Learning the lessons: ORR review into Hitachi AT200/300 rolling stock cracking

Final report

07 April 2022

Contents

1. Executive summary

1.1 On 8 May 2021, Hitachi Class 800, 801 and 802 trains (referred to collectively as Class 80X) operated by London North Eastern Railway (LNER), Great Western Railway (GWR), TransPennine Express (TPE) and Hull Trains were withdrawn from service as a safety precaution after cracks were identified in some carriages of the trains, specifically those in service with GWR and LNER, but not TPE or Hull Trains. The disruption caused by the events on 8 May had an impact on passengers travelling or expecting to do so using the services of these train operators.

1.2 On 7 June 2021, Office of Rail and Road (ORR) informed Ministers at the Department for Transport of our plan to complete a lessons learnt review into the safety and passenger impact of the cracking issues on Hitachi Class 80X trains. The full remit of this lessons learnt review is set out in Annex 1. We published the 'Passenger Impact review – Hitachi Class 800 trains' on 25 June 2021, and an interim report on 9 September 2021 addressing the initial findings of the lessons learnt review. This final report covers the safety elements of this review and findings to date.

The trains affected

1.3 Class 800, 801, 802 and 803 units are members of the AT300 family of Hitachi rolling stock. The first Class 800 trains entered service in October 2017 with GWR.

1.4 During scheduled maintenance activities, cracks were found in the area of the bolster, a critical area where the load of the vehicle and other forces are transferred to the wheel assembly, commonly referred to as the bogie. Specifically, cracks were found close to the yaw damper bracket and anti-roll bar fixing points on vehicles in these classes. In this report we will refer to the cracking in this area as the 'yaw damper cracks'. Eight trains that were significantly affected were withdrawn from service and on 11 April 2021 GWR issued a National Incident Report (NIR) 3761, describing these yaw damper cracks.

1.5 Subsequently on 7 May 2021, cracks were also identified at the other end of the bolster assemblies, in the vicinity of the weld lines where the lifting plates attach to the vehicle body. Initial assessment concluded that there was a risk of the lifting plates detaching. In this report we will refer to the cracking in this area as the 'lifting plate cracks'.

1.6 The prevalence of the yaw damper and the lifting plate cracks on many vehicles in both the GWR and LNER fleets resulted in the decision on 8 May 2021 to withdraw all Class 800, 801 and 802 rolling stock from service until all vehicles had been checked and a case for safe operation of vehicles with cracks had been made. These actions were fully supported by ORR.

1.7 ScotRail Trains Ltd operates a fleet of Hitachi Class 385 units on suburban, commuter and regional services, having taken over from Abellio ScotRail in April 2022. SE Trains Ltd (SE Trains) operates a fleet of Hitachi Class 395 units on its high-speed services in the south-east of England, having taken over from London & South Eastern Railway (L&SER) in October 2021.

1.8 Class 385 and Class 395 trains were not withdrawn from service on 8 May 2021, as their designs are different to the Class 80X, and the actual and potential incidences of cracking were assessed as low risk. These trains are now included within the scope of Hitachi's recovery programme.

Methodology

1.9 We structured our approach to addressing the aims of this review around two themes:

(a) the capability of the operators' safety management systems (SMS) to manage the withdrawal and reinstatement of vehicles; and

(b) a technical review, from root cause analysis to rectification and modification progress.

1.10 We met with Hitachi, operators, Department for Transport (DfT), Rail Safety and Standards Board (RSSB) and vehicle owners. We attended industry forums and working groups.

1.11 Our review is based on the documentation arising from the industry's work such as safety certificate applications, risk assessments, and detailed technical analyses and reports. We did not undertake an independent technical analysis. We have not undertaken an investigation that uses our powers arising from the Health and Safety at Work etc. Act 1974 because at no point did we identify a potential breach of health and safety law.

Aims of our review

1.12 **Aim 1:** Determine the root cause of the cracking at the lifting end of the bolster and around the yaw damper / anti-roll bar connections to the body.

1.13 **Aim 2:** Examine how the industry went about identifying the problem, assessing the safety risk, withdrawing the trains from service and returning trains to service.

1.14 **Aim 3:** Identify areas for improvement.

Root causes of fatigue cracking at the yaw damper

1.15 The conclusions of Hitachi's technical review are that:

- fatigue cracking was caused by the area of the bolster subject to yaw damper and Anti-Roll Bar (ARB) loads being greater than allowed for in the original design.
- the degree of fusion in the weld between the bolster and the car body was likely to be a factor in relation to the emergence of the cracking.
- Hitachi has identified that the geometry of the components prior to welding contributed to the poor weld fusion identified above.

1.16 The applicable standards define the accelerations to be taken into account when designing rolling stock but do not directly mandate the strength of components, which will depend on the individual vehicle design. Other rolling stock built in conformance to these standards has not presented similar problems. It is not yet known for certain the reason for the in-service fatigue loads on the rolling stock to exceed those Hitachi derived from the standard. Potential factors that have been suggested include wheel wear and track specification. Hitachi's testing has identified a difference in loads arising from new and worn wheel profiles. Further work needs to be undertaken to evaluate whether the characteristics of track on the routes over which Class 80X rolling stock operates differ from those assumed by the standards. There is no evidence that the condition of the track on the routes was anything other than compliant with the applicable standards and therefore conformed to its specification.

1.17 Since the design basis was aligned to the applicable industry standards, the industry should evaluate whether applicable standards take into account the loads arising from operation over track in Great Britain.

Root causes of stress corrosion cracking in the jacking plate

1.18 The conclusion of the technical review is that stress corrosion cracking (SCC) was caused by the use of 7000 series aluminium, and in particular plates exceeding 10mm in thickness. Thicker material is particularly susceptible to SCC in a typical rail environment in the UK, in circumstances where the residual stresses introduced as a result of the welding operation have not been mitigated.

1.19 It is noted that existing industry standards do not make provision for this risk. This may have contributed to it not being fully accounted for in the design, either through avoiding use of the susceptible alloys, or through additional protective measures.

Industry response

1.20 All operators were able to demonstrate that they had appropriate safety management systems in place to manage the fleet stand down, to liaise appropriately with Hitachi and to make suitable and sufficient risk assessments for returning trains with cracks meeting defined criteria back into passenger service.

1.21 Over the weekend of 7/8 May 2021, Hitachi initiated and chaired regular update meetings with key stakeholders including operators, owners, DfT and ORR. These meetings helped manage information flow, coordinate the early industry response and allowed Hitachi to get on with problem-solving. However, this did put further pressure on Hitachi to facilitate these meetings and they would have benefitted from a strong independent chair to maintain focus, pace and ensure all voices were heard.

1.22 Operators were supported by high-level governance within their organisations, and from the owning groups, Abellio and First Group, with board sign-off for key decisions being required. They resisted any commercial pressures to get trains back into service before the correct internal procedures had been followed.

1.23 Each operator implemented their own assurance measures to ensure that the information provided by Hitachi was correct, and the proposals to return trains to service subject to enhanced checks were based on sound evidence. Hitachi has fully cooperated with operators carrying out assurance activities on train checks.

1.24 Interfaces between both AT200/300 users and Hitachi appear well-managed although some operators would prefer more detailed information to be shared from Hitachi to satisfy their safety and assurance processes for fleet management.

1.25 Upon reviewing the Train Service Agreements (TSAs), we have concluded that they are drafted in a way which does not impede the flow of information between Hitachi and the operators.

1.26 Internal communications within Hitachi were seen as effective and Hitachi were able to evidence timely mobilisation of internal governance arrangements.

1.27 Hitachi and its industry partners are about to start the major programme of work to repair 1247 Class 80X vehicles and a further 487 Class 385 and 395 vehicles. This recovery programme is expected to take place over the next six years. It is structured to minimise service disruption by taking the minimum number of vehicles out of use at any one time, coordinated with other planned maintenance activity on the vehicles.

Next steps

1.28 The industry should conduct further work to identify the reasons for the higher levels of fatigue loading experienced by rolling stock. Since the Hitachi design complied with the applicable industry standards, the industry as a whole should evaluate whether the applicable standards take into account the loads arising from operation on the rail network in Great Britain.

1.29 This industry collaboration will require the involvement of those parties responsible for design, manufacture and maintenance of rolling stock including, but not limited to, Hitachi. RSSB is positioned to manage activities like this within the industry. It should also include input from Network Rail and other infrastructure managers, as the parties responsible for the track infrastructure.

1.30 Hitachi should carry out a formal review of the effectiveness of their processes for welding when the component geometry is more challenging, which should include consideration of whether the existing approach adequately mitigates the risks of a weld with insufficient fusion being accepted.

1.31 Designers of rolling stock should understand the risk posed by SCC and give it specific consideration when proposing the use of 7000 series aluminium components.

1.32 The industry should consider whether a standard for mitigating SCC risk should be developed, as no dedicated standard currently exists.

1.33 The industry should develop a process for responding to similar future cross-industry crisis events, agree terms of reference for meetings and appoint a strong, independent chair who can maintain pace, focus and ensure all voices are heard.

Follow-up activity by ORR

1.34 We acknowledge that the cracking of the Hitachi rolling stock was unexpected and arose from a number of factors. We have not identified any potential breach of health and safety law as the train operators have demonstrated effective management of risks throughout the process through working closely with Hitachi and other organisations. We ask the industry to respond to the next steps we have identified. The industry has established processes for improving standards, managed in particular by RSSB, and we expect that these will be followed promptly. We will follow the industry’s actions through our established channels for oversight.

1.35 Our inspectors will draw on the knowledge acquired from the activities described in this report. This will inform our engagement with applicants for authorisation, in particular where novel materials are being used. Where changes are made to standards these are likely to be incorporated into the harmonised framework for interoperability, and in all events the legal requirements to manage risks stands. We will also promote the incorporation of the lessons into operators’ management systems.

2. Background

When and where cracks were found

2.1 During scheduled maintenance activities on GWR Class 800 and Class 802 units, cracks were found in the area of the bolster close to the yaw damper bracket and anti-roll bar fixing points (see **Figure 2.1** below) on vehicles in these classes.

2.2 On 11 April 2021, GWR issued NIR 3761 in accordance with Railway Industry Standard RIS-8250-RST Reporting High Risk Defects Issue 1, describing the yaw damper cracks. These cracks were initially suspected to result from fatigue, which was subsequently confirmed by the technical investigation. Eight significantly affected trains were withdrawn from service.

2.3 Subsequently on 7 May 2021, cracks were also identified in the vicinity of the weld lines where the lifting plates attach to the vehicle body. Initial assessment concluded that there was a risk of the lifting plates detaching.

2.4 The prevalence of the cracks on many vehicles in both the GWR and LNER fleets resulted in the decision on 8 May 2021 to withdraw all Class 800, 801 and 802 rolling stock from service until each had been checked and a case for safe operation of vehicles with cracks had been made. GWR issued NIR 3766 that described the lifting plate cracks. These cracks were initially suspected to result from stress corrosion cracking (SCC), which was then confirmed by the technical investigation.

The Hitachi AT200/300 trains affected

2.5 The trains, also known as rolling stock, referenced in this report are manufactured by Hitachi. The different classes are variants of the Hitachi A-train family of passenger rolling stock and have common design features. Seven operators have Hitachi trains in their fleet that are in the scope of this report:

(a) London North Eastern Railway

(b) Great Western Railway

(c) TransPennine Express

(d) Hull Trains

(e) SE Trains (Southeastern), who took over L&SER services in October 2021

(f) ScotRail Trains Ltd, who took over Abellio ScotRail services in April 2022

(g) Lumo

2.6 The AT200 designation applies to suburban, commuter and regional trains. In the UK, there is one fleet of AT200 rolling stock, the Class 385. These are three and four-car, 100mph alternating current (AC) electric multiple unit trains operated by ScotRail Trains Ltd for suburban and inter-urban services in the Central Belt of Scotland. The trains are owned by Caledonian Rail Leasing Ltd. They entered service during 2018-2019.

2.7 The AT300 designation is used for intercity high speed and long-distance trains. One type of AT300 train is the Class 395. These are high-speed (140mph) six-car AC/DC electric multiple unit trains, now operated by SE Trains and previously by L&SER, on conventional and high-speed lines in the southeast of England. The trains are owned by Eversholt and were introduced in the years 2007-2009.

2.8 The Intercity Express Programme (IEP) is a DfT initiative for rolling stock to operate intercity services on the Great Western and East Coast Main Lines, replacing the existing fleets from 2017. These AT300 variants are:

(a) Class 800. Five and nine-car intercity diesel & AC electric bi-mode multiple unit trains forming part of the IEP and operated by GWR and LNER on routes in England, Scotland and Wales. The trains are owned by the Agility Trains consortium. They entered service between 2017 and 2019; and

(b) Class 801. Five and nine-car intercity AC electric multiple unit trains forming part of the IEP and operated by LNER on routes in England and Scotland. The trains are owned by the Agility Trains consortium. They entered service between 2019 and 2020.

2.9 Further variants of the AT300 design have been, and continue to be, introduced on related routes although they are not part of the IEP. These include:

(a) Class 802. Five and nine-car intercity diesel & AC electric bi-mode multiple unit trains operated by GWR, Hull Trains and TPE on routes in England, Scotland and Wales. The trains are owned by Angel and Eversholt. They entered service between 2018 and 2020.

(b) Class 803. Five-car intercity AC electric multiple unit trains operated by Lumo between London and Edinburgh. They entered service in 2021, after the discovery of cracks on other fleets, and have been included in the inspection and rectification programmes.

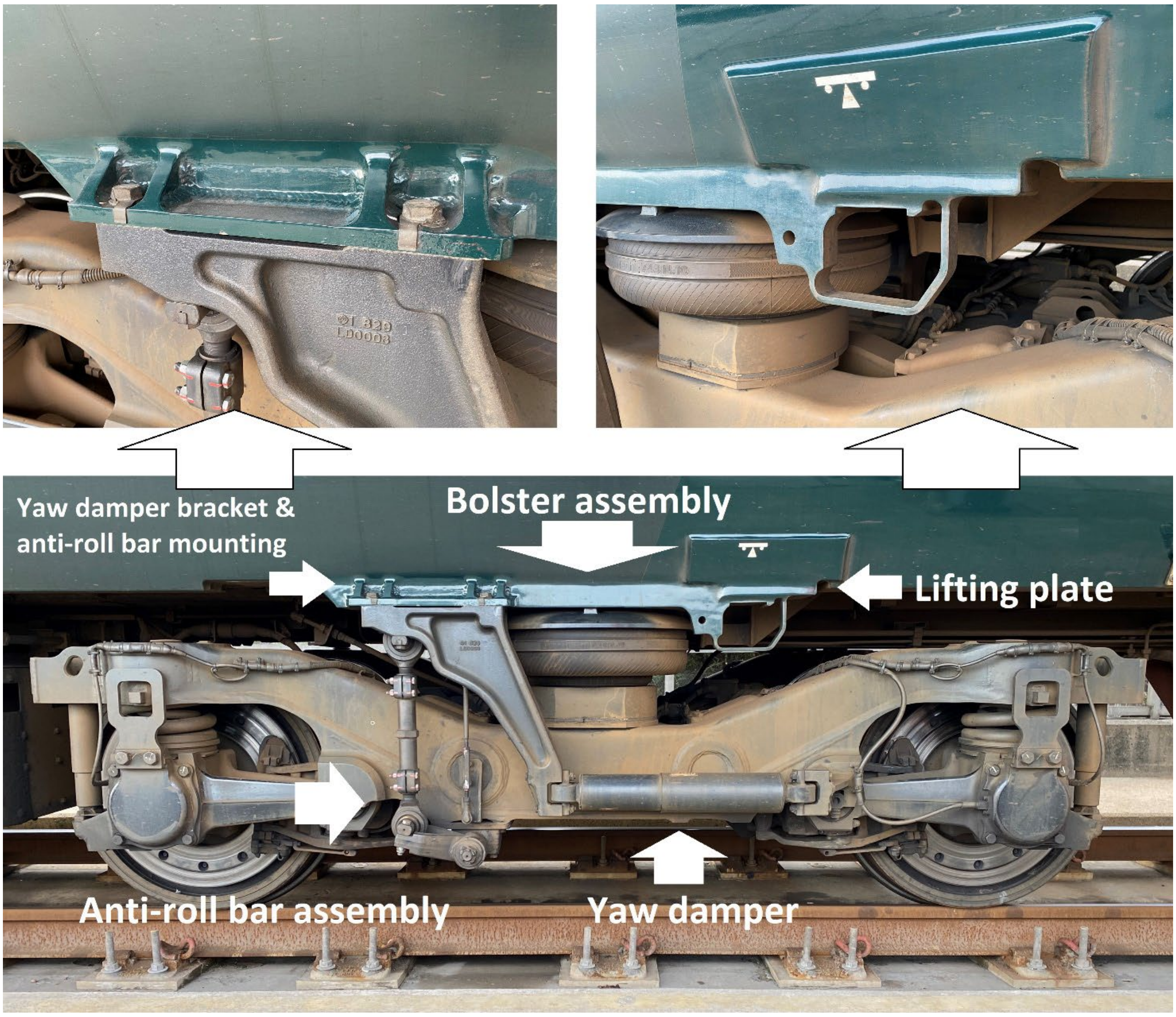
2.10 For clarity, the Class 800, 801, 802 and 803 trains are referred to as Class 80X. They have been designed for 140mph operation but are currently authorised for a maximum speed of 125mph, the highest permitted speed on any of the routes over which they operate.

2.11 The trains are manufactured from a combination of medium strength (6000 series) and high strength (7000 series) aluminium alloys, which Hitachi describes as having a proven track record across various train designs and in other industries, including marine, defence and aerospace. 7000 series aluminium alloys provide the benefit of high strength, enabling weight reduction within the design.

2.12 The car body is assembled by welding together basic aluminium components to form the structure. This uses metal inert gas (MIG) and friction stir welding techniques in line with common manufacturing practices. Any rail vehicle body requires additional strength in the areas where bogie loads are transferred to the bodyshell. This is achieved on the AT200/300 trains by welding additional structural components in the part of the bodyshell above the bogie. This strengthened area is referred to as the bolster.

2.13 **Figure 2.1** below, shows the particular features to note, including the connection points for the anti-roll bar and the yaw damper between body and bogie, and a lifting plate used when the vehicles are being lifted for maintenance.

Figure 2.1 Anti-roll bar & yaw damper connection points, and lifting plate (intermediate vehicle)



Collaboration by Hitachi and operators to return vehicles to service

2.14 On withdrawal of the Class 800, 801 and 802 variants of AT300 rolling stock, Hitachi initiated meetings with stakeholders. Attendees included Hitachi's engineering organisation both in the UK and in Japan, operators, rolling stock companies (RoSCos), Agility Trains, technical consultancies, RSSB, DfT and ORR. These meetings provided a forum for Hitachi to present the activities it was undertaking for feedback and challenge.

2.15 As technical reports and proposals for fleet inspections were developed, they were shared with stakeholders. Many of the meetings were held using video conference facilities, which allowed attendees to join from across the country and for the meetings to be scheduled at times outside of the normal working pattern. When it was required, a physical meeting was arranged at the North Pole maintenance facility in West London, in order to show all the parties involved the cracks and what was being done to evaluate the cracks.

2.16 Initially, efforts were made to define acceptable criteria for both the lifting plate and yaw damper cracks to permit trains to return to service. It became clear that understanding the latter was the more complex of the two areas, however the yaw damper affected a much smaller number of trains. The focus then became the development of criteria to permit vehicles with lifting plate cracks to return to service. Initial proposals included measurement of crack sizes, but the difficulty of measuring crack length quickly and accurately prompted simplification of the process to assess only whether any visible crack was present in each location.

2.17 Hitachi and the train operating company (TOC) engineers made use of independent technical advice, including The Welding Institute (TWI), Ricardo Rail Plc, and Professor Rod Smith of Imperial College London for Hitachi, SNC-Lavalin (SNC-L) for LNER and First Group's central engineering organisation that supports its individual TOCs. RSSB organised workshops to consider the risks and the approach to returning trains to service, as well providing specialist engineering and human factors support.

2.18 The operators understood that their role as safety certificate holders made them responsible for the decision whether to deploy trains. They were able to demonstrate to ORR how they had applied their own safety management systems to assess the risks using information from Hitachi and elsewhere, and to make the decision about the deployment of trains.

2.19 Hitachi developed inspection processes and criteria that permitted trains with cracking within defined limits to return to passenger service from 14 May 2021. The investigation and analysis identified both the potential and actual incidences of related cracking on Class 385 and 395 rolling stock, although their designs are different to the Class 80X. This brought the fleets within the scope of Hitachi's work to address the problems.

How we structured our review

2.20 We structured our evidence collection around two themes:

(a) a technical review, from root cause analysis to rectification and modification progress; and

(b) the capability of the operators' SMS to manage the withdrawal and reinstatement of vehicles.

2.21 Annex 1 includes the terms of reference for the lessons learnt review, as originally issued.

2.22 Our summary of evidence from our technical and SMS capability reviews are set out in the following two sections.

3. Determination of root causes

Evidence collection, investigation and analysis activities

3.1 The technical aspects of the review have been derived predominantly from the activities that took place from 8 May 2021. From this point onwards ORR has been observing, and scrutinising aspects of, the industry's management of the safe operation of AT200/300 rolling stock in the context of fatigue and SCC. This has predominantly drawn on the material arising from:

(a) Hitachi's initial engagement with stakeholders immediately following the withdrawal from service of Class 800, 801 and 802 units on 8 May 2021;

(b) Operators' activities to assess the risks of returning to trains to service with cracks;

(c) Hitachi's Technical Review meeting including TOCs, RoSCos, RSSB, technical consultancies and other parties;

(d) RSSB workshops to review Hitachi's management of the problems; and

(e) the Fleet Recovery Programme Board, established by Hitachi to provide oversight of the programme. The Board is chaired by The Nichols Group (Nichols). Hitachi commissioned Nichols to help manage the programme.

3.2 In order to identify criteria for the reintroduction of the rolling stock to passenger service Hitachi initiated a range of activities to understand the causes of the cracking and the means available for managing it. After achieving the initial aim of returning trains to service the workstreams continued and were strengthened to feed into the ongoing justification for operation of vehicles with cracks and the development of repair processes. These activities were reported to, and scrutinised by, the Technical Review meeting composed of TOCs, RoSCos and other stakeholders with technical expertise and interest in the activities (see below).

3.3 Simple pass/fail visual inspections were implemented to be carried out on all vehicles to provide ongoing reassurance that they were safe for passenger service.

3.4 Evaluation of potential crack growth (propagation) was required in order to support the case for return to service and to optimise inspection frequencies, comparing:

(a) theoretical propagation mechanisms – predictions of worst-case propagation behaviour of the cracks were developed based on analysis of the design; and

(b) measured propagation rates – monitoring of growth of cracks found on vehicles was undertaken to confirm that the theoretical values were conservative.

3.5 'At risk' welds were defined in respect of the level of non-destructive testing (NDT) carried out during welding processes, the technical characteristics and difficulty of the welding activity, and the factor of safety present in the design. This activity identified further areas for inspection.

Structural analysis

3.6 Finite Element Analysis (FEA) is a process of computerised modelling of the behaviour of the complex structure of the vehicle by considering it as many small and simple elements that can each be evaluated, and the results combined in order to predict the behaviour of the overall system.

3.7 Hitachi's principal engineering team at Kasado, Japan, undertook FEA of the affected areas of the vehicles. This activity built on the work undertaken for the original vehicle design by using measured data from vehicle operation. The analysis considered the fatigue performance of the vehicle elements taking into account the variable loads imposed during vehicle operation, notably the anti-roll bar and yaw damper forces. The evaluation included consideration of weld quality and the effects of proposed repair methods. It was refined as further information became available from the range of activities taking place to understand the development of the cracks.

3.8 Ricardo has been commissioned by Hitachi to develop an independent structural model of the bolster for comparison with Hitachi's analysis.

3.9 Ricardo has carried out an analysis of the lifting plates that concluded that the plates will remain attached when four of six welds under consideration are fully cracked, and the remaining two weld areas are significantly reduced below the design specification.

Strain gauge testing

3.10 In order to obtain empirical data for the structural analyses, trainsets were fitted with strain gauges in the areas affected by cracking. These measure the deformation of components under load, and thus allow monitoring of the loads being imposed. The trains were operated on the Great Western and East Coast Main Line routes. The latter are also used by TPE and Hull Trains services.

3.11 The testing was conducted with vehicles in the empty (tare) condition and with ballast on board to simulate being fully loaded (crush laden). The tests were repeated with worn and new wheel profiles. Some testing took place under special arrangements that permitted operation at 137.5mph, 10% faster than the current service speed limit.

3.12 The testing has recorded higher loads from the yaw damper and anti-roll bar than had been expected at the design stage and informed by the testing carried on the first vehicles of the production run.

Short-term repair processes

3.13 Proposals were evaluated for short-term repairs intended to permit trains with cracks to return to service before being subject to the more intrusive permanent repair processes. It was identified that the heat input to the aluminium alloy components of the bodyshell had the potential to degrade the metallurgical properties and therefore any such repairs could only be performed a limited number of times at a given location. A trial repair was carried out on a lifting plate, forming the basis of a submission to stakeholders for acceptance, and further repair procedures were developed for other configurations, including the rectification of the vehicles where bulk material had been removed for detailed crack analysis.

Subsequent activities by RSSB, the Technical Review meeting and the Fleet Recovery Programme Board

3.14 Hitachi asked RSSB to assess the risks associated with the cracks and to consider the actions required for the safe return to service of trains affected by cracks. RSSB organised two workshops. The first involved Hitachi and its technical advisers Ricardo and TWI and sought to assess the potential failure modes and their likelihood of occurring. The second workshop was for the train operators of AT200/300 rolling stock and their train maintainers. Its scope was to review the outcomes of the first workshop, identify hazards relating to the cracks in the jacking plate and to develop a model of the consequences using event trees.

3.15 RSSB was supportive of the approach being taken by Hitachi and did not identify any activities that had been overlooked.

3.16 The RSSB Human Factors team undertook a review of the human factors aspects of Hitachi's processes for carrying out the special checks. Feedback was given and accepted by Hitachi in order to refine the processes.

3.17 The Technical Review meeting was established as a regular forum led by Hitachi where the various activities being undertaken to evaluate the problem and establish a solution could be communicated to a range of stakeholders including TOC, RoSCo, RSSB and technical consultancy representatives. It includes an ongoing issues log where points for resolution can be raised and tracked to completion.

3.18 In July 2021, the Fleet Recovery Programme Board was established to have oversight of the fleet recovery programme, with objectives focusing on the passenger needs and providing an independent advisory board role. It is chaired by The Nichols Group, a consultancy specialising in supporting change.

Fatigue cracking at the yaw damper

3.19 Fatigue is a mechanism whereby cracks develop and grow (propagate) through a material that is subject to cyclic loading, namely the repeated imposition and removal of mechanical stress. This occurs where the load changes in size, alternately opening and closing cracks at a microscopic level, such as the loads imparted by an anti-roll bar as a train moves from a curve to straight track and back onto a curve. For fatigue to occur, the loads must be above a threshold level but are typically much lower than the load required to cause an immediate structural failure of the material. This means that the affected component is initially able to function without breaking, but over time cracks grow and reduce the strength of the component until the remaining uncracked material is not strong enough to take the loads being imparted. At this point, the component fails. The cracks typically initiate at stress concentration points such as those caused by defects in the material, metallurgical features, or the geometric characteristics of the material such as small radius corners.

3.20 For components that are recognised as being at risk of developing cracks during normal operating conditions (such as brake discs) or that are high-risk areas known to be subject to significant fatigue (such as wheelset axles), train systems and components are inspected at suitable intervals to ensure the equipment functions within its acceptable limits. These are in line with the requirements of the original equipment manufacturers, adapted as appropriate to take into account service experience and duty cycles. Typically, brake discs may be inspected for cracks on a monthly basis, and non-destructive testing of wheel set axles undertaken at around 250,000 mile intervals.

3.21 Daily checks of the train include observation for damage caused by impact and damage to paint. As part of Hitachi's maintenance regime a formal visual inspection of underframe-mounted equipment is undertaken to identify damaged paintwork, impact damage, holes, cracks and corrosion on a six-monthly basis. Similarly a visual inspection of the carbody for such issues is carried out on an annual basis. Overhaul provides an opportunity to carry out a more detailed inspection and condition assessment on components or areas of the train that normally have restricted access and gives the opportunity to inspect other areas of the train that are not reasonably capable of inspection during routine maintenance.

3.22 Following the initial identification by Hitachi of cracks in the yaw damper bracket mount on a GWR Class 800 unit, updated safety inspection measures were put in place in agreement with train operating companies (TOCs or Operators) to enable the continued safe operation of the trains. NIR 3761 was raised by GWR in accordance with Railway Industry Standard RIS-8250-RST Reporting High Risk Defects.

3.23 Hitachi's early technical analysis of the yaw damper cracks found on AT300 rolling stock identified that the cracks occurred in the weld material. Hitachi's FEA and subsequent review considered the consequences of a complete failure of the affected welds which run longitudinally. It concluded that there would be no increased stresses imposed on the transverse welds and no risk of the cracks propagating into the rest of the welded structure. A crack of 620mm could therefore be tolerated. Further analysis concluded that the stress levels within the weld material itself would remain below the value for immediate failure of the weld itself to occur for crack lengths of up to 280mm. On the basis of these analyses, and informed by the crack characteristics observed up that point, Hitachi proposed a maximum permitted crack length of 200mm in the affected area for the rolling stock to remain in service.

3.24 The TOCs made their individual decisions to return to service vehicles with cracks that met the criteria. LNER commissioned a technical review from SNC-L which questioned the robustness of Hitachi's assumptions about crack propagation within the weld and recommended a more conservative crack length limit value of 50mm. Hitachi produced an additional check procedure for LNER rolling stock to respect this. Further analysis resulted in the limit for LNER trains being extended to 150mm, and this value continues to be reviewed.

3.25 The cracks were investigated using NDT methods and by removing metal from the weld to observe the material characteristics within the body of the weld, referred to as ‘excavation’. Some porosity was found, where small bubbles are present in the weld metal. Hitachi quoted advice from TWI that the porosity is not uncommon in any welded structure and does not denote a likely failure. However, the excavation also exposed voids and areas of the joint without weld fusion. This has the potential to affect the strength of the joint. Hitachi concluded that the weld under examination was likely to prove more challenging to fuse fully due to the geometry of the yaw damper bolster area.

3.26 The purpose of this analysis was to provide a basis for the safe reintroduction to service of vehicles with fatigue cracks at yaw damper bracket / anti-roll bar end of the bolster while the technical investigations continued and proposals for short- and long-term repair were developed.

Relevant design requirements and standards

3.27 Hitachi designed its rolling stock against:

(a) the relevant Technical Specifications for Interoperability (TSIs) and the notified national technical rules (NNTRs), in each case as applicable at the time of Authorisation to Place in Service (APIS);

(b) the Train Technical Specification (TTS) specified by the Department for Transport; and

(c) the requirements for electrical and physical compatibility with Network Rail infrastructure.

Demonstration of compliance with these requirements formed part of Hitachi’s design approval process.

3.28 The TTS sets out the customer’s requirements for the train. These included requirements such as the speed of the train and the level of ride comfort. The yaw damper and anti-roll bar are suspension components that affect vehicle stability at maximum speed, and passenger ride comfort.

3.29 The maximum loads transmitted to the body are, in part, driven by the characteristics and specifications of the suspension. These were selected to achieve vehicle stability and ride comfort requirements in accordance with both the requirements of the TTS, and with standards GMRT2141 and BS EN 14363, which define acceptable running dynamics performance and vehicle stability on the track.

3.30 The loads transmitted to the body by the anti-roll bar were calculated from vehicle mass, vehicle accelerations and the spring properties of the bar. The first and second of these factors were defined to achieve various design requirements including vehicle stability and ride comfort, in accordance with the requirements of the TTS. The third factor was defined to manage the space envelope occupied by the vehicles and thus achieve compatibility with the fixed elements of the railway infrastructure – to ensure the vehicles don't come into contact with platforms, bridges etc. This predominantly relates to vehicle gauging and pantograph sway requirements, in accordance with standard GMRT2149, which was applicable at the time. The specification of the bar also affects vehicle stability and ride comfort

3.31 The applicable standard for fatigue strength for the Class 385 and Class 80X fleets was Commission Regulation (EU) No. 1302/2014 Locomotives and Passenger Rolling Stock TSI, as amended by Commission Regulation (EU) No. 2016/919 (referred to as the LOC&PAS TSI). Requirements for fatigue strength are defined in the TSI by reference to BS EN 12663-1:2010 Railway Applications – Structural Requirements of Railway Vehicle Bodies.

3.32 In designing a vehicle, the different – and sometimes conflicting – requirements of the specification have to be reconciled. A vehicle that is very stable at high speeds may be uncomfortable for passengers at low speeds. A suspension design that is optimised when the vehicle is fully loaded may not meet comfort standards when only a few seats are occupied.

3.33 Hitachi's compliance with the TSI and NNTRs requirements was checked and supported by the applicable Notified Body (NoBo) or Designated Body (DeBo), in accordance with the interoperability requirements that must be met before authorisation can be given for placing in service (APIS).

3.34 In addition, Hitachi's welding procedures have been periodically audited by TWI for compliance with BS EN ISO 15614, which covers the specification and qualification of welding procedures for metallic materials. Hitachi's procedures were also, in some cases, audited by the NoBo as part of the quality management system assessment forming part of the evidence for APIS.

Testing of rolling stock

3.35 When first built the Class 80X units were tested to validate design assumptions. Acceleration measurements of the bogie and carbody were carried out. These proved to be within the design values and Hitachi concluded that stresses and loads would therefore also be within the design values.

3.36 Hitachi designed the rolling stock based on the applicable design requirements and design standards, as explained above. Fatigue testing is not required by the standards unless the FEA identifies ‘critical uncertainties’, which it did not in this case. Hitachi have advised that such testing would also not have reflected normal industry practice. The NoBo, SNC-L, verified Hitachi’s compliance with the relevant standard and issued a Certificate of Verification.

3.37 Hitachi took wheel wear into account (including relevant standards, for example BS EN 14363 on running characteristics and GMRT2466 on wheelsets) when setting its design value margins. These margins were based on an assumed degree of wheel wear which represented not only the relevant industry standards but are also consistent with the degree of wheel wear that has actually been observed on Class 80X trains.

3.38 It is noted that the track technical data provided to Hitachi as part of the TTS was provided for the purpose of ensuring ride quality. It was not intended to inform the structural design of the rolling stock.

3.39 As part of its investigation into the cracking, Hitachi has undertaken strain gauge testing on the East Coast and Great Western main lines, and:

(a) The results indicate yaw damper forces that are higher than the design values.

(b) The results also indicate ARB loads that are higher than the design values. At the design stage Hitachi did not specify any additional loads caused by the ARB, having used the loads caused by the vehicle acceleration set out in standard BS EN 12663 of +/-0.15G as an input.

3.40 Engineering practice deems that fatigue life is acceptable if a material can withstand up to 10^7 cycles at peak load and Hitachi’s design relied on this principle. It is noted that the actual fatigue experienced by the vehicle bodyshell consists of a range of loads with differing frequencies and magnitudes and the accepted 10^7 figure represents a simplification of an overall level of fatigue which is used to enable fatigue calculations to be undertaken. However, Hitachi explained to ORR that the recently collected data suggests the vehicles are exposed to a higher level of fatigue (equivalent to more than 10^7 cycles at peak load) than that allowed for in the design and went on to say that further investigation is required to understand the causes of this, which might include wheel wear and track quality.

3.41 In respect of wheel wear as a factor in the increased level of fatigue loading, Hitachi referred to the initial testing of the Class 80X trains, where acceleration measurements were taken from vehicles with new wheels. Hitachi considered that these accelerations were sufficiently within the design values that there was a satisfactory margin to accommodate the potential impact of wheel wear.

3.42 Track characteristics inevitably affect loads experienced in service. Hitachi is therefore considering whether the track specification is the reason that the load values observed during recent testing exceed those defined by the design standard. This includes assessing the potential relevance of factors such as rail roughness; the characteristics of gaps, points / switches and crossings; and the profile of the rail head.

3.43 Hitachi is continuing to consider whether there may be other features of the operational environment that may be a cause of higher observed load values.

Root causes of fatigue cracking at the yaw damper

3.44 The conclusions of Hitachi's technical review are that:

- fatigue cracking was caused by the area of the bolster subject to yaw damper and ARB loads experiencing a greater fatigue load than that allowed for in the original design.

- the degree of fusion in the weld between the bolster and the car body was likely to be a factor in relation to the emergence of the cracking.

3.45 The applicable standards define the accelerations to be taken into account when designing rolling stock but do not directly mandate the strength of components. Other rolling stock built in conformance to these standards has not presented similar problems. There is no definitive reason identified for the in-service fatigue loads to exceed those defined in the standard. Potential factors that have been suggested include wheel wear and track specification. Hitachi's testing has identified a difference in loads arising from new and worn wheel profiles. No work has yet been undertaken to evaluate whether the characteristics of track on the routes over which Class 80X rolling stock operate differ from those assumed by the bodyshell fatigue standard. No grounds have been presented for asserting that the condition of the track on the routes was anything other than compliant with the applicable standards and therefore conformed to its specification.

3.46 Since the design basis was aligned to the applicable industry standards, the industry as a whole should consider taking steps to evaluate whether applicable standards are appropriately and adequately defined to take into account the loads arising from operation over track in Great Britain.

3.47 Hitachi has identified that the geometry of the components prior to welding contributed to the poor weld fusion identified above.

Next steps – standards for fatigue

The industry should conduct further work to identify the reasons for the higher levels of fatigue loading experienced by rolling stock. Since the Hitachi design complied with the applicable industry standards, the industry as a whole should evaluate whether the applicable standards take into account the loads arising from operation on the rail network in Great Britain.

This industry collaboration will require the involvement of those parties responsible for design, manufacture and maintenance of rolling stock including, but not limited to, Hitachi. RSSB is positioned to manage activities like this within the industry. It should also include input from Network Rail and other infrastructure managers, as the parties responsible for the track infrastructure.

Next steps – assurance of weld quality

Hitachi should carry out a formal review of the effectiveness of their processes for welding when the component geometry is more challenging, which should include consideration of whether the existing approach adequately mitigates the risks of a weld with insufficient fusion being accepted.

Stress corrosion cracking in the jacking plate

3.48 SCC is a mechanism whereby cracks develop in susceptible materials when they are exposed to a specific corrosive environment while subject to mechanical stress. The stresses involved in SCC are usually significantly lower than those involved in mechanisms where the stress alone is sufficient to cause cracking, thus making certain materials susceptible to cracking under conditions where the mechanical design would otherwise be sufficient to prevent it. SCC has been likened to the fire triangle where fuel, heat and oxygen must all be present for combustion to take place; if any of the three elements are missing then there is no fire. In the case of SCC the three elements are:

(a) the susceptibility of the material;

(b) the specific corrosive environment to which the material is susceptible; and

(c) mechanical stress in the material.

3.49 The susceptible material in this case is the 7000 series aluminium alloy that has been used in specific parts of the AT200/300 vehicle bodyshells. The corrosive environment for the material is one containing chlorides, which is commonly encountered in the UK – particularly in coastal areas and during cold weather when salt-containing products are used to manage snow and ice. Stress may be present in various forms, but notably can be introduced during the welding process when fabricating assemblies containing the susceptible material.

3.50 In May 2021, during visual inspections of yaw damper bracket mounts, cracks were found in an adjoining area on the lifting plate of a Class 800 train. Inspection of lifting plates on other Class 80X units identified additional affected units, which were then withheld from passenger service. A National Incident Report was again raised by GWR (NIR 3766).

3.51 Hitachi drew on specialist advice from TWI to evaluate the lifting plate cracks, updating its analysis as the investigation continued. The investigation confirmed that the crack mechanism in the lifting plate is SCC.

3.52 It identified that the 7000 series aluminium alloy used in the lifting plate has greater susceptibility to SCC than other aluminium alloys also used in the construction of the vehicles. This susceptibility can be heightened by thermal effects giving rise to metallurgical changes within the alloy, by the alignment of the grain within the material, and by machining of the rolled aluminium alloy sections to expose grain boundaries.

3.53 The specific corrosive environment for the alloy is considered to be endemic in the UK, arising from high humidity, rain and seawater exposure.

3.54 The stress input into the SCC mechanism was identified as arising from residual welding stresses. While the bolster assembly was subject to stress-relieving processes following welding, the lifting plate itself was not and therefore retained inherent residual stresses. Service-induced loads in this area were considered to be at such a low level as to be disregarded for the SCC mechanism.

3.55 The growth characteristics of SCC make it difficult to identify when the cracking occurred, but the initiation was thought most likely to have occurred at the manufacturing stage. The cracking continued to develop over time, driven by the stresses present in the material and the presence of an atmosphere to which the 7000 series aluminium alloy was susceptible. Hitachi and its technical advisers have identified a correlation between the extent of cracking and the age of a train, but not the mileage the train has covered.

3.56 The growth mechanism is dependent on the grain structure of the material, which means that propagation beyond the material of the plate itself is unlikely. Adjacent weld areas are subject to low stress and composed of a different type of aluminium alloy which means the factors necessary for SCC to occur do not exist outside of the specifically vulnerable areas.

Mitigation of SCC risk in design, manufacturing and testing

3.57 There was no specific reference to SCC mitigation in the relevant and applicable TSIs and NNTRs at the time of APIS in relation to the Class 385 or Class 80X fleets. There are also currently no relevant and applicable National Technical Specification Notices (NTSNs) or National Technical Rules (NTRs) addressing SCC. Hitachi recognises that the industry should consider developing guidance in relation to SCC, particularly regarding the susceptibility of the different aluminium alloys.

3.58 Hitachi drew on its long experience with the Shinkansen and Class 395 fleets when considering the risks of SCC in the context of its design of the Class 80X. At the time of the Class 385 and Class 80X design there had been no reports of SCC on the Shinkansen (over a period of at least 30 years) or Class 395, so it was considered that the Shinkansen and Class 395 provided an appropriate design benchmark.

3.59 Peening and weld buttering are widely-accepted methods for mitigating SCC risk, and they are being used as part of the ongoing repair work described below. However, since the FEA (paragraph 3.10 above) and the initial strain gauge testing (paragraph 3.14 above) of the Class 80X trains did not indicate high levels of stress in relevant components, Hitachi concluded that peening and weld buttering of all such components was unnecessary. Hitachi did however apply peening and weld buttering to areas of the train which were expected to experience high stress (for example, the centre sill stiffeners near the coupler support plate).

3.60 Hitachi applied a paint coating to help to mitigate the risk of SCC on the AT200/300 fleets. However, it is noted that paint provides only limited protection against SCC.

Surface treatments to protect against SCC

3.61 Treatment of the SCC-susceptible areas was evaluated, having identified that paint treatment was not in all cases effective in preventing SCC in the UK environment. Hitachi had already established the potential to use:

(a) ‘peening’ – residual stresses in welded components are modified by a process of mechanical treatment to remove the stress that must be present for SCC to occur; and

(b) ‘weld buttering’ – a layer of weld material is applied to the ‘at risk’ surface of the parent metal to prevent its exposure to potentially corrosive atmospheres.

Considerations concerning 7000 series aluminium alloy

3.62 The aluminium for the AT200/300 fleets was provided by multiple suppliers. These suppliers are well-known aluminium alloy suppliers in Japan, and they provide aluminium alloy to other Japanese rolling stock manufacturers and other industries. They supply aluminium complying with the relevant specification, being JIS H4100 and JIS H4000 (which are equivalent to European standard BS EN 573-3). The suppliers test the chemical composition and strength of their aluminium alloys before they are supplied to Hitachi; and they provide Hitachi with a Certificate of Conformity with each delivery.

3.63 As part of its technical investigation, TWI has confirmed that the metallurgical composition of the components removed during its investigation is consistent with the relevant specification.

3.64 7000 series aluminium is alloyed with zinc and magnesium, sometimes with copper additions, producing higher strength wrought aluminium alloys. These can beneficially be used in the car body design instead of weaker alloys, with the benefit of reducing the total weight of the vehicle. According to information provided by TWI, these additions can cause the alloy to be susceptible to anodic dissolution or hydrogen absorption. This results in SCC in reasonably benign environments, such as the chloride-containing environments common on the railway in winter or near the coast.

3.65 The microstructure of the alloy is key to determining its susceptibility to SCC. Metallic bodies are composed of microscopic grains within which the atoms are arranged regularly. The interatomic forces are lower at the boundaries of the grains because of misalignment between the ordered structures within the body of the grains. For this reason cracking tends to occur at grain boundaries. The direction in which forces apply is called the working plane, and it is the direction in which the alloy is most susceptible to cracking. The combination of exposure of the grain structure to the corrosive atmosphere, environmental conditions and stresses lead to this susceptibility.

3.66 7000 series aluminium is used in three forms, the SCC-related risks of which have been identified in Hitachi's analysis.

(a) Extruded aluminium. The extrusion process means that exposure of the grain structure only occurs at the ends of a section, and sections are protected from SCC if the ends are welded. The analysis identified that this was typically the case for extruded aluminium used throughout the structure.

(b) Aluminium plates. These are at the greatest risk of SCC. The risk is considered to be lower in plates of less than 10mm thickness, where the residual stresses are lower.

(c) Forged parts. This is only found in the axle box radial arms on the bogie, for which the SCC risk was deemed low.

3.67 TWI has identified the factors to consider in order to avoid SCC in aluminium alloys:

(a) Avoid the use of 7000 series aluminium alloys where lower strength alloys may be used. For example, lower strength solid solution strengthened 5000 series alloys are much more resistant to SCC.

(b) Avoid exposure to the environment of through-thickness planes in the grain structure.

(c) Exposed through-thickness planes may be protected using weld buttering.

(d) Paint is often insufficiently reliable as a protection method against SCC, while the literature data is contradictory regarding the effectiveness of peening.

3.68 Hitachi worked with Ricardo Rail and TWI to assess the risks to components where 7000 series aluminium has been identified in the AT200 and AT300 rolling stock. Hitachi identified 16 areas in the Class 385 vehicles and 17 in the Class 80X and 395 vehicles which are deemed susceptible to SCC.

3.69 Hitachi conducts SCC risk assessment on a case-specific basis. Hitachi notes that the extent to which peening and weld buttering will be used as part of the final repair solutions for the rolling stock is itself subject to ongoing analysis.

Pre-emptive risk assessment

3.70 Having identified the characteristics that appeared to have given rise to cracking, the design of the rest of the vehicles was evaluated to find other areas where those characteristics were also present. This considered experience with Class 395 rolling stock.

3.71 SCC was identified as possible at several locations on AT200/300 vehicles. A 10% fleet check was carried out to assess the areas at risk and concluded that the following 'at risk' areas were not exhibiting SCC currently:

(a) Centre pin base plate.

(b) Centre sill bracket.

(c) Main transformer beam plate.

(d) Yaw damper bracket / anti-roll bar stiffener.

3.72 SCC was identified at the following locations:

(a) Coupler support plates.

(b) Lifting plate (already identified).

(c) Obstacle deflector bracket (already identified on Class 395).

3.73 As a result the coupler support plates were added to the scope of the activities to manage the cracking issues.

Root causes of stress corrosion cracking in the jacking plate

3.74 The conclusion of the technical review is that SCC was caused by the use of 7000 series aluminium, and in particular plates exceeding 10mm in thickness. Thicker material is particularly susceptible to SCC in a typical rail environment in the UK, in circumstances where residual welding stresses are present.

3.75 It is noted that existing industry standards do not make provision for this risk, which may have contributed to it not being accounted for in the design, either through avoiding use of the susceptible alloys, or through additional protective measures such as peening or weld buttering.

Next steps – use of 7000 series aluminium

Designers of rolling stock should understand the risk posed by SCC and give it specific consideration when proposing the use of 7000 series aluminium components, including:

- Avoiding using 7000 series aluminium on components that are likely to be exposed to mildly corrosive atmospheres when residual weld stresses are present.
- Where 7000 series aluminium is to be used in plate components, thinner plates are preferable (less than 10mm thickness).
- Where 7000 series aluminium is to be used in extruded form, take steps to ensure protection of exposed grain structure at the ends of the extruded element, such as welding.
- Where 7000 series aluminium is to be used, take steps to mitigate residual weld stresses.
- Where 7000 series aluminium is to be used, employ surface protection such as weld buttering on all components that present a risk of susceptibility to SCC.
- Avoid relying on paint as a protective measure against SCC, since it is noted to be of limited effect. It is noted that Hitachi proposes further work on the effectiveness of protective coatings.
- While peening has been proposed as a mitigation measure, TWI identifies that published literature disputes its effectiveness.

Next steps – industry standard for SCC risk

The industry should consider whether a standard for mitigating SCC risk should be developed, as no dedicated standard currently exists.

4. Examination of industry response

Safety Management System capability review approach

4.1 Evidence was gathered from each train operating company affected. A series of questions exploring those areas considered by this review was initially put to each operator as a basis for discussion. Meetings were held with the relevant Fleet Engineers, Directors / Professional Heads of Engineering and Heads of Safety for all but one of the operators. Following the publication of our interim report, we engaged with Directors / Professional Heads of Engineering and/or Heads of Safety for each operator to provide updated information and clarify enquiries.

4.2 Where our enquires highlighted further commitments or ongoing work, we made subsequent requests for information or documentation, which all operators assisted with.

4.3 ORR requested sight of risk assessments for returning trains to passenger service from the operators with affected trains. The risk assessments were reviewed as part of ORR's oversight of the initial return of trains to service, but also as part of this review.

4.4 A desktop review was conducted of each operator's safety management system (SMS) signposting documents, which ORR holds as part of an operator's application for a safety certificate to run on the British railway network. The review considered whether the operator's SMS was set up to manage whole fleet withdrawals due to safety concerns.

4.5 We have anonymised responses and endeavour to present their evidence in a way that we can relay the information without it identifying individual operators.

4.6 We also engaged Hitachi and vehicle owners to assist our enquiries and achieve some of the outstanding aims in our interim report.

Identification of the problem

4.7 London & South Eastern Railway (L&SER) issued NIR 3662 in March 2020 to advise of the discovery of cracks in an obstacle deflector support bracket on a Class 395 unit. The cracks were identified while repairs were taking place following an incident that caused damage to the nose cone. Further investigation found that cracks were also present on other units. Initial analysis concluded that the bracket remained secure. Following further analysis, Hitachi concluded that the impact force requirements of the assembly were not compromised. The investigation identified that the principal cause of the cracking was SCC. A modified bracket was developed for implementation across the fleet, and to date has been installed on three units (six vehicles).

4.8 In April 2021, whilst undertaking visual inspections in line with regular maintenance procedures, Hitachi's maintenance team detected what appeared to be hairline cracks in the paintwork of GWR AT300 rolling stock in the vicinity of the anti-roll bar and yaw damper bracket attachments to the bolster. These were initially thought to be light surface scoring, but monitoring indicated that the cracks had substantial depth. An inspection programme using eddy current testing (ECT) was put in place and affected rolling stock was withdrawn from service, initially affecting eight units. NIR 3761 was issued by GWR.

4.9 On 7 May 2021, during visual inspections of yaw damper bracket mounts, cracks were found in an adjoining area along the weld line where the lifting plates are welded to the car body at the lifting points on GWR AT300 rolling stock. Concerns about the potential for the cracks to result in complete structural failure of the affected area resulted in the decision to withdraw all Class 800, 801 and 802 rolling stock from service pending inspection. All trains with cracks in the lifting plate remained out of service awaiting further analysis. NIR 3766 was issued by GWR.

4.10 Unexpected cracks or other damage were checked for while undertaking scheduled maintenance work on the rolling stock, without there being a specific schedule of areas to inspect. This appears to be appropriate in the context of a compliant design and is normal practice in the rail sector. Nonetheless, Hitachi's maintenance staff identified the cracks before they developed to a level that resulted in harm, and subsequent analysis has provided confirmation that action was taken well before any significant risk had developed of a failure that could compromise the safe operation of the rolling stock.

4.11 Following the discovery of the cracks in the lifting plates, Hitachi assessed the potential for SCC to occur in other areas of the AT200/300 rolling stock. A number of areas met criteria derived from analysis of the factors relevant to the cracks in the lifting plates. Sample checks were implemented on all fleets, covering the anti-roll bar bracket and stiffener, the obstacle deflector bracket, the centre sill bracket, the centre pin base plate and the coupler support plate. Cracks were found in coupler support plates, which were added to the scope of the investigation and rectification work.

Initial notification and actions

4.12 All operators reported that by 05:00 on 8 May 2021, their 24-hour/7-day control centres had received notification by Hitachi Maintenance Control of the lifting plate cracking. The whole fleet was withdrawn from service in order for further checks to be made. Whilst detrimental to operations, this was seen as a sensible safety decision.

4.13 Operators confirmed that the method of notification was in line with what they expected, triggering internal processes to ensure the right people in their organisations were alerted, by telephone or notifications through internal 'on-call' arrangements.

4.14 Hitachi also provided the same early notification of the issue with the AT300 vehicles to operators of other Hitachi trains (Class 385 and 395). The equivalent area of the Class 395 rolling stock is of a significantly different design, and L&SER agreed with Hitachi that action was not required.

4.15 Operators reported that the early notification by Hitachi enabled them to initiate their emergency plans early on 8 May 2021 and put in place arrangements for mitigating the significant impact of the decision to stand down the fleet. These arrangements included identifying alternative rolling stock, updating social media for customers, arranging bus replacement services and providing frontline staff information to manage passengers.

4.16 Over the weekend of 7/8 May 2021, Hitachi initiated and chaired a pan-industry forum attended by all the operators, rolling stock owners and other stakeholders, including ORR and DfT.

4.17 Overall, operators felt this approach managed their expectations and allowed Hitachi to get on with the problem-solving in the interim. However, ORR observed that this did put further pressure on Hitachi to facilitate and chair the meetings. One operator commented that meetings fill of engineers resulted in a lot of very good questions being asked, but not enough decisions being made. A strong independent chair would have maintained pace, focus and ensured all voices were heard.

4.18 One operator deployed their engineering team to look at the cracks and noted that:

- the lifting plate cracks were different to the fatigue cracking in the yaw dampers;
- trains had probably been running for some time with lifting plate cracks; and
- no components had actually fallen off.

4.19 This operator considered the safety risk to be low and that it would be safe to return the trains to service whilst further investigation and analysis took place to understand the issue, with continued monitoring of the cracks in the interim. They shared this view at the update meetings chaired by Hitachi over the weekend of 7/8 May 2021.

4.20 We consider that Hitachi provided prompt notification of the matters identified on 7 May 2021, raising this through the expected channels with operators, allowing those operators to initiate their emergency response plans, and put in place appropriate activities to mitigate the immediate withdrawal of the fleet.

Assessment of the safety risk

4.21 Any vehicle found to have a yaw damper crack was withdrawn from service pending analysis and development of criteria to permit operation with cracks. Reasonably foreseeable outcomes of uncontrolled cracking in this area are detachment of components from the train, with the potential to strike persons or infrastructure, and loss of dynamic stability with the potential to result in derailment.

4.22 The scale of the cracking in the lifting plates led to the withdrawal of all Class 800, 801 and 802 vehicles as there could be no confidence that vehicles that had not been checked did not have cracks, and the cracks appeared to have the potential to result in detachment of part of the vehicle. Vehicles that were subsequently checked and found to have cracks remained withdrawn. The principal safety concern was the possibility of a lifting plate becoming detached from a vehicle at high speed and striking persons or infrastructure. Detachment was considered unlikely to affect the safe operation of the train itself.

4.23 Hitachi carried out a technical analysis of the lifting plate cracks, drawing on expertise from TWI. This justified the operation of vehicles with cracks in up to two of the three visible faces of the lifting plate but continued to prohibit operation with other cracks in the bolster area. This was supported by engineering fleet checks of the lifting plate and anti-roll bar / yaw damper bracket bolster areas. Hitachi commissioned Ricardo to carry out an independent review of its work; Ricardo supported Hitachi's conclusions. Hitachi engaged with stakeholders during this process, including the affected TOCs and RoSCos. The TOCs used the Hitachi material to inform the risk assessments they carried out before returning the vehicles to service. LNER commissioned further third-party review from SNC-L, which did not reject Hitachi's approach.

4.24 Hitachi carried out FEA modelling of the affected area of the vehicle and made a case that safe operation was possible with yaw damper crack lengths of up to 200mm. Alongside this, Hitachi developed special checks for visual and NDT inspection of the area. Using Hitachi's material to support their own risk assessments, the TOCs made their individual decisions to return to service vehicles with cracks that met the criteria. LNER commissioned a technical review from SNC-L, which recommended a more conservative crack length limit value of 50mm. Hitachi produced a separate fleet check procedure for LNER rolling stock to respect this. Further analysis resulted in the limit for LNER trains being extended to 150mm, and this value continues to be reviewed.

4.25 Hitachi evaluated the stress in the two types of coupler support plate and considered the way the assembly was welded to the body structure and secured with bolts to the coupler assembly. The risks were mitigated by visual inspection backed up by NDT and torque checks of the associated bolts. The TOCs made use of the Hitachi material in their own risk assessments to support operation with cracks in the support plates.

4.26 Hitachi carried out a technical analysis of obstacle deflector cracks in 2020 following the initial identification of cracking on the Class 395 fleet. This was able to provide a basis for permitting continued operation with similar cracks on other AT200/300 vehicles.

Withdrawal of the trains from service

4.27 Concerns about the potential for the cracks to result in complete structural failure of the affected area resulted in the decision to withdraw all AT300 rolling stock from service pending analysis. Trains that were subsequently inspected and found to have no cracks were returned to service. Trains with any cracks remained out of service until the safety justification for the cracks in question had been produced.

Return of the trains to service

4.28 Initial return of trains to service was based on a fleet check defining an ongoing inspection regime for both the yaw damper area of the bolster, and the lifting plate. The criteria permitted trains to operate with lifting plate cracks present but not yaw damper cracks.

4.29 Hitachi commissioned Ricardo to review its engineering decisions. Ricardo supported Hitachi's proposals to permit operation with cracks in the lifting plate.

4.30 Further investigation and assessment of the risks relating to the cracks in the yaw damper area resulted in simple crack length limit criteria being defined for these cracks, with the intention of permitting additional trains to return to service.

4.31 The TOCs carried out their own engineering assessment of the material provided to them by Hitachi before accepting the case for the return to service. Fleet checks for the yaw damper and anti-roll bar bolster area were developed, covering the GWR, Hull Trains and TPE fleets with a maximum crack length of 200mm, and a limit of 50mm for the LNER fleet.

4.32 As Abellio ScotRail had found no yaw damper cracks, no limit criteria were defined for the Class 385 units and the existing requirement to withdraw any vehicle with a crack in this area remained.

Refinement of inspection processes

Inspection methodologies

4.33 Both yaw damper and lifting plate cracks were initially identified when they became visible to the naked eye. This required the cracks to be present on the surface of the material and to be sufficiently large to be observed. Where a crack was observed in this way it was further evaluated by removing paint and using test methodologies that were developed to improve the ability to identify cracks:

4.34 Dye penetrant crack detection uses a visible dye to penetrate a crack that is present on the surface of the material, which makes it easier to assess. However, it can still be difficult to be precise about the extent of the crack, and it was found that there was variability in the measurement of crack sizes. Furthermore there is a tendency for the dye penetrant itself to leave a residue on the walls of the crack, making it appear smaller on subsequent measurement. The method is only applicable to cracks that have broken the visible surface of the material. In many cases the fatigue cracks were propagating from discontinuities in the welds below the surface, meaning the process was not able to give confidence that the true extent of cracks was being assessed.

4.35 Other technologies exist that non-destructively test for sub-surface cracks, and Hitachi worked with suppliers to identify how they could be applied.

4.36 Eddy current inspection is an electromagnetic non-destructive testing process that uses the disturbance of induced eddy currents introduced by applying an alternating magnetic field to the body of metal under consideration. The principal application of the methodology is to find cracks breaking the surface of the material, as it is not effective for cracks that do not come close to the material surface. For the inspection of the Hitachi vehicles the maximum effective depth is 3mm. Eddy current testing was introduced to provide more repeatable measurement of cracks that had been identified using the visual techniques.

4.37 High Frequency Eddy Current testing optimises the characteristics of the alternating magnetic field in order to obtain information about cracks and other features below the surface of the material. It was introduced to the inspection regime to obtain enhanced detail in response to cracks found by the fleet checks, and subsequently used in conjunction with other techniques.

4.38 Hitachi has worked with Intertek to develop Low Frequency Eddy Current Volumetric NDT Weld Inspection, an eddy current technique that can identify features present at up to 7mm below the surface of the material. This achieves more effective identification of sub-surface crack propagation but has not yet been implemented across all fleets.

Destructive examination

4.39 Destructive examination was carried out on cracked areas of two vehicles. The bulk material of welds that contained cracks was removed in its entirety to allow laboratory examination of the cracks, including scanning electron microscopic analysis of the microstructure on the fracture face, measurement and analysis of the crack geometry, and chemical analysis of the constituents of the aluminium alloy.

4.40 The examination of the cracks suggested that the extent of the fusion of the weld metal to the vehicle body structure was small. This meant that the loads were being transmitted through a relatively small area. This is likely to be significant as a cause of cracking. Hitachi's analysis identified that the design standards include provisions for weld imperfections, making allowances for difficulties in carrying out the weld arising from the geometrical characteristics of the material, the access to the working area, and the heat diffusion characteristics.

Data analysis

4.41 The findings of the fleet checks were recorded in order to monitor the evolution of the cracks on individual vehicles and the development of cracks across the various fleets. The data recorded crack lengths identified on each inspection, and this was used to evaluate crack growth rate for trains that remained in service.

4.42 The majority of data related to GWR and LNER fleets as the factors of fleet sizes and the longer period in service meant that most of the cracks observed were on these vehicles.

4.43 The data covered:

- development of fatigue cracks at the yaw damper bracket / anti-roll bar fixing area.
- number of faces cracked on lifting plates.
- presence of cracks in coupler support plates.

4.44 Fleet check data was shared with the Technical Review meeting and this is ongoing at the time of writing. The data was used to inform the rectification programme as a source of empirical data on the development of cracks and to identify the vehicles for which the modification should be prioritised.

4.45 As the fleet check data became more comprehensive it was used to review previous engineering decisions:

- TWI fatigue crack analysis to determine the maximum crack length for a vehicle to remain in service, and to estimate the remaining life for any detected cracks.
- Ricardo review of crack criteria for lifting plates with the intention of extending the inspection intervals, potentially permitting the checks to be carried out only after lifting plates have been used for a lifting operation.
- Ricardo review of previous work to define maximum fatigue crack length.

Interim repair

4.46 While developing a fleet-wide modification to implement a design that would no longer be susceptible to the crack mechanisms, Hitachi also carried out repairs that allowed vehicles with cracks exceeding maximum dimensions to return to service. The repairs to areas with fatigue cracks involved removing cracked material and replacing it with fresh weld metal. This returned the vehicles to the original design condition, which meant that they remained at risk of developing further fatigue cracks and therefore required continuing inspection in the same way as the rest of the fleet.

4.47 Vehicles with SCC in the lifting plate area that failed the inspection criteria were subject to weld repair.

Long term technical solutions

Class 80X

4.48 Hitachi evaluated the management of fatigue cracking and SCC risk on Class 80X, Class 385 and Class 395 rolling stock, identifying the areas where 7000 series aluminium has been used, whether action is required, and what it should be in each case.

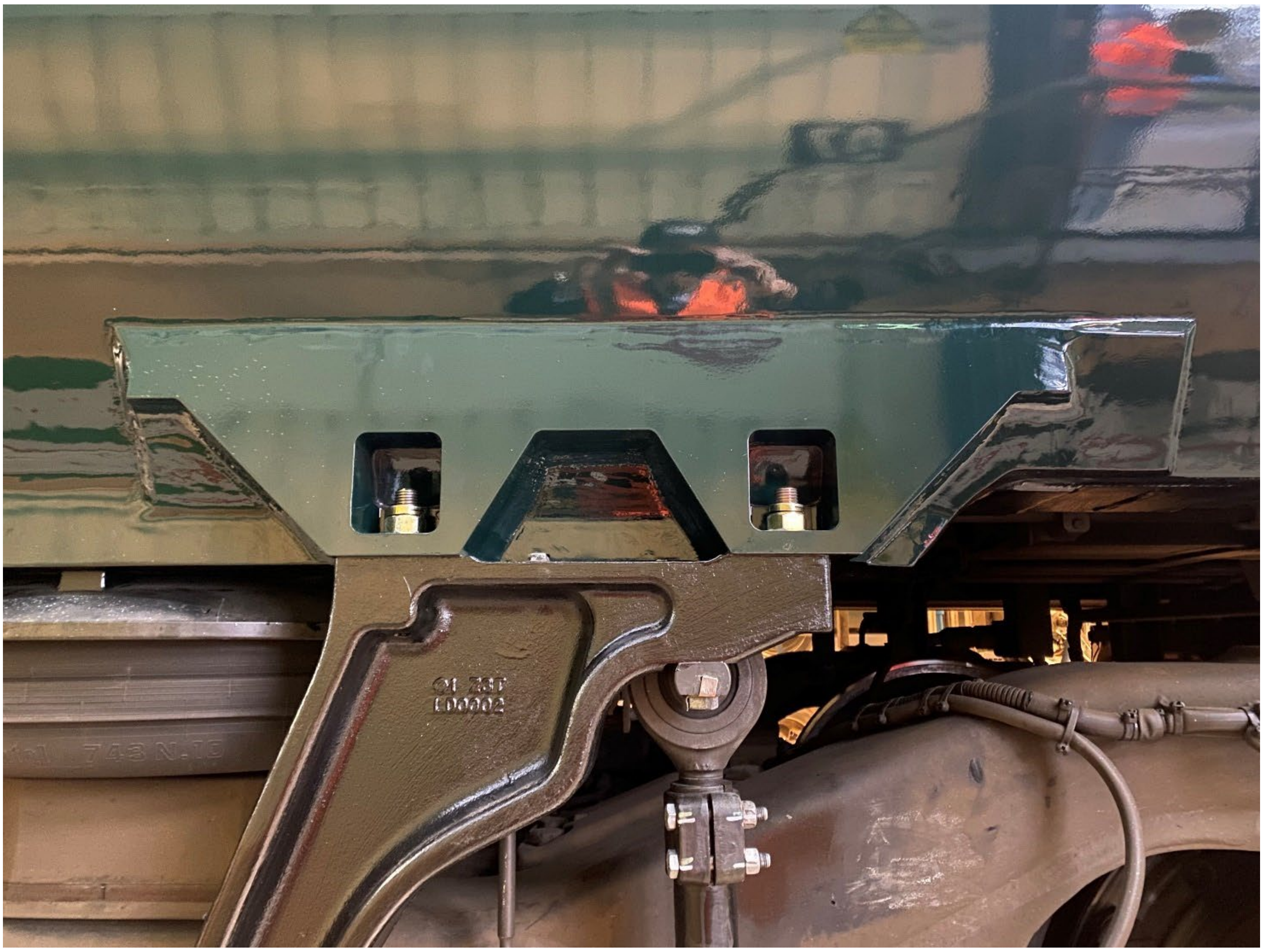
4.49 Hitachi's permanent solution to address the fatigue cracking issues in the bolster area is to remove the affected part of the original body structure, including the longitudinal welds where the fatigue cracks have occurred and the mounting brackets. The structure is rebuilt using a modified design (an example is shown in **Figure 4.1** below) that provides an unchanged interface with the yaw damper bracket and anti-roll bar. The modifications address the load capability of the design and the potential for insufficient fusion in the welded joint arising from weld design and inspection criteria.

4.50 Leading and intermediate vehicles have different designs. Two options were developed for each vehicle type to allow assessment of the effectiveness of the production process for each approach, and so they could be validated by in-service testing before deciding which design to implement across all operators' fleets. All four options involved:

- replacing the longitudinal weld between bolster and carbody.
- removing the original ribs/webs.
- welding stiffeners to the bodyside.
- welding a new bracket onto the bolster and bodyside stiffeners.

4.51 The modified designs were subject to fatigue assessments by Hitachi and Ricardo independently of each other and using different methods.

Figure 4.1 Hitachi’s modification of bolster area (intermediate vehicle)



4.52 In order to repair the yaw damper / anti-roll bar area of the bolster it is necessary to cut out the weld line between the solebar and bolster, and also to machine perpendicular to the yaw damper mounting face. A joint venture between Rolls Royce & Unipart Rail has developed a vehicle-mounted three-axis milling machine that allows the task to be performed in a consistent and repeatable way.

4.53 The first modified design to the yaw damper / anti-roll bar area of the bolster was carried out on Great Western unit 802007. This is known as the “First In Class” modification. The bolster areas of the vehicles were examined for cracks before, during and after the modification process, using ultrasonic and dye penetrant testing. The use of crack detection methods on completion of each stage of the modification programme was intended to ensure that weld penetration met the design requirements before proceeding to the next stage, which would prevent later examination of the stages that had come before.

4.54 On completion of the modification, the vehicles were fitted with strain gauges and subject to in-service testing without passengers. When the data had been analysed from the test operations, Hitachi selected the repair option to be applied across the fleets. The preferred option is characterised by stiffener plates on the outside face of the bolster; the alternative used stiffening ribs on the outer face of the bodyside plate. The decision was primarily driven by the ability of the preferred option to tolerate loads, although it also provides benefits in terms of ease and speed of the modification process.

4.55 Hitachi is prioritising the trains for repair on the basis of the fatigue cracks present on the vehicles, drawing on the monitoring data it has compiled from the engineering fleet checks. The programme initially included a first wave of rectification work intended to take place at maintenance depots to address the trains with the worst degradation in order to prevent them from being taken out of service as a result of exceeding the limits permitted by the fleet checks. The monitoring data have given confidence in the limited growth rates of cracks, so this activity will not be carried out.

4.56 The plan was for the majority of the vehicle modifications to take place away from operational depots, permitting a production line approach that would not disrupt depot operations. This phase of the modification programme will take place at Arlington Fleet Services at Eastleigh, Hampshire. Hitachi had previously assessed the time, cost and disruption of using various locations across the UK before selecting the option of setting up two repair lines at Arlington. The programme will address trainsets containing vehicles with cracks first, prioritising those with cracks in the vicinity of the yaw damper. All vehicles, whether cracked or not, will be modified, with the programme expected to be complete in 2028.

4.57 The modifications to address SCC have been treated as a lower priority, on the basis of the findings of the fleet checks, the level of risk and the measures that can be taken to address the issues.

4.58 Hitachi identified seventeen areas where 7000 series aluminium alloy has been used and concluded that three parts of the vehicle require rework to address SCC risk. These are the lifting plate and the coupler support plate on all vehicle variants and the yaw damper area of the bolster on the driving vehicles only.

4.59 Fourteen other areas have been assessed and Hitachi has proposed that there is no engineering justification for additional work. These decisions have been based on an evaluation that if SCC were to occur on one of the components in question, it would not be detrimental to the function or safe operation of the element as part of the vehicle. The assessment of the implications of SCC takes into account the loading direction and the grain orientation characteristics within the component.

From this consideration the effect of SCC on the function of each component is used to identify the risks to safe use of the vehicle. The conclusions were still being agreed at the time of publication.

4.60 The yaw damper area is subject to significant work to address fatigue risks, as described above, and the vehicle modification will take into account the need to manage SCC risks as well. Machined extrusions, where the grain boundaries become exposed, are protected by being fully covered by weld.

4.61 The lifting plate has been assessed for the risk of detachment. Ricardo carried out a study that showed that the existing welds, even in a degraded state, were sufficient to prevent detachment. Nonetheless Hitachi is proposing to fit secondary retention bolts.

4.62 A fleet of Class 803 rolling stock operated by Lumo was authorised and introduced into service at the end of 2021. The design of the bolster area was unchanged from that of the rest of the Class 80x fleet, as the body shells had already been assembled. These units are subject to the same inspection regime as the rest of the Class 80x fleet and will be incorporated into the modification programme.

Class 385 and 395

4.63 The related cracking identified on Class 385 and 395 is being addressed in a similar way to the measures applied to the Class 80x units. The results of the engineering fleet checks provide confidence that it is appropriate to give them a lower priority. Nonetheless they have been subject to equivalent analyses and risk assessment, and at the time of publication similar rectification programmes were being developed.

4.64 The programme to replace obstacle deflector support brackets (paragraph 4.7 above) has been suspended following Hitachi's detailed assessment of SCC risks on the Class 395 fleet. The assessment concluded that the risks could be managed without the need to replace the bracket. At the time of publication Hitachi, Eversholt Rail and SE Trains were in discussion about the long-term management of the component.

Operators' Lessons Learnt

4.65 A majority of operators have concluded their lessons learnt exercises and most of them have considered that their management system arrangements were sufficient and effective in managing the impact from the train cracks and subsequent vehicle stand down.

4.66 It should be noted that the vehicle stand down impact varied greatly between operators, which depended on their reliance of the AT200/300 stock to facilitate their passenger train service provision.

4.67 Many operators continue to regularly engage with Hitachi to understand and manage the effect of the cracks on fleet and implement solutions.

4.68 Where operators were part of the same overall owning group, this allowed greater collaboration between them and readily accessible access to a greater pool of technical engineering resource.

4.69 Operators are continuing to engage with Hitachi on a frequent basis to continue checks and testing along with agreeing possible short-term solutions on the cracks.

Communications between Operators and Hitachi

4.70 Operators noted that communications between Hitachi and themselves varied depending on contractual arrangements.

4.71 There continue to be regular meetings, often weekly, between Hitachi and the operators. These meetings have been opportunities to discuss short term proposals and long-term plans to address the cracking issues.

4.72 Some operators have real-time access to SAP, Hitachi's asset management system, others do not and rely on Hitachi to compile information. Operators who do not have access to SAP believe it would be beneficial and improve effectiveness of their safety and assurance processes for fleet management.

4.73 One Operator noted that they previously didn't have access to data from SAP due to their TSA with Hitachi (see section below). For reasons unrelated to the work to address cracks, the same operator has now been given access to SAP, but this is limited to a single licence and the restricted viewing access does not meet the operator's needs.

4.74 One operator noted a change in Hitachi's engagement since our interim report findings and has since stated that Hitachi is slower to provide information, which is perceived to be filtered and sometimes contradictory.

4.75 Another operator highlighted that there was a focus by Hitachi mainly on the AT300 train class, but that Hitachi has subsequently made efforts to include the AT200.

4.76 Hitachi engages with a large number of stakeholders through the industry Technical Review meeting. This videoconference forum is attended by representatives of the operators, owners, DfT and ORR, as well as Hitachi participants and their technical advisers. It initially took place weekly, with the frequency reducing to fortnightly towards the end of 2021. At this later stage meetings take place only if there is relevant material for Hitachi to present. The content has evolved as the risk mitigation activities evolved, starting with discussion of the technical investigation and moving on to include the developing findings of the vehicle examinations, and the rectification workstreams. It is now functioning as a Technical and Operational Review Group.

4.77 Managing Director-level operator representatives are among the participants in the Fleet Recovery Programme Board. This sits outside the contractual framework, giving oversight of Hitachi's proposals to eliminate the causes of the cracks in order to allow the exceptional maintenance activities to end. The Fleet Recovery Programme Board meetings began in July 2021 and are chaired by The Nichols Group on Hitachi's behalf.

Train Service Agreements

4.78 We were able to review two TSAs, which outline responsibilities for the maintainer, owner and operators.

4.79 We specifically reviewed elements of maintenance and the exchange of information between parties within the TSAs to understand if there were any barriers to the sharing of safety information between Hitachi and the other parties.

4.80 We established that the TSAs set out clear processes for the retention and exchange of information between the maintainer, owner and operators.

4.81 Whilst the TSAs contain some restrictions on disclosure, we do not consider that any of these would have prevented the prompt disclosure of maintenance (and other) information between maintainer, owner and operators.

4.82 We did not find anything, in our review of the TSAs which precludes operators from having access to SAP. Lack of access should not be a barrier to the exchange of information necessary for operators' safety and assurance processes, as this can be obtained on request from Hitachi. However, we consider it would be useful for all operators to have access.

Internal communications within Hitachi

4.83 During our review, we were provided information on the effective flow of information internally at Hitachi Rail (Hitachi) between the British division and the manufacturing team based in Japan (Kasado Works).

4.84 Hitachi and Kasado staff were mobilised on Saturday 8th May as soon as the decision was made to withdraw the rolling stock from service on the grounds of safety following the identification of cracks.

4.85 Hitachi formed an internal meeting involving the Operational Leadership Team, with the outputs of these meetings being a basis for communicating with operators and other stakeholders. These internal meetings were then repeated daily to ensure a common understanding of the issues and plans to manage them. Information was cascaded to all Hitachi Rail operational staff through the established Hitachi briefing processes to ensure a common understanding of all required arising changes to checks and procedures.

4.86 The Hitachi UK Senior Leadership Team also met weekly to be updated on status and to oversee the response and ensure that the Hitachi Operational team were fully supported with necessary resource, equipment and facilities.

4.87 Hitachi established a dedicated project team from mid-May, representing all relevant business areas, to manage all issues related to the containment, solution development and implementation of the identified issues. At the time of this report the project team remains in place and continues to provide internal updates on a weekly basis and also report into meetings that have been put in place with external stakeholders.

4.88 There are perceived, well established relationships within Hitachi Rail's global organisation, making it easy and quick to source the necessary data or information. The Kasado Design Authority team was mobilised within six hours of the decision being taken to withdraw the rolling stock from service.".

4.89 The time difference between the UK and Japan enabled Kasado staff to provide information during the early hours of the UK day in response to questions raised late in the preceding UK day. This effectively increased the length of the global working day. Staff later travelled from Japan to the UK to support ongoing work in relation to the root cause analysis and the identification of engineering solutions where this was considered beneficial and would help with expediency. As Kasado continued to be integral to Hitachi's containment, solution and implementation team, meetings continued to be held between them and Hitachi on an approximately daily basis.

4.90 Hitachi Rail has used video conference facilities extensively for many years and these continued to be used effectively, benefitting from the enhancements arising from their extensive adoption as a result of COVID 19-enforced travel restrictions. Hitachi believes that internal communication between Hitachi staff was effective and enabled them to manage the situation, irrespective of staff's nominal place of work.

4.91 Externally, many stakeholders perceived effective communications between the Hitachi teams and Kasado. It was seen as being a positive element through the lessons learnt exercises and was widely praised.

Conclusions on the industry response

4.92 Targeted checks for unexpected cracks in the vehicle structure are not normal practice in the rail sector. Nonetheless, Hitachi's maintenance staff identified the cracks before they developed to a level that resulted in harm, and action was taken well before any significant risk had developed of a failure that could compromise the safe operation of the rolling stock.

4.93 All operators were able to demonstrate that they had appropriate safety management systems in place to manage the fleet stand down, to liaise appropriately with Hitachi and to make suitable and sufficient risk assessments for returning trains with cracks meeting defined criteria back into passenger service.

4.94 Operators were supported by high-level governance within their organisations, and from the two main owning groups, with board sign-off for key decisions being required. They resisted any early external pressures to get trains back into service before the correct internal procedures had been followed.

4.95 Each operator implemented their own assurance measures to ensure that the information provided by Hitachi was correct, and the proposals to return trains to service subject to enhanced checks were based on sound evidence. Hitachi has fully cooperated with operators carrying out assurance activities on train checks.

4.96 Interfaces between both AT200/300 users and Hitachi appear well-managed although some operators would prefer more detailed information to be shared from Hitachi to satisfy their safety and assurance processes for fleet management.

4.97 Upon reviewing the TSAs, we have concluded that they are drafted in a way which does not impede the flow of information between Hitachi and the operators.

4.98 Internal communications within Hitachi were seen as effective and Hitachi were able to evidence timely mobilisation of internal governance arrangements.

Next steps – coordination of cross-industry crisis response

The industry should develop a process for responding to similar future cross-industry crisis events, agree terms of reference for meetings and appoint a strong, independent chair who can maintain pace, focus and ensure all voices are heard.

Annex 1 – Lessons learnt review terms of reference

ORR will work closely with all parties to ensure that lessons are learnt from the discovery of cracks in Hitachi AT200 (Class 385) & AT300 (Classes 800, 801 and 802) rolling stock. The review will focus mainly on safety lessons but will also cover the impact on passengers from the withdrawal of trains from service.

ORR will with Hitachi's design and manufacturing teams and all relevant parties to:

- find the root cause of the;
  - cracking in the jacking plate
  - cracking at the yaw damper bracket / anti-roll bar end of the bolster
- examine the industry processes relating to;
  - identification of the problem
  - assessment of the safety risk
  - withdrawal of the trains from service
  - return of the trains to service
- identify potential improvements.

The review will cover:

- The criteria for selecting the materials, the joining methods and any post-joining treatment when designing vehicles to operate for the life of the contract.
- How the design, manufacturing and testing processes addressed the potential for stress corrosion cracking and fatigue cracking in the design.
- Hitachi's processes to identify cracking in components during the life of the train.

- The background to the identification of the cracks in the bolster area, and how Hitachi managed the subsequent investigation and development of solutions.
- Whether the cracks in the jacking plates could have been found earlier.
- The immediate response; considering the roles of Hitachi, the train operating companies (TOCs), Department for Transport (DfT) and ORR.
- The communication flows within Hitachi as maintainer / builder / designer and between Hitachi and the TOCs, including whether they could be improved to speed up identification and resolution of common issues.
- Cooperation between all parties, and whether information flow or decision-making were affected by commercial, organisational, geographic or cultural factors.
- Contractual responsibilities for inspection, maintenance, repair and remedial action, and how these could be improved.
- The effectiveness of the forward recovery planning processes for returning the trains to service, for immediate rectification of defective vehicles.
- The potential for the original design and manufacturing choices to lead to development of cracks elsewhere in the train.
- The long-term management of the technical issues.

ORR will work closely with TOCs and passenger groups to review the impact on passengers from the withdrawal of trains, with a specific focus on the operators of Hitachi class 800 trains – Great Western Railway, London North Eastern Railway, TransPennine Express and Hull Trains (although the impact on the latter was more limited). The passenger review will not include Abellio ScotRail given there was minimal impact to passengers using its services.

The review will cover:

- consistency and clarity of travel information, both over the weekend of 8 May 2021 as the safety issues became apparent but also in the following week(s) including information provided by National Rail Enquiries;

- ticket refunds - information provided by train companies, National Rail Enquiries, and independent rail retailers to passengers about their refund rights and the application of administration fees;
- advice to passengers on alternative travel arrangements including ticket acceptance on other operators; and
- the steps taken to contact passengers who had booked assistance to travel and the accessible alternative arrangements offered.

We will report on the passenger impact by 25 June 2021 and produce an initial report covering the history, withdrawal and reintroduction of the rolling stock by 9 September 2021. A final report will follow when the long-term rectification programme has been established.

Annex 2 – Glossary

Term	Definition
Abellio	Abellio Transport Holdings Ltd, a public transport company that operates road and rail services in Great Britain, referred to as an ‘owning group’. The relevant train operating company within the group was Scotrail until April 2022
Abellio ScotRail	Train operating company within Abellio operating Class 385 rolling stock, manufactured by Hitachi, on electrified lines in the Central Belt of Scotland until April 2022
AC	Alternating current, a characteristic of the electric power supply
ARB	Anti-Roll Bar, a component of the suspension linking bogie and carbody
Agility	Agility Trains is a consortium working with DfT to provide rolling stock for the Intercity Express Programme (IEP), replacing the previous generations of inter-city rolling stock on the Great Western and East Coast Main Lines
Angel Trains	Train owner which leases Hitachi Class 802 trains to both TPE and Hull Trains
APIS	Authorisation to Place in Service, the formal approval granted by the safety authority permitting the operator to put rolling stock into service on the railway
Bi-mode	Rolling stock capable of deriving traction power from more than one source. In the case of bi-mode AT300 variants, the train may draw power from the 25kV overhead contact line or operate using diesel-powered combustion engines
Bogie	A subassembly of a rail vehicle containing wheels and suspension components
Bolster	A strengthened area of a rail vehicle body where loads are transmitted between body and bogie
Class 385	Suburban and inter-urban electric passenger rolling stock of the Hitachi AT200 family, operated by Abellio ScotRail and ScotRail Trains Ltd in the Central Belt of Scotland

Term	Definition
Class 395	High speed electric passenger rolling stock of the Hitachi AT300 family, operated by L&SER and SE Trains on conventional and high-speed lines in the southeast of England
Class 800	Inter-city diesel & electric bi-mode passenger rolling stock of the Hitachi AT300 family, operated by GWR and LNER on routes in England, Scotland and Wales
Class 801	Inter-city electric passenger rolling stock of the Hitachi AT300 family, operated by LNER on routes in England and Scotland
Class 802	Inter-city diesel & electric bi-mode passenger rolling stock of the Hitachi AT300 family, operated by GWR, Hull Trains and TPE on routes in England, Scotland and Wales
Class 803	Inter-city electric passenger rolling stock of the Hitachi AT300 family, operated by Lumo between London and Edinburgh
Class 80X	Term used to refer to all rolling stock of classes 800, 801, 802 and 803
CRL	Caledonian Rail Leasing Ltd, a train owner, which leases Hitachi Class 385 trains to ScotRail Trains Ltd (previously to Abellio ScotRail)
DC	Direct current, a characteristic of an electric power supply
DeBo	Designated Body, an independent accredited commercial organisation employed to conduct conformity assessments against NNTR / NTR
DfT	Department for Transport
ECT	An electromagnetic non-destructive testing process that uses the disturbance of induced eddy currents in a body of metal to find cracks breaking the surface of the material
Eversholt Rail	Train owner, which leases Hitachi Class 395 Javelin trains to SE Trains (previously to L&SER), and Class 802 trains to GWR.
FEA	Finite Element Analysis, a process of computerised modelling of stresses within an assembly
First	FirstGroup plc, a public transport company that operates rail services in Great Britain, referred to as an ‘owning group’. Relevant train

Term	Definition
	operating companies within the group are GWR, Hull Trains, Lumo and TPE
GWR	Great Western Railway, a train operating company within First operating Class 800 and 802 rolling stock, manufactured by Hitachi, on the Great Western Main Line and associated routes to South Wales and the west of England
Hull Trains	Train operating company within First operating Class 802 rolling stock, manufactured by Hitachi, on the East Coast Main Line and in East Yorkshire
IEP	Intercity Express Programme, initiative of the DfT to procure new trains to replace the Intercity 125 and 225 fleets on the East Coast Main Line and Great Western Main Line (see Agility above)
Kasado	Hitachi site in Yamaguchi Prefecture, Japan, developing and manufacturing railway vehicles
LNER	London North Eastern Railway, a train operating company operating Class 800 and 801 rolling stock, manufactured by Hitachi, on the East Coast Main Line
L&SER	London & South Eastern Railway (trading as Southeastern). Train operating company operating Class 395 rolling stock, manufactured by Hitachi, on conventional and high-speed lines in London, Kent and Sussex until October 2021.
Lumo	A train operating company within First operating Class 803 rolling stock, manufactured by Hitachi, on the East Coast Main Line between London and Edinburgh
Nichols	The Nichols Group, a strategic change consultancy
NDT	Non-destructive testing
NIR	National Incident Report, a report of a safety-related technical incident made in accordance with Rail Industry Standard RIS-8250-RST Reporting High Risk Defects Issue 1
NNTR	Notified National Technical Rules, additional national standards published by the state that apply in tandem with the requirements of the TSI. Superseded in the UK by National Technical Rules (NTR) in 2021

Term	Definition
NoBo	Notified Body, an independent accredited commercial organisation employed as part of the processes for interoperability to check and certify compliance with Technical Specifications for Interoperability. Superseded in the UK by Approved Body in 2021
ORR	Office of Rail and Road
Ricardo	Ricardo Rail, a railway engineering consultancy
RoSCo	Rolling Stock Company, an owner of rail vehicles
RSSB	Rail Safety and Standards Board, a body funded by the rail industry to develop standards, manage research, and collect, collate and analyse data
Safety Certificate	Under The Railways and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS) no one is able to operate vehicles on the UK railway unless they have obtained the appropriate safety certificate from ORR
SAP	A software product that is used for asset management
SCC	Stress corrosion cracking, a mechanism of crack formation in certain materials where stress and a corrosive atmosphere are present
ScotRail Trains Ltd	Train operating company operating Class 385 rolling stock, manufactured by Hitachi, on electrified lines in the Central Belt of Scotland from April 2022
SE Trains	SE Trains Ltd (trading as Southeastern). Train operating company operating Class 395 rolling stock, manufactured by Hitachi, on conventional and high-speed lines in London, Kent and Sussex from October 2021.
SNC-L	SNC-Lavalin, a railway engineering consultancy
TPE	TransPennine Express, a train operating company within First operating Class 802 rolling stock, manufactured by Hitachi, between the northwest of England and Edinburgh via the East Coast Main Line
TSA	Train Service Agreement, a contract setting out duties of Maintainer, Owner and Operators of rolling stock

Term	Definition
TSI	Technical Specification for Interoperability, a harmonised standard forming part of the processes for interoperability. Superseded in the UK by National Technical Specification Notice in 2021
TTS	Train Technical Specification, a document containing the technical requirements for rolling stock
TWI	The Welding Institute, a research and technology organisation with specialisation in welding

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