A review of British railway bridge flood failures

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INTRODUCTION

The paper explores the hydrological characteristics of fluvial floods that have induced rail-bridge failure in Britain. Newspaper circulation and central reporting of rainfall data flourished in the improved communications afforded by railways. The research draws on rainfall archives, newspapers and other information to investigate some 30 incidents, and an attempt made to classify each according to the rarity of the flood that triggered failure. During the study, reference was found to a further ten floods in which rail bridges failed.

Objectives

The principal motivation to study rail-bridge flood-failures is to support the design and maintenance of structures that have the potential to fail catastrophically. The last major incident was on the Tywi at Glanrhyd in Carmarthenshire on 18 October 1987, the bridge collapse claiming four lives. A second motivation is to understand the risk of widespread disruption to the railway network occasioned by a spatially extensive extreme event. A lateral view is to see damage to river bridges on the railway network as a thematic source of information about British floods and their variability.

Railway network

Railways spread rapidly across Britain in the mid 19th century, with steadier development thereafter. The resultant network reflected trade routes, civic ambition, land ownership, private enterprise and, of course, topography. The canal network provided something of a precedent, with the railway often tracking the waterway it supplanted. A century or so later, the motorway did much the same (Patmore, 1972).

The railway network was cut back in the second half of the 20th century, most famously in the 1960s (BRB, 1963). The view that, before Beeching, the British railway network was a fixed feature is exaggerated. The private-sector origin of much of the network contributed over-optimism and duplication in route development, and closures soon became more common than openings. Nevertheless, the railway network perhaps represents the most extensive fixed asset present for the last hundred years in the landscape occupied by British rivers.

Features

Because of their need for shallow gradients and gentle curves, railways often run along valleys. Where they cross main rivers, waterway dimensions under railway bridges are typically generous. The railway's approach to the river is often at a higher level than for the road. Formerly at least, the soffits of some road-bridges were set at a higher level than the approach road, allowing floodwater to bypass the structure before it was overwhelmed. This arrangement is rarely possible for a railway bridge, and the structure must generally be designed to accommodate all floodwater. Because of the scope for high velocities, scouring of foundations and abutments is a particular threat. In the exceptional conditions of an extreme flood, debris from the catchment (uprooted trees, unanchored assets) can sweep down the river, damaging the bridge or blocking its waterway.

Much of the British railway network was set out in the 'railway mania' of the mid 19th century. A feature of some railway bridges is that they were built in the dry and the river diverted to run through the new structure (Jeremy Benn, *pers. comm.*) In the context of road bridges, there is experiential evidence that skewed crossings can be particularly susceptible to flood-induced failure (Brian George, *pers. comm.*)

METHODS

Historical flood review tends to be wide-ranging and open-ended. There are many potential sources of information. Bayliss and Reed (2001) and Reed (submitted) provide guidance on establishing and interpreting flood chronologies.

The approach taken in the present study was to augment knowledge within the industry by concentrating primarily on non-railway sources (Table 1). Thus, archive material held by the National Railway Museum was not consulted.

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Table 1. Principal sources used

Item	*Links*	*Location*
British Rainfall yearbooks	library.ceh.ac.uk/CLS_sites wallingford.htmwww.metoffice.com/corporate/library/	Specialist libraries
BHS Chronology of British Hydrological Events	www.dundee.ac.uk/geography/cbhe/	Internet
Daily rainfall data	www.metoffice.com/corporate/library/	National Met. Archives
Environment Agency		
Newspapers	www.bl.uk/collections/newspapers.html	BL Newspaper Library, N London Local libraries
Web-searches	Various	Internet

Historical information often finds its way on to the Internet through the work of enthusiasts, and there are many with an interest in railway history. Thus, web-searches provided extra details for some incidents. Ransom (2001) proved an especially useful reference: confirming, and in two cases correcting, flood dates taken from other sources. Archer (1992) is immensely useful when researching floods in north-east England.

Historical flood review tends to be subjective. There are too many potential sources (to be certain that all relevant information has been found) and too few formal data (to support a quantitative analysis). Where available, the combination of gauged data with historical flood information offers scope for a more objective approach (e.g. Cohn *et al*., 1997). Interpretations tend to be more secure when the gauged record includes a flood of a magnitude comparable with an historically noted flood.

For most of the incidents studied, the flood rarity classification leaned on rainfall rarity assessment and subjective account of other factors (Reed, 2003).

RESULTS

Classification

Where possible, the bridge-failure incidents have been classified according to the scheme of Table 2. The category names have been chosen in the context of rail-bridge flood safety. Whereas a 50 or 100-year event would be considered rare in terms of river flood risk generally, the human and economic implications of rail-bridge failure generally call for higher standards than for flood defence to riparian property. Consequently, Table 2 speaks of a 200 or 500-year flood as being rare. The return periods shown should not be interpreted as implying any perceived or acceptable standard for rail-bridge design against flood-induced failure.

Table 2. Classification scheme

Category	*Associated flood return period(yrs)*
Not induced by fluvial flood	N/A
Flood-assisted failure	2, 5, 10, 20
Induced by a relatively rare flood	50, 200
Induced by a rare flood	200, 500
Induced by an exceptionally rare flood	1000, 2000, 5000

Particular outcomes from the study are the Bridge Incident Review Documents Investigating Extremeness (BIRDIEs) in Reed (2003) and the failure classification in Table 3.

Rarest floods

The flash floods on the Bogbain Burn (8 July 1923), Mochdre Brook (21 June 1936) and Selham (26 December 1886) are thought to be amongst the rarest studied. The Bogbain Burn flood is notable for being rarer than that which precipitated the catastrophic incident on the adjacent Badden (*aka* Baddengorm) Burn nine years earlier, in which five passengers died.

Table 3. Classification of British rail-bridge (mainly) flood-failure incidents

Date	*River*	*Location*	*Classification*	*Comment*
20 Jan 1846	Medway	Tonbridge, Kent	Prob. induced by relatively rare flood.	Aggravated by poor design and gravel extraction. Engine driver died.
~ Feb 1846	Sheppey	Shepton Mallet, Somerset	[Not classified]	Incorrect date researched. Failure occurred in February 1946 not 1846!
29 Sep 1846	Tower Burn	Cockburnspath, Borders	Induced by relatively rare flood.	Many rail-bridges in Berwickshire washed out (a few months after East Coast mainline opened).
24 May 1847	Dee	Chester	Not induced by fluvial flood.	Iron bridge; flawed design.
16 Nov 1866	Aire	Apperley Bridge, West Yorkshire	Induced by flood at least relatively rare.	Ransom (2001): Piers and viaduct reconstructed in five weeks; estimate had been six months.
1 Feb 1868	Severn	Caersws, Powys	Prob. induced by relatively rare flood.	Bridge being “re-planked” but failure was of adjacent embankment; water up to rail-level on both sides. Driver & fireman died.
1 Feb 1868	Carno	Pontdolgoch, Powys	Prob. induced by relatively rare flood.	Floodwater above tracks for 1.6 km locally.
13 Nov 1869	Tees	Cleasby, Darlington	Flood-induced failure, but not rare flood.	Bridge said to have been a temporary structure.
9 Jul 1870	Dee/Dent	Dentdale, Cumbria	Induced by rare flash flood.	Six or seven bridges destroyed. No rail-bridge involved but two workers constructing Settle & Carlisle Railway drowned.
28 Dec 1879	Tay	Dundee	Not induced by fluvial flood.	Wind loading; flawed design.
~ Dec 1886	Thames	Osney, Oxford	Uncertain – but not caused by rare flood.	Probably not the rail-bridge; possibly in 1885 rather than 1886.
26 Dec 1886	Bride	Burton Bradstock, Dorset	Induced by relatively rare flood.	(Road) bridge failed in notable and unusual flood.
26 Dec 1886	Stream	Selham, W Sussex	Induced by rare flood.	Exceptional combination of conditions conducive to flooding on relatively permeable small catchment.
31 Jan 1901	Burn of Buckie		Moray	Not induced by fluvial flood. (Road) bridge failed in wild weather, before completion.
15 Jun 1914	Badden Burn	Carrbridge, Highland	Induced by rare flash flood.	Rail-bridge, and 120-year-old road-bridge, destroyed. Five passengers died.
8 Jul 1923	Bogbain Burn	Carrbridge, Highland	Induced by rare flash flood.	Four rail-bridges swept away. Road-bridge lost in 1914 again destroyed. No deaths, but other impacts more severe than 1914.
9 Jun 1924	Erewash	Pye Bridge, Derbyshire	Not induced by fluvial flood.	Newspaper search revealed that two arches failed spontaneously; no flood.

Table 3, contd.

Date	*River*	*Location*	*Classification*	*Comment*
23 Jul 1930	Esk	Glaisdale, N Yorkshire	Induced by rare flood.	Failed structures were road-bridges. Some rail-bridges damaged; one near Whitby blocked by trees.
4 Sep 1931	Esk	Glaisdale, N Yorkshire	Induced by rare flood.	But less rare than July 1930.
21 Jun 1936	Mochdre Brk	Newtown, Powys	Induced by rare flash-flood.	Houses flooded three times in two days in succession of extreme thunderstorms; bridge failed in third, most severe, event.
12 Aug 1948	Eye Water	Grantshouse, Borders	Induced by rare flood.	Many Berwickshire and Northumberland bridges (railway and other) failed in this widespread heavy-rainfall event.
12 Aug 1948	Wooler Water	Haugh Head nr Wooler, Northumberland	Induced by rare flood.	But less rare than for Eye Water.
26 Oct 1949	Lil Burn	Ilderton, Northumberland	Induced by relatively rare flood.	Rail-bridge collapsed; section of line never re-opened.
19 Nov 1951	Stream	Midhurst, W Sussex	Prob. induced by relatively rare flood.	Antecedent wetness was exceptional.
12 Dec 1964	Ystwyth	Llanilar, Ceredigion	Induced by moderately rare flood.	But not one rare enough to account for failure.
15 Sep 1968	Wey & Mole	Godalming & Cobham, Surrey	Induced by rare (or rel. rare) flood.	Several bridges (railway and others) failed in this widespread heavy-rainfall event.
18 Oct 1987	Tywi	Glanrhyd nr Llangadog, Carmarthenshire	Induced by relatively . rare flood	Researching 1987 flood size at Llandeilo relative to 1852, 1875, 1894 & 1931 events would refine rarity estimate.
6 Feb 1989	Ness	Inverness	Induced by relatively rare fluvial flood.	Effects aggravated by tidal interaction; assessment might be strengthened by historical review.
~ Nov 2000	Exe	Cowley nr Exeter	[Not classified]	Highly disruptive failure.

The Mochdre Brook incident was remarkable in its genesis. Three severe thunderstorms hit the district separated by intermissions of about five and fifteen hours. Some properties adjacent to the Dolfor Brook flooded four times (once from urban runoff), while many properties flooded three times. Rainfall in the third storm was exceptionally severe, precipitating both the rail-bridge failure and a dam safety incident at the water-supply reservoir upstream. A 1933 assessment under the newly implemented Reservoir (Safety Provisions) 1930 Act had shown the spillway of the Mochdre Reservoir to be grossly under-designed. In the 21 June 1936 incident, the bypass channel was overwhelmed, the dam overtopped and considerable damage was done to the toe of the embankment. Fortunately, the dam did not breach.

The Bogbain Burn, Badden Burn and Mochdre Brook incidents exemplify the damage wrought by uprooted trees in severe flash floods. Although very many trees were transported, the rail-bridge at Mochdre was seen to fail when hit by a large tree travelling upright.

The 26 December 1886 failure at Selham was triggered by an exceptional combination of conditions conducive to flood generation on this relatively permeable catchment of just 4.1 km^2: an extremely high antecedent groundwater level, frozen ground, snowmelt and short-duration heavy rainfall.

DISCUSSION

Spatial dependence

There is marked spatial dependence in extreme rainfall, arising from the physical extent of weather systems. The degree of dependence in floods tends to be amplified by spatial dependence in catchment wetness and (when present) snowmelt. The degree of dependence in rail-bridge flood-failures is further heightened where railway lines cross and re-cross the same river.

The many bridge failures in the August 1948 Border floods, and the widespread river flooding experienced in autumn 2000, reflect this spatial dependence. In the context of reservoir safety, Dales and Reed (1989) warn that the typically long interval between flood incidents should not be taken as evidence of over-design. An extreme event — when it finally arrives — may trigger multiple failures.

Prevention or warning?

A consequence of riverside living is that some degree of flood risk must be tolerated. River flood defence therefore seeks a balance between flood alleviation and flood warning. In contrast, the potential impact of a dam-burst flood is so great that the focus in reservoir safety is principally on the prevention of failure.

Rail-bridge flood design appears intermediate to these two cases. The main need is to design and maintain structures to a high standard, so that failures are tolerably infrequent.

However, there is a subsidiary requirement to take precautionary action to reduce impacts when a major flood threatens. A feature of bridge failure due to scour is that pier movement often precedes collapse. Is there scope to consider a generic real-time monitoring system to detect abnormal displacements?

Climate

It is prudent for the railway industry to be alert to the possibility that flood risks are increasing in consequence of global climate change. There is much hyperbole that flood risks are set to increase manifold. However, the true position is that the effects on river flood risk are largely unknown.

While it can be prudent to take a precautionary approach — i.e. to assume that river flood risks will increase significantly as a consequence of human-induced global climate change — there are ambiguities in overstating what is known about the impact of climate change on fluvial flood risk. *When exposure to flood risk resurfaces in a major incident, climate change provides an all-too-convenient fig-leaf.*

Citation of climate change tends to discourage research of past flooding. A baseline period such as 1961–90 is drawn, and earlier history deemed irrelevant with words like: *How can we understand climate change impacts on flooding if we continue to base our assessments on floods drawn from a past climate?* But the downside is considerable. Only by exploiting rainfall and river-level records from the 19th and 20th centuries can we hope to distinguish climate change from climate variability.

Ignoring climate variability is misleading and potentially dangerous. The consequence of making flood risk assessments from short-term records is typically to underestimate design floods and to overestimate the rarity of specific incidents. For example, an extreme value analysis of 34 years' flood data for the Eye Water led to the flood of 22 October 2002 being assessed as a 275-year event (Cargill, 2003). Despite acknowledging that a much greater flood occurred in August 1948, Cargill allows the exaggerated rarity estimate to appear. It seems likely that the October 2002 event was also eclipsed by the September 1846 flood (see Table 3).

Awareness of history

Recent fatality statistics (Evans, 2003) suggest that there are other priorities in improving railway safety. It is therefore timely that the review should remind that flood risk is an important consideration when maintaining, renewing and developing Britain's railway infrastructure. The historical record of rail-bridge flood-failures provides examples of:

- Severe flash-floods with a particular capacity to kill (e.g. 1923 Carrbridge and 1936 Newtown incidents);
- Events leading to many bridge-failures on one line (e.g. 1846 and 1948 Eye Water incidents and under-researched 26 September 1915 Findhorn/Spey incidents);
- Events leading to bridge failures on several railway lines (e.g. under-researched 14 May 1886 incidents in Herefordshire and Worcestershire);
- Localities that have experienced bridge failures in consecutive years (e.g. Glaisdale and Wooler);
- Failures where antecedent catchment condition (extreme wetness and/or frozen ground) played a crucial role (e.g. 1886 Selham and 1951 Midhurst incidents);
- Events where heavy rainfall coincided with other severe weather phenomena (e.g. 18 October 1987 Tywi incident and 1886 Selham incident).

Railway embankment acting as a dam

The study uncovered no incident where a railway embankment inadvertently acted as a dam *and* subsequently failed. This may reflect the remit to investigate rail-bridge flood-failures. A near-miss occurred in the 1948 Eye Water incident, when waters of the Horn Burn impounded to a depth of 9 to 12 m. Communities downstream were placed on alert, in fear that the railway embankment might not hold.

Such an incident occurred in South Wales as recently as 1979. A culvert under the embankment of a disused mineral railway near Merthyr Tydfil became blocked during an unusually long period of heavy rainfall on 26–27 December 1979 (Reed, 1987). Waters were impounded to the full height of the 7-metre embankment, before the structure failed abruptly. Two lives were lost when the dam-burst flood met obstructions in the watercourse, the waters rapidly filling the ground floor of housing at Rhydycar. The quantity passing down the watercourse in consequence of the embankment collapse was estimated to be barely 20 000 m^3, and part of the flood wave safely overflowed into an adjacent railway cutting. The fatal impacts were precipitated by steep slopes and jetting, as the flood wave passed through further culverts.

FINDINGS

The 18 October 1987 bridge-failure at Glanrhyd is considered something of a point of reference in British rail-bridge safety assessments. It is noteworthy that each of the ten rail-bridge failures classified in Table 3 as coming from a flood rarer than this benchmark occurred in the period 1870 to 1948. The uneven pattern of occurrences might reflect that the standard of rail-bridge flood safety has improved (i.e. that vulnerable structures have been identified and remedied), that there are now fewer rail-bridges to fail, or that the study has researched older events to the neglect of more recent incidents. However, the uneven pattern could also reflect the caprice of climate.

With regard to railway bridges:

- Many of the floods that have washed out railway bridges in Britain have been unusual in more respects than rainfall rarity;
- Some sites have experienced more than one flood giving rise to rail-bridge failure;
- There is scope for a cascade of failures where railway lines cross and re-cross the river (e.g. 1846 and 1948 Eye Water incidents);
- Inadequate bridge-waterway capacity can lead to floodwater being diverted to the wrong side of the tracks, leading to failure of an auxiliary structure (e.g. 1846 Medway and 2000 Exe incidents);
- Through their fixed position in the landscape, railway bridges and their associated embankments can provide a frame of reference for comparing historical events with recent major floods.

More generally:

- Particular care is needed when quoting incident dates, because of the special scope that an incorrect date gives for abortive research;
- The extent of unknown factors prior to commencing a historical flood review, and the importance of accuracy and thoroughness, sit uncomfortably with fixed-price contracts;
- Incidents are reported according to the scale of impact rather than the rarity of flood;
- Historical floods (i.e. major floods that occurred prior to river flow gauging) are often overlooked in river flood-risk assessment;
- This amnesia is prone to develop in any prolonged flood-free period, notwithstanding the richness of the historical documentation (e.g. Acreman and Horrocks, 1990);
- Some professionals consider a particular historical flood to be too extreme in magnitude, or too unusual in character, to be relevant to modern-day decisions;
- Viewed at the national level, there is greater scope to experience exceptionally rare events on quickly responding catchments, because the effective number of independent sites is greater for extreme rainfalls of short duration than for those of long duration;
- Commerce based on just-in-time delivery is likely to be vulnerable to exceptional conditions of spatially extensive heavy rainfall/snowmelt which wash out many structures on many rivers.

Reed (2003) has identified additional flood events that have led to rail-bridge failures in Britain. Consideration should be given to reviewing these and to identifying further incidents. Under-reporting of incidents leads to underestimation of risk: in the railway sector as in others.

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