Railway Accident Investigation Unit

Investigation Report 2011-R002

Secondary suspension failure on a train at Connolly Station

7th May 2010

Document History

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Function of the Railway Accident Investigation Unit

The Railway Accident Investigation Unit (RAIU) is a functionally independent investigation unit within the Railway Safety Commission (RSC). The purpose of an investigation by the RAIU is to improve railway safety by establishing, in so far as possible, the cause or causes of an accident or incident with a view to making recommendations for the avoidance of accidents in the future, or otherwise for the improvement of railway safety. It is not the purpose of an investigation to attribute blame or liability.

The RAIU's investigations are carried out in accordance with the Railway Safety Act 2005 and European railway safety directive 2004/49/EC.

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Executive Summary

At approximately 22:50 on the 7th May 2010 the 21:05 passenger service from Longford to Connolly Station arrived into Platform 1 at Connolly Station in Dublin. The service was operated by a four carriage Class 29000 Diesel Multiple Unit referred to as Unit 10. A member of the contract cleaning staff subsequently observed that there was a problem with one of the carriages and advised Iarnród Éireann personnel. Unit 10 was found to have returned from passenger service with its secondary suspension system over-inflated on one of the bogies of carriage 29310. The over-inflation had led to the failure of the centre pivot retaining plate bolts and the airbags lifting the centre pivot pin out of the bogie centre. Unit 10 had been undergoing maintenance prior to being released for passenger service on the 6th May 2010 and had entered passenger service with the secondary suspension functioning incorrectly on the trailer bogie of carriage 29310.

The immediate cause of the accident was:

- The secondary suspension levelling valves were fitted to the incorrect sides of the bogie.

The contributory factors were:

- The lack of clear instruction for maintenance personnel on the maintenance procedures to be carried out;
- The lack of clear visual markings or written advice in procedures for maintenance personnel to distinguish between the two different levelling valves;
- A job card was not generated to ensure sign off of the necessary post installation checks as complete.

The underlying factors were:

- The design of the secondary suspension system allowing the fault to develop to the point that the train entered an unsafe state;
- The ineffectiveness of maintenance and operational controls in place in managing the risks relating to over-inflation of the secondary suspension;
- The ineffectiveness of the hazard log in addressing the hazards relating to the over-inflation of the secondary suspension;
- The ineffectiveness of the hazard log in addressing the hazards relating to the failure of the centre pivot pin to perform its intended function.

The following safety recommendations are made:

- Iarnród Éireann should ensure all work in rolling stock maintenance depots is carried out in accordance with its control process;
- Iarnród Éireann should review its process of managing the hazard log in relation to the Class 29000s to ensure the adequacy of this process and verify that implementation of closure arguments in the hazard log is effective;
- Iarnród Éireann should evaluate the risks relating to failure of the centre pivot pin to perform its function due to over-inflation of the secondary suspension and determine if any design modifications are required to avoid future failures.

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1 Factual information

1.1 Parties involved

Iarnród Éireann (IÉ)[1] is the *Railway Undertaking*[2] that operates mainline railway services in Ireland. IÉ is also the railway *Infrastructure Manager*, managing the design, installation, testing, inspection, maintenance and renewal of the railway's physical assets.

The IÉ departments involved were:

- The Operations Department (Dept.) – responsible for the operation of train services and stations, including the management of train and station personnel;
- The Chief Mechanical Engineer's (CME) Dept. – responsible for the specification, purchasing, commissioning and maintenance of rolling stock, including management of the maintenance depots, associated personnel and procedures.

The CME Projects Office is the section within the CME Dept. responsible for the specification, purchasing and commissioning of rolling stock.

Drogheda Depot (the Depot) is the IÉ maintenance facility with responsibility for the maintenance of the Class 29000 Diesel Multiple Unit (DMU) fleet. The Depot Manager is the person with overall responsibility for the work that is carried out in the Depot.

Construcciones y Auxiliar de Ferrocarriles (CAF) is the train supplier.

A cleaning company contracted by IÉ to carry out the cleaning of trains at Connolly Station.

The roles of those that were involved in the accident were:

- Train drivers – responsible for the driving of trains and in service inspections;
- Duty managers – the persons that manage the work to be carried out in a maintenance depot on a specific shift;
- Fitters – the personnel in the Depot that carry out rolling stock maintenance;
- Contract cleaner – responsible for cleaning of the train interior.

[1] All abbreviations are explained in the list of abbreviations.

[2] All terms in italics are explained in the glossary of terms.

1.2 The accident

At approximately 22:50 on the 7th May 2010 the 21:05 passenger service from Longford to Connolly Station, train identification number (no.) P729, arrived into Platform 1 at Connolly Station in Dublin, see Figure 1 for the location map. The service was operated by a four carriage Class 29000 DMU referred to as Unit 10. A member of the contract cleaning staff subsequently observed that there was a problem with one of the carriages and advised IÉ personnel.

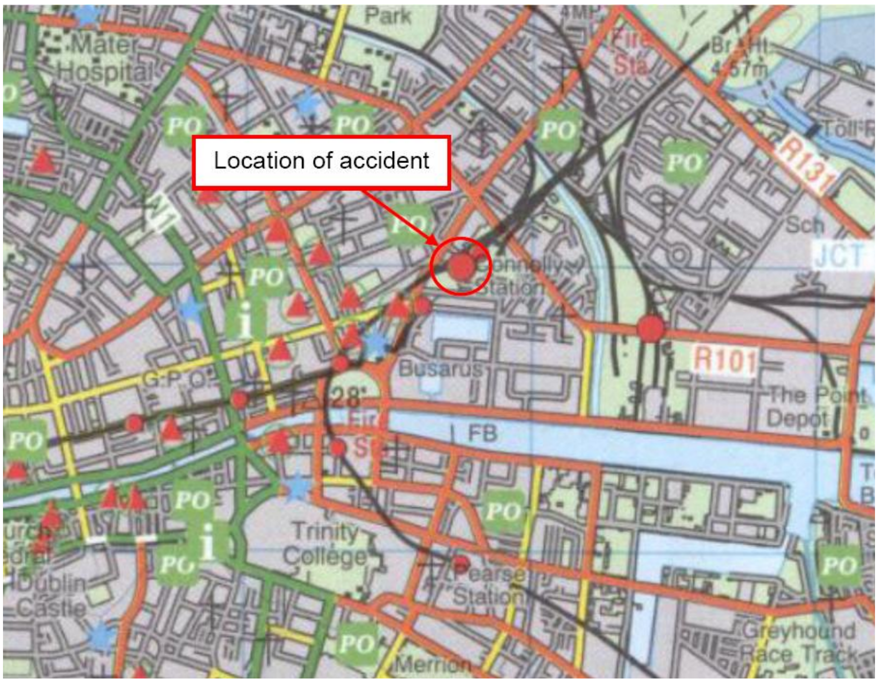
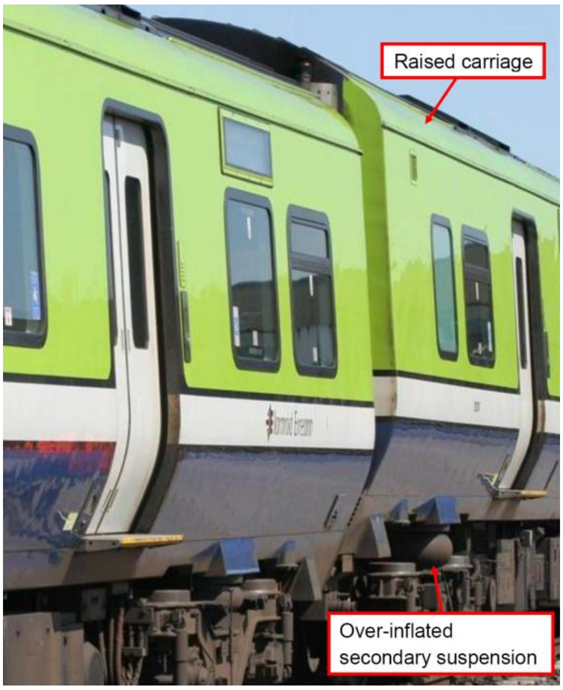
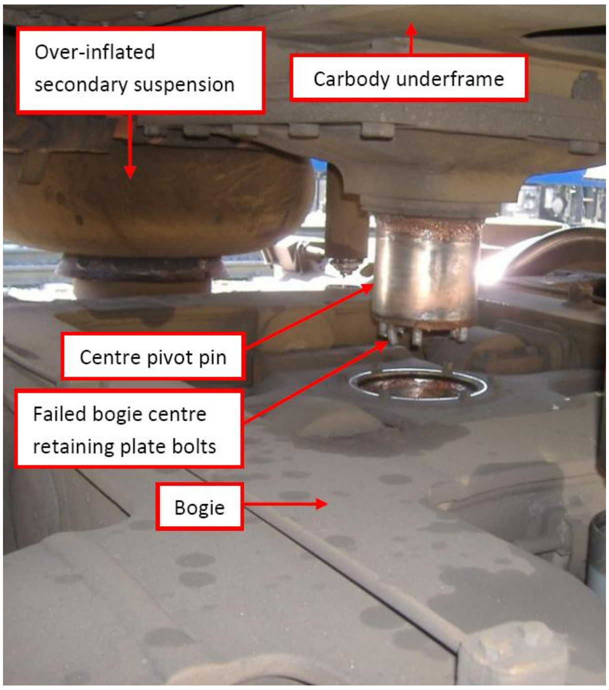


Figure 1 – Location Map (Ordinance Survey Ireland, 2005)
Ordinance Survey Ireland licence no. EN 0058211

The leading end of the second carriage, carriage 29310, was raised relative to the first carriage, carriage 29410, see Photograph 1. Upon examination it was observed that the *secondary suspension* on the leading *bogie* on carriage 29310 was over-inflated and the underframe of the carbody was no longer held in place on the bogie by the *centre pivot pin* as the *bogie centre retaining plate* bolts had failed, see Photograph 2.



Photograph 1 – Raised carbody



Photograph 2 – Bogie to carbody connection

1.3 Infrastructure

The track on the route that Unit 10 had been operating is ballasted track with a combination of *continuously welded rail* and *jointed track*.

1.4 Signalling and communications

The signalling system on the route Unit 10 was operating is a combination of *three aspect* and *four aspect colour light signalling*.

Communications between train drivers and the controlling signalman is by means of a cab secure radio system and *signalpost telephones*.

1.5 Traction and rolling stock

1.5.1 General description

The train involved was a Class 29000 DMU manufactured by CAF that entered passenger service in 2003. They consist of four carriages, DM1, MDT, MT and DM2, see Figure 2. They have a maximum speed of 120 kilometres per hour (km/h), a mass of 170,515 kilograms (kg) and are 81.26 metres (m) long. Each carriage has a motor bogie and a trailer bogie. The particular train involved was Unit 10 of the Class 29000s with carriages DM1, MDT, MT and DM2 numbered 29110, 29210, 29310 and 29410 respectively to uniquely identify them.

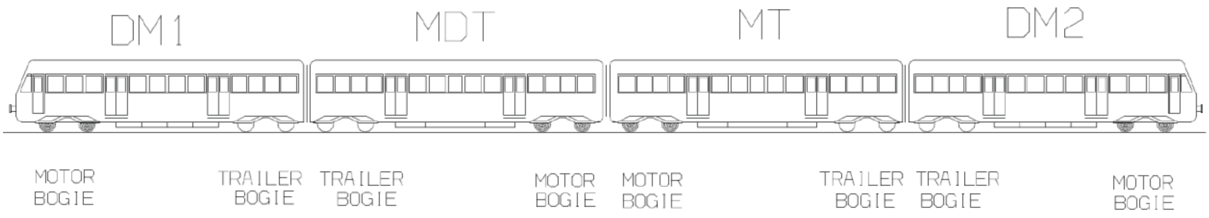


Figure 2 – Train layout (CAF, 2002)

1.5.2 Management of rolling stock design risks

The project for the purchase of the Class 29000s involved the management of potential *risks* that were ascertained through *hazard* identification. This led to the production of preliminary safety reports containing a hazard log that evolved with the project. At the end of the project a Final Safety Report (FSR) (CAF, 2004) was produced containing the final hazard log. The hazard log provides the means of logging the identification, quantification and resolution of the risks associated with the hazards in one document. These safety reports, including the hazard logs, were reviewed and accepted by the IÉ CME Projects Office.

According to the FSR, hazards were addressed based on the following premises (CAF, 2004):

- No single or credible failure sequences shall result in a hazard causing loss of life;
- Any hazards identified shall be eliminated using design engineering solutions whenever possible.

According to the FSR (CAF, 2004), each hazard was evaluated based on its severity, see Table 1, and its frequency of occurrence, see Table 2. The resulting risk assessment was broken into three risk categories, see Table 3, for which the action was defined as:

- Unacceptable risk – Hazards are not acceptable, additional corrective actions required;
- Undesirable risk – Only acceptable when risk reduction is impracticable and with the agreement of the *Railway Authority*;
- Acceptable risk – Shall be considered acceptable.

Table 1 – Hazard severity categories

Description	**Category**	**Definition**
Catastrophic	I	Death, system loss or severe environmental damage.
Critical	II	Severe injury, severe occupational illness, major system or environmental damage.
Marginal	III	Minor injury, minor occupational illness, or minor system or environmental damage.
Negligible	IV	Less than minor injury, occupational illness, or less than minor system or environmental damage.

Table 2 – Hazard frequency of occurrence

Description	**Level**	**Specific Individual Item**	**Fleet or Inventory**
Frequent	A	Likely to occur frequently.	Continuously experienced.
Probable	B	Will occur several times in the life of an item.	Will occur frequently.
Occasional	C	Likely to occur sometime in the life of an item.	Will occur several times.
Remote	D	Unlikely but possible to occur in the life of an item.	Unlikely but can reasonably be expected to occur.
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced.	Unlikely to occur, but possible.

Table 3 – Hazard risk classification

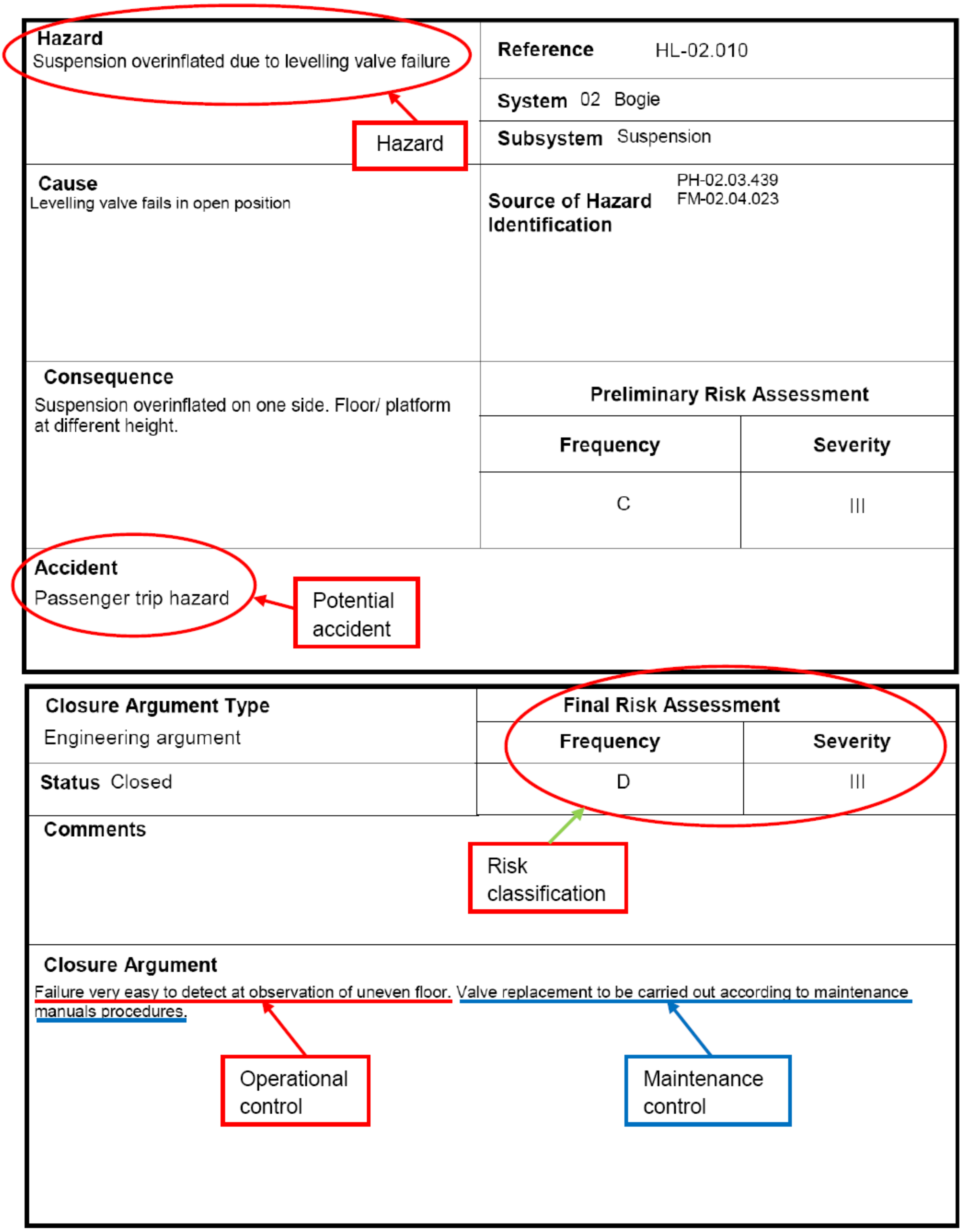
	Severity			
Frequency	**I- Catastrophic**	**II- Critical**	**III- Marginal**	**IV- Negligible**
A- Frequent	Unacceptable risk			
B- Probable				
C- Occasional		Undesirable risk		
D- Remote			Acceptable risk	
E- Improbable				

Based on the risk category established as part of the project, closure arguments were identified that detail the steps taken to eliminate, control or mitigate the hazard, these are one of four types (CAF, 2004):

- Engineering based argument – demonstrates that the rolling stock is robust in all approved operating modes and the risk has been reduced to an acceptable level;
- *Fault Tree Analysis* based argument – based on likelihood of occurrence and qualitative demonstration of acceptability;
- Outside CAF's scope of work – the solution is outside of CAF's involvement, this includes IÉ maintaining the rolling stock in a safe state and carrying out the required maintenance as identified by CAF;
- Logical argument – the risk is considered very low without further engineering argument.

Over-inflation of the secondary suspension due to failure of a single levelling valve was identified as hazard HL-02.010 in the hazard log, see Figure 3. The failure of a single levelling valve in the open position was addressed by the hazard. The potential consequence was identified as being over-inflated secondary suspension and the carriage floor and station platform being at different heights. The frequency was considered to be remote and the severity was considered to be marginal, with the potential accident being a passenger tripping whilst moving between the carriage and the platform. A design engineering solution was not used to mitigate this hazard, it was mitigated by operational and maintenance controls. A levelling valve fitted to the incorrect side of a bogie would result in the levelling valve remaining in the open position, leading to the levelling valve failing to perform its intended function and resulting the same consequence and accident as hazard HL-02.010. The failure of both levelling valves on a bogie was not identified and therefore no action was taken to specifically manage this hazard.

Failure of the centre pivot pin was identified as hazard HL-02.011 in the hazard log, see Figure 4. This addresses the mechanical failure of the centre pivot pin, which is intended to hold the carbody in place on the bogie whilst allowing of the relative movement of the carbody and the bogie in curves. The potential consequence was identified as being a loss of linkage between the carbody and the bogie with the carbody likely exceeding the *kinematic envelope* of the carriage. The frequency was considered to be improbable and the severity was considered to be catastrophic, with the likely accident being derailment of the train. This was mitigated by the closure arguments that identified controls based on previous experience with in service performance of similar vehicles as well as a combination of simulation based analysis and physical testing. Failure of the centre pivot pin to perform its intended function by being raised out of the bogie centre, as in the case of this accident, would result in the same consequence and accident as hazard HL-02.011. IÉ has advised that there are no retaining links as mentioned under the consequence in Figure 4.



Hazard
Suspension overinflated due to levelling valve failure

Reference HL-02.010

System 02 Bogie

Subsystem Suspension

Cause
Levelling valve fails in open position

Source of Hazard Identification PH-02.03.439 FM-02.04.023

Consequence
Suspension overinflated on one side. Floor/ platform at different height.

Preliminary Risk Assessment	
Frequency	**Severity**
C	III

Accident
Passenger trip hazard

Closure Argument Type
Engineering argument

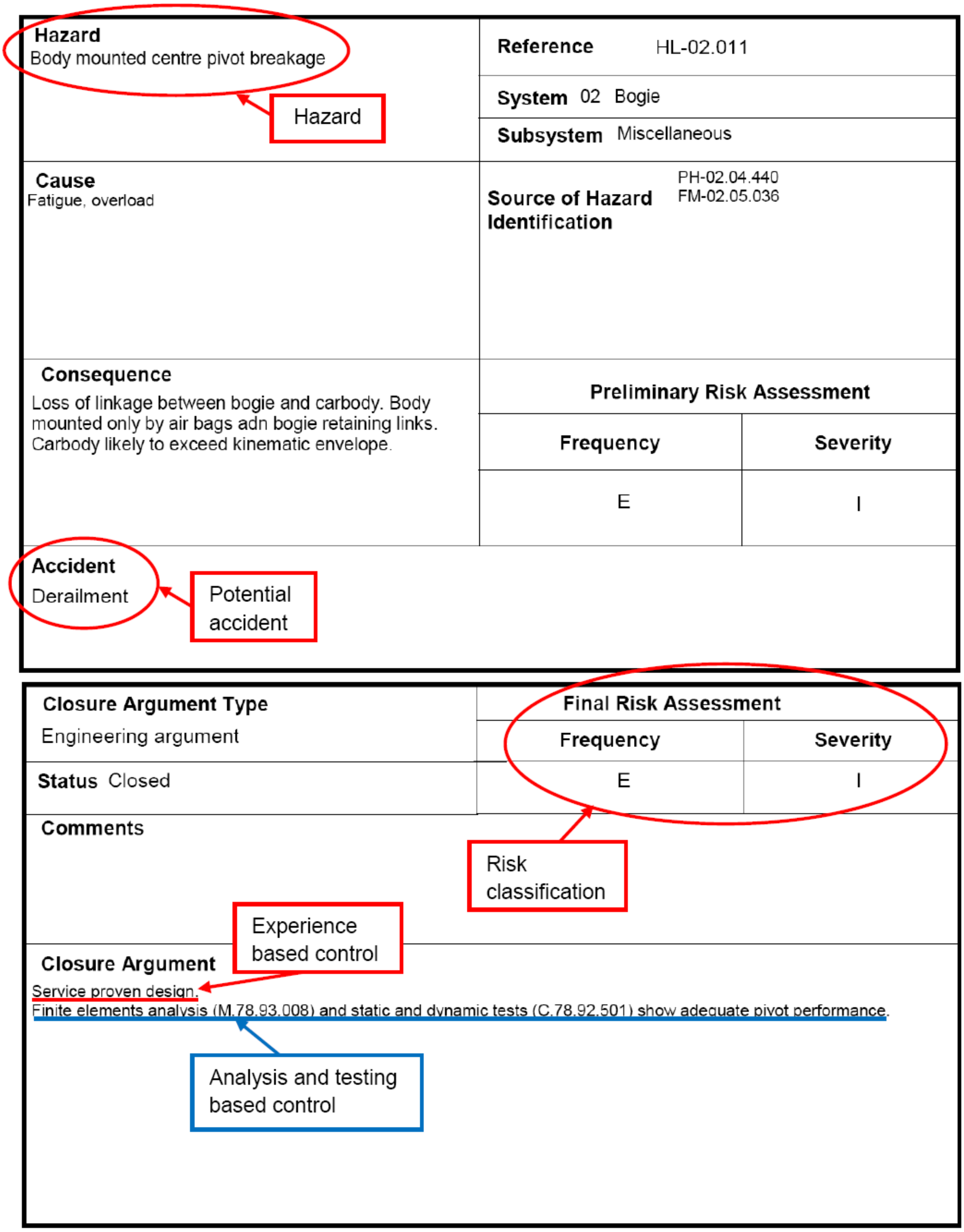
Status Closed

Final Risk Assessment	
Frequency	**Severity**
D	III

Comments

Closure Argument
Failure very easy to detect at observation of uneven floor. Valve replacement to be carried out according to maintenance manuals procedures.

Figure 3 – Hazard log extract on secondary suspension over-inflation (CAF, 2004)



Hazard Body mounted centre pivot breakage	**Reference** HL-02.011 **System** 02 Bogie **Subsystem** Miscellaneous
Cause Fatigue, overload	**Source of Hazard Identification** PH-02.04.440 FM-02.05.036
Consequence Loss of linkage between bogie and carbody. Body mounted only by air bags adn bogie retaining links. Carbody likely to exceed kinematic envelope.	**Preliminary Risk Assessment** Frequency: E Severity: I
Accident Derailment	

Closure Argument Type Engineering argument	**Final Risk Assessment** Frequency: E Severity: I
Status Closed	
Comments	
Closure Argument Service proven design. Finite elements analysis (M.78.93.008) and static and dynamic tests (C.78.92.501) show adequate pivot performance.	

Figure 4 – Hazard log extract on centre pivot pin failure (CAF, 2004)

1.5.3 Secondary suspension

The purpose of the secondary suspension on a passenger train is to minimise the transfer of forces between the bogies and the carbody of a carriage and improve ride comfort for passengers. The secondary suspension on the Class 29000s is a pneumatic system. It allows the height of a carriage to be controlled by adjusting the air pressure in the system depending on the passenger load in the carriage.

Each carriage on the Class 29000s has two sets of secondary suspension equipment, one mounted between each bogie and the underframe of the carriage, see Figure 5. The secondary suspension consists of two levelling valves, two levelling valve control rods, two airbags incorporating two conical springs, an average relay valve, a compensating valve and two auxiliary air reservoirs.

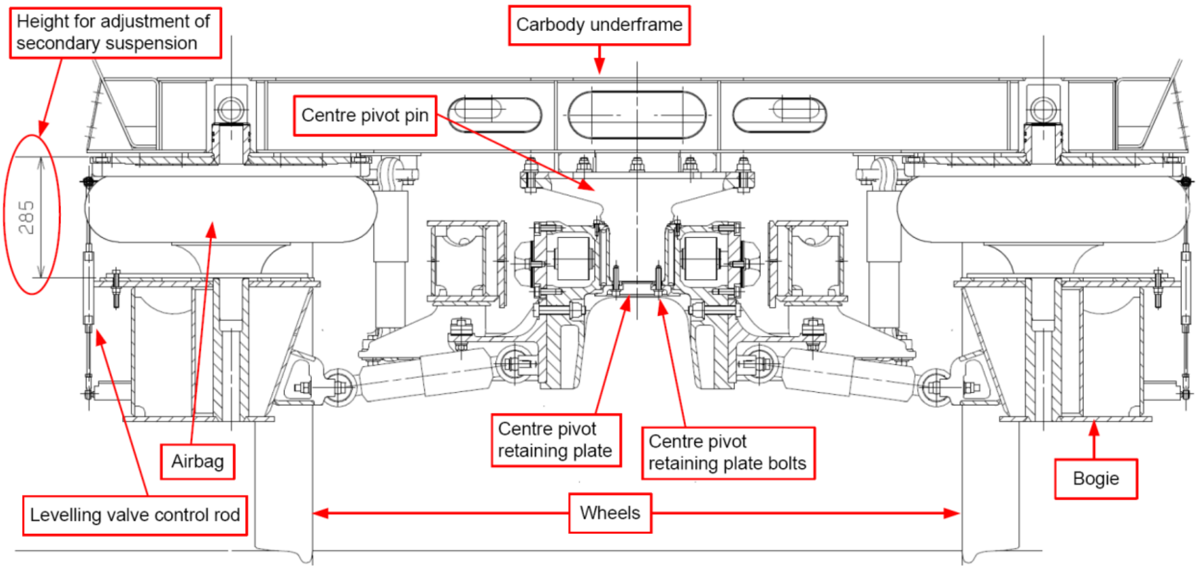


Figure 5 – Equipment between bogie and carbody (CAF, 2003a)

Air is fed from the main air reservoir on the carriage to the airbags on each bogie separately through two levelling valves. The height of the carbody is controlled by the levelling valve control rods, which maintain a gap of approximately 285 millimetres (mm) between the carbody and the bogie, see Figure 5. When the gap is less than the required height, the levelling valve control rod forces the arm of the levelling valve upwards allowing air to enter the airbag. When the gap is greater than the required height, the levelling valve control rod forces the arm of the levelling valve downwards causing the valve to vent air from the airbag. This allows the system to compensate for changing passenger loads.

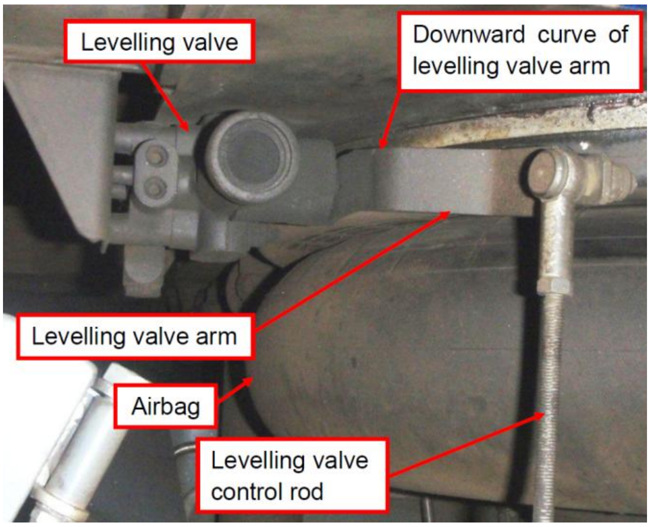
The pressure in the airbags on each side of the bogie is kept within 1.5 bars of each other by the compensating valve, which allows air to pass from the airbag with greater pressure to the other airbag once there is a pressure different of 1.5 bars between the airbags. The two sides of a carriage over the bogie are kept approximately level with each other by the levelling valve control rods. The normal operating pressure range for the secondary suspension is between approximately 3.8 and 6 bars, for an unladen carriage and a laden carriage respectively. The secondary suspension system is not pressure limited to prevent over-inflation.

The secondary suspension airbags on the trailer bogie of carriage 29310 were found to have over-inflated due to the mounting of the levelling valves upside down on the incorrect side of the bogie. The design of the secondary suspension permits the levelling valves to be fitted to either side of the bogies. The levelling valves for each side of the bogie are mirror images of each other and have few distinguishing features, see Photographs 3 and 4. They have the same part name and are distinguished by different part numbers written on them as shown in Photograph 4, which were not visible due to a build up of dirt in service as seen in Photograph 5. The slight downward curvature of the levelling valve arms is the main visible difference between the valves, see Photograph 5.


Photograph 3 – Levelling valve, part no. 82662

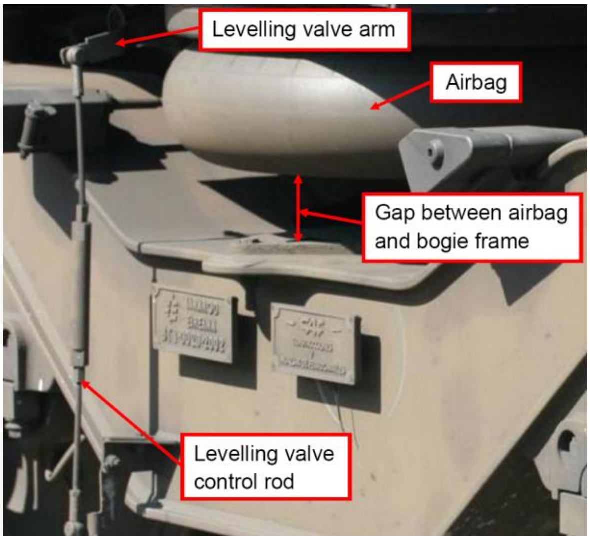

Photograph 4 – Levelling valve, part no. 82663

Mounting the levelling valve on the incorrect side of the bogie led to the valves remaining open constantly due to the downward curvature of the levelling valve arms when fitted correctly. Once the train was powered up and the air compressors were functioning, a continuous feed of air from the main reservoir passed through the open valves, allowing the airbags to continue to fill until the pressure in the airbags reached that of the main reservoir, 7.8 bar. As the pressure increased, the volume of air in the airbags increased and the height of the airbags increased relative to the bogie frame, raising the height of the carbody, see Photograph 1.

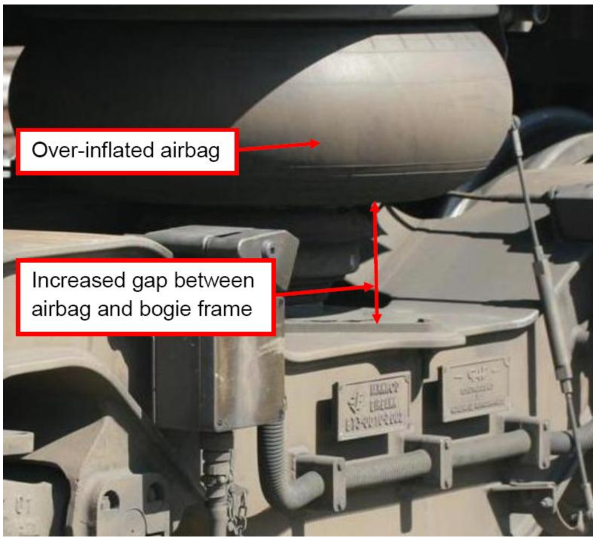


Photograph 5 – Levelling valve

The pressure in the airbags created a vertical load on the centre pivot retaining plate bolts. The combination of the load from the pressure in the airbags and the load due to the movement of the carriage on the track led to the failure of the centre pivot retaining plate bolts, see Photograph 2. Once the bolts failed, the volume of air in the airbags was allowed to increase further. A normally inflated airbag and the over-inflated airbag after failure of the centre pivot retaining plate bolts are shown in Photographs 6 and 7.



Photograph 6 – Normal suspension inflation



Photograph 7 – Over-inflated suspension

1.5.4 Maintenance of the Class 29000s

The maintenance requirements were originally specified by CAF and maintenance procedures for the Class 29000s were supplied to IÉ. Subsequently, IÉ developed a set of *balanced exams* and adopted the CAF maintenance requirements and procedures into their vehicle maintenance instructions, updating the procedures as necessary.

1.6 Maintenance depot

1.6.1 Maintenance activities in the Depot

The Depot has a defect repair and light maintenance team that operates two shifts from 08:00 to 20:00 and from 20:00 to 08:00. There is also a heavy maintenance team that work from 08:00 to 16:45. Maintenance is controlled by a duty manager for each shift based in the Depot control room.

A computer system is used to identify the work required on each unit and work orders are generated for each task by the duty managers. The control room contains boards for logging the work required on each unit maintained in the Depot and the identified tasks are logged on the board by the duty manager. The duty manager assigns the tasks to fitters and ensures they are signed off as complete. Procedures and any associated sign off sheets are issued to the fitters carrying out the work. Outstanding work and parts missing from any unit are recorded in the computer system and logged on the control room board. Co-ordination of work between shifts is managed through handover reports produced by the duty managers.

Maintenance is carried out through balanced exams, which are spread work out in a manner that allows the time for the maintenance work to be consistent for each type of exam to facilitate planning of work in depots. The types are referred to by a letter and then broken down into order by a number. An example of this is B exams which are four weekly maintenance exams starting at B1 with the next B exam being B2. These exams were developed by IÉ taking into account the maintenance requirements identified by CAF. Planned maintenance is signed off as complete on the balanced exam sign off sheet. Tasks are broken down into three types on the sign off sheet:

- General tasks that may be deferred if necessary with supervisor approval;
- Safety critical tasks that must be carried out in full are highlighted in grey;
- Tasks that must be completed in full for which a report form must be completed are highlighted in yellow.

Unplanned maintenance does not require any sign off sheets to be completed. Job cards are created for this work on the computer system and the tasks are logged on the control room boards. Where parts are removed from one carriage for use on another carriage it is common practice not to generate the required job cards.

Replacement parts are sourced from the stores in the Depot when required. Where replacement parts are not available in the stores, parts from other vehicles undergoing maintenance may be used as replacement parts or for fault finding as test components. The parts that have been removed from trains are recorded in the duty manager hand over report under a section entitled parts robbed (IÉ, 2010a). The required parts are then ordered and the new parts are used to replace the parts taken from other trains.

1.6.2 Maintenance of Unit 10

Unit 10 had been undergoing heavy maintenance in the Depot prior to the failure. The train was undergoing a four weekly balanced exam, B2, for which the B2 balanced exam sign off sheet, reference ME/TS/MM/29/B2 (IÉ, 2010b), shows no requirement to work on the secondary suspension. Additionally, no maintenance work was scheduled to take place on the secondary suspension while Unit 10 was in the Depot as the secondary suspension system was functioning correctly.

During the shift from 20:00 on the 4th May 2010 to 08:00 on the 5th May 2010 the light maintenance team were carrying out fault finding checks on another Class 29000 that required two levelling valves. There were no levelling valves available from the stores, therefore, the Duty Manager instructed the staff to use levelling valves from Unit 10. The levelling valves on the trailer bogie of carriage 29310 were removed. Once the levelling valves were no longer required, they were tagged and placed in the duty manager’s office for refitting on carriage 29310 during the next shift. The removal of the parts was logged in the duty manager handover report under the parts robbed section (IÉ, 2010a). A job card was produced for fitting of the levelling valves on the other unit. No job card was produced for refitting the levelling valves to Unit 10.

During the next shift a member of the heavy maintenance team was asked to refit the levelling valves to carriage 29310. The levelling valves were visually examined and no differences between them were observed, the valves were then mounted on the trailer bogie of carriage 29310.

Fitting of a levelling valve requires that maintenance procedures 'Levelling valve – Renew', job code BV 29A0426 (CAF, undated a) be carried out and post installation check 'Levelling valve – Air-tightness and performance inspect', job code BV 29A0427, (CAF, undated b) be completed to ensure the levelling valve is functioning correctly. BV 29A0427 requires that the levelling valve arm be raised to verify the airbag inflates and the levelling valve arm is lowered to verify the airbag deflates (CAF, undated b).

No procedures were given to the Fitter who was assigned the task of fitting the levelling valves and no post installation checks were identified and brought to the attention of the heavy maintenance team as being required.

The maintenance personnel were not aware that there were two different levelling valves for each side of the bogie. The part names are the same and part numbers are normally only used when dealing with the stores. The sole maintenance procedure available that identifies the valves as being different is job code BV 29J0428 'Levelling valve – overhaul' (CAF, undate c). IÉ do not overhaul the levelling valves as this task is outsourced and the parts are sent off site, therefore this procedure is not used by IÉ maintenance personnel. Performance of the activity in vehicle maintenance instruction 'Secondary suspension – Examine', reference US29J5676, is highlighted in grey in the sign off sheets for balanced exams B1, C1, C2, C3 and C4, indicating that it is safety critical and must be signed off as complete, this includes measurement of the 285 mm gap between the bogie and carbody (IÉ, 2009a). It should be noted that IÉ has advised that US29J5676 was included in balanced exam B1 in error.

Following all heavy maintenance work, the units involved undergo a trial run with maintenance personnel on board from Drogheda to Dundalk and back to ensure all systems are functioning correctly and a post trial run inspection is then carried out in the Depot. Unit 10 underwent these checks. The over-inflated secondary suspension on carriage 29310 was not identified during the trial run or the post trial run inspection.

1.7 Operations

1.7.1 General Description

Train operations on the IÉ network are controlled centrally in Centralised Traffic Control with certain functions being delegated to remote *signal cabins* where appropriate.

The Class 29000 trains are operated in what is referred to as Driver Only Operation, this means that the only member of staff on board is a train driver. The maximum permitted speed for the Class 29000s is 120 km/h.

1.7.2 Train inspections

As part of their duties train drivers carry out inspections of trains in operation at designated times. The IÉ class 29000 train preparation procedure (IÉ, 2009) specifies the inspections of trains to be carried out by train drivers as part of their duties. As part of these inspections visual inspections of the train are to be carried out as defined in Table 4.

Table 4 – Train inspections (IÉ, 2009)

Activity	Description	Type of inspection
Train preparation	Following departure from a maintenance facility.	Walk outside train; walk through train.
Changing ends	When a train arrives at a terminal station and the train is not scheduled to depart for at least 20 minutes.	Walk outside train.
Mobilisation	When a train has been immobilised or there is no direct driver to driver handover and the train has not received a full CME examination.	Walk outside train; walk through train.
Immobilisation	When a train arrives at a terminal station or location where the train is not receiving a full CME examination and the train is not planned to depart for at least 45 minutes.	Walk through train.
Stabling	Undertaken when a train arrives at a maintenance facility.	Walk through train; walk outside train.

Train drivers are instructed on the identification of faults with rolling stock. This involves the identification of faults with the secondary suspension system. The training documentation produced by CAF (CAF, 2003b) and IÉ (IÉ, 2003) on the secondary suspension addresses deflation of the system, no mention is made in the documentation of over-inflation of the secondary suspension.

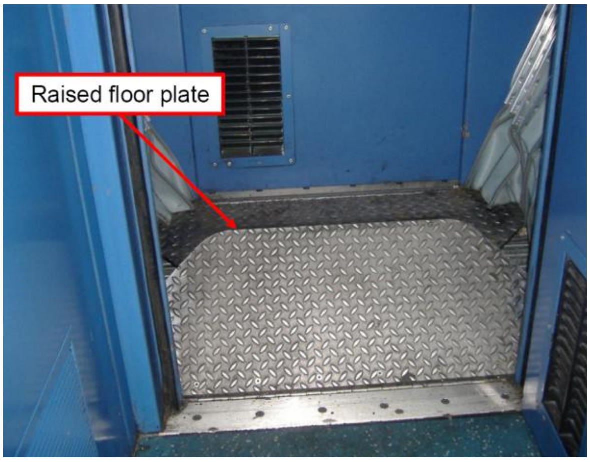
1.7.3 Inspections of Unit 10

Unit 10 entered service on the morning of the 6th May 2010. Once in service it underwent thirteen inspections by train drivers over the course of the 6th and 7th May 2010. The over-inflated secondary suspension on carriage 29310 was not identified during these inspections.

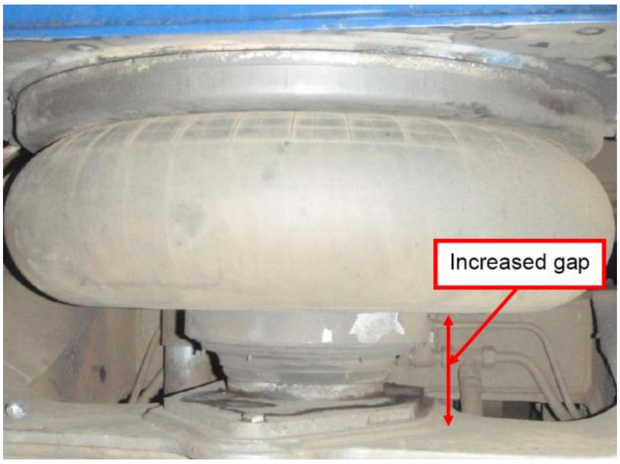
Over-inflation of a single airbag on a bogie causes a slope in the level of the carbody from the one side of the vehicle to the other over the bogie with the over-inflated airbag. This may be apparent at a platform due to the gap between the carriage and the platform at a station depending on the normal gap between the platform and the carriage. It would be apparent when walking through the train due to the slope of the floor across the bogie.

Over-inflation of both airbags on a bogie causes a slope in the level of the carbody from one end of the carriage to the other. This may be apparent at a platform due to the gap between the carriage and the platform at a station depending on the normal gap between the platform and the carriage. It would not be apparent walking through the train due to the height difference being between the bogie centres prior to the failure of the bolts. Once the bolts failed, the fault would have become apparent when walking through the train as the plates of the floor of the gangway were no longer laying flat over the coupling due to the difference in the height of the carriages, see Photograph 8.

A test was carried out following the accident to determine the extent of the visibility of the over-inflated secondary suspension. The secondary suspension was over-inflated to 6.8 bars. The floor plate between the carriages did not raise. The gap between the bottom of the airbag and the bogie increased by 35 mm to 320 mm, see Photograph 9, however, the airbag did not appear inflated beyond normal inflation, see Photograph 6.



Photograph 8 – Raised gangway floor plate



Photograph 9 – Over-inflated airbag

It was not possible to determine at what stage between entering passenger service at 08:00 on the 6th May 2010 and finishing passenger service at 22:50 on the 7th May that the bolts failed.

1.8 Fatalities, injuries and material damage

1.8.1 Fatalities and injuries

There were no fatalities or injuries as a result of this accident.

1.8.2 Infrastructure damage

There was no infrastructure damage as a result of this accident.

1.8.3 Traction and rolling stock damage

The damage was isolated to carriage 29310. The centre pivot pin was raised out of the bogie centre. The eight bogie centre retaining plate bolts were stretched and broken in two. The upper and lower sections of the two vertical dampers on the bogie had separated. The mounting points of the levelling valve control rods suffered minor damage.

1.9 History of similar occurrences

There were no previous occurrences of secondary suspension failures due to over-inflation on the IÉ railway network.

2 Analysis

2.1 Fitting of the levelling valves

Unit 10 began its B2 balanced exam with no requirement for work to be carried out on the secondary suspension system (IÉ, 2010b). Whilst undergoing maintenance two levelling valves were removed from carriage 29310 for use on another unit and were subsequently refitted to carriage 29310. In the process of being refitted, the levelling valves were mounted on the incorrect side of the bogie. This was permitted by the design of the levelling valves. The downward curvature of the levelling valve arms meant that once they were fitted and connected to the levelling valve control rods, the levelling valves were fixed in the open position and would allow air to be continuously fed into the airbags once the secondary suspension system was active. The lack of robust maintenance controls in the Depot meant that the functionality of the valves was not verified and Unit 10 was released for passenger service on the morning of the 6th May 2010 with its secondary suspension operating incorrectly.

The hazard log, which forms part of the design process for the rolling stock, is based on a premise of robust maintenance control (CAF, 2004). However, the maintenance controls in place in the Depot were not sufficiently robust to prevent the train from entering passenger service with the levelling valves fitted incorrectly. A job card was not produced for the fitting of the levelling valves to Unit 10, allowing it to go undocumented and sign off of the necessary tasks not to be verified. No maintenance procedures were provided to the heavy maintenance team working on the levelling valves, meaning that the need for a post installation check to be carried out was not known by maintenance staff. This meant that the correct performance of the levelling valves in accordance with procedure BV 29A0427 (CAF, undated b) was not verified and the gap between the bogie and the carbody exceeded the 285 mm required, which forms part of safety critical procedure US29J5676 on examination of the secondary suspension (IÉ, 2009a). Fitters were not aware that the valves were side specific, they were not issued with documentation advising them of this or alerting them to the slight downward curvature of the arm and the part no.s were obscured by dirt. The similarity in design of the levelling valves and the ability to fit them to either side of the bogie meant that there were no obvious signs that the valves were fitted in the incorrect location.

2.2 Secondary suspension over-inflation

Once Unit 10 was powered up and the secondary suspension system was active, air was continuously fed into the airbags through the open levelling valves, this caused the pressure in the secondary suspension system to increase beyond its normal operating range of between 3.8 and 6 bars to that of the main reservoir, 7.8 bars. The airbags then lifted the carbody 35 mm beyond the 285 mm normal gap between the carbody and the bogie to a height of 320 mm, increasing the gap between the underside of the airbags and the bogie frame as shown in Photograph 9. The pressure in the airbags applied a vertical load on the bogie centre retaining plate bolts, this load combined with the load due to the motion of the train on track caused the bogie centre retaining plate bolts to fail over time. Once the centre pivot pin was no longer retained in the bogie centre by the retaining plate, the upward lift created by the pressure in the airbags caused the centre pivot pin to lift out of the bogie centre as seen in Photograph 2. It was not possible to determine at what stage between entering passenger service at 08:00 on the 6th May 2010 and competing passenger service at 22:50 on the 7th May 2010 that the bogie centre retaining plate bolts failed. However, it was possible to establish that the maintenance and operational controls were ineffective in identifying the over-inflated secondary suspension.

Over-inflation of the secondary suspension due to failure of a single levelling valve was recognised as a potential hazard in the hazard log (CAF, 2004), for which operational and maintenance controls were identified as the closure arguments to mitigate the risk, see Figure 3, rather than a design engineering solution as mentioned in the FSR (CAF, 2004). Incorrect mounting of a levelling valve resulted in the same effect as a failed levelling valve as the levelling valve remained in the open position, failing to perform its intended function. Hence, the consequences and potential accident would be the same for failure of a levelling valve and the failure of a levelling valve to perform its intended function in this instance, giving the consequence in each case as over-inflation of the secondary suspension and the carriage floor and station platform not being at the same height with the potential accident being a passenger tripping at the interface between the train and the platform.

Two levelling valves failing to perform their required function was not considered in the hazard log and thus the effectiveness of the controls for a single levelling valve in managing the case of two levelling valves was not considered and any additional consequences were not identified. Over-inflation of the secondary suspension due to the failure of the two levelling valves to perform their required function led to the bogie centre retaining plate bolts failing and the centre pivot pin lifting out of its bogie centre, which would not result from over-inflation due to a single levelling valve. This meant that the hazard log did not address the hazard of secondary suspension over-inflation due two levelling valves failing to perform their required function.

The operational control of identifying the uneven floor level shown in Figure 3 was found not to have been covered in either the CAF or the IÉ documentation for the training of train drivers, thus rendering this control ineffective for a single levelling valve. However, had this control been put in place, it would not have been effective in managing the failure of two levelling valves to perform their required function. The ability to detect the 35 mm height difference would be reduced as the height difference was over the length rather than the width of the carriage. This was not taken into account in the hazard log since the failure of both levelling valves was not considered. A test was carried out to establish if the height difference would be sufficient for train drivers to observe the over-inflation prior to the bogie centre retaining plate bolts failing. The test showed that over-inflation of both airbags would not be sufficiently apparent to alert staff to the fault. This result was reinforced by the over-inflation not being observed by maintenance personnel during or following the pre-service trial run. Hence in service inspections by train drivers were not an effective control to mitigate the hazard in the case of two levelling valves.

2.3 Failure of centre pivot pin to perform its function

Once Unit 10 began to operate with the levelling valves mounted on the incorrect side of the bogie, the secondary suspension began to over-inflate as it was not pressure limited. The lack of pressure limiting combined with the bolts being loaded in a manner that was not intended permitted the bogie centre pivot retaining plate bolts to become overloaded due to the combination of the vertical load caused by the secondary suspension system and the loads caused by the movement of the train on track, and failure of the bolts to occur. As the incorrect fitting of the levelling valves was not found in maintenance and the over-inflation was not observed in passenger service it was possible for an unsafe condition to develop due to the over-inflation of the secondary suspension, whereby the centre pivot pin was raised out of the bogie centre and could no longer perform its intended function. The potential for this to develop was not controlled through the hazard log.

Mechanical failure of the centre pivot pin in the form of a breakage was recognised as a hazard in the hazard log as shown in Figure 4, for which *finite element analysis* as well as static and dynamic testing were carried out as closure arguments in order to mitigate the risk. Failure of the centre pivot pin to perform its function was not considered in the hazard log, however, this failure resulted in the consequences identified in the hazard log for the failure of the centre pivot pin. This was that the train connection between the carbody and the bogie was only being maintained by the airbags and other equipment connected to both that was not designed for this purpose. As indicated in Figure 4, CAF identified that the failure of the centre pivot pin could have led to a derailment, the failure of the centre pivot pin to perform its function could have led to the same potential accident.

3 Conclusions

Unit 10 of the Class 29000s was found to have returned from passenger service with its secondary suspension system over-inflated on one of the bogies of carriage 29310. The over-inflation had led to the failure of the centre pivot retaining plate bolts and the airbags lifting the centre pivot pin out of the bogie centre. Unit 10 had been undergoing maintenance prior to being released for passenger service and the two levelling valves on the trailer bogie of 29310 were fitted to the incorrect side of the bogie.

The activity of fitting the levelling valves to the trailer bogie of carriage 29310 was not carried out in accordance with IÉ's maintenance controls, resulting in the necessary job card not being generated, the associated tasks not being carried out and no verification of sign off of the necessary tasks. In addition, the maintenance procedures did not highlight the difference between the levelling valves and the dirt on the valves combined with their similarity in design meant that staff were unaware that the levelling valves were not identical.

Over-inflation of the secondary suspension due to the failure of two levelling valves to perform their function was not identified in the hazard log. The hazard log addresses the over-inflation of the secondary suspension due to failure of a single levelling valve, which was not mitigated by a design engineering solution. The operational control of identifying the uneven floor was ineffective as train drivers were not trained to identify this. Testing carried out also demonstrated that observation of the uneven floor by train drivers would not be effective for two levelling valves as the slope in the floor would not be noticeable over length of a carriage.

The failure of the centre pivot retaining plate bolts was a result of fatigue and overloading as a consequence of over-inflation of the secondary suspension, this then allowed the centre pivot pin to be raised out of the bogie centre thus preventing it from performing its intended function and permitting the train to enter an unsafe state. The physical failure of the centre pivot pin was addressed in the hazard log and this demonstrated the potential consequence and resultant accident for the failure of the centre pivot pin to perform its function.

The *immediate cause* of the accident was:

- The secondary suspension levelling valves were fitted to the incorrect sides of the bogie.

The *contributory factors* were:

- The lack of clear instruction for maintenance personnel on the maintenance procedures to be carried out;
- The lack of clear visual markings or written advice in procedures for maintenance personnel to distinguish between the two different levelling valves;
- A job card was not generated to ensure sign off of the necessary post installation checks as complete.

The *underlying factors* were:

- The design of the secondary suspension system allowing the fault to develop to the point that the train entered an unsafe state;
- The ineffectiveness of maintenance and operational controls in place in managing the risks relating to over-inflation of the secondary suspension;
- The ineffectiveness of the hazard log in addressing the hazards relating to the over-inflation of the secondary suspension;
- The hazard log not addressing the hazards relating to the failure of the centre pivot pin to perform its intended function.

4 Relevant actions already taken or in progress

As of the 17th January 2011, IÉ had advised that the following actions have been taken in relation to the accident:

- All components that are changed/repaired are entered onto a works arising sheet by the maintenance personnel and from that entered onto the computer system by a shift duty manager. When the task is completed and testing is carried out it is then technically completed on the computer system;
- When a set enters the Depot for maintenance all open work orders from the computer system are printed and also placed on the production board and each task then assigned to staff members, there are briefings at 08:05, 13:00, 17:00, 20:05, 01:00 and 05:00, briefing over the two shifts where exam sheets and the computer system work orders are reviewed before sets are allowed return to service;
- Heavy maintenance personnel have been competency assessed on bogie replacement and are to be trained on carrying out vehicle height checks as part of their competency training;
- The possibility of retro-fitting a secondary suspension height limiting valve designed specifically to prevent over-inflation of the secondary suspension is being considered for all DMUs;
- The Depot have introduced a daily briefing at 08:05 and a review at 16:30 each day with the heavy maintenance team where open work orders and component refitting sheets are reviewed. Before any trial run takes place static checks are completed and paper work reviewed. After the trial run the set returns to the Depot and is inspected again before it returns to service.

5 Previous RAIU recommendations

No previous RAIU reports and their recommendations were found to be relevant to this investigation.

6 Recommendations

As a result of the RAIU investigation, three safety recommendations[3] have been made.

The activity of fitting the levelling valves to the trailer bogie of carriage 29310 was not carried out in accordance with IÉ's maintenance controls hence a job card was not created. This has led to the following safety recommendation:

IÉ should ensure all work in rolling stock maintenance depots is carried out in accordance with its control process.

The hazard log was found to be ineffective in addressing the hazards relating to the over-inflation of the secondary suspension. The hazard log addresses the over-inflation of the secondary suspension due to failure of a single levelling valve and provides operational and maintenance controls to mitigate the hazard. These controls were found to be ineffective as the operational control was not in place and the maintenance control relied on robust maintenance controls that were not in place. This has led to the following safety recommendation:

IÉ should review its process of managing the hazard log in relation to the Class 29000s to ensure the adequacy of this process and verify that implementation of closure arguments in the hazard log is effective.

The hazard log did not address the failure of the centre pivot pin to perform its intended function or the potential for the failure to occur due to over-inflation of the secondary suspension. This has led to the following safety recommendation:

IÉ should evaluate the risks relating to failure of the centre pivot pin to perform its function due to over-inflation of the secondary suspension and determine if any design modifications are required to avoid future failures.

[3] Recommendations shall be addressed to the safety authority and, where needed by reason of the character of the recommendation, to other bodies or authorities in the Member State or to other Member States. Member States and their safety authorities shall take the necessary measures to ensure that the safety recommendations issued by the investigating bodies are duly taken into consideration, and, where appropriate, acted upon. (Railway Safety Directive, 2004/49/EC)

7 Additional information

7.1 List of abbreviations

CAF	Construcciones y Auxiliar de Ferrocarriles
CME	Chief Mechanical Engineer
Dept.	Department
DMU	Diesel Multiple Unit
IÉ	Iarnród Éireann
Kg	Kilogram
km/h	Kilometres per hour
M	Metre
Mm	Millimetre
no.	Number
RAIU	Railway Accident Investigation Unit
RSC	Railway Safety Commission
The Depot	Drogheda Depot

7.2 Glossary of terms

Accident	An unwanted or unintended sudden event or a specific chain of such events which have harmful consequences including collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others.
Balanced exam	Maintenance exams that are structured to ensure equal time is required for all examinations of the same type to facilitate planning of maintenance activities in a depot.
Bogie	A frame that supports a carriage and rests on wheelsets.
Bogie centre retaining plate	A plate that connects the bogie to the centre pivot pin by means of bolts connecting the retaining plate to the centre pivot pin.
Causal factors	Any factor(s) necessary for an occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.
Centre pivot pin	A pin that holds the carbody in place on a bogie whilst allowing of the relative movement of the carbody and the bogie in curves.
Colour light signalling	A signalling system that conveys the limit of movement authority to train drivers by means of coloured lights.
Continuously welded rail	Sections of rail that are welded together to form track.

Contributory factors	Any factor(s) that affects, sustains or exacerbates the outcome of an occurrence. Eliminating one or more of these factor(s) would not have prevented the occurrence but their presence made it more likely, or changed the outcome.
Diesel Multiple Unit	A train powered by diesel with the engines distributed along its length under the carriages.
Fault tree analysis	The analysis of the failure of a system to determine the possible combinations of subsystem and or environmental factors that can lead to the stated failure.
Finite element analysis	The analysis of the stresses on a component or system through the use of a computer model in order to determine its behaviour.
Four aspect colour light signalling	A signalling system that conveys the limit of movement authority to train drivers by means of a four aspect coloured light system.
Hazard	A condition with the potential for harm.
Immediate cause	The situation, event or behaviour that directly results in the occurrence.
Incident	Any occurrence, other than an accident or serious accident, associated with the operation of trains and affecting the safety of operation.
Infrastructure Manager	Organisation responsible for the maintenance of railway infrastructure.
Jointed track	Sections of track that are made up of rails that are connected by joints.
Kinematic envelope	The maximum cross-section of space occupied by a carriage in all given load conditions.
Railway Authority	The body with overall responsibility to the railway regulator.
Railway Undertaking	Organisation responsible for the operation of train services.
Risk	An expression of the rate of occurrence of a hazard and its severity.
Rolling stock	Rail vehicles.
Secondary suspension	The suspension system between the bogie of a rail vehicle and the carbody.
Signal cabin	A cabin from which the signalling system is controlled.
Signalpost telephones	Telephones position beside the track that allow communication with the controlling signalman.
Three aspect colour light signalling	A signalling system that conveys the limit of movement authority to train drivers by means of a three aspect coloured light system.
Traction	Means of providing power to move rail vehicles.
Underlying factors	Any factor(s) associated with the overall management systems, organisational arrangements or the regulatory structure.

7.3 References

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