Rail Accident Investigation Branch

Rail Accident Report

Locomotive failure near Winchfield
23 November 2013

Report 13/2014
June 2014

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

Any enquiries about this publication should be sent to:

RAIB	Email: enquiries@raib.gov.uk
The Wharf	Telephone: 01332 253300
Stores Road	Fax: 01332 253301
Derby UK	Website: www.raib.gov.uk
DE21 4BA	

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(Cover photo courtesy of Christopher Ward)

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Contents

Summary

At about 18:50 hrs on Saturday 23 November 2013, while a steam-hauled passenger train from London Waterloo to Weymouth was approaching Winchfield in Hampshire at about 40 mph (64 km/h), the right-hand connecting rod of the locomotive became detached at its leading end (referred to as the small end), which dropped down onto the track. The driver stopped the train immediately, about one mile (1.6 km) outside Winchfield station. There was some damage to the track, but no-one was hurt. The accident could, in slightly different circumstances, have led to derailment of the train.

The immediate cause of the accident was that the small end assembly came apart, allowing one end of the connecting rod to drop to the ground. The reasons for this could not be established with certainty because some components could not be found after the accident. It is possible that the gudgeon pin securing nut unwound following breakage of the cotter and previous loosening of the nut. A possible factor is that the design of some components had been modified during the restoration of the locomotive some years earlier, without full consideration of the possible effect of these changes. There were deficiencies in the design and manufacture of the cotter. It is also possible, but less likely, that the securing nut split due to an inherent flaw or fatigue cracking.

RAIB has made four recommendations, directed variously to West Coast Railway Company, the Heritage Railway Association, and the Main Line Steam Locomotive Operators Association. They cover the maintenance arrangements for steam locomotives used on the national network, a review of the design of the small end assembly on the type of locomotive involved in the accident, guidance on the design and manufacture of cotters, and assessment of risk arising from changes to the details of the design of locomotives.

Introduction

Preface

1 The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability.

2 Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

3 RAIB's investigation (including its scope, methods, conclusions and recommendations) is independent of all other investigations, including those carried out by the safety authority, police or railway industry.

Key definitions

4 Dimensions in this report are given in metric units, except where industry practice is to work in imperial units. In such cases, these have been used in the report and the equivalent metric value is also given.

5 The report contains abbreviations and technical terms (shown in *italics* the first time they appear in the report). These are explained in appendices A and B.

The accident

Summary of the accident

6 At about 18:50 hrs on Saturday 23 November 2013, train number 1Z94, the 17:48 hrs service from London (Waterloo) to Weymouth, was approaching Winchfield station in Hampshire, travelling at about 40 mph (64 km/h) (figure 1). The right-hand *connecting rod* of the steam locomotive hauling the train became detached at its leading end (known as the small end), which dropped onto the *conductor rail*, causing an electrical short circuit and consequent arcing. The train was stopped by the action of the locomotive crew, about one mile (1.6 km) east of Winchfield, when they saw the flashes from the electrical arcing.

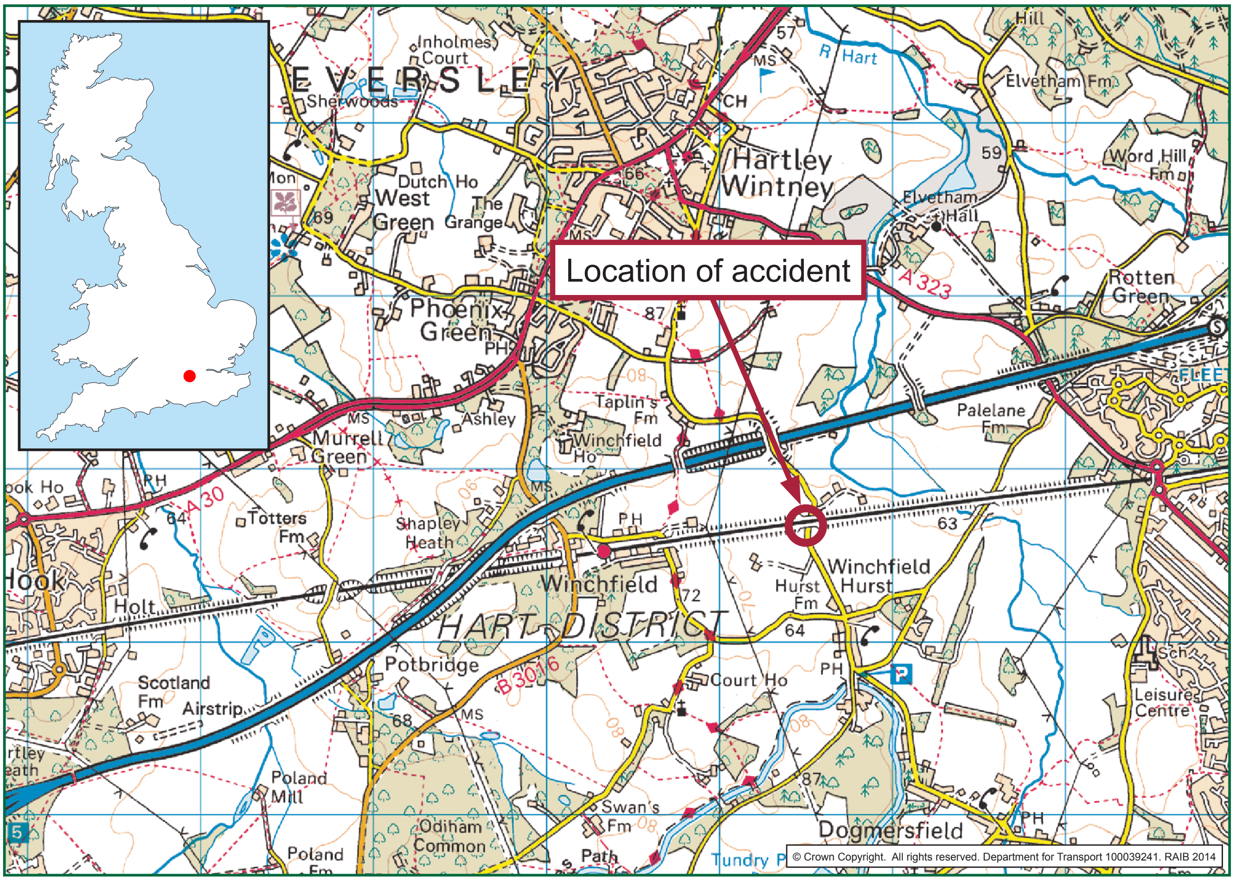

Figure 1: Extract from Ordnance Survey map showing location of accident

7 No-one was hurt. After the detached components had been secured, the train was propelled to Basingstoke station by the diesel locomotive attached to its rear, and the passengers continued their journey on other services.

8 There was some minor damage to the track: about twenty insulated conductor rail supports needed replacement. The locomotive's right-hand *crosshead* and *gudgeon pin* were damaged, and other parts of the assembly have not been found (see paragraph 31). The locomotive's connecting rod was superficially marked where it had made contact with the conductor rail and the ground, but was not distorted. If the small end of the connecting rod had landed on the ground while the train was still moving at an appreciable speed, it could have caused a potentially serious derailment.

Context

Location

9 The accident occurred on the down slow[1] line between Fleet and Winchfield stations, which is part of the main line from London (Waterloo) to Southampton and Weymouth, on Network Rail's Wessex route. The down slow is the southernmost of four tracks. At the point where the train came to rest, near milepost 39¼, the line is on an embankment about 9 metres (30 feet) high. The line in the area is straight.

Organisations involved

10 The train was operated[2] by West Coast Railway Company Ltd (WCRC), which employed the driver, fireman, the rest of the train crew and the operating engineer who was responsible for the inspection of the locomotive. The locomotive and coaches are owned by Carnforth Railway Restoration and Engineering Services (CRRES), which trades as West Coast Railways, and shares a common ownership with WCRC.

11 The railway infrastructure is owned, operated and maintained by Network Rail, Wessex route.

12 WCRC, CRRES and Network Rail freely co-operated with the investigation.

Train involved

13 Train 1Z94 was formed of ten coaches, hauled by 'West Country' class 4-6-2[3] steam locomotive number 34067 (98767[4]) 'Tangmere' (figure 2), with a class 47 diesel locomotive number 47580 attached to the rear (but not providing power at the time of the accident).

Staff involved

14 The driver and fireman of the locomotive had, respectively, 54 and 4 years' experience of main line steam operation. The driver had worked for many years as a driver on the routes out of Waterloo and was very familiar with the area where the accident occurred. He had been driving 'Tangmere', among other steam and diesel locomotives operated by WCRC, since 2007, and was trained and certified by WCRC to drive the locomotive.

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[1] One of two lines used by trains travelling away from London.

[2] 1Z94 was a charter service 'The Capital Christmas Express', the return working of an excursion from Weymouth to London. Tickets were sold and marketed through the Railway Touring Company, which was not involved in the operation of the train.

[3] This is a description of the wheel arrangement of the locomotive, indicating that it has four leading wheels, six driving wheels, and two trailing wheels.

[4] The number 34067 was carried by 'Tangmere' during its service with British Railways. The number 98767 is allocated to the locomotive for use in the computer systems associated with present-day railway operations, but is not displayed on the outside of 'Tangmere'.

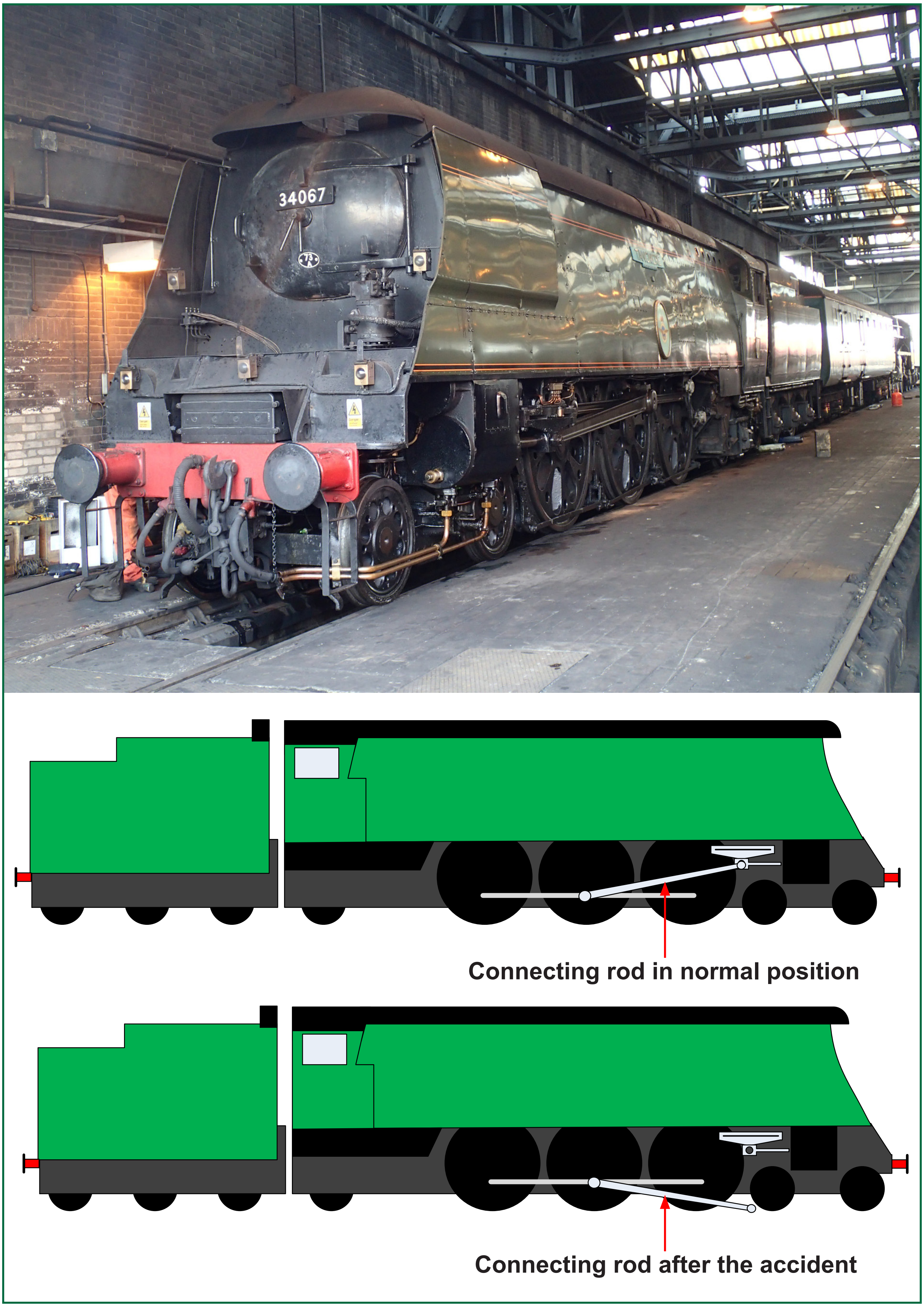

Figure 2: the locomotive 'Tangmere', showing how the connecting rod dropped

15 The operations engineer who accompanied the train had over forty years' experience in the restoration, overhaul and operation of steam locomotives, and had previously been in charge of the fleet of steam locomotives of a heritage railway in the south of England. He had been employed by WCRC to look after 'Tangmere' since 2007. His duties included riding with all the trains that the locomotive operated, and carrying out all inspections and minor servicing and maintenance work on it. In the days before the accident, he had accompanied the locomotive on its journey from Carnforth to London following the completion of repairs to the *boiler* (see paragraph 17).

External circumstances

16 It was dark at the time of the accident, and the weather was fine. The day had been dry. Weather conditions did not play any part in the occurrence.

Events preceding the accident

17 'Tangmere' left Carnforth following the completion of repairs to its boiler on Thursday 21 November 2013. With a *support coach* in tow, it ran to Southall depot in west London, with a stop for water and inspection at Crewe. The operations engineer rode on the locomotive from Carnforth to Crewe, and he was satisfied with its performance and condition.

18 On Friday 22 November, the locomotive and its train were hauled to Weymouth by the diesel locomotive, 47580, which remained as part of the train throughout the next few days. The train arrived at Weymouth early in the evening, and the operations engineer carried out a 'fitness to run' (FTR) examination (see paragraph 54), and oiled the *motion*.

19 On Saturday 23 November, 'Tangmere' and its train left Weymouth at 07:25 hrs and ran to London (Waterloo), calling at Poole, Bournemouth, Southampton Central, Eastleigh, and Winchfield, where it stopped for ten minutes to take on water. It arrived at Waterloo at 12:03 hrs.

20 The diesel locomotive then hauled 'Tangmere' and the train to the WCRC depot at Southall, arriving about 13:44 hrs, and the locomotive and carriages were serviced. The operations engineer carried out a further FTR examination of the locomotive, and again oiled the motion. The train left Southall at 15:55 hrs, hauled by 'Tangmere', and ran via Acton Canal Wharf Junction to Willesden Junction, where it reversed and ran via Mitre Bridge Junction to Waterloo hauled by the diesel. It therefore arrived with 'Tangmere' facing west, ready to haul the train to Weymouth.

21 Train 1Z94 left Waterloo at 17:49 hrs. It was routed out of the station via the Windsor reversible line, and then on to the down fast line from Queenstown Road.

Events during the accident

22 The train made good progress during the early part of its journey, and passed the junction at Woking (24½ miles (39.4 km) from Waterloo) on time at 18:22 hrs. It was scheduled to be switched from the down fast to the down slow line at Brookwood, but because of a late-running service on the slow line, train 1Z94 was kept on the fast line as far as Farnborough. The train's speed was reduced in response to the lineside signal indications, and it ran through the junction onto the slow line at Farnborough (east) at 18:39 hrs.

23 At about this time, the fireman noticed an unusual noise, described as a knocking sound, from the front of the locomotive. He mentioned this to the driver, but when the driver adjusted the position of the *reverser* in response to restrictive signals (the train was now closely following another), the knocking noise was reduced. Aware that the train was scheduled to stop to take on water at Winchfield, six miles away, and that they were following a stopping passenger train, the crew decided to continue at reduced speed and examine the locomotive during the water stop.

24 As the train approached Winchfield, about one mile before reaching the station, the fireman saw sparks coming from the right-hand side of the locomotive, and informed the driver. The driver braked the train gently with the intention of reaching the station. Very soon afterwards there was a bang and a flash as the connecting rod made contact with the conductor rail, and the driver stopped the train immediately. The locomotive came to rest near milepost 39¼ at 18:50 hrs. Evidence from the site indicates that, just before it stopped, the connecting rod dropped off the conductor rail and ran along the ground.

Events following the accident

25 The driver contacted the signaller at Basingstoke signalling centre and reported the situation. The driver and signaller arranged for the isolation of the electric current on the down slow line, and for the down fast line, adjacent to the train, to be blocked to enable the train crew to examine the train. The driver and operations engineer examined the locomotive and discovered the extent of the failure. They informed the signaller that it would take about 30 minutes to dismantle the connecting rod and make the locomotive secure for onward travel.

26 Because the train was blocking the down slow line, it was some time before the backlog of trains had been cleared to enable a further line blockage of the down fast line to be taken for this work to begin. The need for further trains to pass on the fast line meant that the work was interrupted once.

27 Under the protection of the isolation and line blockage taken for the dismantling work, the support crew searched the immediate area for detached components. The gudgeon pin was found lodged on the locomotive near the *bogie*, and pieces of the *brake gear* were recovered from the track. However, the nut and *cotter* from the small end assembly (figure 4), and the crosshead lubricator (figure 3), could not be located (see paragraph 31).

28 The train moved off, propelled by the diesel locomotive 47580, at 22:20 hrs and ran to Basingstoke, where arrangements had been made for a scheduled train to pick up the passengers to enable them to continue their journey to Weymouth.

29 ‘Tangmere’ and its train were hauled back to London by 47580, and returned to Southall depot on Monday 25 November.

The investigation

Sources of evidence

30 The following sources of evidence were used:

- witness evidence;
- examination of the locomotive and components;
- discussions with steam locomotive engineers and users, including heritage railways and owners and operators of *Bulleid pacifics*;
- analysis of the possible failure mechanisms of the small end assembly by an independent consultant specialising in the behaviour of bolted joints; and
- a review of previous investigations that had relevance to this accident.

31 At the request of RAIB, Network Rail's track patrol staff searched the track between Woking Junction and the site of the accident near Winchfield, to try to locate the nut and cotter. They were unable to find the missing components.

Acknowledgements

32 RAIB is grateful for the assistance given by members of the public who provided photographs and video recordings of the train during its journey from Weymouth to Waterloo, and Waterloo to Winchfield. We also acknowledge the help given by many steam locomotive engineers and operators, including heritage railways and owners of Bulleid pacifics, who provided advice and information during the investigation. RAIB is grateful to Transport Safety Victoria for providing a report on an accident which occurred in Australia in 2001 (paragraph 111), which also involved the failure of a small end assembly.

Key facts and analysis

Background information

History of the locomotive

33 The 'West Country' class locomotive 34067 (originally numbered 21C167) 'Tangmere' was built in 1947. It was one of 140 similar locomotives (the 'West Country/Battle of Britain' and more powerful 'Merchant Navy' classes, together known as the Bulleid pacifics[5]) built between 1941 and 1951 by the Southern Railway (SR) and British Railways (BR). They were superseded by diesel and electric traction between 1963 and 1967, but there are 31 of these locomotives still in existence, many of which have been restored to working order. The Bulleid pacifics were designed to haul passenger and freight trains, and were scheduled to run in service at speeds up to 90 mph (145 km/h).

34 'Tangmere' was withdrawn from service in November 1963. It was sold by British Railways to a scrap merchant in south Wales, and sent to his scrapyard at Barry, along with over 200 other steam locomotives. For various reasons, most of these locomotives were not cut up, and from 1968 onwards those remaining began to be bought for preservation, by societies and individuals. 'Tangmere' remained at Barry until 1981, when it was privately purchased and taken to the Mid-Hants Railway.

35 Some work was done on it there, but in 2001 it was moved to the works of Riley & Son (E) Ltd at Bury, Lancashire, where restoration to a condition in which it could run on the main line was completed in 2004. The restoration process required the manufacture of many components which had been removed during its period in the scrapyard, including the connecting rods, gudgeon pins and associated fasteners. The locomotive came into the ownership of CRRES in 2007.

Details of the crosshead assembly

36 Both the 'Merchant Navy' and 'West Country/Battle of Britain' classes had a number of unconventional features, some of which (such as the one-piece crosshead and piston rod) are relevant to the events of 23 November. The locomotives were built at a time when materials were in very short supply, and the need to save weight influenced the design in several ways.

37 The drive from the pistons is converted to rotary motion via the connecting rods and cranks. The Bulleid pacifics have three *cylinders*, one on each side (the outside cylinders) and one between the frames of the locomotive (the inside cylinder). The pistons move within the cylinders, and the piston rod emerges from the rear of each cylinder and is linked to the connecting rod by the gudgeon pin which passes through the crosshead (see figure 3 and paragraph 39). On the Bulleid pacifics as originally built, the piston rod and crosshead were forged from a single piece of steel[6]. A drawing of the crosshead and piston assembly is at figure 4.

[5] 'Pacific' is the name given to locomotives with the 4-6-2 wheel arrangement.

[6] The Bulleid pacifics were extensively rebuilt from 1956 onwards to improve their reliability and coal consumption. The rebuilding programme was stopped in 1961 after all thirty Merchant Navies and sixty of the West Country/Battle of Britain locomotives had been completed. As part of this process, the crosshead and piston rod were redesigned as separate components. From 1962, the new design of crosshead was fitted to the outside cylinders of unrebuilt locomotives on overhaul. 'Tangmere' was not rebuilt, and was last overhauled by British Railways before this change was introduced, and so it is now the only surviving Bulleid pacific with the original design of crosshead on the outside cylinders.

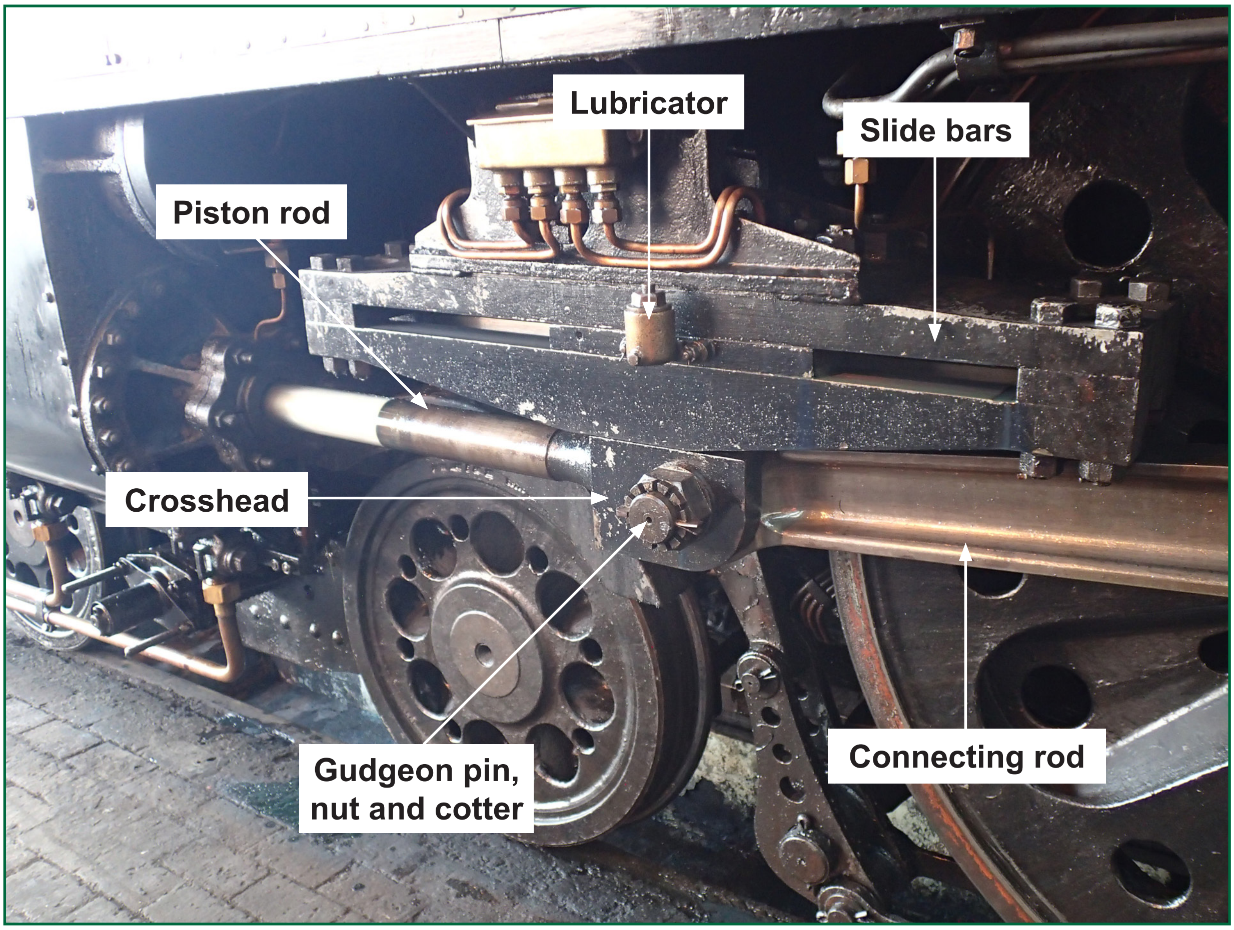

Figure 3: Left-hand side of 'Tangmere', showing principal components

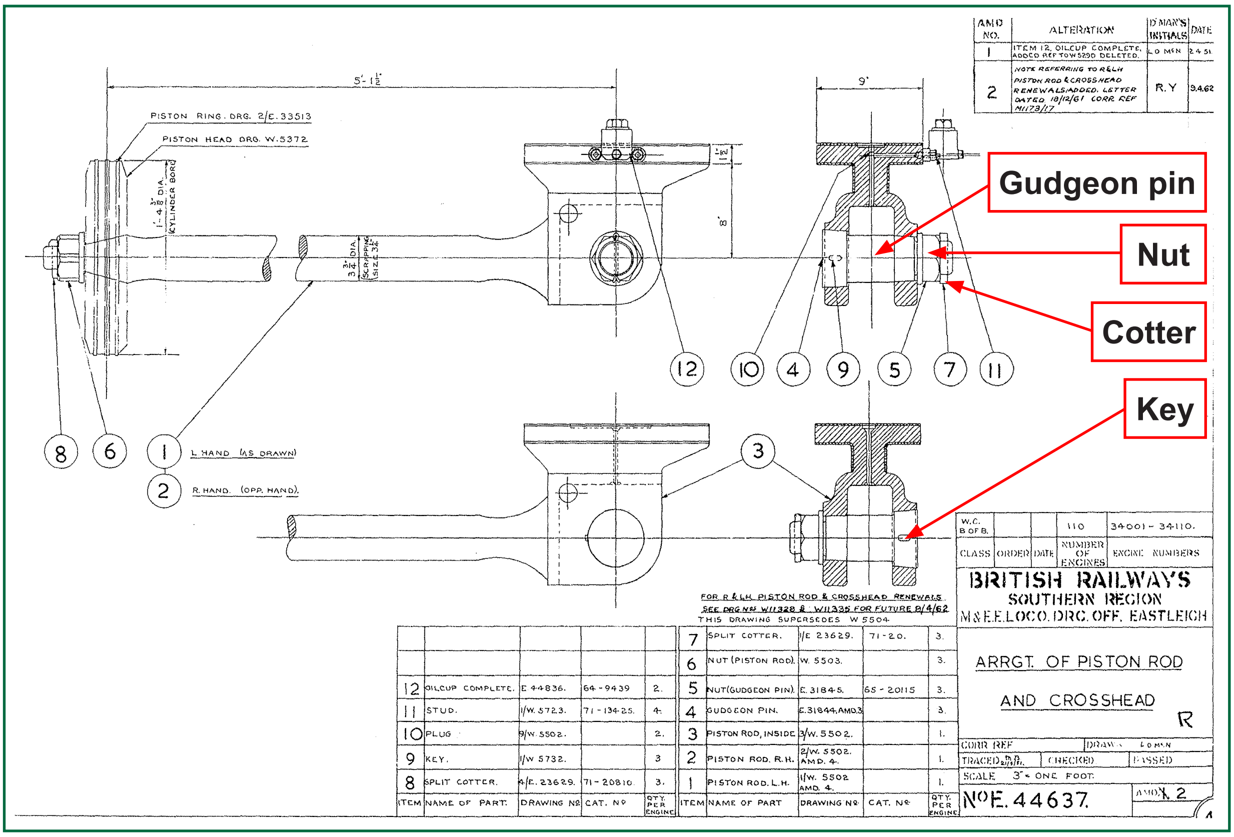

Figure 4: Crosshead and piston assembly (British Railways (Eastleigh) drawing E44637). Drawing reproduced by courtesy of the National Railway Museum/Science & Society Picture Library

38 The T-shaped upper part of the crosshead runs in the *slide bars*, which are bracketed off the locomotive frames above the piston rod. There is thus nothing to prevent the connecting rod from dropping to ground level if it becomes detached at the small end, unlike other designs of locomotive which have a crosshead which runs between upper and lower slide bars (figure 5).

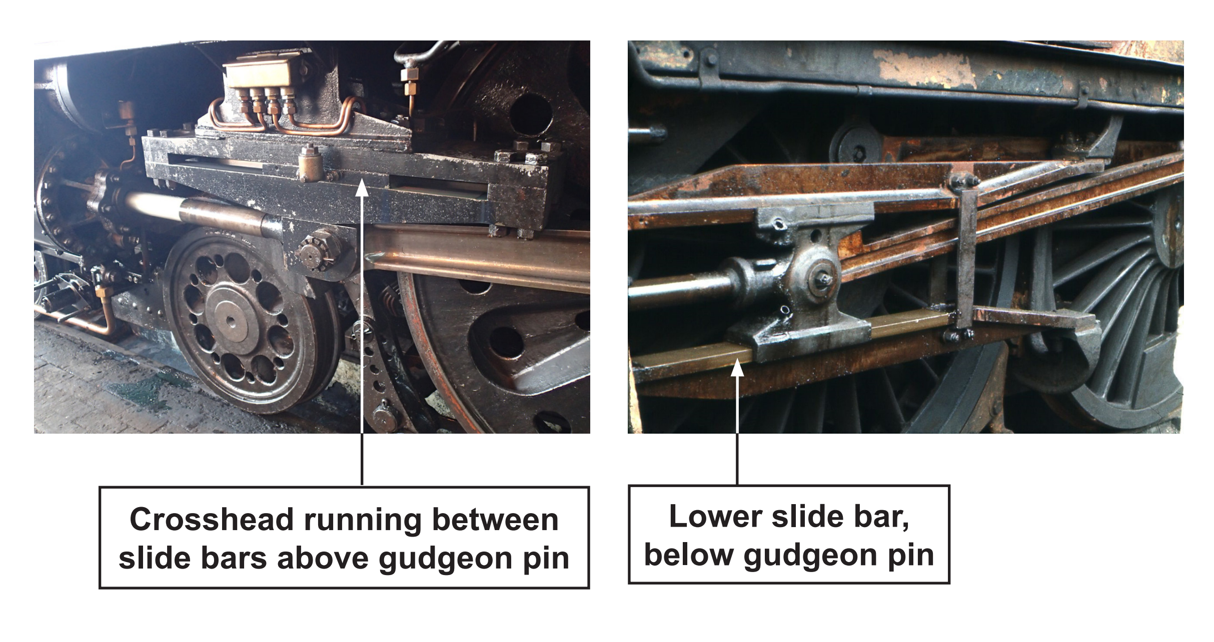

Figure 5: Comparison of single and double type slide bar arrangement

39 The connecting rod is linked to the crosshead (and thus to the piston rod) by the gudgeon pin. This allows the connecting rod to oscillate relative to the piston rod, as the locomotive's wheels turn. The gudgeon pin is tapered (1 in 6 on diameter) and mates with a similar taper in the crosshead. A key in the larger portion of the gudgeon pin mates with a slot in the crosshead bore to orient the gudgeon pin and prevent it from rotating. The gudgeon pin is pulled into the taper by the gudgeon pin nut[7]. If the two tapers have been machined correctly, they will lock together (see paragraph 46) and the gudgeon pin will be hard to separate from the crosshead, even when the securing nut has been removed[8]. A split cotter[9] is then driven through a slot in the gudgeon pin to further secure the nut (figure 4).

40 The original design of this assembly used a plain nut. However, when the locomotive was restored from scrapyard condition between 1981 and 2004, new gudgeon pins and nuts were manufactured. The nuts, which in the original design were 2" (51 mm) thick, were given an extra thickness of ½" (13 mm), and twelve slots 5/16" (8 mm) wide were machined in this ring to make a *castellated nut*. These slots have no radius at the base (a drawing and photograph of the modified designs of nut and cotter are in figure 6). The original design used a split cotter, but for the restoration a cotter was made from 5/16" (8 mm) thick plate with a saw cut to form the 'legs' (paragraph 62 and figure 6).

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[7] The gudgeon pin and nut are threaded 3" (76 mm) diameter by 8 threads per inch.

[8] Release of the pin normally requires either jacking or punching out with a sledgehammer.

[9] A split cotter is a fastener which is passed through a hole or slot in another component (often requiring to be driven into place) and then its ends are split or opened out to help to retain it in position.

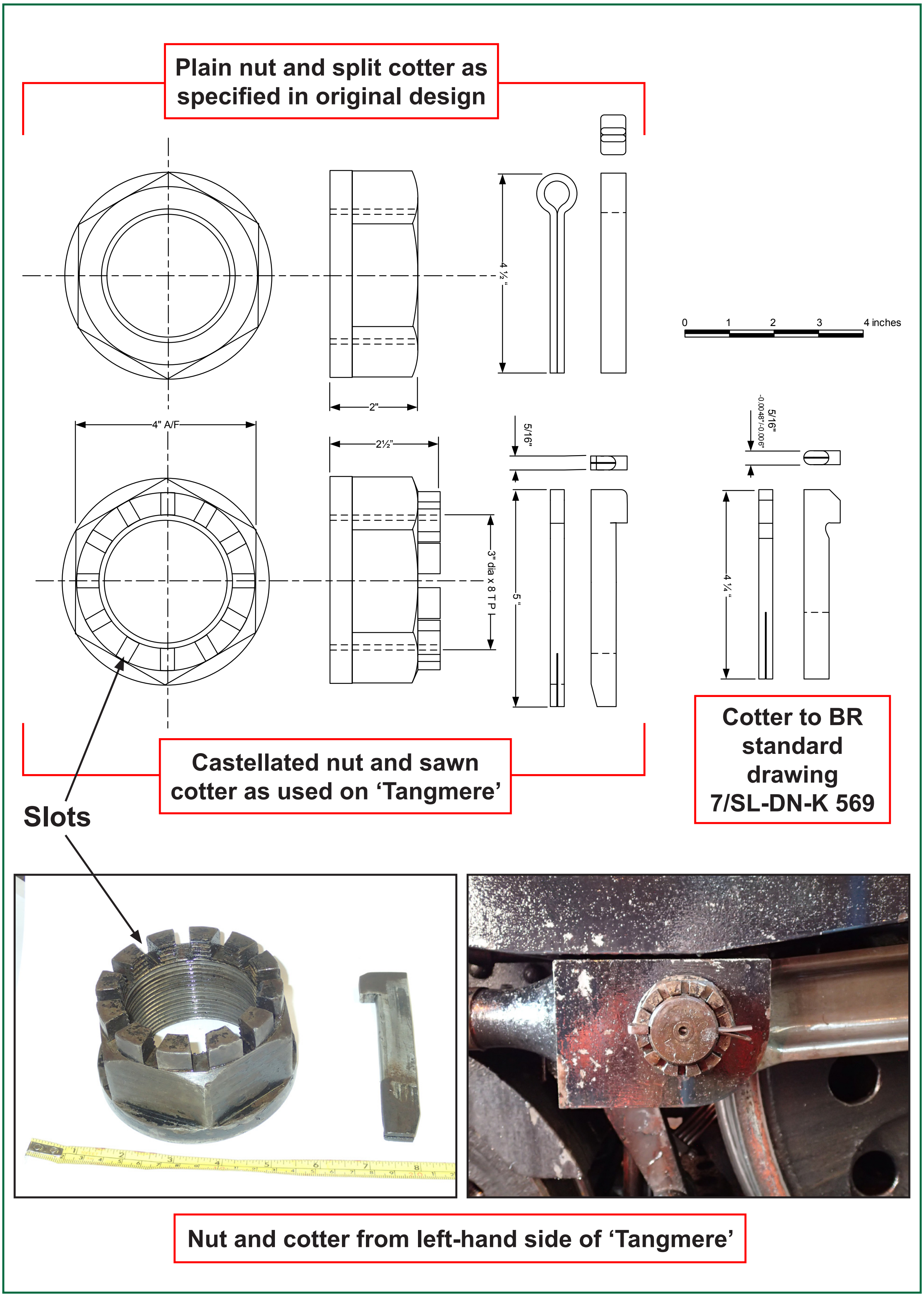

Figure 6: Nut and cotter

Identification of the immediate cause[10]

41 **The immediate cause of the accident was that the small end assembly came apart.**

42 After the accident, the connecting rod was found with its small (leading) end resting on the ground. The gudgeon pin was lodged on the bogie *splasher* of the locomotive. The nut and cotter which secured the gudgeon pin have not been found.

Identification of causal factors[11]

43 Although the loss of components means that RAIB cannot be certain why the assembly came apart, the investigation has identified two possible failure mechanisms:

- following the loss of the cotter, the nut unwound from the gudgeon pin; or
- the nut fractured and it, and the cotter, flew off.

These mechanisms and their relative likelihood are discussed in paragraphs 44 to 80. RAIB commissioned a report on the possible failure modes of the joint from an independent specialist consultant, and his findings are summarised in paragraphs 46 to 49 and 78 to 80.

Cotter breakage leading to unwinding of gudgeon pin nut

44 **It is possible that the cotter came out following the breakage of one or both of its legs, the gudgeon pin nut then unwound, and the pin then came out.**

45 The cotter is intended to be made so that it has to be driven into the slot in the gudgeon pin with a hammer, once the securing nut has been tightened. The practice in steam locomotive workshops is to tighten these nuts by '*flogging*', ie by using a suitable spanner which is struck with a heavy hammer.

46 The action of tightening the nut draws the gudgeon pin into the tapered bore of the crosshead. If the bore and pin have been accurately machined to the same taper, this provides a very solid seat for the pin, the tapered portion of which bears the load induced by the tightening of the nut. However, any mismatch between the tapers will reduce the solidity of this seat. When the locomotives were built, the gudgeon pins were required to be lapped[12] into the crosshead to achieve a good fit (figure 7), which would make the two components lock together, requiring some force to separate them. Dismantling a small end assembly for examination normally requires the use of a jack or punch bar and sledgehammer to release the gudgeon pin. Restoration of 'Tangmere' from scrapyard condition would have required re-boring of the existing crossheads to remove corrosion and achieve a good surface finish in the bores, which would then have been matched with new gudgeon pins.

[10] The condition, event or behaviour that directly resulted in the occurrence.

[11] Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

[12] Lapping is a hand (or machine) fitting process in which two mating components are rubbed together with a fine abrasive compound between them, to remove surface irregularities and achieve a close fit.

47 The nature of the joint and the size of the components is such that the tightening of the nut will lead to only a very small extension of the gudgeon pin. The nominal *free length* (in a bolted joint, the length between the nut face and the bolt head) (figure 7) between the tapered section of the pin and the face of the nut is of the order of 6 mm (¼”). However, the sharing of the internal stresses between the various components means that some of the tapered section, the thread and nut deflection (compression during tightening) will contribute to make a greater effective free length. Assuming that the actual effective free length is of the order of 25 mm (1”), and a *preload* of 400 kN (90000 lbf) could be achieved, the extension of the gudgeon pin over the free length would be approximately 0.012 mm (0.0005”). This very small extension means that only a very small movement of the nut on the thread is required to greatly reduce or even eliminate the preload, which makes the nut susceptible to non-rotational loosening processes such as embedding loss. Besides embedding, relaxation of the joint can occur as a result of *creep* and similar effects. The joint would behave very differently if there was any mismatch between the tapers of the gudgeon pin and the crosshead bore, but there is no evidence that this was the case in this instance.

48 Embedding is the term used for the plastic flattening of the surface roughness at the areas bearing the preload, the loaded flanks of the mating threads and at other interfaces within the joint. There are three sets of mating surfaces in the crosshead to gudgeon pin joint (crosshead tapered surface to gudgeon pin, nut face to crosshead, and nut thread to gudgeon pin thread). These, combined, are likely to result in an embedding loss in the order of 0.009 mm (0.00036”). To prevent complete loosening from this cause, a preload of the order of 300 kN (67500 lbf) in the gudgeon pin would be required[13]. This level of initial load would mean that the joint should remain tight after embedding takes place. To achieve this, a torque of the order of 4 to 6 kNm (3000 to 4400 lbf-ft) would be required. With a flogging spanner 0.5 metres (19”) long, an applied load of 8 to 12 kN (1800 to 2400 lbf) would be needed. This is unlikely to be achieved by using a sledgehammer for flogging the nut. However, as noted in paragraph 46, a properly fitted gudgeon pin should, once embedded, remain locked into the crosshead bore, reducing the likelihood that the nut will work loose.

[13] These figures are calculated from information derived from Verein Deutscher Ingenieure, VDI 2230 – Part 1 Systematic calculation of high duty bolted joints. Joints with one cylindrical bolt. 2003.

49 If the nut loosens there will be a reduction of the clamping force in the joint. This can result in the nut rotating due to inertial and vibrational forces associated with the reciprocating movement of the crosshead when the locomotive is running. The oscillating action of the connecting rod will try to rotate the gudgeon pin, and any small rotational movement of the gudgeon pin (although limited by the key that engages with the crosshead[14]) would have the effect of loosening the nut. Once loose, with the castellated nut as fitted to 'Tangmere', the rotational movement would be transmitted by the nut to the head and one leg of the split cotter. There is a clearance between the sides of the slots in the nut, and the body of the cotter, which is likely to contribute to movement of the nut. With the sawn slot formed in the cotter having its base at the point where the bend is formed (as observed on the cotter from the left-hand side of 'Tangmere' (figure 6), which is likely to be similar to the missing cotter from the right-hand side as it was made at the same time), repeated alternating stress at this point is likely to produce fatigue, which could eventually lead to fracture. Fatigue fracture of one or both legs would mean that the cotter was no longer secured in the gudgeon pin.

50 The original design of the Bulleid pacific small end had the cotter in a vertical plane, ensured by the keyway slot and cotter slot in the gudgeon pin being at right angles to each other (figure 4). When 'Tangmere' was restored from scrapyard condition, new gudgeon pins were manufactured which had the two slots in line. RAIB has not been able to establish whether the restorer intended to make this modification to the design, or if it arose from a misreading of the only available detail drawing (figure 7). The effect of this was that when the components were assembled on the locomotive, the cotters lay horizontally. RAIB's examination of other steam locomotives now used on the main line and on heritage railways shows that vertical cotters predominate, but there are many examples of horizontal ones, and some locomotives have a vertical cotter on one side and a horizontal one on the other. At least one other Bulleid pacific has had new gudgeon pins made with the same modification to the design, during restoration from scrapyard condition.

51 With the cotter horizontal, the forces produced by the reciprocating motion of the crosshead and piston assembly would tend to eject the cotter. If the preload on the nut was lost as described above (paragraph 48), it is possible that the cotter could have then become loose in the slot[15].

52 Once the cotter was ejected, there would have been nothing to restrain the nut from unwinding. This could happen very quickly in the environment of a fast-running steam locomotive. 'Tangmere' ran at about 60 mph (97 km/h) for much of the journey from Waterloo, as far as Farnborough (33 miles (53 km)).

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[14] The manufacturing tolerances for the width of the key and the keyway are both ½" +0.0012"/- nil. Therefore, if fitted correctly, there should be no possibility of pin rotation.

[15] The material from which the cotter is made should be a clearance fit across the width of the slot: the only interference is against the back of the nut, across the depth of the slot, and the cotter should be hand-filed to achieve this at the time of fitting.

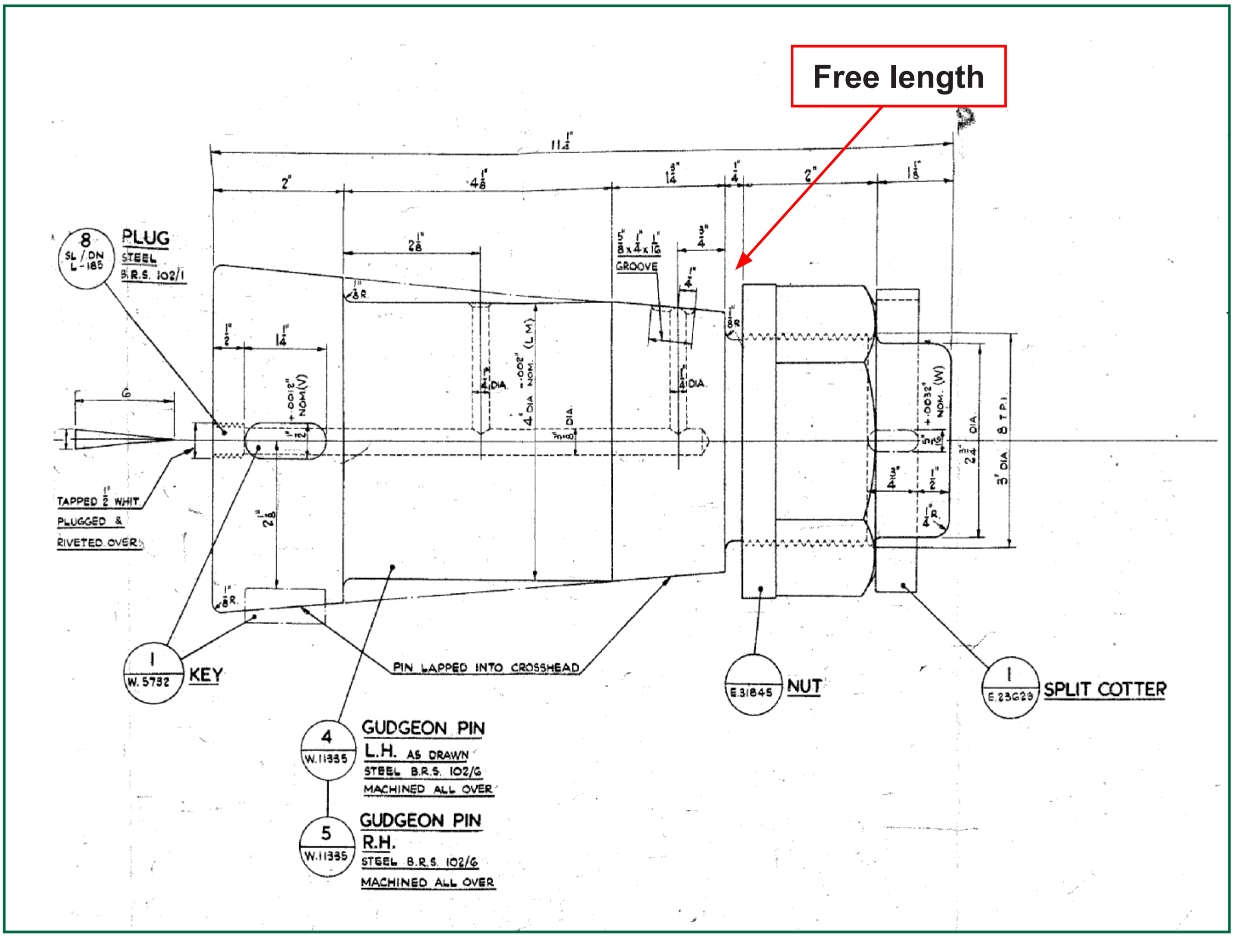

Figure 7: Detail drawing of gudgeon pin (extract from British Railways (Eastleigh) drawing W11335). Drawing reproduced by courtesy of the National Railway Museum/Science & Society Picture Library

53 Photographic evidence shows that the cotter was present, with both its legs intact, when 'Tangmere' arrived at Waterloo shortly after midday on 23 November, following its journey from Weymouth. Witness evidence indicates that the assembly was intact, and apparently tight, when the locomotive was examined at Southall by the WCRC operations engineer and another member of the locomotive's support crew during the afternoon of that day. However, it is possible that a small looseness of the gudgeon pin may not have been detected by this examination.

54 This examination was carried out as required by WCRC's document WI056 'Arrangements for fitness to run examinations', issue 5, dated September 2011. WCRC's procedures require this 'fitness to run' (FTR) examination, also known as an 'A' examination, to be carried out daily by the operations engineer when the locomotive is in use. The detailed requirements for a FTR examination are in the company's maintenance schedules issue 4f, dated October 2013. The relevant sections are:

(A04) Connecting and coupling rods: Examine all connecting and coupling rods, eccentrics, other motion parts and axlebox bearings for signs of dryness, indicating lack of lubrication or metal slivers/particles which could be an indication of the bearing running hot.

(A05) Motion: Check security of split pins, cotters and other locking arrangements.

These requirements are derived from the British Rail document MT276 'Examination Schedule for Preserved Steam Locomotives Running on BR Lines', revision 2, January 1990.

55 If the sequence of events described above took place, starting with the loss of one of the legs of the cotter, it could only have happened over the journey of about 50 miles (80 km) from Southall, via Waterloo, to Winchfield.

56 The final loss of the gudgeon pin nut was probably accompanied by the violent movement of the pin in the crosshead. The energy imparted to the nut was evidently sufficient to fracture the studs which secure the oil cup which is fitted to the upper part of the crosshead, directly above the gudgeon pin. The oil cup has not been found, but RAIB believes that its loss was a consequence of the small end failure, and was not among the causes of the event. There was no evidence of any heating of the gudgeon pin surface, as would have been the case if it had been starved of oil for any length of time. Following the detachment of the nut, the gudgeon pin was free to move in the taper bore of the crosshead. This movement damaged the end of the thread and the small end of the taper on the pin (figure 8). The gudgeon pin finally came out of the back of the crosshead, catching on the brake rigging and breaking the hanger of the brake block of the right-hand leading coupled wheel. It then lodged on the top of the bogie wheel splasher[16] of 'Tangmere', where it was found after the accident.

57 The original design of this assembly used a plain, rather than a castellated nut (figure 7). There is no evidence that this design caused any problems when the locomotives were in service with British Railways (BR), and many of the locomotives that have been preserved, either directly after leaving BR service or via the Barry scrapyard, have plain nuts on the small end assembly.

58 Witness evidence indicates that when the Bulleid pacifics were in service with BR, the practice in some depots when assembling the small end was to back off the (plain) gudgeon pin nut slightly after the cotter was fitted, so as to tighten the nut against the cotter rather than relying on the preload in the gudgeon pin. The smaller section of the cotter would make it easier to achieve a relatively high preload with the tools available at a depot. This action would not be possible with a castellated nut, and the practice is not likely to have been followed in the SR and BR works where the locomotives were built and overhauled.

[16] The splasher is the arc-shaped component above the rear wheels of the bogie, which deflects dirt from the piston rod.

Figure 8: Gudgeon pin of 'Tangmere' after the accident

59 RAIB has not been able to determine the reason why Riley & Son modified the design of the gudgeon pin fastener (see paragraph 69). It has been suggested that, if the nut and cotter work loose, the castellated nut is prevented from rotating more effectively than a plain nut, thus giving more time for the looseness to be detected during routine examination. It appears equally possible that the additional fretting of the slots of the castellated nut on the legs of the cotter may encourage fatigue and fracture of the cotter, as may have been the case in this accident. It is also the case that, unless the nut is removed and machined to make the slots align, the need to back-off a castellated nut to align the slots to enable the cotter to be fitted will have a severely adverse effect on the preload of the joint.

60 Many other steam locomotives, notably ex-LMS, LNER and BR standard types, make use of castellated nuts to secure the small end. However, there are significant differences in the design of the small end, notably the use of smaller diameter threads (in which a preload can be more easily achieved), and a bush between the crosshead and the gudgeon pin, with both external and internal tapers, which may affect the way in which the assembly behaves.

61 The reasons for these changes cannot now be established with certainty, although it is likely that the changes to the nut and cotter arose because the restorers copied the practice of other railway companies with which they were more familiar, rather than using the original Southern Railway design, for which they may not have had detail drawings. The original design of nut and cotter had remained unchanged throughout the service life of the locomotives.

Cotter design and fabrication

62 **There were deficiencies in the design and manufacture of the cotter.**

63 The original design of this assembly used a split cotter with a loop head. This type of component is no longer available as a manufactured item in the required size. During the investigation RAIB found that restorers of steam locomotives generally fabricate their own cotters (since suitable proprietary items are no longer manufactured), often without reference to any drawings, and varying widely in the details of how they are made.

64 The cotters on 'Tangmere' were made from a single piece of 5/16" (8mm) thick mild steel, with a 'gib' head ¾" (19 mm) deep and a saw cut up the centre to form the legs. This saw cut is, on the cotter that was fitted to the left-hand side of the locomotive, about 1¼" (30 mm) long, in a cotter that is 5" (127 mm) long overall. This means that when the cotter is fitted to the gudgeon pin, the base of the saw cut is outside the gudgeon pin, and therefore forms a hinge at which the legs of the cotter are bent outwards.

65 Making the slot in the cotter of this length is undesirable, firstly because having the base of the legs beyond the outer diameter of the gudgeon pin will permit the cotter to move in the slot if it becomes loose for any reason (paragraph 49), and secondly (in this application with a castellated nut) because the castellations of the nut can bear on the hinge point, where the stress concentration is greatest and the material has been weakened by the bend, and act as an initiating point for a fatigue crack as described in paragraph 49.

66 The sharp corner under the head of the cotter will also create a stress concentration, and may initiate development of a crack which could eventually lead to detachment of the head.

67 There is a British Railways (Doncaster) drawing, reference SL-DN-K 569, of 'Bright Cotters' which is reproduced as part of appendix C, and gives dimensions for a range of cotters for BR standard locomotives. Having consulted with experts in the field, RAIB considers that the details in this drawing represent good practice. In particular, the slot should be of adequate length so that the root of the slot is well within the component in which the cotter is fitted. There should also be a radius formed in the corner under the head of the cotter (figure 6).

68 On 17 March 2014, RAIB issued an Urgent Safety Advice notice to steam locomotive operators and maintainers, covering the manufacture of cotters and the potential risks of modifications to locomotive designs. A copy of the notice is at appendix C.

Design modifications

69 **The design of some components had been modified during restoration of the locomotive, possibly without full consideration of the potential effect of these modifications.**

70 As discussed in paragraphs 57 to 59, when 'Tangmere' was restored from scrapyard condition, several minor changes were made to the detail design of the components of the crosshead and connecting rod assembly. In particular, the relative position of the slots in the gudgeon pin for the keyway and the cotter was changed from the original design, in which the slots were at 90 degrees to each other, to being in line (figures 7 and 8). Castellations were added to the gudgeon pin nut, and the securing cotter was changed from a pre-formed component made from folded steel strip, with a loop head, to a cotter made from a piece of steel bar, with legs made by sawing a slot up the centre (paragraph 64 and figure 6).

Control of design modifications

71 Vehicles which do not comply with modern standards of design and construction (such as *Railway Group Standards*) can be authorised for use on the national network under the provisions of Appendix H of Railway Group Standard GM/RT2000 (issue 3) 'Engineering Acceptance of Rail Vehicles'[17]. Each such vehicle must have a Certificate of Engineering Acceptance issued by a registered Vehicle Acceptance Body (VAB), which must be renewed annually. This provides an opportunity for a detailed examination, including a check of whether a vehicle has changed from the expected design or configuration, but this relies heavily on the experience of the examiner. It may not be reasonable for an examiner to know whether every nut and bolt is the same as the original design.

72 It is for the train operator to satisfy the VAB that the design of the vehicle was previously accepted for operation on BR or its successors, and proved satisfactory when in service. Clause H1 (e) of the standard says:

> 'Any replacement part used in the construction that is redesigned, or manufactured by a different manufacturing method (including the situation where the original, proven method of manufacture or manufacturing standards are unknown) shall be confirmed to be at least as good in its performance as the original by the VAB.'

[17] http://www.rgsonline.co.uk/Railway_Group_Standards/Rolling%20Stock/Railway%20Group%20Standards/GMRT2000%20Iss%203.pdf.

73 WCRC has a safety management system (SMS)[18], which includes a Maintenance and Overhaul Policy. Section 4.11 of this states:

> '<u>Arrangements for the Authorisation of Modifications</u>
>
> When service experience or other reasons lead to the need to modify the locomotive or a component of the locomotive, the [WCRC] Engineering Manager will be responsible for ensuring that proper engineering principles are applied to the design process, and that a full risk assessment is provided for the proposal. The Engineering Manager will then seek approval from the Vehicle Acceptance Body for the execution of the modification, and then provide an update to the maintenance policy documentation for final approval prior to the locomotive re-entering service on the Network Rail Controlled Infrastructure. Similar approvals must also be sought from any other Railway Company on whose railway the locomotive is to run.
>
> All modification work effected is recorded in the locomotive maintenance records.'

74 The restoration and last overhaul of 'Tangmere' was carried out before it came into the control of WCRC (paragraph 35). There is no record of any detailed consideration of the changes to the design of the gudgeon pins, nuts and cotters, either during restoration or subsequently. However, 'Tangmere' has been examined annually since 2007 by the VAB used by WCRC.

Fracture of the gudgeon pin nut

75 It is possible, but less likely, that the gudgeon pin nut split as a result of either an inherent flaw or fatigue cracking.

76 The gudgeon pin nut used on 'Tangmere' had twelve slots, in which the cotter could be located (figure 6). Each of these slots had sharp corners at the base. If the nut experienced high levels of stress and/or vibration, it is possible that fatigue cracks could be initiated at these corners: these might over time develop to the point where the nut fractured.

77 The nut was manufactured at the same time as the gudgeon pin, and witness evidence indicates that it is likely that it was made from the same material, steel to specification EN3b (as defined in British Standard BS970:1955), or a similar grade. This is a mild steel having a tensile strength of around 430 MPa (63000 lbf/sq in, which is lower than the original specification for these components[19]). The use of a lower grade of steel than originally specified, although it may wear more rapidly, is unlikely to have been significant in practice, as the gudgeon pin and nut are not highly stressed.

78 The side of the nut with the slots is likely to experience very little stress, and it is difficult to understand how stresses could be introduced which would initiate such a fracture. It is considered unlikely that cracking could have been initiated from the bearing face of the nut, because this part of the nut is in compression.

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[18] The organisation and arrangements established by a transport operator to ensure the safe management of its operation (as defined in the Railways & Other Guided Transport Systems (Safety) Regulations 2006 (SI 2006 no. 599)).

[19] The specified gudgeon pin material (see figure 7) was BR Spec.102/6; that for the nuts old British Standard spec. BSS9C. Equivalent BS specs. were BS24: 1955 Railway Rolling Stock Material, part 4, no. 8D and 8C respectively. Tensile strength for Class D was 620 – 700 MPa (90,000 – 101,000 psi); class C 500 – 590 MPa (72000 – 85000 psi).

79 It is also the case that, if the nut had split, the cotter would remain in the gudgeon pin as long as its legs and head were intact. While the battering the gudgeon pin experienced as it came free of the crosshead is quite severe, and could have contributed to the destruction of the cotter, no trace of any part of it remained in the slot in the gudgeon pin, nor was there any battering of the edges of the slot.

80 For these reasons RAIB considers that it is less likely that the assembly failed because the nut split. However, because the nut and cotter have not been recovered, this failure mode cannot be discounted.

Factors affecting the consequences of the accident

The running of the train

81 **The train continued in service after an unusual noise was identified.**

82 Train 1Z94 travelled on the down fast line from Queenstown Road, about three miles (5 km) after leaving Waterloo. It ran generally at about 60 mph (97 km/h), the speed required to keep to the scheduled timings, although the locomotive was permitted to run at up to 75 mph (121 km/h) if necessary. Members of the public have provided RAIB with video recordings of the train on the journey from Waterloo (as well as some taken earlier in the day, on the way from Weymouth in the morning). RAIB has discussed the recordings with people experienced in the operation of Bulleid pacifics. The sound on them is of variable quality, but there is nothing that can be identified as unusual for this type of locomotive.

83 The train was scheduled to stop at Winchfield for the locomotive to take on water. This required it to be switched from the down fast line to the down slow line, which took place at Farnborough. To carry out this move, the train was required to reduce speed to 40 mph (64 km/h). It continued to run at about that speed once on the slow line, because it was following a stopping passenger train and therefore receiving restrictive signal aspects.

84 For these reasons, the train was travelling relatively slowly when the engine crew became aware of an unusual noise on the approach to Farnborough (paragraph 23). If the driver had stopped the train immediately, it is possible that the detachment of the connecting rod would have been avoided.

85 Steam locomotives produce a considerable amount of noise when running. Crews become accustomed to the various sounds, and drivers in particular are constantly using sound to judge the performance and state of health of their locomotive. In this case, the knocking noise that had developed by the time 'Tangmere' approached Farnborough seemed to reduce when the driver altered the setting of the reverser. On this basis the crew decided to carry on to the water stop at Winchfield, about six miles (10 km) away, and examine the engine there. Witness evidence indicates that they made this decision because to stop on the main line away from a station would have been very disruptive (as turned out to be the case), and would have made evacuating the passengers more difficult. However, it was very fortunate that when the connecting rod did become detached, it dropped down at a location where there was a smooth surface (the conductor rail) underneath it.

Design of the crosshead and slide bars

86 **There was nothing to prevent the connecting rod dropping to the ground after the small end joint came apart.**

87 The design of the Bulleid small end uses slide bars only above the gudgeon pin, so that there is no lower slide bar to restrain a connecting rod if the small end becomes detached (figure 5). This arrangement was first used in Britain in 1918 on the Great Northern Railway (GNR) and from 1925 on the Southern Railway. It has been generally accepted for over 90 years.

88 The potential hazard from this arrangement was shown by the accident near Settle on 21 January 1960, in which the slide bars on the right-hand side of a British Railways standard class 7 locomotive became detached, and the piston rod, crosshead and connecting rod dropped to the ground. The locomotive was hauling an express passenger train, travelling at about 45 mph (72 km/h), and the detached motion dug into the ground and struck and damaged the adjacent line, on which a freight train was approaching. This train was derailed, and collided with the express train; five people were killed and nine injured.

89 Following that accident, the design of the slide bars on BR standard locomotives was modified to improve the security of their fastenings. There has been no similar event involving the detachment of motion on a UK main line steam locomotive since then, until the accident on 23 November 2013. This differed from the 1960 event in that it was the small end joint, rather than the slide bars, which came apart.

Location of the conductor rail

90 When it became detached from the crosshead, the leading end of the connecting rod dropped down and made contact with the conductor rail, which at that location is on the right-hand side of the line. The end of the rod ran along the rail for some distance before dropping off just before the train stopped.

91 If the connecting rod had not landed on a smooth surface such as the conductor rail, it might have become caught against a sleeper or other equipment at ground level. In such a case, the rod might have dug into the ground. The consequences of this could have been catastrophic, in that the track could have been distorted, leading to derailment of the train (paragraph 88), and/or the locomotive could have been pushed into derailment towards the left-hand side, at a point where the railway is on an embankment.

Discounted factors

Other damage to 'Tangmere'

92 When the front cover of the right-hand cylinder of 'Tangmere' was removed at Southall depot after the accident, under the supervision of RAIB, the piston head was found to be loose on the piston rod. The piston head is held on a steep cone (tapered 1 in 2 on diameter) by a nut with a 2¾" (70 mm) diameter thread, which is secured by a split cotter in a ¼" (6 mm) slot in the end of the rod.

93 The remains of part of the cotter were found in the cylinder (figures 9 and 10). The body of the cotter and one of the legs were present, though detached, and the other leg could not be found.

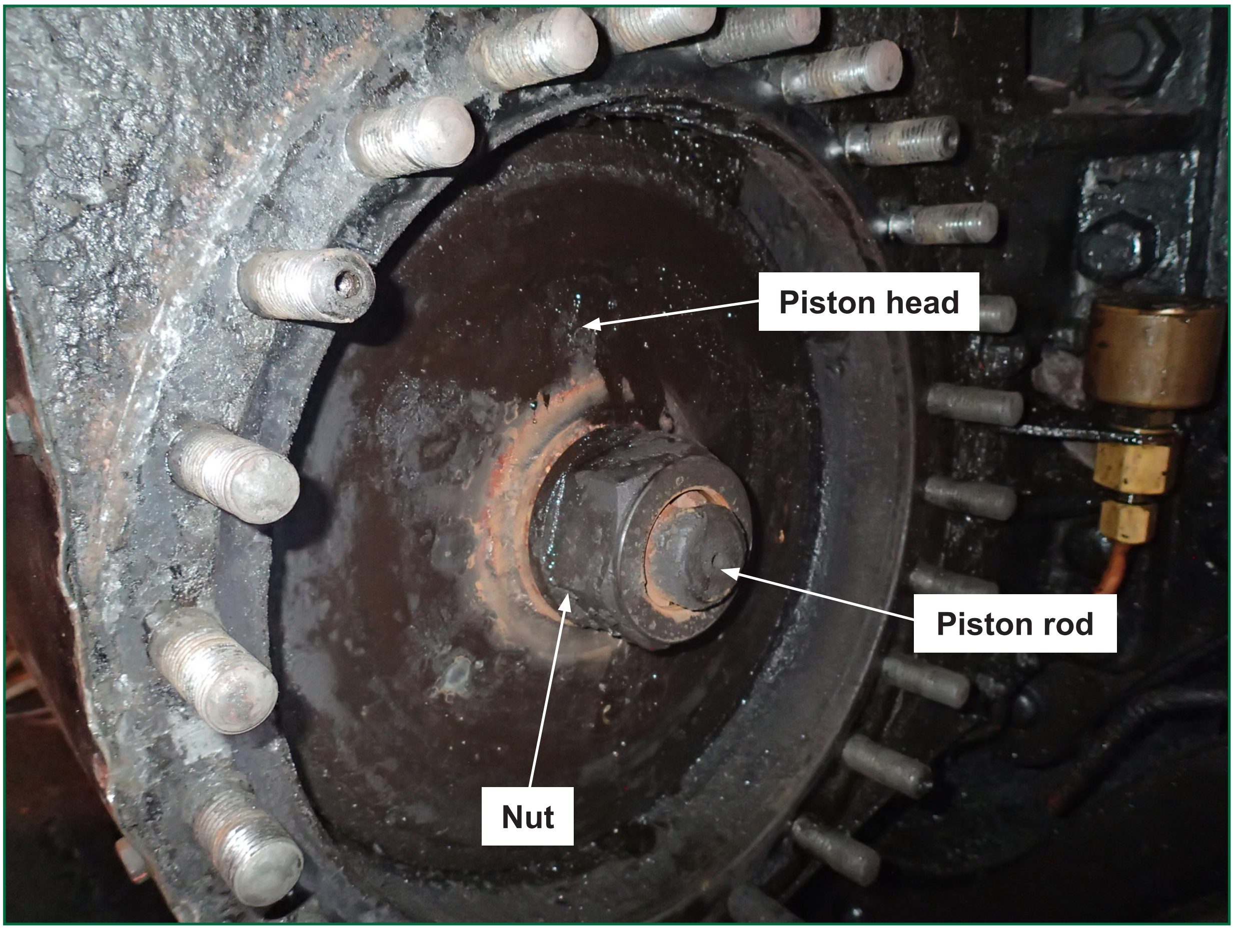


Figure 9: Loose piston head

Figure 10: Remains of cotter from piston rod

94 The nut had unwound by about one turn when found, so that the piston head had about 1/8" (3 mm) free movement on the rod. There was evidence that the piston head had contacted the cylinder cover. The method of securing the piston on the rod had not been modified from the original design.

95 RAIB has considered whether the condition in which the piston head was found was causal or consequential to the failure of the small end assembly.

96 When the gudgeon pin came out, 'Tangmere' was coasting with the *regulator* almost closed. In this condition a small amount of steam is admitted to the cylinders. Once the restraint created by the link between the crosshead and the connecting rod was removed, the crosshead and piston assembly would have been free to move within the cylinder under the action of the steam, and this movement would have been violent. It is possible that, in the distance that it took the locomotive to come to a stop, the unrestrained piston head would have contacted the cylinder cover with enough force to loosen the nut by forcing the piston head further up its taper, and fracture the head of the cotter, leading to the rest of the cotter dropping out of the slot and the nut starting to unwind.

97 If the piston head had come loose before the small end failure, the slack between the piston head and piston rod would have created some additional shock loading on the small end joint, which would have been transmitted through the gudgeon pin. However, the small amount of movement that was present after the accident is unlikely to have had a significant effect on the loading of the joint. More importantly, the piston head nut, once loose and without its cotter, would have unwound quite quickly, because of the vibrational and inertial forces on it, leading to complete failure of the right-hand cylinder in a short time. RAIB therefore discounts this as a cause of the small end failure, and concludes that the looseness of the piston head was a consequence of the failure of the small end assembly.

98 After the accident, the crosshead was restrained with wood packing and rope so that the piston could not move in the cylinder while the locomotive was being recovered and returned to the depot at Southall.

Observations[20]

Maintenance arrangements

99 The maintenance arrangements for 'Tangmere' were not in accordance with the principles of WCRC's safety management system.

100 'Tangmere' is based at WCRC's Southall depot while it is in service, but major overhauls and other work take place at the company's main base at Carnforth.

[20] An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but does deserve scrutiny.

101 The company's safety management system is written for the circumstances in which maintenance of steam locomotives is carried out by the owners of the locomotive, who act as suppliers to WCRC and certify that maintenance has been carried out in accordance with a plan which has been validated by WCRC. Competent WCRC staff should then carry out a FTR examination before each journey to confirm that the locomotive is in a safe condition. However, because 'Tangmere' is owned by a company associated with WCRC (paragraph 10), the same person (the operations engineer) certified that maintenance had been done, and then carried out the FTR examinations. He had been doing this since 2007, as part of his role as the person responsible for looking after 'Tangmere' during its main line service, out-stationed with the locomotive at Southall.

102 The management of WCRC had complete confidence in the operations engineer. Consequently, his work with 'Tangmere' was not subject to any monitoring, supervision or audit. He had completed full paper records for scheduled maintenance and FTR examinations, corresponding to 'Tangmere's' movements over the period that he had been in charge of it during which time it had run about 50,000 miles (80,000 km).

103 There is no evidence that the maintenance or inspection of 'Tangmere' was in any way deficient, or causal to the accident on 23 November. However, the absence of any checks on the work that had been carried out, and the potential for a conflict of interest between the maintenance and inspection roles, meant that this situation was not in accordance with the principles of WCRC's safety management system.

On-train data recorder

104 **The on-train data recorder fitted to 'Tangmere' did not record the details of the locomotive's movements on 23 November 2013.**

105 In common with all other traction units which operate in normal service on Network Rail, 'Tangmere' is require to be fitted with an on-train data recorder (OTDR) to record significant details of each journey. On a steam locomotive the data that can be recorded is quite limited, but should include speed, brake cylinder pressure, and information on the operation of the AWS and TPWS systems.

106 'Tangmere's' OTDR was downloaded by WCRC following the accident. It has not been possible to identify data for the locomotive's movements on 23 November 2013, including the journey from Waterloo to Winchfield. The last data recorded on the OTDR is not positively date stamped, but RAIB believes that it may be a record of the journey from Southall to Weymouth on 22 November, when the locomotive was being hauled tender-first. The large volume of witness evidence as to 'Tangmere's' running on 23 November means that the absence of the relevant OTDR data for that day was not crucial to the investigation.

107 After the accident, the OTDR was sent to the manufacturer for analysis and repair. The manufacturer reported that the failure to record on 23 November was probably due to the condition of the internal battery, which was subsequently renewed.

108 The daily FTR examination (paragraph 54) includes an element relating to the data recorder:

> (A29) OTMR[21]: Power on the OTMR (switch on the circuit breaker) check that blue LED ‘healthy’ light is illuminated. Visually check the security & integrity of OTMR equipment and pipework & fittings.

109 This check would not have detected the poor condition of the internal battery, and WCRC considers that it is not practicable to do a more detailed check (that might discover a defective internal battery) as part of the FTR examination.

Previous occurrences of a similar character

110 Instances of connecting rods becoming detached were uncommon when steam locomotives were in regular service, and the accident on 23 November 2013 is the first example officially recorded on the UK main line network for over sixty years (although anecdotal evidence suggests that it happened at least once in the 1960s).

111 RAIB is grateful to Transport Safety Victoria for providing a report on an accident that occurred in Australia in 2001. The left-hand connecting rod of R class 4-6-4 locomotive R766 (built in the UK in 1951) became detached while the locomotive was travelling at about 115 km/h (71 mph). The rod dug in to soft ground, and rotated through 180° to finish in the trailing position, but there was no derailment.

112 The R class has two outside cylinders, and was intended for express passenger work. The design of the small end joint on the R class is broadly similar to that on the Bulleid pacifics, but the gudgeon pin is secured by a washer, two nuts and a split pin. As at Winchfield, the nuts, washer and split pin had come off and were not recovered after the accident.

113 The gudgeon pin thread was extremely worn along its entire length, with most of the thread being worn down to the root. There was no sign of any recent presence of a split pin, and there was also evidence to suggest that the gudgeon pin had been loose in the crosshead and that the taper of the gudgeon pin did not match the bore in the crosshead. The investigation concluded that the nuts had been loose for some time and had worked off following wear to the thread. It was not clear how far the locomotive had run since the tightness of the assembly had last been checked, but it had been put into service one month before the accident, after extensive modifications had been carried out.

114 There are some parallels between this accident and the ‘Tangmere’ case, notably the example of how a small end joint can deteriorate very rapidly in service. However, the absence of wear to the gudgeon pin thread in the ‘Tangmere’ case, means that the similarity is limited.

[21] OTMR is an alternative term for the OTDR.

115 In Britain, the last accident of this type to be officially investigated occurred near Northolt Junction, Middlesex, on 28 August 1950. A connecting rod of an inside-cylinder 0-6-0 goods engine (ex-LNER class J39) became detached at the leading end. The connecting rod, confined between the frames of the locomotive, was bent double and punctured the outer shell of the firebox. The engine crew left the cab in haste, and the driver was scalded by escaping steam. The gudgeon pin thread was found to be extensively worn, and although the nut was not found, it was clear that it had sheared the split pin before coming off.

116 The investigation concluded that recent examinations of the locomotive had failed to identify the loose nut, and that the design of the crosshead was poor. The design was subsequently modified, but none of this type of locomotive has survived and the details of the modification have been lost.

117 The accident at Settle in 1960, referred to in paragraph 88, did not involve the failure of the small end joint, although the potential consequences were similar. An accident at Weedon on the London & North Western Railway in 1915 involved the detachment of the leading end of a coupling rod of the locomotive hauling an express train travelling at about 60 mph (97 km/h). The rod dug into the ground and distorted the track, derailing a train travelling in the opposite direction on the adjacent line and resulting in the death of ten people and injury to 31 others. In this case, it is likely that the ends of a split cotter had not been properly opened out when it was fitted, as a replacement for a missing one, a few minutes before the accident. The locomotive had only run about twelve miles (19 km) when the rod came off, and the pin was found on the track five miles (8 km) further back. The design used screwed washers, rather than nuts, to hold the rods in place, and relied heavily on the integrity of the split pin to fasten the assembly together. There do not appear to be any other previous accidents on standard gauge railways that were in any way relevant.

Summary of conclusions

Immediate cause

118 The immediate cause of the accident was that the small end assembly came apart (**paragraph 41**).

Causal factors

119 It is likely that one or more of the following factors was causal, but the loss of some components means that RAIB cannot be certain which one:

a. The cotter may have come out following the breakage of one or both of its legs; the gudgeon pin nut may then have unwound and the pin may have come out (**paragraph 44, Recommendation 1**).

b. The design of some components had been modified during restoration of the locomotive, possibly without full consideration of the potential effect of these modifications (**paragraph 69**, **Recommendation 4**).

c. As a consequence of (b), there were deficiencies in the design and manufacture of the cotter (**paragraph 62, Recommendation 2**).

d. The gudgeon pin nut may have split, as a result of either an inherent flaw or fatigue cracking (**paragraph 75, no recommendation**).

Factors affecting the consequences of the accident

120 Factors that exacerbated the consequences of the event were as follows:

a. The train continued in service after an unusual noise was identified (**paragraph 81**).

b. There was nothing to prevent the connecting rod dropping to the ground after the small end joint came apart (**paragraph 86**).

Additional observations

121 Although not linked to the accident on 23 November 2013, RAIB observes that:

a. The maintenance arrangements for ‘Tangmere’ were not in accordance with the principles of WCRC’s safety management system (**paragraph 99, Recommendation 3**).

b. The on-train data recorder fitted to ‘Tangmere’ did not record the details of the locomotive’s movements on 23 November 2013 (**paragraph 104, Learning point 1**).

Actions reported as already taken or in progress relevant to this report

122 WCRC reports that it has repaired 'Tangmere' and returned it to service. On the locomotive itself, the right-hand side gudgeon pin, nut and cotter have been renewed in accordance with the original BR (Southern) drawing number W11335. This means that the castellated nut previously fitted has been replaced with a plain nut and a Southern Region style split cotter which is now aligned vertically. The left-hand side and middle cotters have been renewed and the nuts have been examined and subjected to non-destructive testing. All motion cotter pins have been renewed. The piston rod/crosshead, connecting rod and brake hanger have all been stress relieved by a specialist contractor and checked for straightness and alignment. The right-hand connecting rod has been through a thorough non-destructive testing process using an Eddy Current system.

123 WCRC also reports that it has modified its maintenance processes for its locomotives to highlight the need to change the internal battery of the OTDR at the manufacturer's recommended frequency.

Learning point

124 The RAIB has identified the following learning point[22] for the railway industry.

1 In addition to regular checks on the function of the on-train data recorder, operators of steam locomotives should take appropriate action (such as regular changes) to keep the internal batteries in good condition.

[22] 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when the RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where the RAIB has not identified management issues that justify a recommendation) and the consequences of failing to do so. They also record good practice and actions already taken by industry bodies that may have a wider application.

Recommendations

125 The following recommendations are made[23]:

1 *The intent of this recommendation is that the design of the Bulleid small end should be reviewed to establish the benefit or otherwise of using a castellated nut.*

West Coast Railways, in consultation with the Main Line Steam Locomotive Operators Association, the Bulleid Pacific Locomotive Association and the Heritage Railway Association, should review the design of the small end joint on the Bulleid pacific locomotive to establish the safety benefits, and risk, of using a castellated nut. The results of this review should be shared with other owners of these locomotives (paragraph 119a).

2 *The intent of this recommendation is that the details of the design of cotters fitted to steam locomotives should be reviewed, to reduce the risk of failure arising from fatigue.*

The Heritage Railway Association and the Main Line Steam Locomotive Operators Association should prepare guidance for their members on the design and manufacture of split cotters to encourage the use of best engineering practice. This may include considering:

- reference to the British Railways drawing SL-DN-K.569; or
- other methods of fabrication such as the use of folded strip, welded at the head, which is widely used in the industry.

(paragraph 119c)

continued

[23] Those identified in the recommendations, have a general and ongoing obligation to comply with health and safety legislation and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation to enable it to carry out its duties under regulation 12(2) to:

(a) ensure that recommendations are duly considered and where appropriate acted upon; and

(b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 200 to 203) can be found on RAIB's website www.raib.gov.uk.

3 *The intent of this recommendation is that the maintenance arrangements for steam locomotives operated by West Coast Railway Company should be consistent and in accordance with the provisions of its safety management system.*

West Coast Railway Company should review and improve its safety management system to take account of the need for assurance that the standards of maintenance work carried out on locomotives owned and/or operated by the company are adequate, consistent and subject to monitoring and supervision independent of those doing the work (paragraph 121a).

4 *The intent of this recommendation is that restorers of steam locomotives should be made aware of the need to thoroughly evaluate and risk assess design changes proposed or made during the restoration process, or subsequently.*

The Heritage Railway Association and the Main Line Steam Locomotive Operators Association should bring this report to the attention of their members and invite them to consider thoroughly evaluating and risk assessing changes to the design of steam locomotives that are made during restoration, overhaul or maintenance. The following should be considered:

- whether the purpose and function of the original design, and the reasons for making the change are fully understood;
- whether any additional risk will be introduced by the change; and
- any measures that may be needed (during overhaul, operation or maintenance) to reduce the risk associated with the change, and to assess its impact.

(paragraph 119b)

Appendices

Appendix A - Glossary of abbreviations and acronyms

BR	British Railways
CRRES	Carnforth Railway Restoration and Engineering Services
FTR	Fitness to run
GNR	Great Northern Railway
HMRI	HM Railway Inspectorate
LMS	London, Midland & Scottish Railway
LNER	London & North Eastern Railway
OTDR	On-train data recorder
SR	Southern Railway
VAB	Vehicle Acceptance Body
WCRC	West Coast Railway Company

Appendix B - Glossary of terms

All definitions marked with an asterisk, thus (*), have been taken from Ellis's British Railway Engineering Encyclopaedia © Iain Ellis. www.iainellis.com.

Bogie	A metal frame equipped with two or three wheelsets and able to rotate freely in plan, used under rail vehicles to improve ride quality and better distribute forces to the track.*
Boiler	In a steam locomotive, the pressurised vessel in which steam is generated by heat applied externally.
Brake Gear	The mechanical components of the braking system of a rail vehicle, including brake shoes, hangers, and pull rods.
Bulleid pacific	A steam locomotive of the 'Merchant Navy' or 'West Country/ Battle of Britain' classes, designed under the supervision of O V S Bulleid and built by the Southern Railway and British Railways between 1941 and 1951.
Castellated nut	Internally threaded fastener with one side having a series of slots across the diameter.
Conductor rail	An additional rail, used to convey and enable collection of electrical traction current at track level.*
Connecting rod	In a piston engine, the link which connects the piston or piston rod to the crankpin or crank axle, and converts reciprocating to rotary motion.
Cotter (split)	A fastener consisting of a split rod or flat bar, which is fitted through a slot or hole in a shaft to retain another component in place.
Creep	Deformation over time when a component is subjected to constant stress, which can occur in metals at elevated temperatures.
Crosshead	In a piston engine, the component which supports the joint between the piston rod and connecting rod.
Cylinder	In a steam locomotive, the chamber in which the steam expands to move the piston, converting pressure into movement.
Flogging up	Tightening a nut by using a long spanner and a sledgehammer.
Free length	In a bolted joint, the total distance between the underside of the nut and the bearing face of the bolt head; includes washer, gasket thickness etc. (also called grip length).
Gudgeon pin	In a piston engine, the pivot for the end of the connecting rod that is closer to the piston.

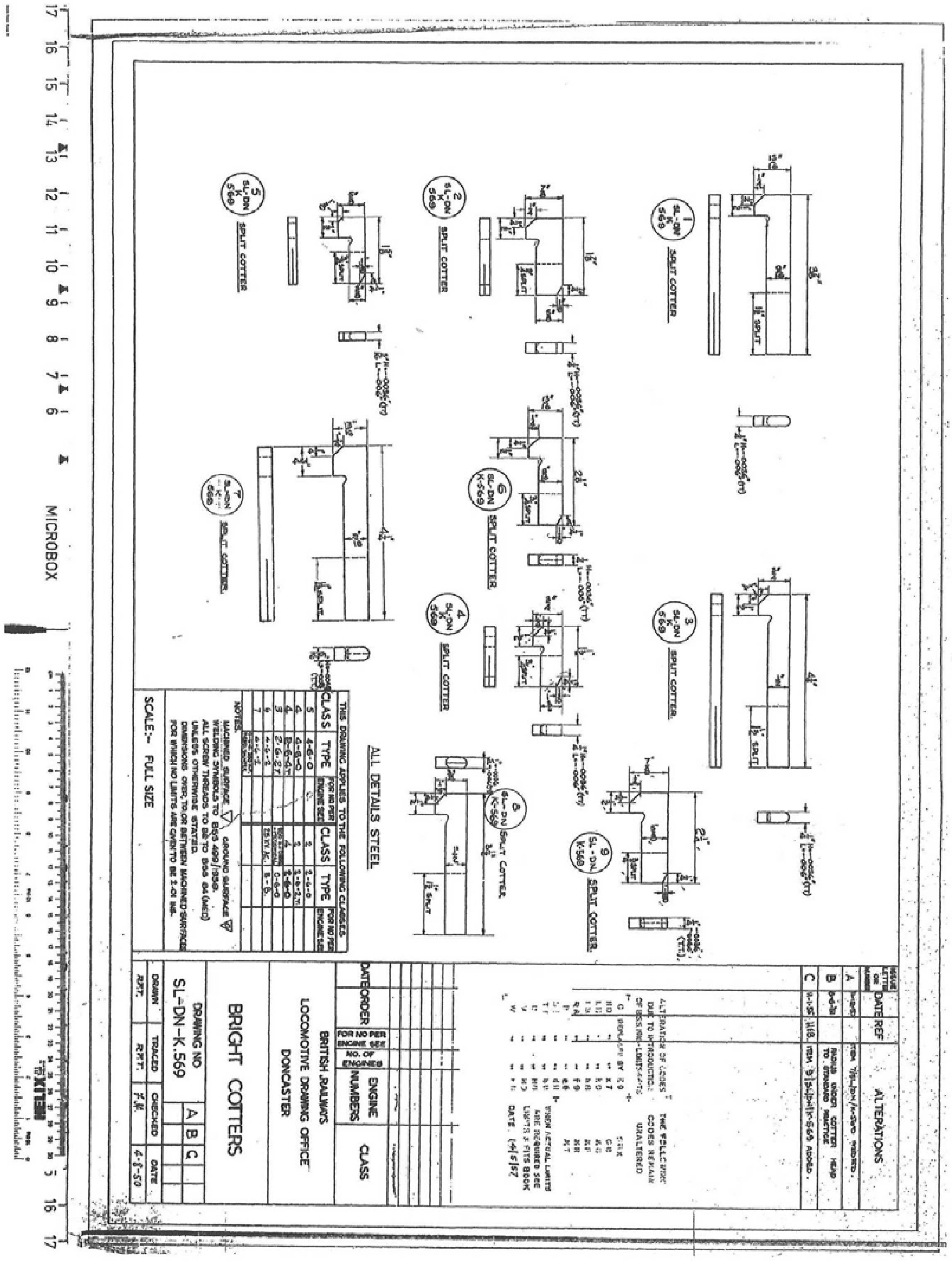
Motion	The machinery associated with the working of the cylinders and wheels of a steam locomotive, including the connecting rods, coupling rods, and valve gear.
Preload	The internal load induced in a bolted joint by the tightening of the fasteners.
Railway Group Standard	A document mandating the technical or operating standards required of a particular system, process or procedure to ensure that it interfaces correctly with other systems, process and procedures. Railway Group Standards are maintained by RSSB on behalf of the railway industry.
Regulator	The valve, operated by a lever in the locomotive cab, which controls admission of steam to the cylinders.
Reverser	The control mechanism for the valve gear of a steam locomotive, which regulates its direction of movement and the utilisation of the steam in the cylinder.
Splasher	The arc-shaped component above the rear wheels of the bogie, which deflects dirt from the piston rod.
Support coach	A railway carriage which provides accommodation for the staff and equipment needed to support the operation of a steam locomotive on the main line. It is usually coupled next to the locomotive, at the front of a train.

Appendix C - Urgent Safety Advice

1. Incident Description			
Lead / Inspector		**Contact Tel. No.**	
Incident Report No	**698**	**Date of Incident**	23 November 2013
Incident Name	Locomotive failure at WInchfield		
Type of Incident	Dangerous occurrence		
Incident Description	At about 18:50 hrs, train 1Z94, the 17:48 hrs charter service from London Waterloo to Weymouth, was approaching Winchfield, where it was due to stop for the locomotive to take on water. While the train was travelling at about 40 mph, the right-hand connecting rod of the locomotive, former British Railways (Southern Region) 4-6-2 34067 “Tangmere”, became detached at the leading end (referred to as the small end), and dropped down. The end of the detached rod struck the conductor rail, and there was some electrical flashing. This was noticed by the locomotive crew, and the driver stopped the train immediately, about one mile from Winchfield station. After running along the conductor rail for some distance, the connecting rod dropped onto the sleeper ends just before the locomotive came to rest.		
Supporting References	http://www.raib.gov.uk/publications/current_investigations_register/131123_winchfield.cfm		

2. Urgent Safety Advice	
USA Date:	17 March 2014
Title:	Detail design of cotters
System / Equipment:	Connecting rod small end assembly
Safety Issue Description:	Possible design/manufacture deficiency
Circumstances:	The small end assembly came apart while the locomotive was travelling at about 40 mph. The reasons for the failure have not been fully established because the nut and cotter which secure the gudgeon pin in the crosshead have not been located following the incident. Analysis of the possible failure mechanisms suggests that the most likely sequence of events involved the detachment of the cotter, leading to the detachment of the nut. Examination of the components from the other side of the locomotive found that the cotter was made from a single piece of steel bar 5/16” (8 mm) thick, with a saw cut up the centre to form the ‘legs’ of the cotter. The cotter was 5” (127 mm) long, and the saw cut was approximately 1” (25 mm) deep.  As installed, this meant that the legs of the cotter were bent outwards at the root of the saw cut (see photo), potentially giving rise to stress concentration in that area. It is not possible to be certain that this contributed to any failure of the cotter, but it represents poor practice in the design and manufacture of the component.

Consequences	The original design of this assembly used a split cotter with a loop head. RAIB has found that restorers of steam locomotives have fabricated their own cotters, sometimes without reference to any drawings, and varying widely in the detail of how they have been made. Owners and operators of steam locomotives should be aware of the implications of the way cotters are made, and consider making them in accordance with an appropriate drawing or other good practice. The factors that RAIB has identified include the adequacy of the length of the slot, so that the point at which the legs are formed is well away from the root of the slot. If a sawn slot has to be used, the cut should be made centrally and straight, to ensure that the legs of the cotter are of equal thickness. There should be a radius (undercut) formed in the corner under the head of the cotter, to reduce the risk of cracks developing from this corner. In considering the cotter design owners and operators might wish to consider the following (although this is not an exhaustive list): a) British Railways (Doncaster) drawing, reference SL-DN-K 569, of 'Bright Cotters' (although not the same as the original SR design of 'Tangmere') which is attached, and gives dimensions for a range of cotters for BR standard locomotives (an appropriate size should be selected for each specific application); and b) using folded strip, welded at the head. The original design of the Bulleid pacific also used a plain nut, rather than a castellated nut, and the cotter was designed to lie in a vertical plane, rather than horizontally. The full effects, if any, of these changes (which were made during the restoration of 'Tangmere' from scrapyard condition) are not clear at present, and will be discussed in RAIB's final report. However, people restoring, overhauling and operating steam locomotives should make sure that any variations from the original design, even those which may seem to be only minor matters of workshop practice, are fully considered, and the potential implications assessed, by suitably competent engineers.
Reasons For Issue:	To alert owners and operators of steam locomotives to risks arising from the methods of manufacture and inspection of cotters used to secure small end nuts and other assemblies, and the need to assess the risks associated with design changes that may be introduced during restoration or overhaul.



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Any enquiries about this publication should be sent to:

RAIB	Telephone: 01332 253300
The Wharf	Fax: 01332 253301
Stores Road	Email: enquiries@raib.gov.uk
Derby UK	Website: www.raib.gov.uk
DE21 4BA	