉ-RU had evaluated the extent of the fracture. The RAIU conducted a preliminary examination and the RAIU's Chief Investigator (CI) made the decision to conduct a full investigation into the failure, given its impact on railway safety (*Article 20* (2) (c)), as under slightly different circumstances the failure may have led to serious accident with the potential for fatality or serious injuries due to risk of derailment as a result of the fracture.

3 In terms of categorisation, the EU Agency for Railways categorisation for this occurrence is a: Incident – Rolling Stock.

4 The RAIU's CI allocated RAIU Senior Investigators, trained in accident investigation, to conduct this investigation. The RAIU also engaged the services of a Metallurgical Specialist to assist with the technical *metallurgy* aspects of the fracture failure mode.

Scope & limits of investigation

5 The RAIU have established the scope and limits of the investigation as follows:

- Establish the sequence of events leading up to the failure;
- Identify any other precursors which led to the failure;
- Establish, where applicable, contributory factors, underlying factors and root causes;
- Examine the relevant elements of previous weld repairs;
- Examine the relevant risk assessments and registers;
- Review the Safety Management System (SMS) documentation in relation to competency of welders;
- Evaluate the quality of weld repairs to locomotives and the potential risk they pose;
- Review the IÉ training and supervision of welding on IÉ rolling stock;
- Review the relevant European Railway welding standards.

Communications & evidence collection

6 During this investigation, the RAIU collected evidence through the submission of Requests for Information (RFIs) and interviewing. Related to this investigation, the RAIU collected and logged the following evidence:

- Witness statements from parties involved in the investigation into the failure;
- Correspondence from GM in relation to the design and review process for the 201 Locomotives;
- All IÉ-RU standards, instructions or mandatory procedures in relation to the weld repairs on IÉ rolling stock;
- The IÉ Chief Chemist and Metallurgist investigation report into the failure, entitled "Examination of failed chassis plate ex Locomotive 224", reference number CME-CCM-FR-041, published on the 11th September 2020.

7 All relevant parties co-operated fully with the RAIU investigation; with no difficulties arising.

Other stakeholder inputs

8 No judicial authorities or emergency service were involved in this incident.

Other information relevant to the investigation process

9 IÉ's Chief Chemist and Metallurgist was requested by the CME Department to carry out an investigation into the failed Chassis Plate from Locomotive 224. The RAIU engaged a Specialist Metallurgist to work alongside the IÉ Chief Chemist and Metallurgist. A report was produced and agreed by both parties into the investigation, paragraph 6.

RAIU report format

10 The RAIU report is divided into a number of key sections, namely:

- Summary of the failure & background information – which provides factual information surrounding the incident including:
    - Synopsis of the incident, which provides an abridged version of failure events;
    - External circumstances surrounding the failure or accident location (such as weather conditions or location geography);
    - Consequences of the failure, including fatalities, injuries or material damage;

  - Parties and roles associated with the incident;
  - Description of the relevant parts of infrastructure, rolling stock, signalling and communications, operations or other equipment associated with the incident; this maybe expanded in the Evidence section of the report if further detailed descriptions are required.

- Evidence – which provides further factual details on supporting information for the background information, for example, this section may include details on: SMS documentation, standards and procedures; risk assessments, etc;
- Events before, during and after the accident – which gives a proximate chain of events:
  - Leading up to the occurrence including actions taken by persons involved; the functioning of rolling stock and technical installation and the operating system;
  - During the occurrence, by describing the occurrence;
  - After the occurrence including: consequences of the occurrence; measures taken to protect the site of the occurrence; and, the efforts of the rescue and emergency services.
- Similar occurrences – which outlines occurrences similar in nature to the occurrence subject to this report.
- Analysis – which analyses the combined findings from the above established facts which resulted in the causation of the occurrence, such as: Roles and duties; Rolling stock and technical installations; Human factors; Feedback and control mechanisms, including risk and safety management as well as monitoring processes; Trends related to similar occurrences.
- Conclusion – which includes: Concluding information from the analysis of the factual findings; Measures taken since the occurrence; Additional observations.
- Safety Recommendations – where appropriate, safety recommendations will be made with the sole aim of preventing a similar occurrence in the future; safety recommendations may also be made as a result of additional observation with the aim of prevent another type of occurrence. The absence of safety recommendation shall be explained.

Summary of the failure & background information

Synopsis of the incident

11 On the 6th July 2020, while working the 14:25 hrs Cork Kent to Dublin Heuston passenger service (Train A219), Locomotive 224 developed a coolant leak and electrical fault that shut down the locomotive on the approach to Limerick Junction. Train A219 was deemed a failure and taken from service before being hauled to Heuston Station, Dublin.

12 On 7th July 2020, while waiting a transfer to Inchicore Works a train driver noticed the body of Locomotive 224 was sagging close to the centre (Figure 1) and notified his supervisor, who in turn alerted the relevant parties. Locomotive 224 was assessed by IÉ-RU CME maintenance staff before transferring to Inchicore Works, where 201 Locomotives are maintained.

Figure 1 - Locomotive 224 at Dublin Heuston prior to transfer to Inchicore Works

13 At Inchicore Works a preliminary examination identified a Chassis Plate fracture on Locomotive 224. The engine and generator were removed from Locomotive 224 to allow for further investigation and a clear view of the fracture area. The removal of the engine and generator exposed a Bed Plate fracture that propagated into the left hand side of the Chassis Plate (facing Number 1 Cab, Figure 2) and the subsequent tear of the Chassis Plate on the opposite side.

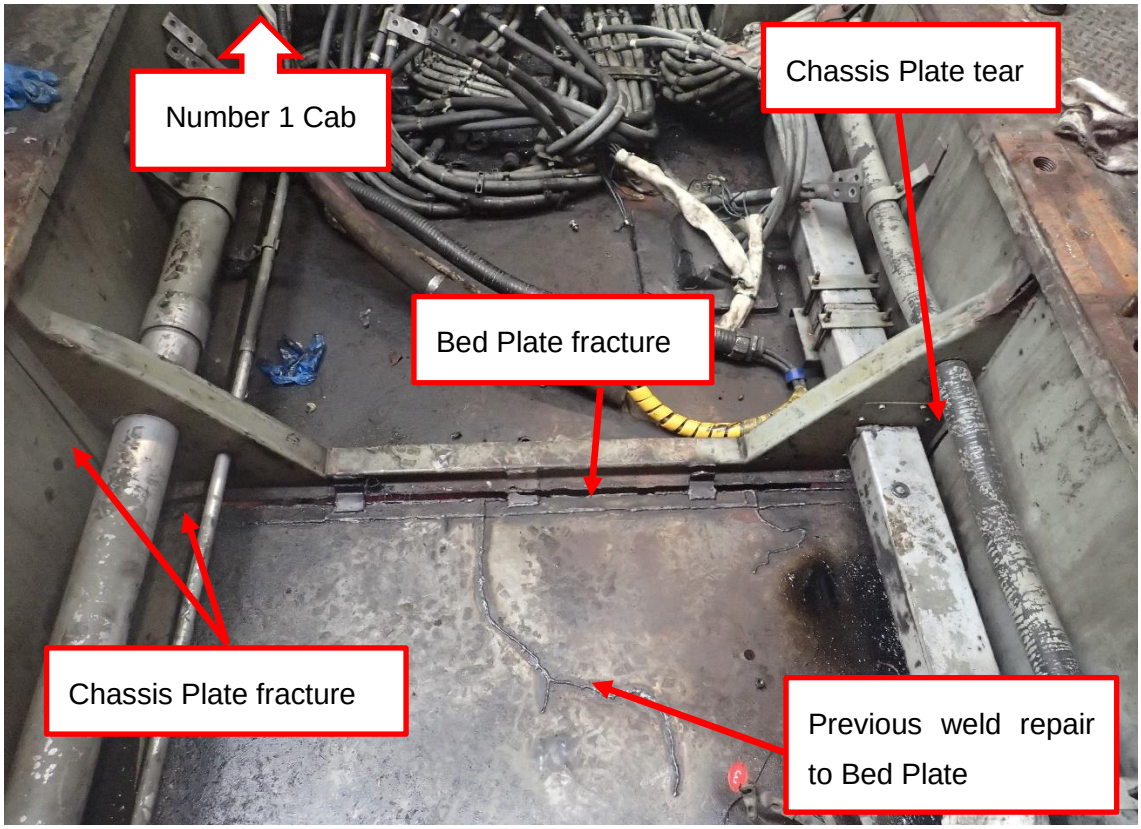

Figure 2 – Locomotive 224 with engine and generator removed

14 Also identified were earlier weld repairs carried out to the Bed Plate (a flat sheet of steel covering the area between two Chassis Plates that run on either side of the locomotive; and prevents oil leaks dropping onto the track, see Figure 3). These welds could only have been carried out when the engine and generator was removed (i.e. during Heavy Maintenance in 2010 or 2019, discussed in paragraph 72).

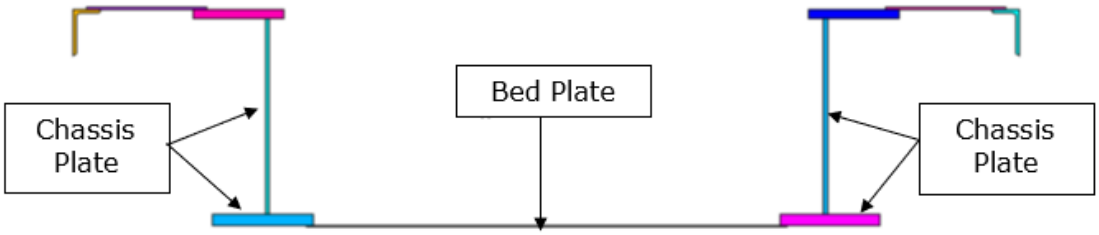

Figure 3 – Schematic of Chassis Plates and Bed Plate on 201 Locomotive

15 It was identified that on the 6th February 2008, GM issued Service Advisory, SA 08-007, Underframe Bed Plate Crack Rev B (to be known as SA 08-007 for the remainder of this report) detailing a repair process for the Bed Plate cracking; including replacement of the flat Bed Plate with a cupped Bed Plate. This repair process was not implemented by IÉ-RU, who continued to weld the Bed Plate cracks by welding the two sides of the crack together; and on occasions a second plate (*doubler plate*) was welded in over the crack.

16 There is no documented evidence to demonstrate that IÉ-RU CME management considered implementing SA 08-007, prior to the incident, when cracks were found in the Bed Plate of 201 Locomotives. Access to SA 08-007 was available to CME maintenance staff through the CME Maintenance Work Stations but there was no evidence that welders accessed the document or requested the recommended cupped Bed Plates.

External circumstances at the incident location

Weather

17 The weather was cloudy and fine; weather data taken from the nearest Met Éireann Weather Station at Gurteen, 50 kilometres (km) east of the site, recorded that there was 12.5 millimetres (mm) of rainfall for the day, with 1.6 mm falling at the time of the incident. The maximum temperature was recorded at 16.2º C and the minimum temperature was 10.1º C. The mean wind speed was recorded at 7.7 knots.

18 Weather conditions were not contributory to the incident.

Fatalities, injuries & material damage

Fatalities & injuries

19 There were no fatalities or injuries to staff as a result of the incident.

Material damage

20 The Chassis Plate fracture on the left hand side facing the Number 1 Cab and a tear of the Chassis Plate on the opposite sides of Locomotive 224, see Figure 4.

21 The engine coolant pipe suffered a leak.

22 The main generator suffered severe damage as a result of misalignment due to the Chassis Plate fracture, see Figure 5.

Figure 4 – Fracture to Chassis Plate

Figure 5 – Damage to Main Generator

23 There was no damage to the rail infrastructure as a result of the incident.

Parties & roles associated with the incident

Parties involved in the incident

Iarnród Éireann – Railway Undertaking

24 IÉ-RU is the railway undertaking who owns and operates mainline and suburban railway services in Ireland and operates under a safety certificate issued by the Commission for Railway Regulation (CRR). The RU Safety Certificate is issued in conformity with European Directive 2004/49/EC and S.I. 249 of 2015; the Safety Certificate was renewed on 23rd March 2018 for a period of five years.

25 The IÉ-RU department involved in the incident and relevant to this in investigation is:

- IÉ-RU CME Department – Responsible for the specification, purchasing, commissioning and maintenance of rolling stock, including management of the maintenance depots, associated personnel, and procedures. Support on technical matters is provided through the CME's Fleet Technical Support staff.

General Motors

26 201 Locomotives were manufactured by GM, in Canada, and entered service in Ireland in 1994. GM's last supply of locomotives to IÉ was the 071 class locomotives in 1976.

27 GM have supplied locomotives to the United States and export market since 1941 and have never previously had a Chassis Plate structural failure of a locomotive.

28 However, GM were aware of Bed Plate cracking on the 201 Locomotive and other JT42 series locomotives (supplied worldwide by GM) and issued a Service Advisory related to this issue, this is discussed later in this report.

29 In should be noted that in 2005 GM sold its Electro-Motive Diesel (locomotive manufacturing) division to Greenbriar Equity Group and Berkshire Partners. In 2010 Progress Rail Services completed the purchase of Electro-Motive Diesel. For this report, the manufacturer of the IÉ 201 Class Locomotives will be referred to as GM for ease of understanding.

Infrastructure

30 The failure (coolant leak and electrical fault) of Locomotive 224 occurred at Limerick Junction, see Figure 6, at the 107 Mile Post (MP) on the Dublin Heuston (0 MP) to Kent Station Cork (165 ¼ MP). The mile post datum is Heuston Station Dublin (0 MP).

Figure 6 – Location of incident

31 The track is a double line throughout comprising of plain line with flat bottom continuously welded rail mounted on concrete sleepers in ballast.

32 The maximum permissible line speed on the route is 100 miles per hour (mph) (160 kilometres per hour (km/h)) subject to permanent and temporary speed restrictions.

Rolling Stock

33 The train involved in the incident was the 14:25 hrs passenger service from Kent Station Cork to Heuston Station Dublin, Train ID A219. This service was operated by 4008 Generator Car (leading unit), seven Mk4 carriages and a 201 Locomotive; with the train consist being: 4008 Generator Car, 4201 First Class, 4402 Catering Car, 4119, 4139, 4114, 4117, and 4105 Standard Carriages with Locomotive 224 at the rear. The total length of the train is approximately 210.35 m with a mass of 438 tonnes. The maximum permitted speed of this train is 100 mph (160 km/h).

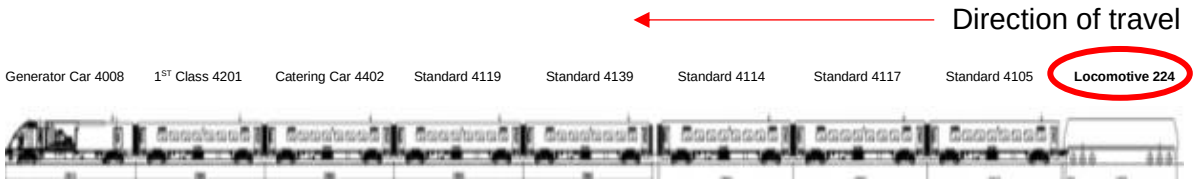

Figure 7 – Illustration of the eight carriage Mk4 and 201 Locomotive configurations

34 Locomotive hauled Mk4 train sets operating on the Dublin to Cork route are configurated in *Push-Pull* mode with the locomotive leading when travelling to Cork and the generator car leading while travelling to Dublin.

Signalling and communications

35 The line is signalled using three and four aspect colour light signals, controlled by the Mainline Signalman, located at Centralised Traffic Control (CTC) Connolly Station, and the Signalling Equipment Room, Heuston Station. Track Circuit Block regulations apply to this route and train detection is achieved by a combination of track circuits and axle counters. The line is fitted with *Continuous Automatic Warning System* (CAWS).

36 The means of communication between the train drivers and the signalman on this route is through train radio.

37 No factors in relation to the condition of the signalling and communications systems were found to have contributed to the incident.

Operations

38 Trains travelling to Dublin are travelling in the Up direction, and trains travelling towards Cork are travelling in the Down direction.

39 The maximum permissible line speed on the route is 100 mph (160 (km/h).

40 No factors in relation to the operation of the trains were found to have contributed to the incident.

Evidence

201 Locomotives

Design specification of the 201 Locomotive

41 The IÉ 201 Class Locomotives were manufactured by GM[1] in Canada and entered service in 1994.

42 At the time of tender for the design of 201 Locomotives, IÉ specified a maximum axle loading of 17.9 ton (18.1 Tonne), for a six axle 3,000 horsepower (HP) locomotive.

43 GM had previously supplied IÉ with the 071 class locomotives in 1976, which had a maximum weight of 99 Tons (100.5 Tonne) and an axle load of 16.5 Tons (16.7 Tonne), producing 2,250 HP.

44 GM proposed to supply a 3,000 HP locomotive with a maximum weight of 107 Tons (108.7 Tonne) and a maximum axle load of 17.9 Tons (18.1 Tonne).

45 IÉ specified a strength requirement of 440,000 pound *buff loading* (load applied at the buffers). At the time GM advised, from experience, that 440,000 pound buff loading would lead to underframe fatigue failure after approximately forty years and proposed a change to the specification to give a buff loading of 660,000 pound and with an infinite fatigue life. IÉ agreed to the GM proposal.

46 On completion of the design, GM carried out general stress calculations along with *finite element analysis* of critical points in the underframe before conducting actual stress testing of the complete underframe, simulating the vertical loading as well as the 660,000 pound buff load. Finally, a jacking test was performed at both the end plate and jacking pods to ensure the unit could be lifted safely from either end with the bogie assemblies attached. The successful passing of the tests gave GM confidence of an infinite fatigue life for the 201 Locomotives and ensured they were fit for operation on the IÉ network providing they were maintained to GM's specification.

[1] GM have supplied locomotives to the United States and export market since 1941 and have never previously had a Chassis Plate structural failure of a locomotive.

Design features of the 201 Locomotive

47 A 201 Locomotive weighs 107 Tons (108,717kg) is 68 feet 9 inches (20.95 metres (m)) long and 8 feet 8 inches (2.64 m) wide. Two “I” beam section Chassis Plates run the length of the 201 Locomotives on either side, to provide structural strength, see the yellow rectangle showing the Chassis Plates in Figure 8 (the red line shows the location of failure). The Chassis Plate strength is supplemented at the centre of the locomotive by the attachment of the locomotive engine and generator moving the stress from the centre point of the locomotive to the Cab 2 end of the engine and the Cab 1 end of the generator.

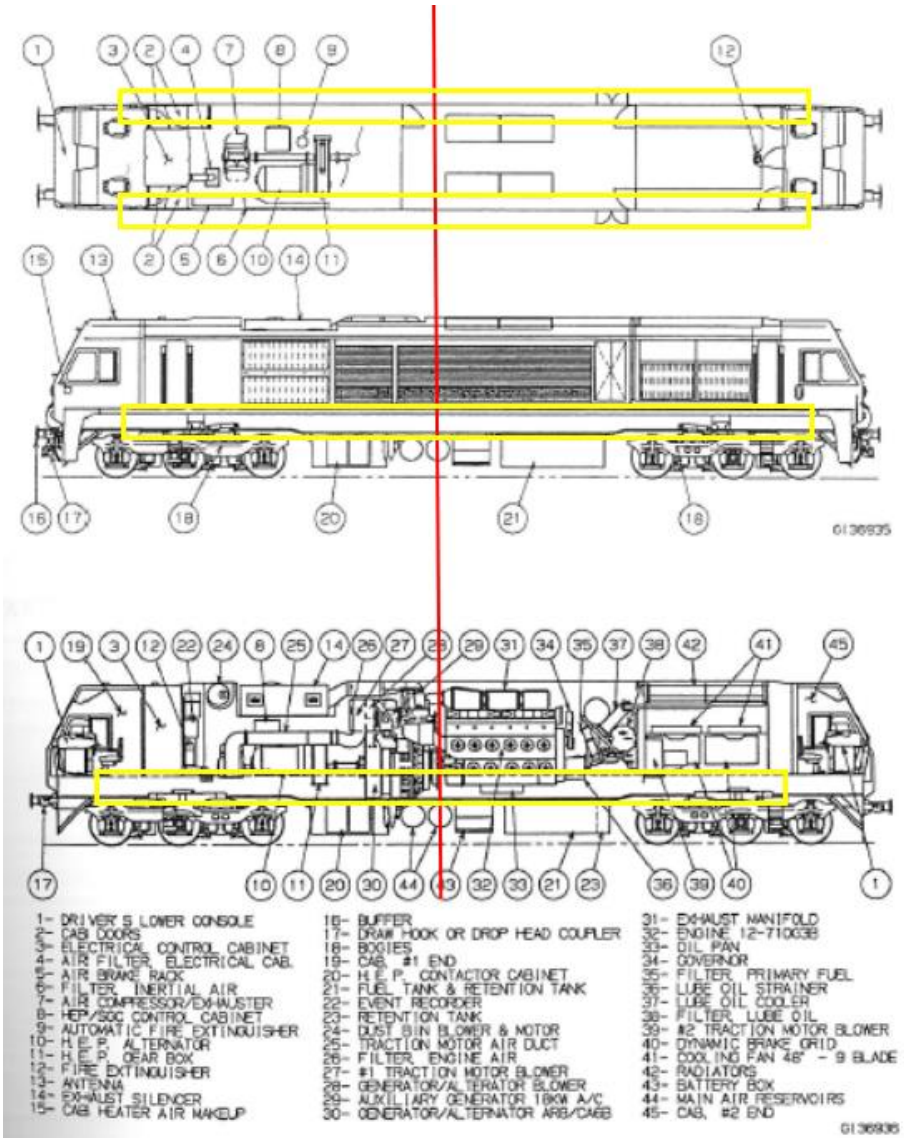

Figure 8 – Illustration of the 201 Locomotive configurations

48 The 201 Locomotives are designed with a *fish belly* underframe, meaning the underframe is lower in the middle section accommodating the engine and generator compared to the higher elevation over the bogies, giving greater strength.

49 Between the two Chassis Plates a number of flat mild steel sheets are fitted to collect oil spillage from the engine and prevent oil contamination of the track. The plates are collectively known as Bed Plates (these are non-structural). The original design of the Bed Plate was a flat sheet seam welded externally and tack welded internally to the Chassis Plate during manufacture. The Chassis plate is manufactured from ASTM A572 Grade 50 steel plate and the Bed Plate is made to MS 4361 hot rolled mild steel sheet.

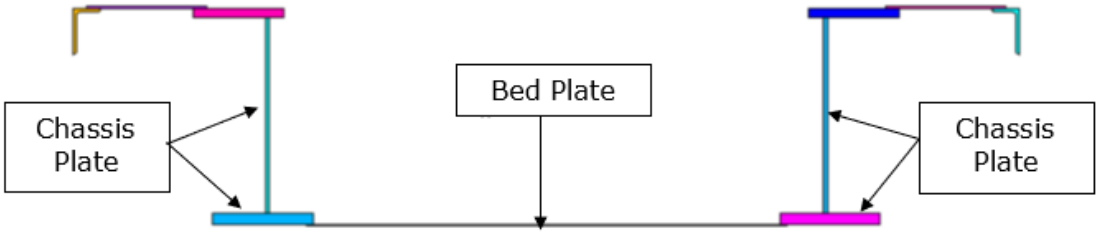

Figure 9 – Schematic of original Bed Plate arrangement on a 201 Locomotive

Design modification to the Locomotive 201 Bed Plates

50 During commissioning of the 201 Locomotives GM were alerted to a number of Bed Plate cracks on the 201 Locomotive fleet, and other JT42 series locomotives (supplied worldwide by GM) and issued SA 08-007 in June 2008.

51 When cracks were found in the existing Bed Plate, SA 08-007 recommended a change in the design of the Bed Plate from a flat Bed Plate (Figure 9) to a cupped Bed Plate (Figure 10).

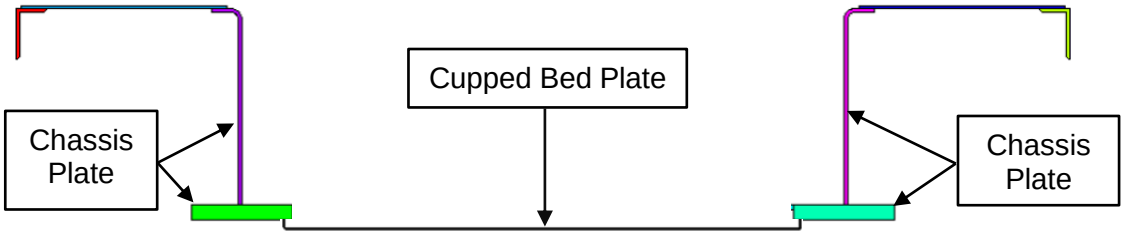

Figure 10 – Schematic of Bed Plate arrangement recommended by SA 08-007

52 There is no documented evidence to demonstrate that IÉ-RU CME management considered implementing SA 08-007, prior to the incident, when cracks were found in the Bed Plate of 201 Locomotives. Access to SA 08-007 was available to CME maintenance staff through the CME Maintenance Work Stations but there was no evidence that welders accessed the document or requested the recommended cupped Bed Plates.

Locomotive Maintenance

Introduction

53 201 Locomotive maintenance is split into two main activities, namely:

- Running Maintenance – consisting of planned servicing of the locomotives;
- *Heavy Maintenance* – consisting of line replacement and overhaul of major components, including the engine and generator.

54 During Running or Heavy Maintenance intervention additional tasks that come to light and require remedial attention are classified as *"work arising*".

Running Maintenance

55 Running Maintenance exams consists of a list of maintenance tasks that are required to be carried out at a set mileage or time frequency. Each list item is backed up by a Vehicle Maintenance Instruction (VMI) detailing how the task must be carried out. The Running Maintenance exams are carried out in the Running Shed, Inchicore Works.

56 Since May 2019, Running Maintenance "A" Exam are mileage based and carried out every 5,000 km or every six weeks.

57 There are four "B" Exams (B1 – B4) which are carried out in a one year period, three months apart.

58 The "A" Exam and "B" Exams do not specify a visual check of the Chassis or Bed Plate (e.g. for cracks).

59 The engine or generator are not removed during Running Maintenance and as such maintenance repairs to some areas of the Bed Plates cannot be carried out.

Heavy Maintenance

60 Heavy Maintenance consists of major overhaul and line replacement of components and is carried out in the Locomotive Overhaul Workshop, Inchicore Works.

61 Since November 2019, Heavy Maintenance exams are mileage based in a cycle of 500,000 kilometres (km), 1,000,000 km and 2,000,000 km. Prior to this from 2013 to 2019, Heavy Maintenance exams were time based in a cycle of two-year, two-year, six-year. And prior to 2013, exams were in a cycle of two-year, four-year, two-year. The four and six-year exams required the engine and generator to be removed from the locomotive.

62 It should be noted that in 2016, the CME considered a re-engine project for the 201 Locomotives and stopped all 6-year Heavy Maintenance on the 201 Locomotives. The 6-year Heavy Maintenance task was replaced by a 2-year-plus exam which included safety

critical tasks from the 6-year exam. In 2019 the CME decided against the re-engine project for the 201 Locomotives and the 6-year Heavy Maintenance exam recommenced.

63 Heavy Maintenance exams do not specify a visual check of the Chassis or Bed Plate (e.g. for cracks).

Work arising

64 During both Running and Heavy Maintenance if additional tasks are identified and require maintenance intervention the work is classified as “work arising”.

65 Bed Plate cracks were often identified when evidence of oil was observed to be seeping on to the track at running maintenance. A temporary overhead weld repair was often carried out to prevent further oil seepage until full access could be gained when the engine and generator would be removed at Heavy Maintenance. When the engines were removed on the 201 Locomotive fleet at Heavy Maintenance, further Bed Plate cracking was often identified.

66 IÉ welders developed their own repair method for managing the cracks consisting of welding over the cracks in the Bed Plate and adding doubler plates with intermittent stiffeners.

67 The issuance of SA 08-007 did not result in any of the 201 Locomotives undergoing the recommended design modification to the Bed Plate from a flat plate to a cupped plate when cracks were found in the existing Bed Plate (paragraph 50 and 51).

Welding

68 The CME Department is required to hold an Entity in Charge of Maintenance (ECM) certificate for Freight Fleet. The first fleet to receive the ECM was the wagon fleet in 2013[2] and the CME Department voluntarily worked their way through the certification process for the passenger fleets resulting in ECM certification for all Fleet Passenger[3] and Freight being issued in October 2020 (after the incident). As part of the certification, the CME Department must have a Quality Management System (QMS) to cover all welding activities i.e. a Welding Management Plan.

69 To achieve this, the CME Department decided to voluntarily adopt the European Committee for Standardization’s (CEN) standard series for welding, entitled “The Welding of Rail Vehicle and their Components” (EN 15085) during the certification process. This

[2] 2013 was after the weld repairs in 2010.

[3] The certification of the passenger fleets was achieved on a voluntary basis.

standard series of documents comprised of five parts (i.e. EN 15085-1 – EN 15085-5) entitled: General; Requirements of Welding Manufacture; Design Requirements; Production Requirements; Inspection / Testing and Documentation, which were first published in 2007; with some undergoing revisions in 2020 (this suite of documents will be referred to as EN 15085 standard series for the remainder of this report). However, the EN 15085 standard series had not been adopted at the time of the incident.

70 In summary, the EN 15085 standard series applies to the design, manufacturing, testing and conformity assessment of welded railway vehicles, components and assemblies. It sets requirements for the quality system, welding process approvals, as well as performance qualifications for welder and welding operator. This series of standards applies to welding of metallic materials in the manufacture and maintenance of railway vehicles and their parts. The parts:

- Provide general recommendations and definitions for welding railway vehicles and associated components. Except for specific provisions which are laid down contractually, this standard applies to all assemblies, sub-assemblies or parts welded by any welding process, either manual, partly mechanised, fully mechanised or automatic welding (EN 15085-1);
- Defines the certification levels as well as the requirements for welding manufacturers and describes the procedure for the recognition of welding manufacturers (EN 15085-2);
- Specifies design and classification rules applicable to the manufacture and maintenance of railway vehicles and their parts (EN 15085-3);
- Describes the production requirements (i.e. preparation and execution) of the welding work (EN 15085-4);
- Specifies: inspections and testing to be executed on the welds; destructive as well as non-destructive tests to be performed; necessary documentation to issue to declare the conformity of the products (EN 15085-5).

Maintenance of Locomotive 224

71 Locomotive 224 underwent the required Running Maintenance at the required frequency (paragraphs 55 - 57). In terms of work arising, a IÉ's *SAP Software* computer system (a tool used by IÉ to co-ordinate resources and activities in order to manage work) gives some indication of the repair works carried but no specific details; it also could not identify the individuals who conducted the weld repairs; and as a result their competency cannot be ascertained. Outlined below are details on what maintenance was carried out on Locomotive 224. it should be noted that the exam times were affected by the re-engine proposals outlined in paragraph 62).

72 In 2010, Locomotive 224 received a four-year exam which included removal of the engine and generator. There was no record of any welding repairs, however, this does not mean that weld repairs were not carried out.

73 In 2013, Locomotive 224 received a two-year-plus exam (paragraph 62) along with the main generator being changed. There was no record of any welding repairs, however, this does not mean that weld repairs were not carried out.

74 In 2014, a crack in the floor was welded on Locomotive 224 but this was not in the area of the 2020 failure.

75 In 2015, Locomotive 224 received another two-year-plus exam. There was no record of any welding repairs, however, this does not mean that weld repairs were not carried out; however, the engine and generator were not removed, and any weld repairs that were carried out could not be in the location of the 2020 failure.

76 In 2016, Locomotive 224 received repairs to the underfloor under the engine, however, the this was not in the area of the 2020 failure.

77 In 2019, Locomotive 224 received a six-year exam. There was no record of any welding repairs, however, this does not mean that weld repairs were not carried out.

78 The weld repair resulting in the 2020 failure (the weld repair from the Bed Plate into the Chassis Plate) on Locomotive 224 could only have been carried out when the engine was removed (i.e. in 2010 or 2019) as evident from the profile of the weld and the access required to carry out the weld repair.

79 On one of these occasions, when the Bed Plate on Locomotive 224 was being repair welded, the welder unnecessarily continued the weld from the Bed Plate into the Chassis Plate[4], see Figure 11.

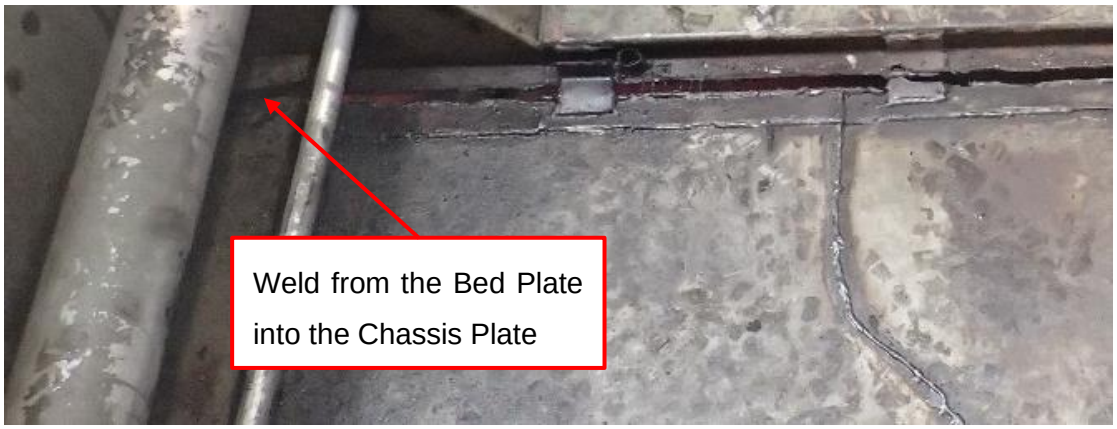

Figure 11 – Weld from the Bed Plate into the Chassis Plate

80 This weld repair was not carried out in accordance with the EN 15085 standard series (although it is noted that these were not mandatory) or any IÉ weld repair specification (paragraph 69 and 70).

[4] Locomotive 224 was the only 201 Locomotive where the Bed Plate was welded directly onto the Chassis Plate during repairs.

Post-incident inspection of Locomotive 224

Introduction

81 As part of the investigation, the IÉ Chief Chemist and Metallurgist and a specialist contracted by the RAIU produced an investigation report into the failure, entitled "Examination of failed chassis plate ex Locomotive 224" (paragraph 6). This investigation included visual, *fractographic* (fracture surface of the material) and *metallographic* (study of the microstructure) analysis.

82 To carry out the required analysis, the engine and generator of Locomotive 224 was removed to reveal cracking had occurred across the width of the Bed Plate (as seen in Figure 2) and upwards in the left hand side, facing Number 1 Cab, resulting in a subsequent tear to the Chassis Plate on the opposite side. To facilitate an examination of the fracture surfaces, the affected areas in the Bed Plate and Chassis Plate were removed.

Visual examination

83 A visual examination showed that a doubler plate had been welded on top of the cracked Bed Plate during a previous repair; this doubler plate was reinforced with small stiffeners that had been welded intermittently across the surface of the doubler plate, see Figure 12.

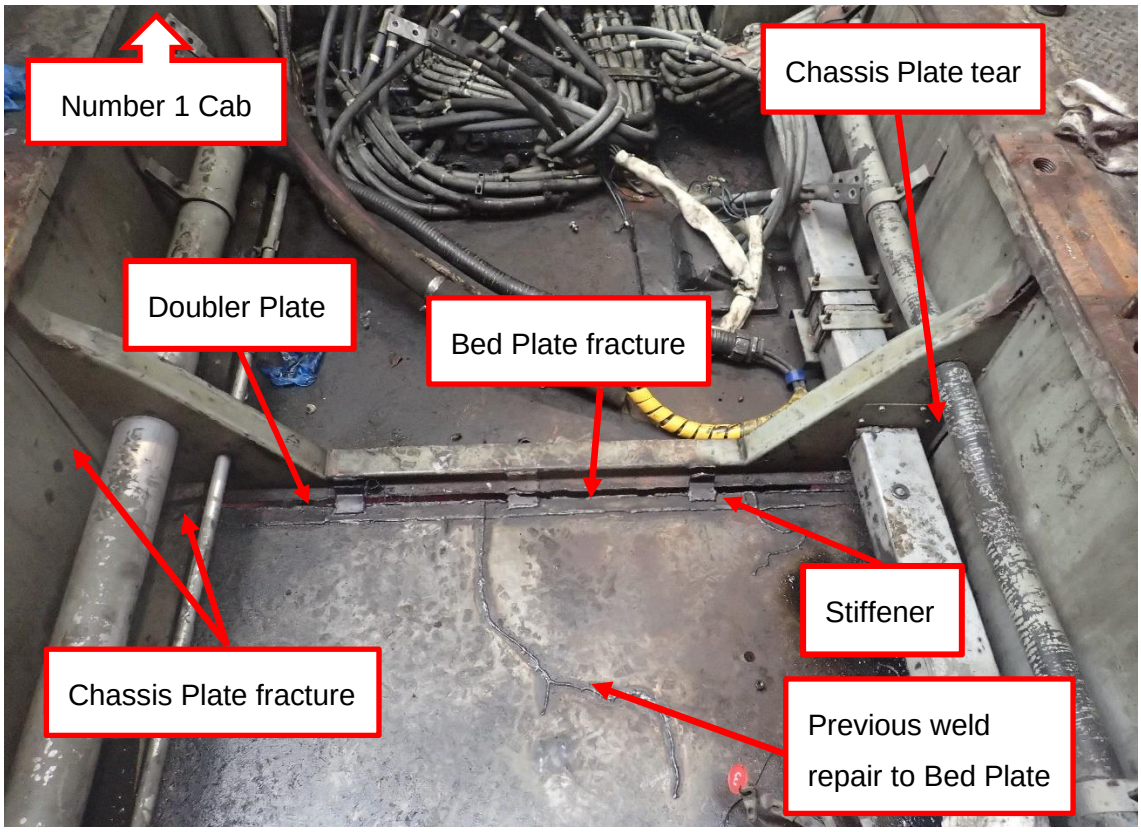

Figure 12 – Locomotive 224 with engine and generator removed

Fractography

Bed Plate

84 Much of the surface of the Bed Plate had undergone polishing and hammering damage as the fracture faces rubbed against each other while Locomotive 224 was in service. All of the fracture faces show multiple *fatigue crack* initiation sites indicating that the Bed Plate was under considerable stress. While most of the fatigue cracks had originated on the lower Bed Plate surface, some sites of crack initiation were also noted on the upper surface.

Chassis Plate

85 No defects were found in the *weldments* within the failure zone, but the repair weld area would have resulted in a high residual tensile stresses as the mass of the Chassis Plate would act as a *heat sink* from the heat of the weld. The rapid cooling of the weld would create an area of high residual tensile stress in the zone.

86 Examination showed multiple fatigue cracks which originated at the base of the repair weld. These cracks had propagated upwards into the Chassis Plate material at an approximate angle of 70°. After a short distance, the cracks coalesced to form a combined crack front which then developed outwards at right angles along the Chassis Plate. The *beach marks* were very finely divided and formed an almost flat fracture surface which would indicate slow fatigue crack progression, see Figure 13.

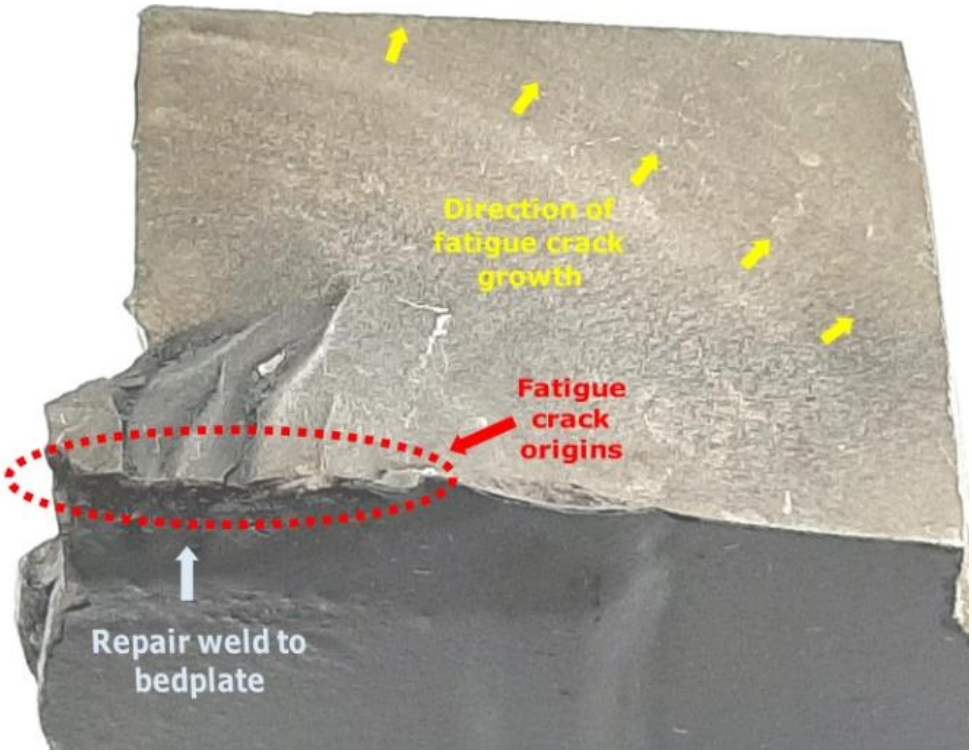

Figure 13 – Chassis plate fracture surface

87 Inspection of the tear origin at the side of the Chassis Plate showed that the cracking which had originated at the repair weld progressed upwards to the doubler plate and had then developed through the doubler plate and Bed Plate section under the applied stresses during service.

Metallography

88 Microsections were taken from the edge of the Chassis Plate (Microsections A and B). These microsections were encapsulated in edge retaining resin, ground and polished[5]. Both microsections showed that the Chassis Plate material consisted of a banded low carbon steel microstructure, with alternating bands of ferrite and pearlite[6]; and the microstructure of the doubler plate was that of a low carbon mild steel; very similar to the mild steel used in the Bed Plate, so there would have been no incompatibilities in using this material for the repair.

89 Microsection A (Figure 14) shows that the welding of the doubler plate created a large *undercut* in the Chassis Plate at the top of the weld. A fit-up gap between the doubler plate and the Chassis Plate was also evident (red square in Figure 14). Examination of the microstructure showed good fusion and depth of penetration of the weld to the chassis plate. No inclusions, *slag, porosity* or other defects were detected. The *heat affected zone* (HAZ) was uniform between the weld material and the chassis plate.

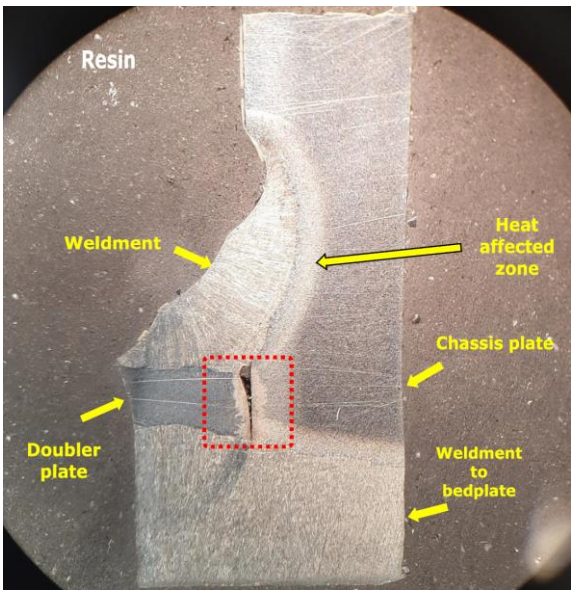

Figure 14 – Microsection A

[5] Metallographic analysis showed that all materials used by GM in the manufacture of the locomotive conformed to their required specification.

[6] A Brinell hardness test was carried out on the chassis plate at the point of failure which gave a hardness value of 179 HB (10/3000) or a tensile strength of 88ksi. This satisfies the minimum tensile strength requirement for ASTM A572 Grade 50 of 65ksi (450 MPa).

90 Microsection B (Figure 15) shows the welding repair of the Bed Plate to the Chassis Plate, HAZ and a small fit-up gap between the Bed Plate and the Chassis Plate. A section of the chassis plate fracture surface is about to fall away from the right hand side due to cracks initiating near the *toe* of the weld. No material defects were detected in the Chassis Plate, Bed Plate or weld material. This particular weld runs at right angles to the length of the Chassis Plate and parallel to the Bed Plate/doubler plate.

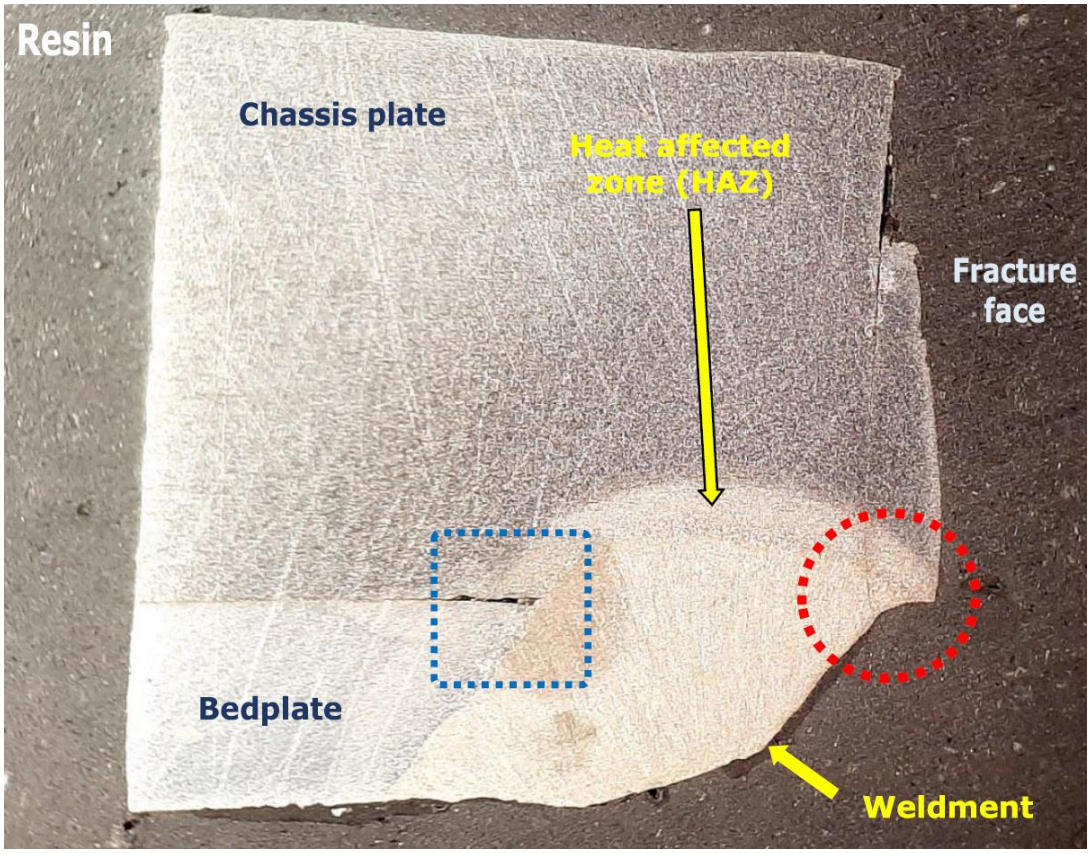

Figure 15 – Microsection B

91 A large fatigue crack had initiated close to the toe of the weld and had propagated vertically upwards through the chassis plate material. Also faintly visible in the circled region are crack indications within the weld material.

Events prior to, during and after the incident

Events prior to the incident

92 The weld repair resulting in the Chassis Plate fracture (the weld repair from the Bed Plate into the Chassis Plate) on Locomotive 224 could only have been carried out when the engine was removed (i.e. in 2010 or 2019) as evident from the profile of the weld and the access required to carry out the weld repair (paragraph 78). IÉ records cannot establish a definitive date for the weld repair.

93 On one of these occasions (2010 or 2019), when the Bed Plate on Locomotive 224 was being repair welded, the welder unnecessarily continued the weld from the Bed Plate into the Chassis Plate (paragraph 79).

94 In service cyclic loading, particularly bending stress on the underside of the Chassis Plate that had high residual tensile stresses generated from within the repair weld (Bed Plate to Chassis Plate weld), resulted in the development of multiple fatigue initiation sites.

95 Locomotive 224 received a scheduled “A” Exam on 30th June 2020 (paragraph 56), seven days before the incident; there were no work arising items recorded during this exam. An “A” exam does not specify an examination of the Chassis Plates or Bed Plates. This was the last maintenance intervention prior to the failure on the 7th July 2020.

96 Locomotive 224 returned to service on 5th July 2020 and operated a return service from Dublin to Cork.

Events during the incident

97 On the 6th July 2020, Locomotive 224 operated the 07:00 hrs passenger service from Kent Station, Cork to Heuston Station, Dublin (Train ID A205); CCTV footage from Cork Station did not identify any issue with the locomotive. The driver who prepared the train did not identify any cracks just a smell of diesel which was more than would normally be expected.

98 The train arrived at Heuston Station and no faults were observed with Locomotive 224. The train then departed, operating the 11:00 hrs passenger service to Kent Station, Cork (Train ID A210). The train arrived at Cork without any issues being reported.

99 CCTV from stations along the route from these journeys was reviewed and a slight sag in the centre of Locomotive 224 can been seen, which becomes more visible as the day progresses. It is noted that the prominence of the sagging from the CCTV was dependent on the angle and distance the cameras were from the locomotive.

100 The train then operated the 14:25 hrs passenger service from Kent Station, Cork to Heuston Station, Dublin (Train ID A219). Prior to arrival at its first stop Mallow, the fire

alarm activated. The driver examined the locomotive in Mallow and observed smoke which was believed to be from the exhaust. Prior to the train's arrival into Limerick Junction, the locomotive lost power and the train coasted into Limerick Junction.

101 While in service on the 6th July 2020, the Chassis Plate at the location of failure would have been under the action of cyclic bending loads which would have put tensile stresses on the underside of the Chassis Plate. This would have resulted in the multiple fatigue initiation sites further developing and merging into a common crack that propagated from the Bed Plate through to the Chassis Plate during the journey.

102 The cracking of the Chassis Plate resulted in a twisting load been exerted on the Chassis Plate on the opposite side, causing it to tear.

103 The failure of the structure of Locomotive 224 resulted in a strain on an engine coolant pipe causing it to leak and the misalignment of the generator, resulting in a shutdown fault on Locomotive 224 on approach to Limerick Junction (paragraph 100).

104 It should be noted that during the services on the 6th July 2020, axle load data from the acoustic bearing monitoring site[7] located on the Up road near Inchicore on the Cork to Dublin line showed that the 17.9 Ton axle load (static) was exceeded for Locomotive 224[8,9] (with the highest axle load being recorded as 20.45 Ton axle load (dynamic)).

Events after the incident

105 Locomotive 224 was declared a failure at Limerick Junction and on the 6th July 2020, arrangements were made to have the locomotive hauled to Inchicore Works via Heuston Station.

106 On the 7th July 2020, while awaiting transfer at Heuston Station, a train driver noticed that Locomotive 224 was sagging near the centre point and notified his supervisor who in turn alerted the relevant parties.

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[7] IÉ operate three acoustic bearing monitoring sites on its network. The sites record the noise from the journal bearing on rail vehicles as they pass the site and compare the noise level to the database of previous passages over the system. Maintenance staff are notified of any abnormal change in noise levels as the change is a precursor to a bearing failure. The site also measures the axle load as rail vehicle pass the site.

[8] It should be noted that the data did not provide any axle loading imbalance that could have indicated a misalignment due to a Chassis Plate failure.

[9] The RAIU have made an additional observation in relation to this finding, which has resulted in a safety recommendation, see paragraphs 137, 141 and 151.

107 CME staff examined Locomotive 224 and when the seriousness of the failure was identified all relevant parties were notified.

Similar Occurrences

108 The RAIU are not aware of any previous rail vehicle structural failures on the IÉ Network.

109 GM have never previously had a Chassis Plate structural failure of a locomotive.

Analysis

201 Locomotive Design

110 IÉ had operated the GM manufactured 071 Class Locomotives since 1976 (paragraph 43). In the early 1990s, GM won a tender to provide a bigger fleet of more powerful locomotives to IÉ, a locomotive with an extra 750 HP for a weight gain of only 8 Tons (8.1 Tonnes), paragraph 44.

111 IÉ initially specified a strength requirement of 440,000 pound buff loading (load applied at the buffers); with GM proposing, and IÉ agreeing, to a 660,000 pound buff loading, which would give an infinite fatigue life as opposed to a forty life i.e. the new proposal was an improvement, paragraph 45. Ultimately, Locomotive 201 passed all design tests

112 On completion of the design, GM carried out general stress calculations, finite element analysis of critical points in the underframe, actual stress testing of the complete underframe and jacking tests. The successful passing of the tests gave GM confidence of an infinite fatigue life for the 201 Locomotives and ensured they were fit for operation on the IÉ network providing they were maintained to GM's specification (paragraph 46).

201 Locomotive Maintenance

113 201 Locomotives undergo maintenance at specified frequencies, with any additional tasks classed as work arising (paragraph 53 and 54). Importantly, some maintenance requires that the engine and generator be removed from the locomotive (paragraph 61).

114 During the maintenance of the 201 Locomotive, cracks were often identified in the Bed Plates (paragraph 65); and these cracks were repaired by IÉ welders (paragraph 66).

115 Based on the cracking of the Bed Plates on JT42s, GM issued SA 08-007 in June 2008, which recommended a change in the design of the Bed Plate from a flat to a cupped plate when cracks were found in the existing Bed Plate. IÉ did not implement the specifications of SA 08-007 prior to the incident, and in its place, continued with the welding process the IÉ welders had already adopted (paragraph 66). Although maintenance staff had access to SA 08-007 through the CME Maintenance Work Stations three was no evidence that SA 08-007 was discussed at management level as a decision to carry out the work would have resulted in the procurement of cupped Bed Plates.

116 In terms of the welding activity, the CME Department had not received its ECM Certificate (and hence not adopted the EN 15085 standard series) for the Locomotive 201 fleet when Locomotive 224's engine was removed prior to the failure and as a result the

Bed Plate repairs would not have been carried out in accordance with the EN 15085 standard series (paragraph 79).

Maintenance of Locomotive 224

117 Locomotive 224 underwent the required Running Maintenance, at the required frequency (paragraph 71). Locomotive 224 received its last Running Maintenance intervention, prior to the failure, on 30th June 2020 but it would have been difficult to identify cracking of the Chassis Plate if cracking were present and the "A" exam did not specify a check of the Chassis or Bed Plate for cracks (paragraph 56).

118 In terms of welding repairs, it appears some weld repairs were carried out in 2014 and 2016 (according to SAP Software records), paragraphs 74 and 76.

119 The weld repair resulting in the 2020 failure (the weld repair from the Bed Plate into the Chassis Plate) on Locomotive 224 could only have been carried out when the engine and generator were removed as evident from the profile of the weld (i.e. in 2010 or 2019) as evident from the profile of the weld and the access required to carry out the weld repair (paragraph 78).

120 An examination of Bed Plate to Chassis Plate weld repair post failure, clearly show that the weld repair could only have been carried out when the engine and generator were removed from locomotive, however, no records of the welding work carried out or by whom were recorded by IÉ (as a result, the competency of the welder could not be verified). It is important to note, in terms of welding, the CME Department had not received its ECM Certificate for the 201 Locomotive fleet in 2010 or 2019 when Locomotive 224 last had its engine and generator removed and as a result the Bed Plate to Chassis Plate weld repairs would not have been carried out in accordance with the EN 15085 standard series (paragraphs 68 - 69).

Locomotive 224 Mechanism of failure of the Chassis Plate

121 The 201 Locomotives have a history of Bed Plate cracking due to the stresses acting on them during service (paragraphs 96 and 94). Repairs had been carried out previously on Locomotive 224, with the post-incident inspection identifying welds and the use of a doubler plate with intermittent stiffeners (paragraph 83).

122 On one occasion during the repair of Bed Plate cracks on Locomotive 224, the Bed Plate was unnecessarily welded to the Chassis Plate (paragraph 79).

123 Welding is a significant cause of residual stresses and typically produces large residual tensile stresses in a weld. In turn, high tensile residual stresses have a very significant effect on a material's susceptibility to fracture and fatigue resistance which can decrease considerably. The weld on Locomotive 224 would have generated high residual tensile stresses in a plane at right angles to the length of the chassis plate.

124 In service, the Chassis Plate at the location of failure would have been under the action of cyclic bending loads which would have put tensile stresses on the underside of the Chassis Plate.

125 Given the thickness of the Chassis Plate, pre-weld heat treatment would have been needed as the chassis plate would have acted as a large heat sink, rapidly cooling down the weld material and locking in high welding stresses (paragraph 85).

126 Tensile stresses also concentrated at the toe of the weldment at the Bed Plate to Chassis Plate junction. This resulted in several sites of fatigue crack initiation. With fatigue crack growth, these cracks coalesced into a combined crack front which propagated through the horizontal and vertical Chassis Plates under the application of cyclic in-service loads[10].

[10] Note, some of the information in paragraphs 121 to 126 is taken from the "Examination of failed chassis plate ex Locomotive 224" investigation report.

Conclusion

201 Locomotive Design & Maintenance

127 GM have a history of supplying locomotives to the export market since 1941 with no previous Chassis Plate structural failure of a locomotive (paragraph 41).

128 At the design stage, GM proposed, and IÉ agreed, to an upgraded specification for the 201 Locomotives, which would give an infinite fatigue life rather than a forty year life (paragraph 111).

129 On completion of a prototype, GM carried out the appropriate tests to provide confidence in the infinite fatigue life for the 201 Locomotives and ensured they were fit for operation on the IÉ network providing they were maintained to GM's specifications (paragraph 112).

130 The Running and Heavy Maintenance specifications of the 201 Locomotives has been amended many times over the years (in terms of inspections and frequencies); this is as a result of IÉ learnt experience of operating the locomotives (paragraph 113) and this is normal practice in asset maintenance of rail vehicles.

131 During maintenance, cracks were often identified in the Bed Plate and repaired by welding; however, these welds were not carried out in accordance with the EN 15085 standard series during the initial phase of cracking (paragraph 116); although it is noted that these were not mandatory at the time.

132 In addition, when SA 08-007 was issued to IÉ, IÉ did not carry out the recommended design change. Instead, IÉ allowed the welders to continue with their adopted welding practices (paragraph 114).

Locomotive 224 Maintenance & Mechanism of Failure

133 Locomotive 224 underwent the required maintenance (Running and Heavy) (paragraph 117). Major Bed Plate weld repairs could only be carried out when the engine and generator were removed (paragraph 118); the last occasions of the engine and generator being removed were in 2010 and 2019. In one of these years, when the Bed Plate on Locomotive 224 was being repair welded, the welder unnecessarily continued the weld from the Bed Plate to the Chassis Plate (paragraph 122).

134 IÉ did not document any welding work carried out to Locomotive 224 (paragraph 120); in addition, the welding that did occur, was not in accordance with the EN 15085 standard

series. Furthermore, Locomotive 224 did not undergo the design modification specified by SA 08-007 (paragraph 120).

135 The welding of the Bed Plate to the Chassis Plate and the subsequent rapid cooling down of the weld material due to the Chassis Plate acting as a large heat sink created an area of high residual tensile stress. This area of high residual tensile stress combined with the high stresses exerted on the Chassis Plate by the locomotive being in service resulted in fatigue cracking initiating in the weld and culminating in the amalgamation of multiple cracks into one large crack and the subsequent failure of the Chassis Plate (paragraphs 121 - 126).

136 In conclusion, the Chassis Plate would not have failed if the Bed Plate had not been unnecessarily welded to the Chassis Plate during Bed Plate crack repairs.

Additional observations

Acoustic bearing monitoring sites

137 Axle load data from the acoustic bearing monitoring site located on the Up road near Inchicore on the Cork to Dublin line showed that the 17.9 Ton axle load (static) was exceeded for Locomotive 224 on the days before the failure, up to a value of 20.45 Ton axle load (dynamic), paragraph 104.

Causal, contributing, and systemic factors

138 The Chassis Plate of Locomotive 224 failed as a result of the following causal factor:

- CaF-01 – The flat Bed Plates were not replaced with cupped Bed Plates when Bed Plate cracks were identified as set out in the OEM Service Advisory SA 08-007;
- CaF-02 – During a weld repair of the Bed Plate the Bed Plate was unnecessarily welded to the Chassis Plate.

139 Contributory factors include:

- CoF-01 – IÉ-RU had not adopted the EN 15085 standard series, entitled “Railway applications – Welding of railway vehicles and components” which were first published in 2007; although it is noted that this standard series is not mandatory;
- CoF-02 – While Service Advisory (SA 08-007) was available to the welder carrying out the repair through the CME Maintenance work stations, the implications of the modification were not discussed at IÉ management level prior to the incident and materials for the modification (cupped Bed Plates) were not procured.

140 Systemic factors include:

- SF-01 – There was an over-reliance on the knowledge of the welder to develop and carry out a repair procedure without any formal instruction or supervision.

141 Although not causal, contributing or systemic, the RAIU make the following additional observation:

- AO-01 – The 201 Locomotive axle loads recorded by the acoustic bearing monitors indicate that the specified axle load may have been exceeded.

Measures taken by IÉ-RU since the incident

142 Since the Chassis Plate failure of Locomotive 224, and as of the date of publication of this RAIU report, the IÉ-RU CME Department:

- Carried out a visual fleet check on all 201 Class locomotives within twenty-four hours of the Chassis Plate fracture being identified;
- Have included an enhanced visual examination of the Chassis Plate to the "A" maintenance examination;
- Are carrying out a detailed fleet check to examine the structure of every 201 Locomotive in service;
- Have introduced weld repair history books for all in service 201 Locomotives to record the location and detail of every new weld, including photographs before and after with commentary of the repair;
- Have adopted the EN 15085 standard series;
- Have included a visual weld inspection of the locomotive to identify welds that need to undergo non-destructive testing or re-welded due to location, access or quality;
- Have discussed SA 08-007 at the fleet risk register meeting on the 22nd June 2021 and have decided not to adopt SA 08-007, with future repairs being carried out in accordance with the EN 15085 standard series.

143 At the time of publication of this report, a tender has been issued to GM for the repair specification; with a view to possibly repairing Locomotive 224 and re-entering it to service.

144 At the time of publication of this report, IÉ-RU have not published their internal investigation report into the incident.

Safety Recommendations

Introduction to safety recommendation

145 In accordance with the Railway Safety Act 2005 (Government of Ireland, 2005a) and the European railway safety directive (European Union, 2020), recommendations are addressed to the national safety authority, the CRR. The recommendation is directed to the party identified in each recommendation.

Absence of safety recommendations due to measures already taken

146 In relation to the risk of Chassis Plate failures on other 201 Locomotives IÉ-RU CME have carried out a fleet check on the Chassis Plates on the full in service 201 Locomotive Fleet. All 201 Locomotives examined did not have a repair weld on the Chassis Plate and did not require remedial work; as such the RAIU do not consider any further safety recommendation is warranted in relation to the 201 Locomotive Chassis Plate fleet check (CaF-01).

147 In relation to continuous inspection of the 201 Locomotive Chassis Plate the IÉ-RU CME Department have included a visual examination of the 201 Locomotive Chassis Plate to the 201 Locomotive Running Maintenance “A” exam and the RAIU do not consider any further safety recommendation is warranted in relation to this matter.

148 In relation to the quality of future welds on the Locomotive fleet and recording of who carried out the weld repair; the IÉ-RU CME Department have adopted the EN 15085 standard series. As a result, the RAIU do not consider any further safety recommendation is warranted in relation to this matter (CoF-01).

Safety recommendations as a result of this incident

149 ECM certification was not gained for all passenger and freight fleets until October 2020. In terms of the structural weld repairs carried out to other rail vehicles prior to the issuing of the ECM certification these fleets that may pose a risk if weld repairs have been carried out to the structure of the vehicle prior to the implementation of ECM. As a result, the RAIU make the following safety recommendation:

Safety Recommendation 2021004-01

IÉ-RU CME should review all weld repairs carried out to structures of all rolling stock to assess the risk posed by such weld repairs and mitigate against the failure mode.

150 GM sent IÉ a copy of Service Advisory (SA) 08-007 Underframe Bed Plate Crack Rev B 6th February 2008. There is no documented evidence of the decision process carried out by IÉ, prior to the incident, not to proceed with the recommendations of SA 08-007 or evidence that the welders were given a copy of the document. As a result, the RAIU make the following safety recommendation (CoF-02, SF-01):

Safety Recommendation 2021004-02

IÉ-RU CME should develop a procedure for evaluating maintenance advice received from OEMs or other railway organisations to determine applicability to IÉ fleets and assess any associated risks.

Safety recommendations as a result of additional observations

151 Although noted as not being a contributory factor in the Chassis Plate failure of Locomotive 224. The design specification for the 201 Locomotive did require a maximum axle load of 17.9 ton (static). Data from the Acoustic Bearing Monitor showed the maximum axle load for Locomotive 224 may have been exceeded. As a result the RAIU make the following safety recommendation (AO-01):

Safety Recommendation 2021004-03

IÉ-RU CME and IÉ-IM CCE should carry out a risk assessment on the implications of the increased axle load of a 201 Locomotive.

Additional Information

List of abbreviations

AO	Additional Observation
CaF	Causal Factor
CAWS	Continuous Automatic Warning System
CCE	Chief Civil Engineer
CEN	European Committee for Standardization
CI	Chief Investigator
CME	Chief Mechanical Engineers
CoF	Contributory Factor
CRR	Commission for Railway Regulation
CTC	Centralised Traffic Control
CWR	Continuous Welded Rail
DART	Dublin Area Rapid Transport
DOT	Department of Transport
ECM	Entity in Charge of Maintenance
GM	General Motors
HAZ	Heat affected zone
HP	Horse Power
hr	hour
IÉ-IM	Iarnród Éireann Infrastructure Manager
IÉ-RU	Iarnród Éireann Railway Undertaking
km	kilometre
m	metre
mm	millimetres
MP	Milepost
mph	Miles per hour
OEM	Original Equipment Manufacturer
RAIU	Railway Accident Investigation Unit
RFI	Request for Information
RMME	Rail-mounted maintenance equipment
RU	Railway Undertaking
SA	Service Advisory
SER	Signalling Equipment Room
SET	Signalling, Electrical and Telecommunications
SF	Systemic Factor

SMS	Safety Management System
TCB	Track Circuit Block
VMI	Vehicle Maintenance Instruction

Glossary of terms

Accident	An unwanted or unintended sudden event or a specific chain of such events which have harmful consequences. For heavy rail, the EU Agency for Railways divides accidents into the following categories: collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others.
Article 20 of Directive (EU) 2016/798, Obligation to investigation	Article 20 (1) Member States shall ensure that an investigation is carried out by the investigating body referred to in Article 22 after any serious accident on the Union rail system. The objective of the investigation shall be to improve, where possible, railway safety and the prevention of accidents. Article 20 (2) The investigating body referred to in Article 22 may also investigate those accidents and incidents which under slightly different conditions might have led to serious accidents, including technical failures of the structural subsystems or of interoperability constituents of the Union rail system. The investigating body may decide whether or not an investigation of such an accident or incident is to be undertaken. In making its decision it shall take into account: (a) the seriousness of the accident or incident; (b) whether it forms part of a series of accidents or incidents relevant to the system as a whole; (c) its impact on railway safety; and (d) requests from infrastructure managers, railway undertakings, the national safety authority or the Member States.
Beach marks	Macroscopic progression marks on a fatigue fracture or stress-corrosion cracking surface that indicate successive positions of the advancing crack front. They take the form of crescent-shaped macroscopic marks on fatigue fractures representing positions of the crack propagation, radiating outward from one or more origins.
Bed Plate	A non-structural sheet of steel covering the area between the Chassis Plates used to prevent oil spillage on to the track.
Buff Load	A horizontal compressive load applied to the Locomotive centreline at the Buffer.

Causal Factor	Any action, omission, event or condition, or a combination thereof that if corrected, eliminated, or avoided would have prevented the occurrence, in all likelihood.
Chassis Plate	An "I" beam running along the length of the Locomotive on either side providing structural support to the Locomotive.
Continuous Automatic Warning System	Continuous Automatic Warning System is a form of cab signalling and train protection system used to help train drivers observe and obey lineside signals.
Contributing Factor	Any action, omission, event or condition that affects an occurrence by increasing its likelihood, accelerating the effect in time or increasing the severity of the consequences, but the elimination of which would not have prevented the occurrence.
Doubler Plate	A plate that is added to the top of a defective area and welded around the plate's perimeter.
Down Direction	In this incident, trains travelling to Cork are travelling in the Down direction.
Finite Element Analysis	Finite Element Analysis is the process of simulating the behaviour of a part or assembly under given conditions so that it can be assessed using the finite element method.
Fatigue crack	A fatigue crack is a fissure which is formed when a material experiences continuous and repeated force or load at various points on the material.
Fish belly	The underframe of the Locomotive is designed to be lower in the middle section accommodating the engine and generator compared to the higher elevation over the bogies, to give greater strength.
Fractography	The study of fracture surfaces of materials.
Hazard	CCE-SMS-001 defines a hazard as "a condition, event or practice with the potential to cause an injury, damage or loss".
Heat Affected Zone	In welding, the heat affected zone is the area of base material e.g. metal, which is hot melted but has had its microstructure and properties altered by welding or heat intensive cutting operations.

Heat sink	A material that absorbs or transfers heat away from a critical element or part.
Incident	Any occurrence, other than an accident or serious accident, associated with the operation of trains and affecting the safety of operation. For heavy rail, the EU Agency for Railways divides incidents into the following categories: infrastructure; energy; control-command & signalling; rolling stock; traffic operations & management and others.
Investigation	A process conducted for the purpose of accident and incident prevention which includes the gathering and analysis of information, the drawing of conclusions, including the determination of causes and, when appropriate, the making of safety recommendations
Metallography	The study of the structure of metals and alloys by various methods, especially by optical and electron microscopy.
Metallurgy	The science and technology of metals and alloys.
Milepost	Marks distances.
Push-Pull	Push-Pull describes an unpowered train set with a propulsion unit (locomotive) at one end and a control car at the opposite end. The control car has control equipment enabling control of the propulsion unit. The fixed consist train set utilised the locomotive to pull in one direction and to push in the opposite direction.
Porosity	Caused by the absorption of nitrogen, oxygen and hydrogen in the molten weld pool which is then released on solidification to become trapped in the weld metal.
SAP Software	Computer programme that co-ordinates all resources, information and activity needed to complete an enterprise wide information system, it includes an accounting and finance function.
Serious Accident	Any train collision or derailment of trains, resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment, and any other similar accident with an obvious impact on railway safety regulation or the management of safety. For heavy rail, the EU Agency for Railways divides serious accidents into the

	following categories: collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others.
Service Advisory	Maintenance document issued by GM detailing the steps to be taken to rectify known Locomotive fault.
Slag	Non-metallic particles trapped in the weld metal or at the weld interface.
Systemic Factor	Any causal or contributing factor of an organisational, managerial, societal, or regulatory nature that is likely to affect similar and related occurrences in the future, including, in particular the regulatory framework conditions, the design and application of the safety management system, skills of the staff, procedures and maintenance.
Toe	Where the base metal “ties in” to the weld material along the weldment face.
Undercut	A groove that develops in the base metal near the toe or root of the weld.
Up Direction	In this incident, trains travelling from Cork are travelling in the Up direction.
Weldment	An assembly of parts welded together.
Work arising	A maintenance task that was not specified during scheduled maintenance but was identified and requires maintenance intervention.

References

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