Rail Accident Investigation Branch

Rail Accident Report

Class investigation into landslips affecting Network Rail infrastructure between June 2012 and February 2013

Report 08/2014
April 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.

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Class investigation into landslips affecting Network Rail infrastructure between June 2012 and February 2013

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Summary

In response to six landslips which occurred on Network Rail infrastructure between June 2012 and February 2013, RAIB has undertaken a class investigation into earthwork issues related to land neighbouring the railway and to risk management during adverse weather. The landslips occurred at Loch Treig (near Tulloch) on 28 June 2012, at Falls of Cruachan (on the line to Oban) on 18 July 2012, at Rosyth (near Edinburgh) on 18 July 2012, at St Bees (Cumbria) on 30 August 2012, at Bargoed (South Wales) on 30 January 2013 and at Hatfield Colliery (South Yorkshire) on 11 February 2013.

The landslips were caused by factors including heavy rain, absent or ineffective drainage and activities undertaken, or not undertaken, on neighbouring land. In several instances trains were being operated without special precautions when there was a significant risk of encountering a landslip.

Many of Network Rail's earthworks were constructed with steeper slopes (and therefore a greater likelihood of landslips) than would be achieved with modern design procedures. Network Rail's on-going earthwork improvement programme is unlikely to achieve modern criteria in the foreseeable future.

Network Rail's process for managing the resulting earthwork risk includes consideration of risk arising outside the railway boundary. RAIB has found that, in some circumstances, key information provided by specialist staff examining earthworks is not considered when the slope management strategy is determined during evaluation. There is a lack of clarity about who should be carrying out visual checks for risks which can develop on neighbouring land between examinations which take place at intervals of up to ten years. The mandated process for collecting information about neighbouring land is, in parts, difficult to implement and not usually followed. Recent technological developments could offer means of improving the collection of this information.

The location and timing of landslips is difficult to predict but they are almost always triggered by relatively high rainfall. When the landslips described in this report took place, Network Rail's adverse weather risk management process used forecasts of heavy rainfall to implement special precautions at locations where landslips were considered relatively likely. During the investigation, Network Rail has introduced a new process which also takes account of ground saturation and (in addition to likelihood) the possible consequence of a landslip.

The RAIB has made five recommendations, addressed to Network Rail, relating to improving management of earthwork and drainage risk arising from neighbouring land; considering all information provided by examiners when undertaking evaluations; and enhancing the new adverse weather risk management process.

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, or railway industry.

Key definitions

4 All dimensions in this report are given in metric units, except train speeds and locations on the railway which are given in imperial units in accordance with normal railway practice. Where appropriate 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.

Background

6 RAIB commenced an investigation into a derailment on 28 June 2012 caused by a landslip at Loch Treig (near Tulloch) on the West Highland line serving Fort William. The scope of this investigation was subsequently extended into a class investigation considering similar issues apparent from several other landslips which affected Network Rail infrastructure during the following eight months.

7 The location and date of the landslips considered during this investigation are listed below and shown on figure 1:

- Loch Treig (near Tulloch) on 28 June 2012;
- Falls of Cruachan (on the line to Oban) on 18 July 2012;
- Rosyth (near Edinburgh) on 18 July 2012;
- St Bees (Cumbria) on 30 August 2012;
- Bargoed (South Wales) on 30 January 2013; and
- Hatfield Colliery (South Yorkshire) on 11 February 2013.

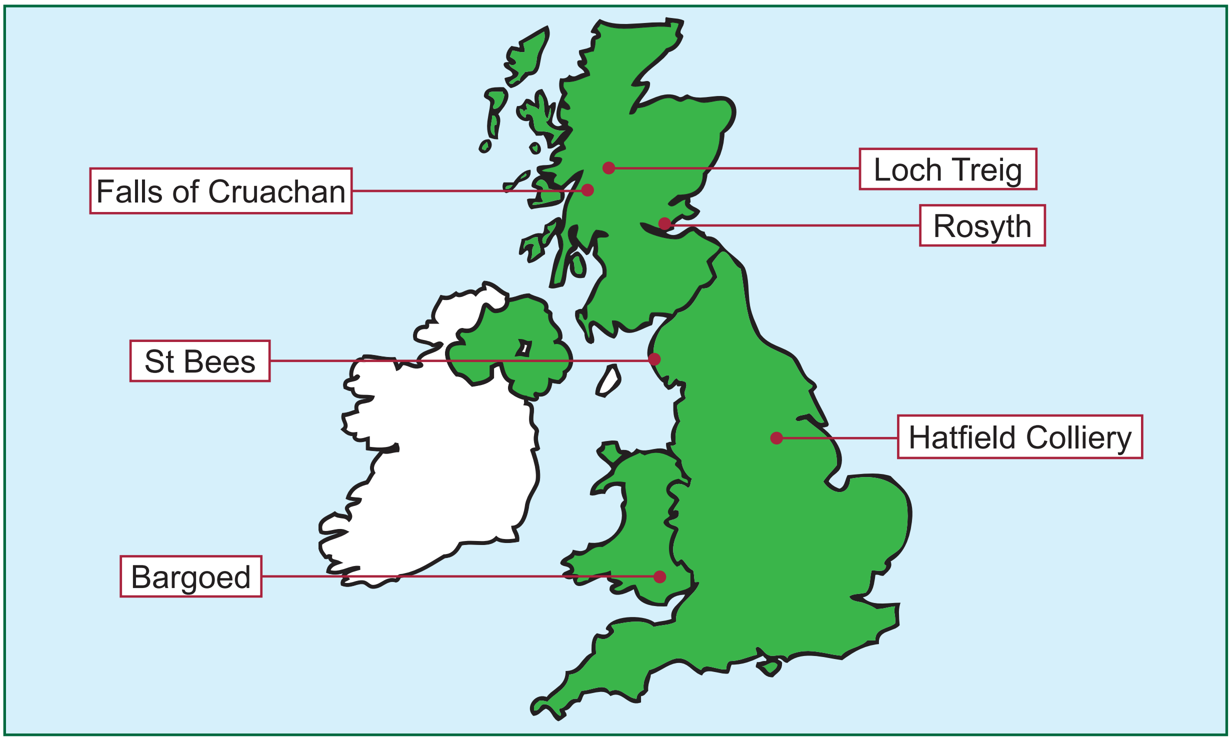

Figure 1: Location of events

8 The present investigation has concentrated on *earthwork* issues related to effects from neighbouring land and responses to unusual weather conditions[1]. This report contains a brief summary of each event and then addresses common factors relevant to these themes. Some of the resulting recommendations are intended to lead to actions which will also mitigate risk arising from earthworks within the railway boundary.

[1] RAIB's previous report, 'Network Rail's management of earthworks' (Report 25/2008), dealt mainly with issues related to the performance of earthworks within the railway boundary but also addressed some aspects of the issues covered by the present report.

Loch Treig

9 At approximately 19:05 hours on Thursday 28 June 2012 a locomotive and five wagons were derailed when a freight train running on the West Highland line between Corrour and Tulloch hit a landslip alongside Loch Treig (figure 2). There were no injuries but three of the derailed wagons overturned and the locomotive ran part way down the *natural slope* leading to the loch (figures 3 and 4).

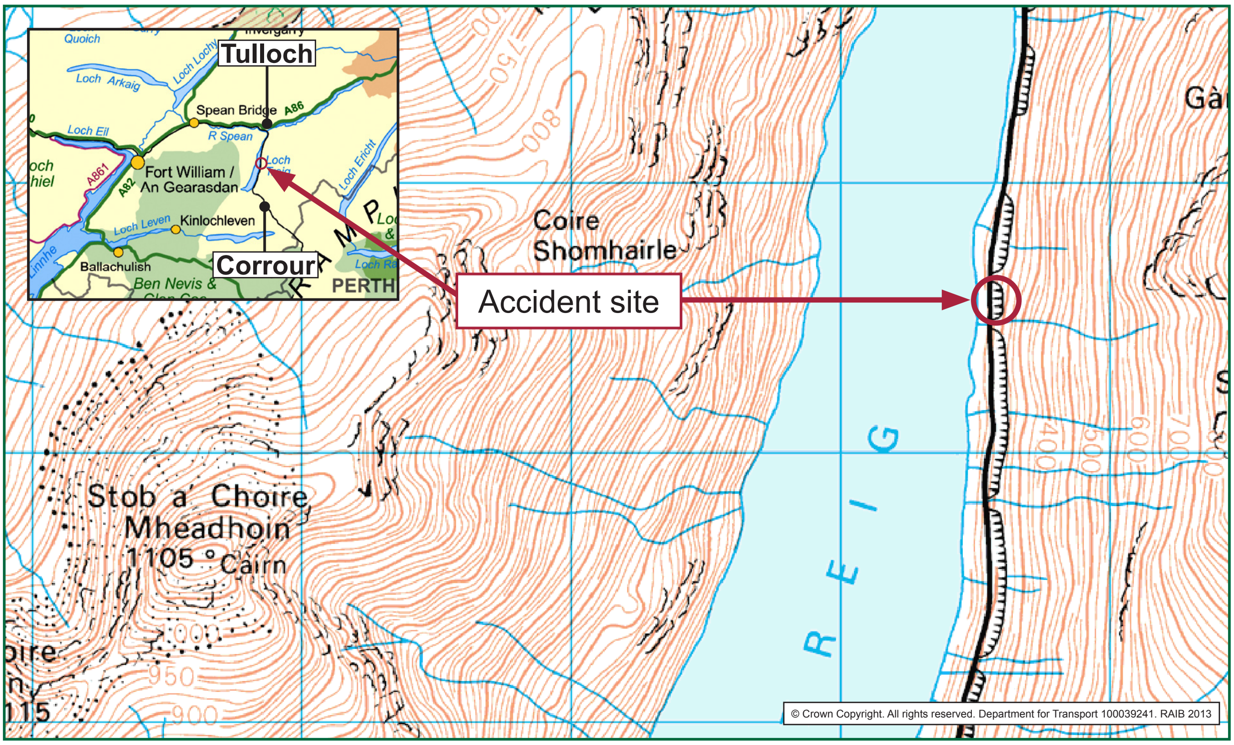

Figure 2: Loch Treig: accident location

Figure 3: Loch Treig: derailed wagons

Figure 4: Loch Treig: derailed locomotive (image courtesy of Network Rail)

10 The train, reporting number 6S45, comprised a class 66 locomotive pulling three empty wagons and 21 wagons carrying alumina[2] powder from North Blyth to Fort William. It weighed approximately 913 tonnes and was descending a 1 in 67 gradient at a speed of approximately 30 mph (48 km/h), the maximum permitted speed for freight trains on that section of line, when it rounded a curve and the driver saw landslip debris, including boulders, on the line about 200 metres ahead of him. He applied the *emergency brake* but the train was still travelling at about 28 mph (45 km/h) when the locomotive hit a boulder and derailed, at 77 miles 55 *chains*[3].

11 At the site of the accident, the railway comprises a single line running along the side of a mountain which rises about 700 metres above the line with a slope of about 1 in 1.5. Below the railway a slope of 1 in 1.4 and a small retaining wall leads down to a ledge about 6 metres below track level. This ledge slopes downwards towards Loch Treig which is about 25 metres below the railway (figure 5).

12 The debris had come from a landslip which had occurred in the natural slope about 35 metres upslope of the railway boundary (figure 6). RAIB noted that the slip had developed in a shallow valley area which was waterlogged. RAIB (and Network Rail) consider that the slip was triggered by water accumulating in this valley and destabilising the soil.

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[2] Aluminium oxide.

[3] The mileage is measured from Craigendoran Junction.

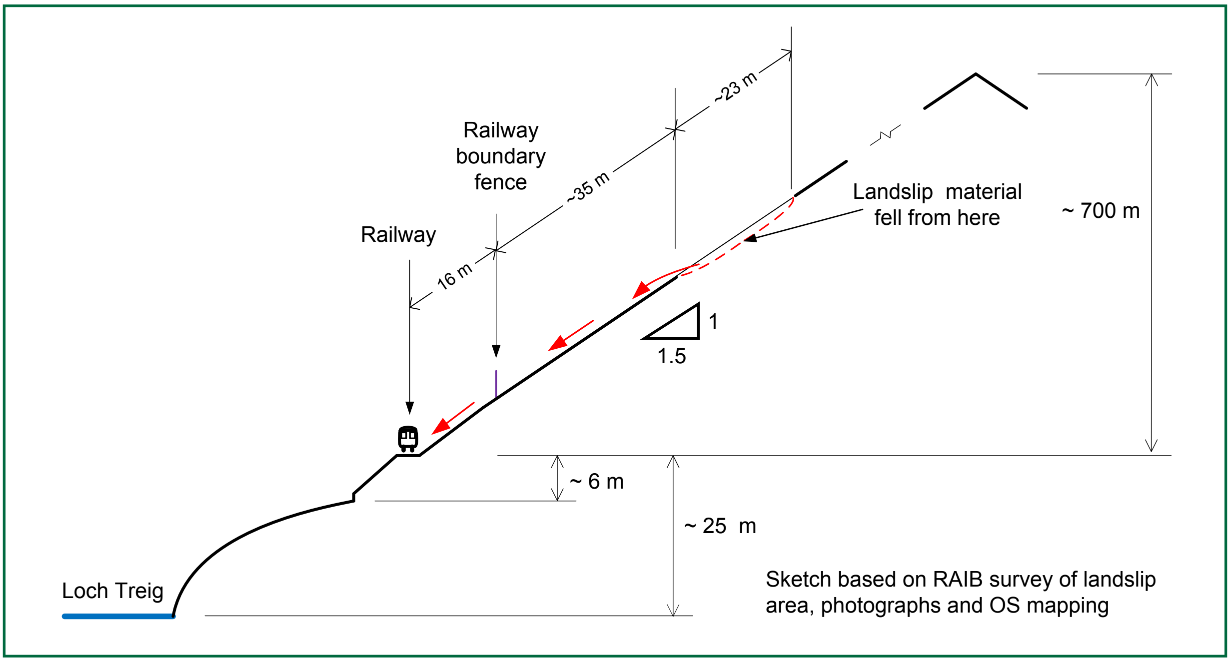

Figure 5: Loch Treig: slope geometry (cross-section)

Figure 6: Loch Treig: landslip

13 The amount of rain falling in the area of the accident cannot be obtained from standard *rain gauge* readings, because *rainfall intensity* at the time of the accident varied significantly over short distances and there were no rain gauges in the immediate vicinity of the accident. The Met Office used weather radar data to estimate that about 23 mm of rain fell in the 24 hours starting at 10:00 hrs on 28 June including about 18 mm between 16:00 hrs and 19:00 hrs. It states that events of this type are likely to occur more than once a year. It also reports that about 6 mm of rain fell between 18:05 hrs and 18:35 hrs, an event likely to occur only once a year[4,5]. This relatively intense period of rainfall is a probable trigger for the landslip.

[4] A likely occurrence once each year is sometimes described as a one year return period.

[5] The Met Office uses the Flood Estimation Handbook to establish likely return periods.

14 It is possible that the rainfall in the immediate vicinity of the accident site was more intense than indicated by the Met Office. The *weather radar* data used by the Met Office has a resolution of 2 km and may not fully represent areas of localised intense rainfall which can occur during storms in highland areas. This variability is illustrated by a rain gauge six kilometres north of the accident site which recorded 23 mm of rain between 18:00 hrs and 19:00 hrs on 28 June, an event which the Met Office estimates will occur only every 14 years.

15 A separate report, also based on weather radar data, commissioned from MeteoGroup, shows that there was considerable variation in the amount of rain which fell around Loch Treig on 28 June. The wettest area is reported to have received 56 mm of rain in a 24 hour period but the precise location is not given.

16 The landslip had occurred in a part of the slope where there was no evidence of distinct stream channels which would help prevent water accumulating in the ground. Distinct stream channels are apparent elsewhere on the slope, including two streams which enter the railway boundary near the slip location.

17 Slopes in the vicinity of the accident site were being examined on a routine basis as part of Network Rail's earthwork stewardship process (paragraph 102). The last *examination* before the accident took place on 5 March 2011. The *earthwork examiner* reported the presence of streams entering the railway boundary and being channelled into *culverts* beneath the railway. No defects in the drainage system were reported. He described the natural slope as 'rough grass' with a 'natural watercourse < 20m of crest'.

18 Network Rail geotechnical staff and examiners have stated that earthwork examiners are not expected to go outside the railway boundary but, provided it is safe to do so, they are expected to view slopes outside the boundary by standing at the boundary. Drainage conditions in the landslip area could not be viewed from the boundary due to vegetation and the shape of the slope. However, these conditions were typical of other slopes visible from the railway boundary fence near Loch Treig and were considered when Network Rail developed the management strategy for slopes in this area.

19 The examination on 5 March 2011 categorised the slope as '*marginal*' based on a process, described in paragraphs 103 to 108, which results in slopes being categorised as *poor*, marginal or *serviceable*. Although the earthwork was classified as marginal, Network Rail geotechnical staff were already aware that the slopes above the railway alongside Loch Treig had the potential to adversely affect railway safety. These staff had judged that the greatest risk was from individual boulders rolling down the hillside and they had installed strengthened fencing, intended to catch boulders before they reached the railway, at the locations where they judged this risk to be greatest. The accident site was not one of these locations and RAIB considers it unlikely that a fence of this type would have stopped the large amount of debris arising from the June 2012 landslip.

20 Although the slope above the railway had been recognised as having the potential to adversely affect railway safety, Network Rail had not asked the owner about how the land was being managed (paragraph 119). The landowner's representative has stated that the land was being managed to encourage wildlife. This was being achieved by the removal of sheep which had been grazing in the area and by the culling of wild deer. There was no active management of slope stability issues. Since Network Rail staff had viewed the hillside in the context of dealing with boulder risk (paragraph 19), RAIB considers it unlikely that a Network Rail review of the landowner's management strategy would have triggered actions which would have prevented the accident.

21 Network Rail takes special measures, including special inspections of earthworks considered to be '*at risk*', when particularly heavy rainfall and other adverse weather conditions are forecast (paragraphs 128 and 135). The accident site was not included on the register of 'at risk' earthworks (the *'at risk' register*) so, although special inspections were required at other sites along the same line due to the amount of rain forecast, there was no requirement for a special inspection at the accident site and none took place.

22 The landslip blocked the railway relatively quickly. A passenger train had passed the accident site about 43 minutes before the accident and the driver of this train did not report anything unusual.

Falls of Cruachan

23 At 13:35 hrs on Wednesday 18 July 2012, the 12:56 hrs Oban to Glasgow First ScotRail passenger service, reporting number 1Y24, struck landslip debris near Falls of Cruachan but did not derail (figure 7). There were no reported injuries but the train suffered minor damage. If the train had been derailed by the landslip debris, it is possible that it would have fallen down an adjacent slope (paragraph 26).

24 The four coach train comprised two 2-car class 156 diesel multiple units (numbers 156478 and 156453) and was carrying 70 passengers and two crew. It was travelling at approximately 30 mph (48 km/h) and rounding a curve when the driver saw debris on the line and immediately applied the emergency brake. Although the train did not derail, landslip debris beneath the front two coaches prevented these being moved until the debris was cleared (figures 8 and 9).

25 The accident occurred at 52 miles 22 chains[6] on the Crianlarich to Oban line where the maximum permissible speed for trains had been reduced from 45 mph (72 km/h) to 30 mph by a temporary speed restriction imposed to mitigate the risk associated with falling rocks (this is the reason given by a member of Network Rail geotechnical staff although the formal instruction to train drivers[7] states it is due to 'condition of embankment').

[6] The mileage is measured from Callendar along a route which is now disused.

[7] Weekly operating notice SC16, 14 to 20 July 2012.

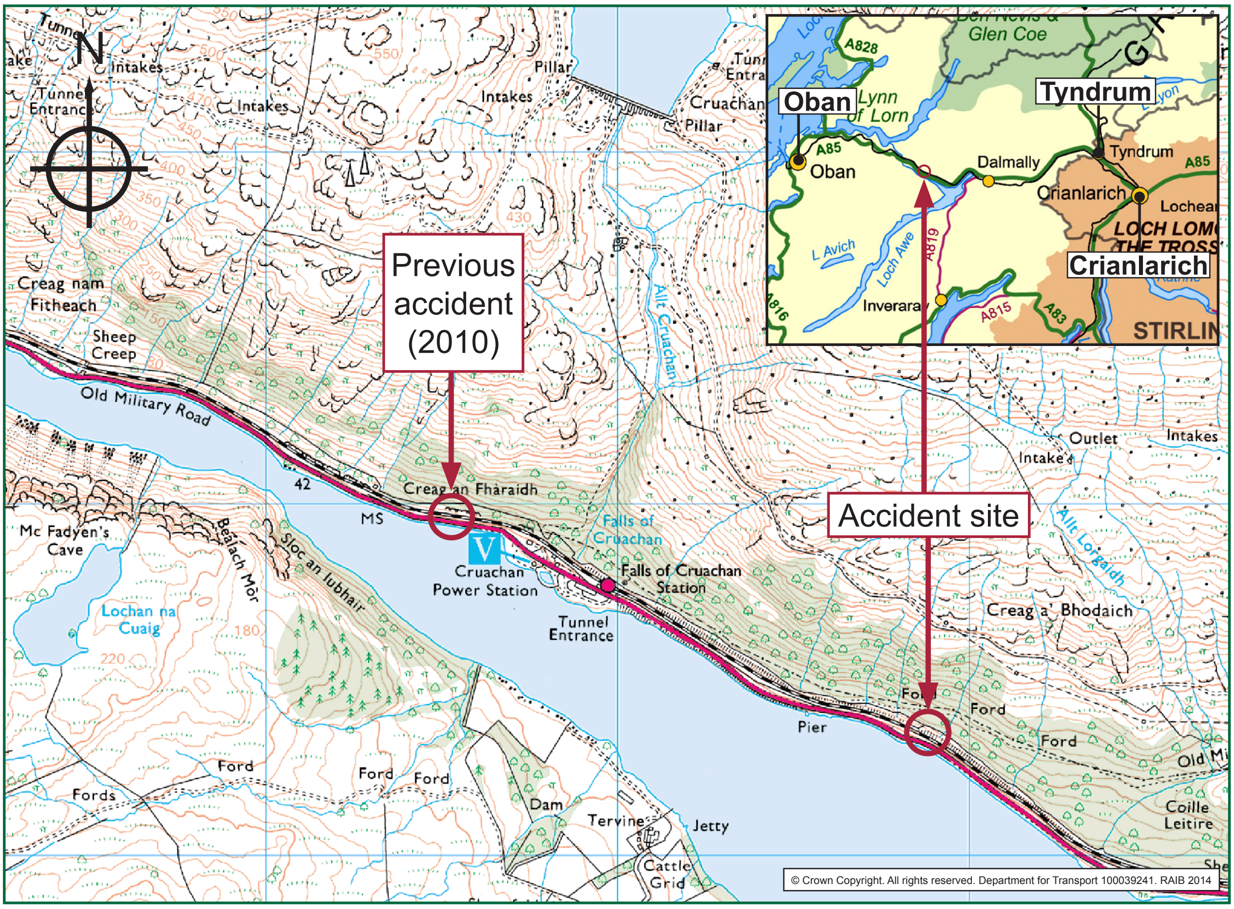

Figure 7: Falls of Cruachan: accident location

Figure 8: Falls of Cruachan: debris preventing train movement (image courtesy of Network Rail)

Figure 9: Falls of Cruachan: view after train moved clear of boulder shown on figure 8

26 At this location, the railway comprises a single line running through the Pass of Brander on a ledge some 15 to 20 metres above Loch Awe. The north side of the railway comprises a rock *cutting* about seven metres high with a slope of about 1 in 0.8 with a fence at the top of the cutting marking the railway boundary. Beyond the fence, a natural hill slope rises at a slope of about 1 in 2.4 towards the summit of Beinn a Bhuiridh about 830 metres above the railway. On the south side of the railway, the ground slopes downwards at about 1 in 0.8 for a vertical height of about nine metres to the top of a retaining wall which runs alongside the A85 trunk road (figure 10).

27 A post-incident inspection of the site undertaken by Amey staff on behalf of Network Rail[8] showed that the landslip had been triggered by a flow of water which had been diverted from its normal course by a blocked culvert about 60 metres upslope of the north side of railway (figure 11). The flow had therefore entered the cutting at a location where there was no channel to control the flow of water and the uncontrolled flow was sufficient to dislodge soil and boulders from the cutting face (figure 12).

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[8] The slope geometry and geotechnical information given in this report is based mainly on information collected during this inspection.

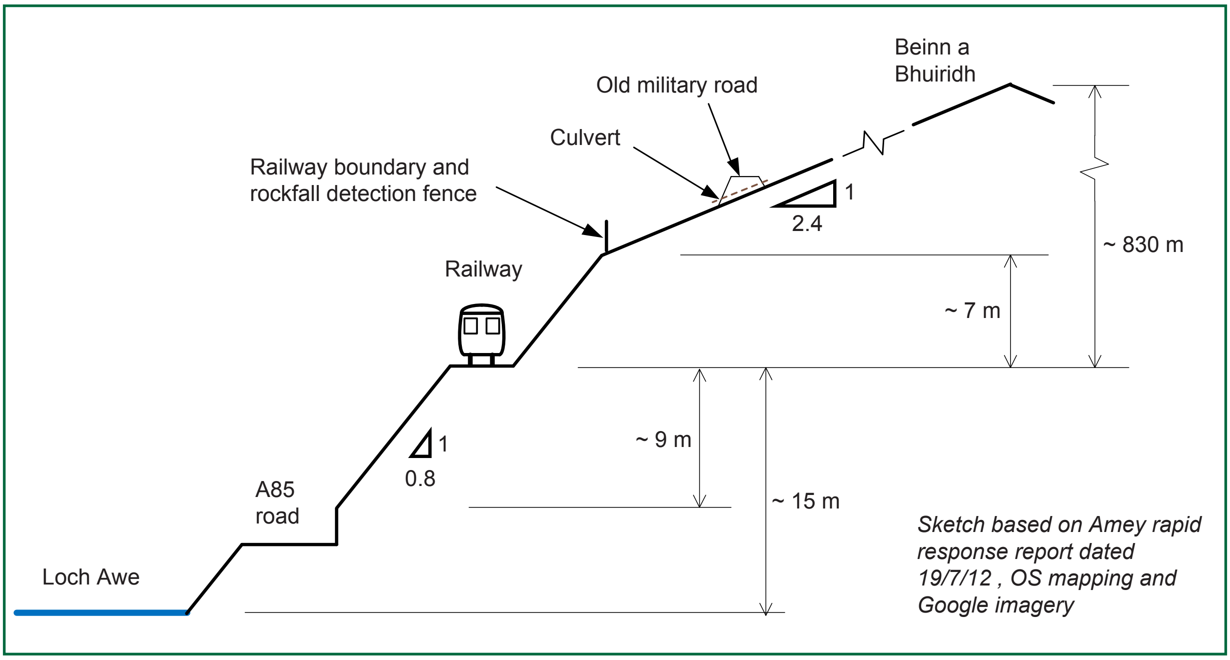

Figure 10: Falls of Cruachan: slope geometry (cross-section)

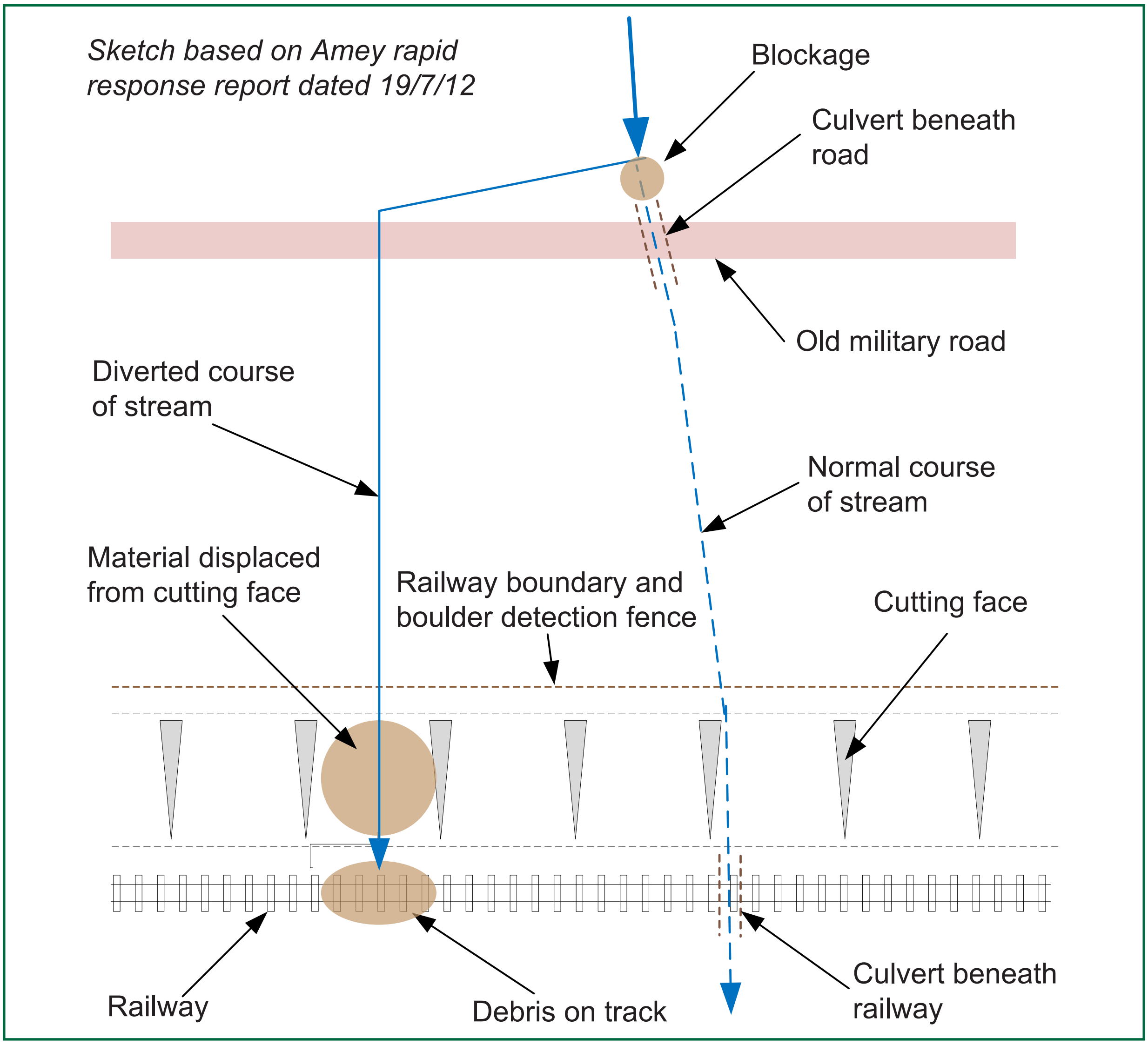

Figure 11: Falls of Cruachan: sketch plan

Figure 12: Falls of Cruachan: material washed from cutting face

28 The risk of boulders falling from the hillside above the railway was recognised in the late nineteenth century and ‘stone signals’ were installed. These provide a warning to train drivers if a boulder strikes detection wires suspended on posts along the railway boundary. The stone signals did not provide a warning on this occasion because the water flowed below the lowest detection wire and displaced rocks from within the railway boundary.

29 An analysis by the Met Office on behalf of the RAIB, undertaken using rainfall radar data, shows that approximately 37 mm of rain fell at the accident location in the 17 hours before the accident including about 5 mm in the hour before the accident. Both of these events are likely to occur at least once a year.

30 The last earthwork examination was undertaken on 21 April 2009 and resulted in the cutting being categorised as marginal, meaning that no further action except routine maintenance was required until another examination after an interval of five years.

31 The examination report indicates that there was no evidence of poor drainage at this time. However, the steep cutting face meant that the examiner could neither see the culvert from the railway nor access the railway boundary. If the boundary had been accessible, vegetation and topography would almost certainly have prevented the culvert being seen.

32 The data given in paragraph 29 indicates that rainfall on the day of the accident was less heavy than that which had probably occurred on other days since the April 2009 examination. It is therefore likely that the culvert had become blocked after the examination in 2009.

33 A forecast of heavy rain on the day of the accident meant that Network Rail control staff had given instructions for special inspections of earthworks 'at risk' due to heavy rain (paragraphs 128 and 135). The accident site was not included in this category so no special inspection was carried out.

34 The culvert was located in woodland forming part of a *site of special scientific interest*. Witness evidence describes the culvert as a plastic pipe intended to carry water beneath an *old military road* constructed in the mid eighteenth century and no longer used as a road. The landowner's estate manager has stated that, although issues such as fencing and control of deer population were dealt with as necessary, there was limited active management of the woodland area. Neither the landowners nor the estate manager were aware of the culvert although the presence of a plastic pipe shows that the culvert was installed or replaced after the road was first constructed.

35 Although the slope above the railway had been recognised as having the potential to adversely affect railway safety (paragraph 28), Network Rail had not sought information from the landowners concerning how they were managing the slope (paragraph 119). However, since the landowner was unaware of the presence of the culvert, RAIB believes that it is unlikely that obtaining such information would have prevented the accident.

36 It is uncertain how quickly the landslip blocked the line. The same train had passed the accident site while travelling towards Oban, 2 hours 40 minutes before the accident, and the driver reported seeing nothing unusual.

Rosyth

37 At about 16:10 hrs on Wednesday 18 July 2012, the 14:17 hrs First ScotRail service from Newcraighall to Edinburgh, reporting number 2K05, was derailed when it struck landslip debris between Rosyth and Dunfermline (figure 13). There were no injuries. The track and train suffered minor damage.

38 The train comprised a 2-car class 158 diesel multiple unit, number 158739, and was travelling at approximately 55 mph (88 km/h) when the train came over a crest in the track and the driver saw slip debris around 250 metres in front of the train. He made a full *service brake* application but the train was still travelling at about 45 mph (72 km/h) when it struck the debris and the leading *bogie* derailed. The train then travelled about 160 metres before stopping (figure 14).

39 At this location the railway comprises two tracks with a maximum permissible speed of 65 mph (104 km/h). The railway is running in a northwest-southeast direction through a cutting which is about five metres deep and with a side slope of about 1 in 1.7. The slip occurred on the northeast side of the cutting at 15 miles 68 chains[9], adjacent to the boundary between an area of waste ground and a recent commercial development (figures 15 and 16).

[9] The mileage is measured from Edinburgh Waverley.

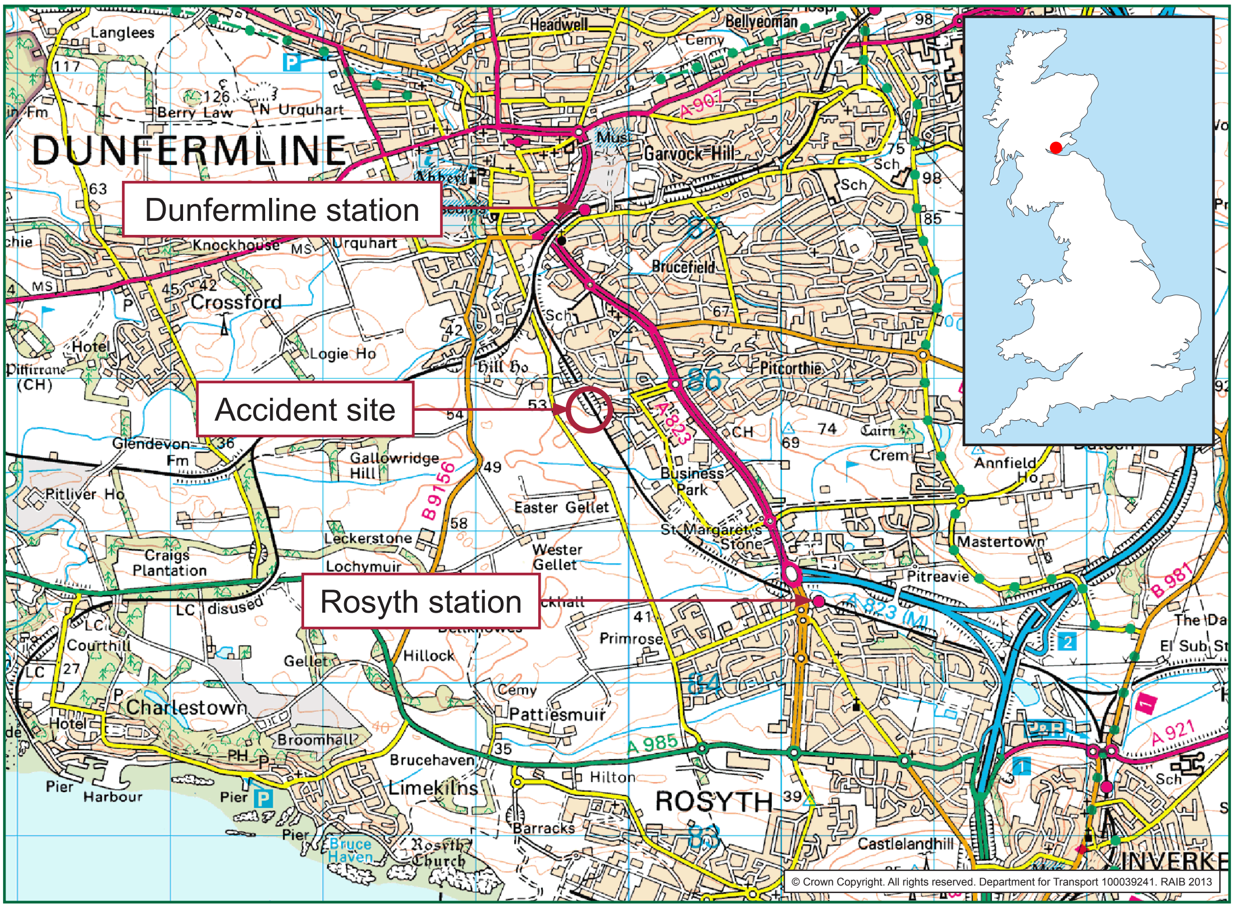

Figure 13: Rosyth: accident location

Figure 14: Rosyth: derailed train

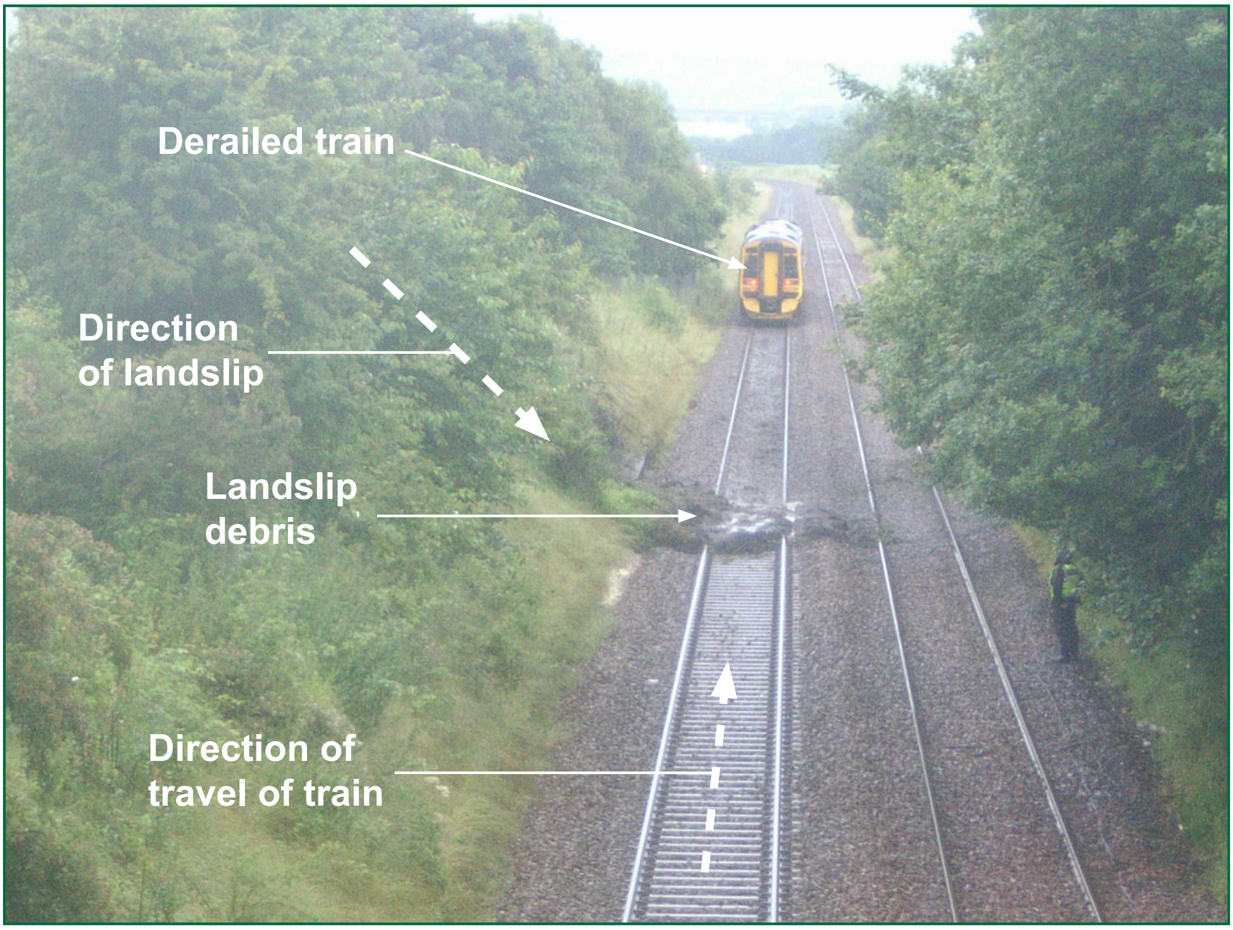

Figure 15: Rosyth: landslip

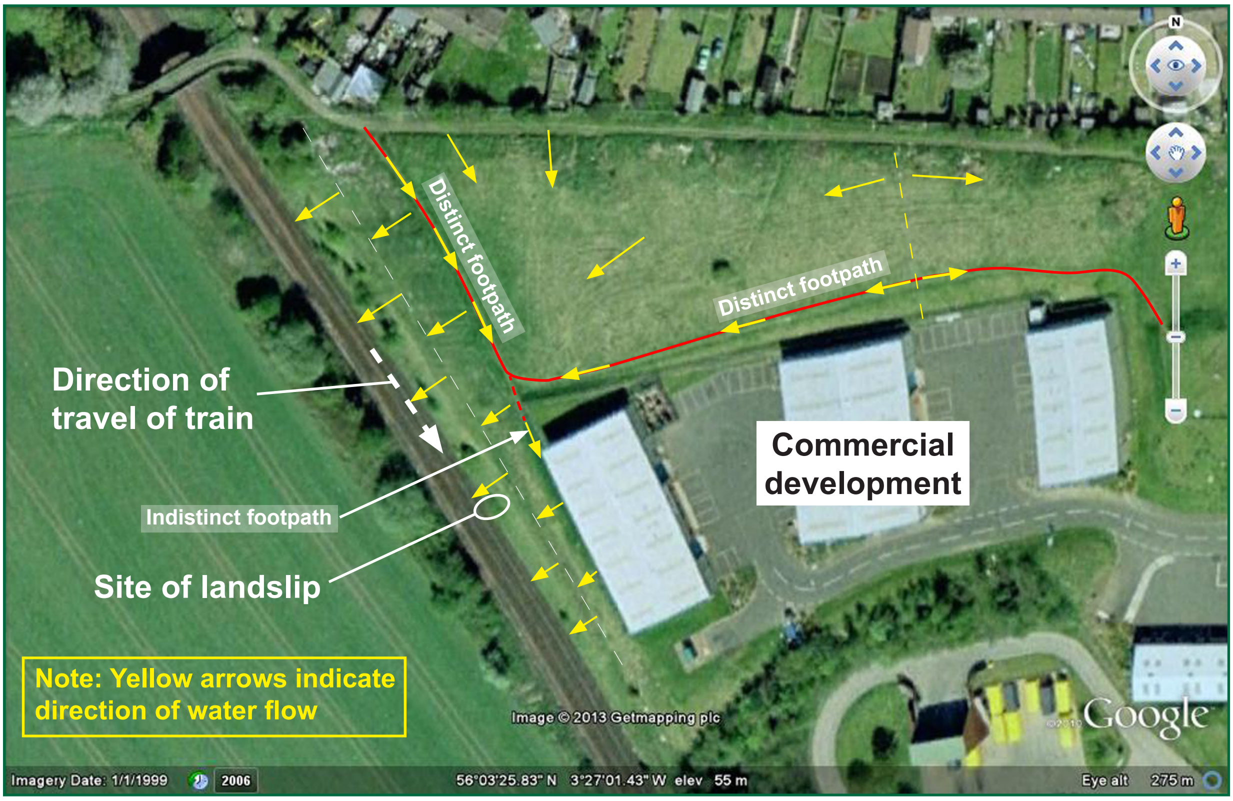

Figure 16: Rosyth: landslip and surrounding land features (pre-incident photograph)

40 The waste ground is roughly grassed and slopes at typically 1 in 50 in a direction which encourages surface water to flow almost, but not directly, towards the railway. No distinct drainage system serves the waste ground but informal footpaths provide preferential drainage routes which encourage surface water flows towards the top of the railway cutting close to the location of the landslip (figure 16).

41 The commercial area comprises predominantly buildings, parking areas and roadways. Rainfall collected from building roofs by gutters is piped into soakaway pits from which the water seeps into the surrounding ground.

42 An analysis of rainfall records undertaken by the Met Office on behalf of the RAIB using rainfall radar data shows that 12 mm of rain fell in the 24 hours from 10:00 hrs on 17 August and 28 mm in the following 24 hour period. This included rainfall of 35 mm in the 17 hours starting at 03:00 hrs on 18 August and extending beyond the time of the accident. This event is likely to occur once in three years. Approximately 7 mm of rain fell in the hour before the accident, an event which is likely to occur at least once in a year.

43 The rainfall radar had a one kilometre resolution and it is possible that rainfall was locally more intense at the accident site. Witness evidence describes an exceptional event with standing water on the waste ground and rainfall overwhelming the gutters in the commercial development. The variability of rainfall and confirmation of an unusual event is provided by records from the Forth Replacement Crossing, about 6 km from the accident site. These records show that 58 mm of rain fell on 18 August, an event likely to occur only every 17 years. RAIB and Network Rail consider that unusually heavy rainfall triggered the Rosyth landslip. It is possible that changes to the historic drainage pattern due to the commercial development meant that the slope was more likely to fail than if a similar rainfall event had occurred in the past. In particular, the commercial development may have encouraged development of the footpaths which directed surface water towards the landslip location. The extent to which the commercial development affected historic drainage patterns has not been established and would not alter the RAIB recommendations relating to management of railway risk arising from neighbouring land.

44 The last examination of the cutting slope had been undertaken during two visits, one in December 2004 and one in April 2005. The reasons for the split examination have not been established and there is no evidence that this adversely affected the examination. The slope had been categorised as serviceable with no further action being required until the next examination in December 2014.

45 A forecast of heavy rain meant that Network Rail control staff had given instructions for special inspections of 'at risk' earthworks on the day of the accident. These did not include an inspection of the accident site, because the accident site was not on the 'at risk' register.

46 There is no evidence that Network Rail should have recognised that the gently sloping land outside the boundary posed a significant risk to the railway and so there was no requirement for Network Rail to review the owner's land management policy (paragraph 119). No review took place and there is no evidence that a review would have led to actions likely to have prevented the accident.

47 It is uncertain how quickly the landslip blocked the line. Network Rail states that nothing unusual was reported by the driver of the previous train, which passed the site on the same line about 35 minutes before the accident, or by the driver of the train which passed the site on the opposite line about 20 minutes before the accident.

St Bees

48 At approximately 06:43 hours on Thursday 30 August 2012 the leading bogie of a passenger train derailed when it hit a landslip between St Bees and Nethertown on the Cumbrian coast (figure 17). There were no reported injuries and only relatively minor damage to the train. If the train had derailed to a greater extent, it is possible that it would have fallen down an adjacent slope (paragraph 50).

49 The train comprised two class 153 single-car diesel multiple units which formed the 06:00 hrs Northern Rail service from Maryport to Lancaster, train reporting number 2C32. It was carrying more than 100 passengers and three crew when, after departing from St Bees station and accelerating to 49 mph (78 km/h), it encountered the first of four earthwork failures between St Bees and Nethertown at 68 miles 64 chains[10] (figure 18). The driver applied the emergency brake as the train ran through the debris from this landslip. The train remained on the track and the speed had reduced by about 2 mph (3 km/h) when the train reached a second landslip at 68 miles 59 chains (figure 19). This landslip had deposited debris on the railway and removed ground from beneath one side of the track. The leading bogie of the train derailed at this location, and the train continued for a distance of about 121 metres before stopping (figure 20).

50 The accident occurred in an area where the railway has a maximum permissible speed of 60 mph (96 km/h) and comprises a single line running on a ledge cut into the sea cliffs which rise about 19 metres above the railway at a slope of approximately 1 in 3. This slope continues at a steeper angle of about 1 in 2 to the toe of the cliff about 9 metres below the railway (figure 21). The land at the top of the cliff is grassed, relatively level and used for grazing farm animals. At both 68 miles 64 chains and 68 miles 59 chains, the debris on the line was the consequence of landslips which had occurred in the cliff slopes above the railway.

51 The accident occurred after exceptionally heavy overnight rainfall which RAIB and Network Rail believe triggered both landslips, when water percolated into the predominantly sand and gravel soil causing a loss of soil strength, possibly accompanied by water washing out soil. There were no major drainage channels in the vicinity of the landslips. Site inspections, information provided by Network Rail and aerial photographs indicate that, at 68 miles 64 chains, it is probable that ditches, local topography and permeable ground concentrated water in the area of the landslip. The same sources of evidence indicate that, at 68 miles 59 chains, water was probably concentrated in the landslip location by a combination of local topography and permeable ground.

[10] The mileage is measured from Carnforth.

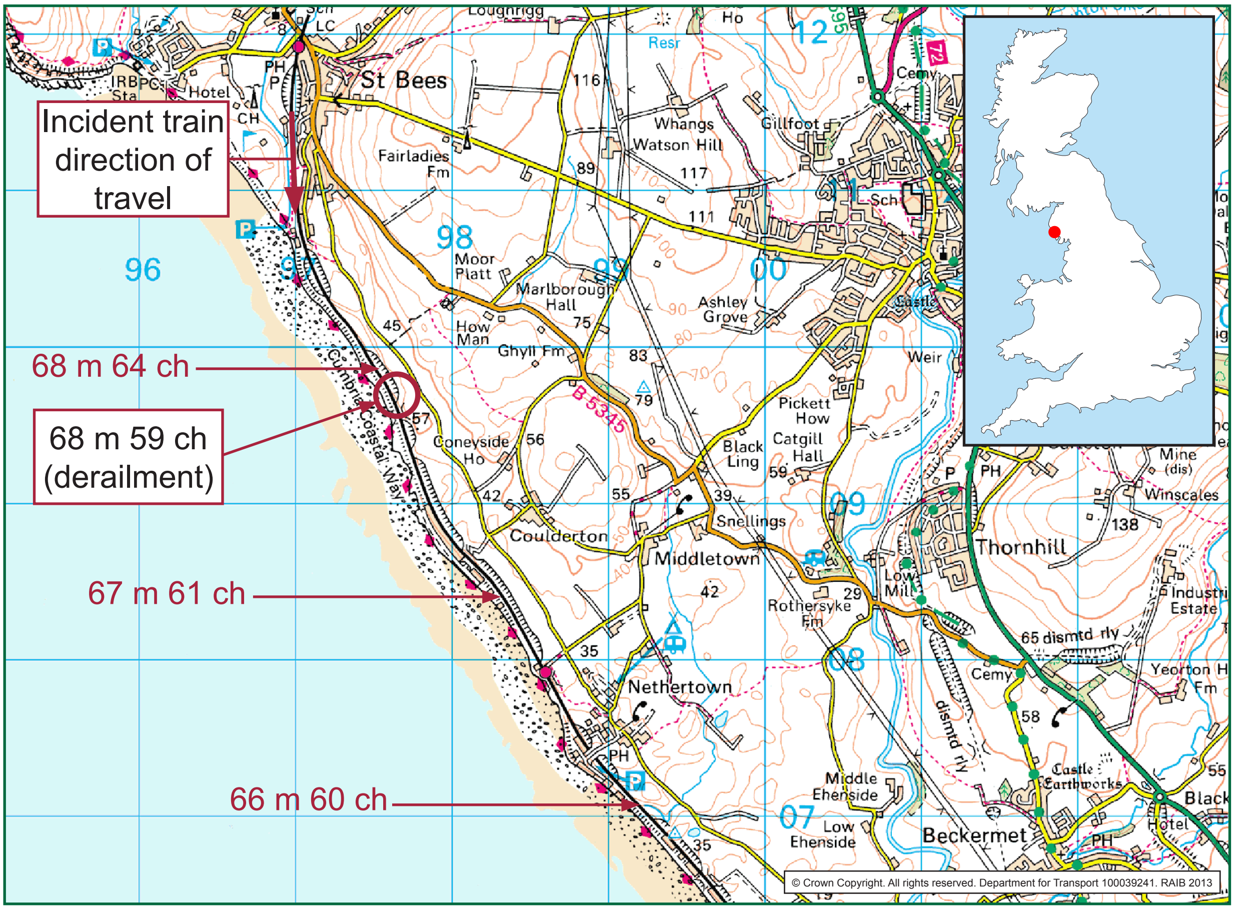

Figure 17: St Bees: accident location

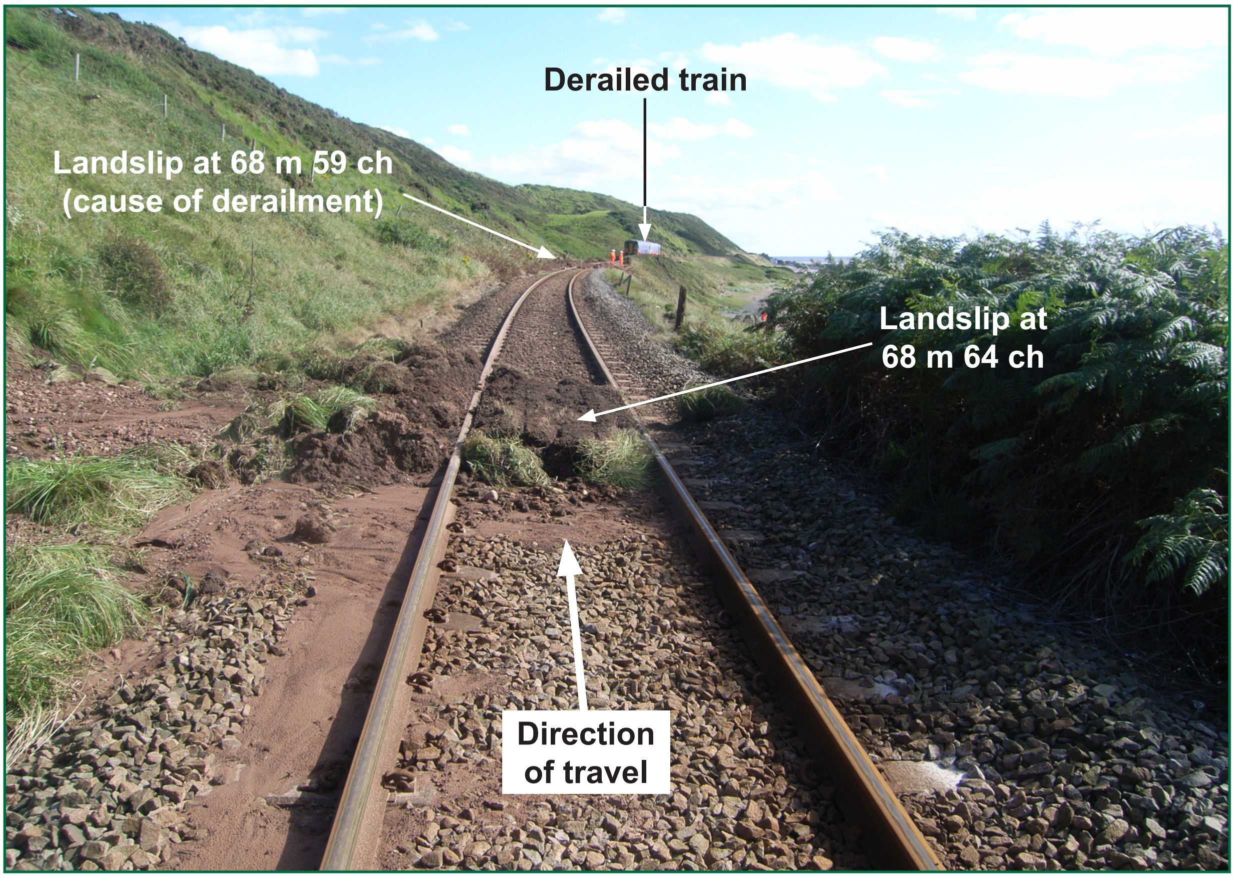

Figure 18: St Bees: landslip at 68 miles 64 chains

Figure 19: St Bees: landslip at 68 miles 59 chains (main image courtesy of Network Rail)

Figure 20: St Bees: derailed train

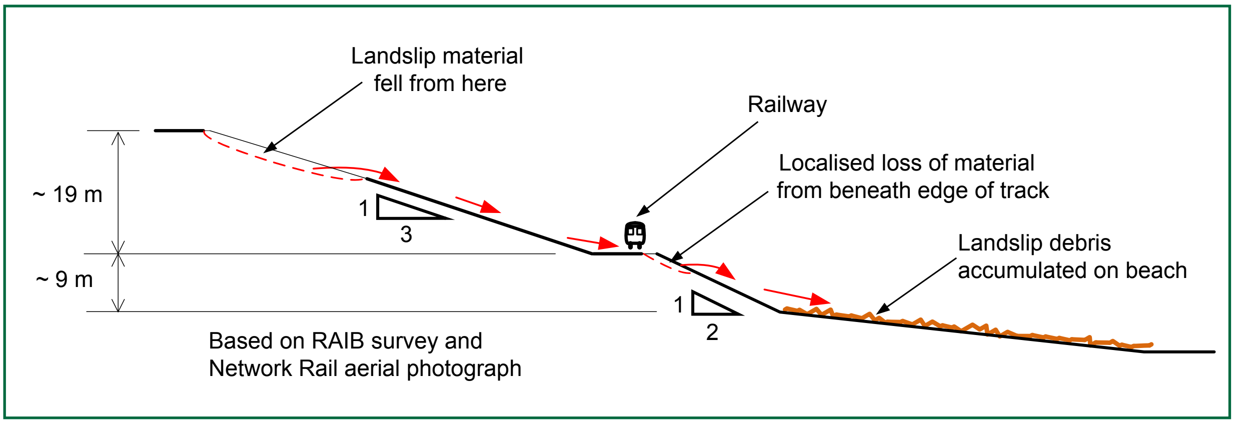

Figure 21: St Bees: slope geometry (cross-section)

52 Data collated by the Met Office for Network Rail shows that the total amount of rainfall in the area of the accident during July 2012 was about twice the average for July and that the ground was saturated. Work commissioned from the Met Office by RAIB shows that 51.6 mm of rain fell at St Bees, about two kilometres from the accident site, in the 24 hours from 10:00 hrs on 29 August. Data from an hourly rain gauge at St Bees Head, about six kilometres from the accident site, suggests that this rainfall was entirely concentrated into the period between 22:00 hrs on 29 August and 03:00 hrs on 30 August. Assuming that the amount of rainfall at St Bees fell in the timeframe recorded at St Bees Head, the event was likely to occur once in 57 years. The rainfall caused serious flooding and disruption to property outside the railway boundary.

53 The earthwork slopes above the railway at 68 miles 64 chains and at 68 miles 59 chains had last been examined on 4 April 2005 when they had been categorised as serviceable and therefore, in accordance with Network Rail standard NR/L3/065, 'Examination of Earthworks', no further action was programmed until the next routine inspection in 2015.

54 Although scattered heavy showers had been forecast, the predicted amount of rain was not sufficient to trigger adverse weather earthwork inspections (paragraph 135). Even if adverse weather inspections had been implemented, these would not have been targeted at the slopes above the railway at 68 miles 64 chains and at 68 miles 59 chains as these were not on the 'at risk' register.

55 RAIB notes that the topography of the cliff slopes is characteristic of a natural slope suffering repeated natural landslips, although the interval between such events could be many years. At RAIB's request, a senior Network Rail geotechnical engineer reviewed the classification of the cliff slopes above the railway after the incident and believes that a marginal categorisation was probably more appropriate than serviceable. This would have increased the frequency of earthwork examinations but would not have triggered any actions likely to have affected the accident.

56 Both landslips occurred within, or very close to the top of, the cliff slope. This slope was, with the exception of a small area on the upper part of the slope at 68 miles 59 chains, within the Network Rail boundary. Aerial photographs suggest that the small area of cliff outside the railway boundary is similar to the area within the boundary. The relatively gentle slope of the adjoining neighbour's fields meant that this area was not considered a significant risk to the railway. Network Rail staff did not review the neighbouring landowner's land management strategy (paragraph 119) and there is no evidence suggesting that such a review would have led to Network Rail implementing a different slope management strategy.

57 The last train through the area before the accident passed the accident site at about 20:07 hrs on the previous evening, several hours before the heavy rain which caused the landslips.

58 The heavy rain also triggered a landslip at 67 miles 61 chains and a washout of material from beneath the track at 66 miles 60 chains (figures 22 and 23). Although the southbound train involved in the accident did not reach these locations, these events prevented another train being used to rescue passengers from the train involved in the accident.

59 The landslip at 67 miles 61 chains occurred in the natural slope below the railway and undermined the track. It was probably triggered by water running off the slope above the railway. The washout of material from beneath the track at 66 miles 60 chains was caused when a build up of water on one side of an embankment resulted in water forcing its way through poorly compacted embankment material around a culvert. This culvert was intended to prevent water building up behind the embankment but it lacked the capacity to carry the exceptional amounts of water draining from the surrounding land.

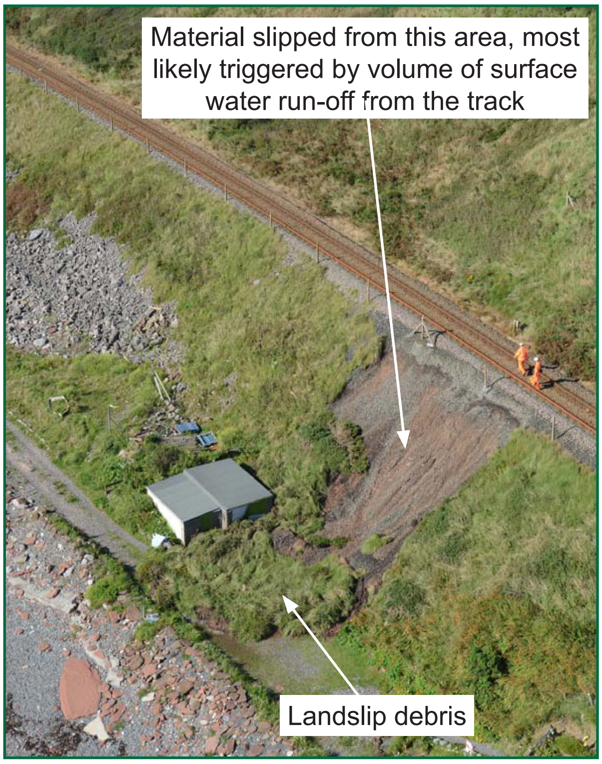

Figure 22: St Bees: landslip at 67 miles 61 chains (image courtesy of Network Rail)

Figure 23: St Bees: landslip at 66 miles 60 chains (image courtesy of Network Rail)

60 Permanent repair works were still awaiting completion at 68 miles 59 chains when a further incident occurred on 17 October 2012. Network Rail reported to RAIB that heavy rain (24 mm in 5 hours) during the afternoon of 17 October caused soil to be washed out from the slope above the railway in the area of the August 2012 landslip. A small amount of this material passed around the ends of a temporary barrier wall and was deposited on the railway (figure 24). The presence of this material was reported by the driver of a passing train and train services were suspended until the debris was removed from the track.

Figure 24: St Bees: October 2012 incident (image courtesy of Network Rail)

Bargoed

61 At approximately 06:20 hrs on Wednesday 30 January 2013, the 06:10 hrs Arriva Trains Wales service from Rhymney to Barry Island struck a tree which had been displaced onto the track by a landslip on the approach to Bargoed station (figure 25). The leading bogie derailed, the train suffered minor damage and a passenger was taken to hospital suffering from shock (figure 26).

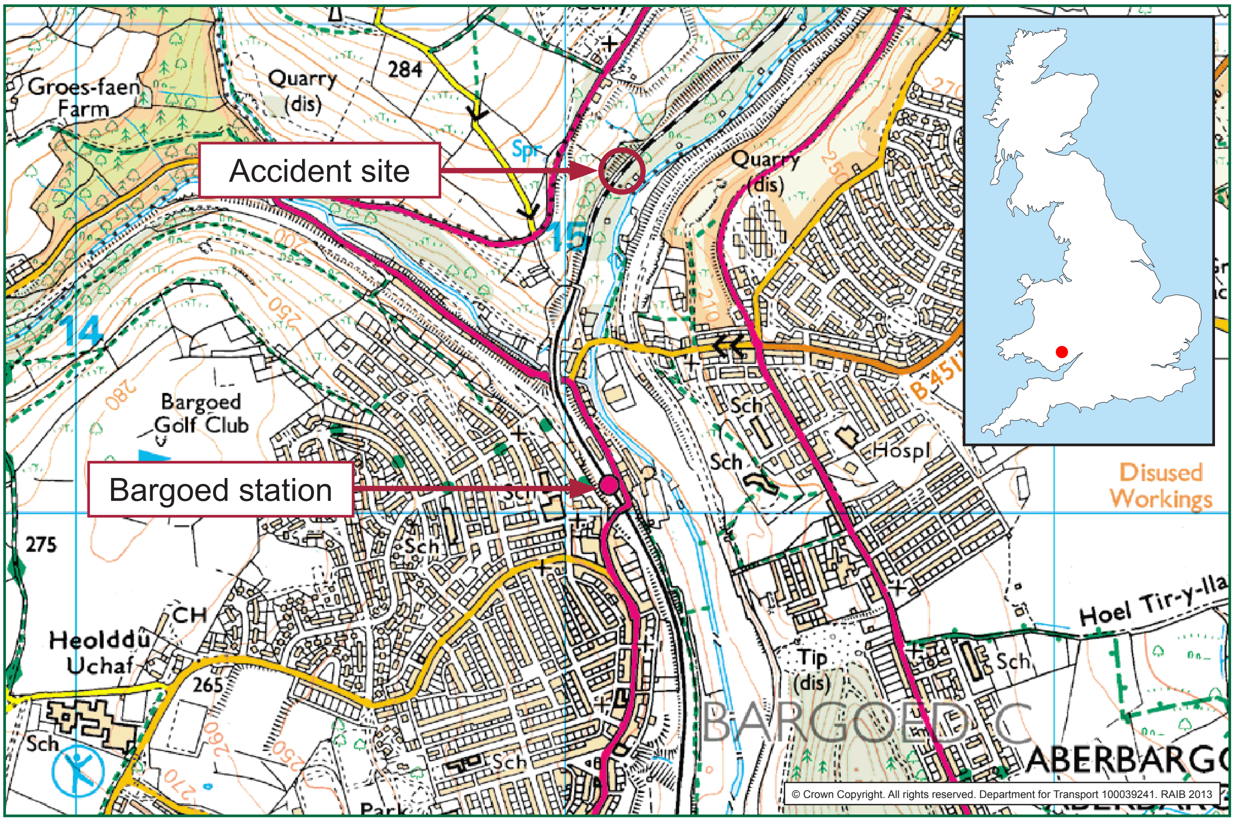

Figure 25: Bargoed: accident location

Figure 26: Bargoed: derailed train

62 The train, reporting number 2Y09, comprised a two-car class 150 diesel multiple unit (number 150258) carrying eight passengers and two crew. It was travelling at about 30 mph (48 km/h) when it struck the displaced tree, ran a distance of about 7 metres before the leading bogie derailed, and then ran a further 8 metres before coming to a stop. The accident occurred in an unlit area during darkness so the driver was unable to see that debris was blocking the line until just before the impact occurred; the driver then applied the emergency brake. The permanent speed restriction applicable to this section of line is 30 mph (48 km/h).

63 The landslip occurred at 18 miles 38.5 chains[11] alongside a section of single track railway running on a ledge cut into a hillside above the Rhymney River. Construction of the railway created a cutting face approximately 15 metres high and with a slope of 1 in 1.3 on the west side of the railway. Above this, the natural hillside rises a further 30 metres at a slope of about 1 in 4 to a road. The natural hillside continues to rise a further 140 metres above the road to a ridge. Below the railway, the natural hillside slopes at about 1 in 2 down to the Rhymney River which is about 20 metres below the railway (figure 27).

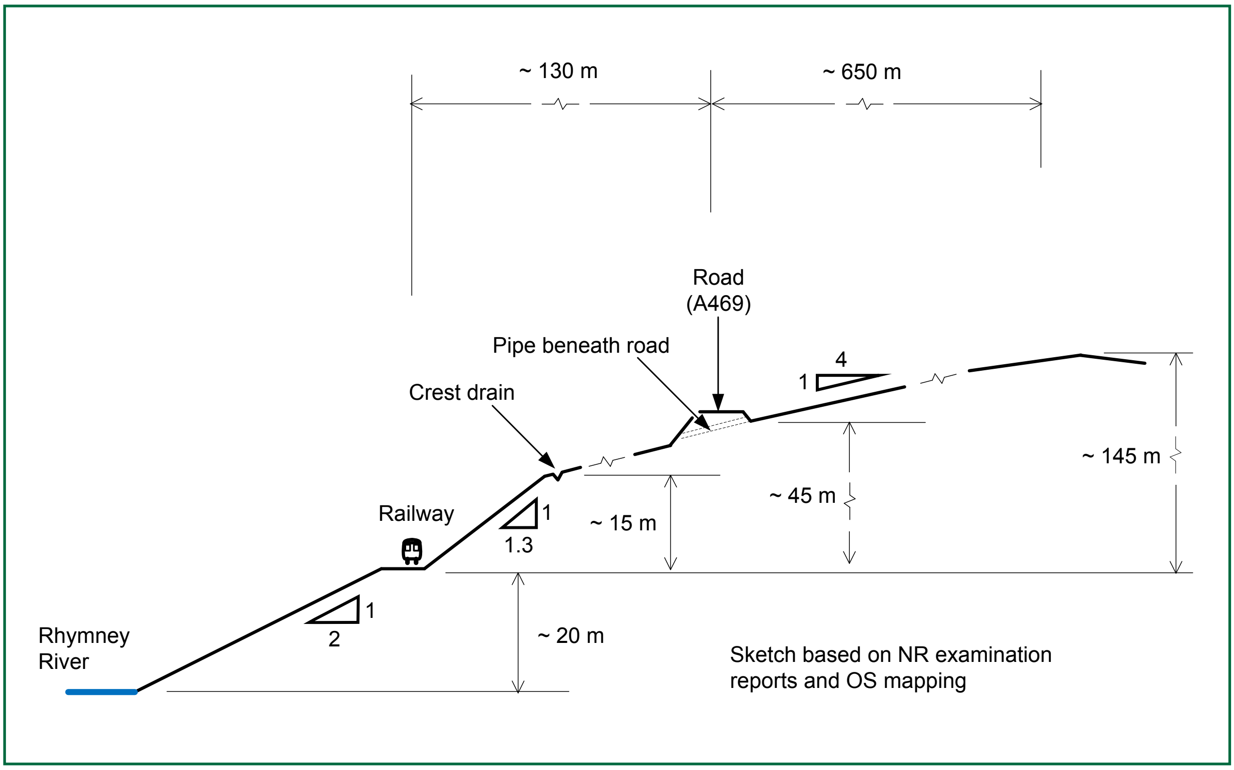

Figure 27: Bargoed: slope geometry (cross-section)

64 The hillside above the railway forms a natural valley directing surface water towards the area of the slip. There was no formal stream channel within the valley but, a few hours after the accident, RAIB observed water being discharged from a pipe into the valley immediately downslope of the road. It is likely that this pipe was acting as a drain intended to prevent water accumulating upslope of the road (figure 28).

[11] The mileage is measured from Cardiff.

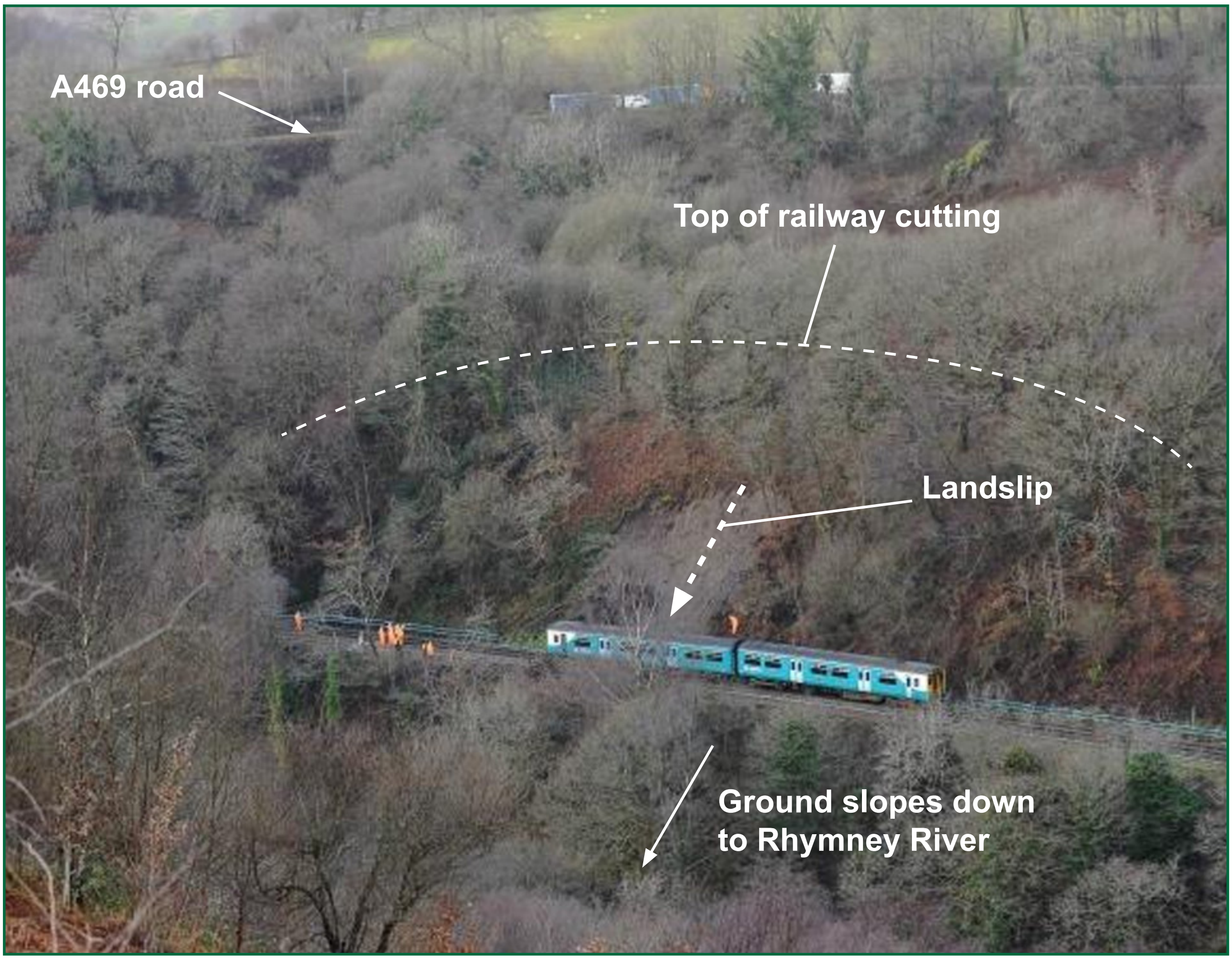

Figure 28: Bargoed: site overview (image courtesy of ITV Cymru Wales)

65 The Met Office, as part of a commission for RAIB, reported that a rainfall gauge at Ty Fry, about two kilometres from the accident site, recorded a daily rainfall of about 29 mm in the 24 hours from 10:00 hrs on 29 January. The Met Office also used rainfall radar data with a resolution of two kilometres to estimate that 40 mm of rain fell at the accident site in the same period and states that both these amounts of rain are likely to occur at least once a year in this area.

66 A total of 125 mm of rain fell in the five days before the accident, an event likely to happen only once in seven years, according to analysis carried out by the Met Office for RAIB. This is consistent with data provided by the Met Office to Network Rail which shows that the ground had been saturated throughout the nine weeks before the accident. It is very likely that moderately heavy rainfall falling on saturated ground was the trigger for the landslip at Bargoed.

67 The amount of rain forecast for the day of the accident meant that Network Rail had not implemented the extreme weather management procedure so there were no special inspections of 'at risk' earthworks. Even if the procedure had been implemented, the accident site would not have been inspected as it was not on the 'at risk' register (paragraph 135).

68 The train involvd in the accident was the first train to use the line since the previous evening, about seven hours before the accident.

69 The last routine earthwork examination had taken place at the accident site on 23 November 2011 and had resulted in the cutting slope being categorised as marginal, so no further action was required until a routine examination after an interval of five years. However, a landslip in July 2012, immediately adjacent to the January 2013 accident site, had led to a re-*evaluation* of the earthwork with Network Rail recategorising it as poor and ranking it as the 16th highest risk slope in Wales. Network Rail therefore decided to implement slope stabilisation work encompassing both the July 2012 landslip and adjacent areas of cutting including the area which slipped in January 2013.

70 Network Rail's contractor commenced stabilisation work on the day before the January 2013 landslip. Work on this day comprised clearing ditches (drains) at the top of the cutting and within the Network Rail boundary. This had the intended beneficial effect of diverting surface water away from the cutting slope. RAIB has considered the possibility that clearing of the drain encouraged water seepage into the ground. Network Rail has discounted this possibility because clearance only involved removal of organic material formed by rotting vegetation. The RAIB consider that there is insufficient evidence to be certain that ditch clearance played no part in the incident.

71 The potential for the slope above the railway to affect railway safety by discharging water onto the cutting slope had been recognised by Network Rail and drain clearance was in progress to mitigate this risk. There is no evidence that Network Rail staff had formally reviewed the neighbouring owner's land management strategy (paragraph 119) but RAIB does not consider that a review would have led to any actions which would have prevented the accident. A desk top or on-site review before the July 2012 landslip was unlikely to have resulted in action because the earthwork was considered to be in a marginal condition, rather than in the less satisfactory poor condition. Responses by Network Rail staff after the July 2012 landslip, particularly the decision to improve drainage, shows that they were then taking account of water flowing from neighbouring land.

72 The drainage works started the day before the derailment were intended to prevent landslips of this type. It is therefore probable that the accident would have been avoided if works had been undertaken earlier. The need for works had been recognised immediately after the July 2012 landslip (paragraph 69) and Network Rail geotechnical staff considered the level of risk to justify undertaking the works as a 'reactive remit'. This results in slower implementation than 'emergency works' but is quicker than using the standard process for capital works.

73 Network Rail company standard RT/CE/P/044, 'Managing Structures Works', requires that those with responsibilities relating to implementation of works shall 'understand and be able to judge when urgent or immediate action is necessary for safety reasons'. Given the nature of the July 2012 event, the warning this gave of potential further instability and the decision to use a reactive remit for slope mitigation works, RAIB considers that the accident site should have been added to the 'at risk' register until appropriate physical works were implemented. A senior Network Rail geotechnical engineer formed the same opinion when asked by the RAIB.

74 Inclusion on the 'at risk' register until completion of physical works would have been consistent with sections 6.5.3 and 6.5.4 of Network Rail standard NR/L2/CIV/086, 'Management of earthworks'. This effectively requires actions to be completed at times 'deemed necessary to maintain an acceptable level of safety'. The people making these decisions are required to understand and be able to judge when urgent or immediate action is necessary for safety reasons (Network Rail company standard RT/CE/P/044, 'Managing Structures Works', section 5).

75 Although RAIB considers that the accident site should have been on the 'at risk' register (Recommendation 4[12]), this would not have prevented the accident because inspections were not taking place on that day (paragraph 67).

Hatfield Colliery

76 On 9 February 2013 a train driver noticed a track defect when passing Hatfield Colliery, near Stainforth, South Yorkshire at 7 miles 25 chains[13] on the four track section of railway between Doncaster and Scunthorpe (figure 29). At this location, the maximum permissible speed is 40 mph (64 km/h) on the outermost lines and 60 mph (96 km/h) on the central pair of tracks. Network Rail staff attended site when the driver reported the defect and implemented progressively lower speed restrictions as on-going track movements became apparent (figure 30). Due to these movements, three of the lines were closed to traffic on 11 February and the fourth line was closed on 12 February.

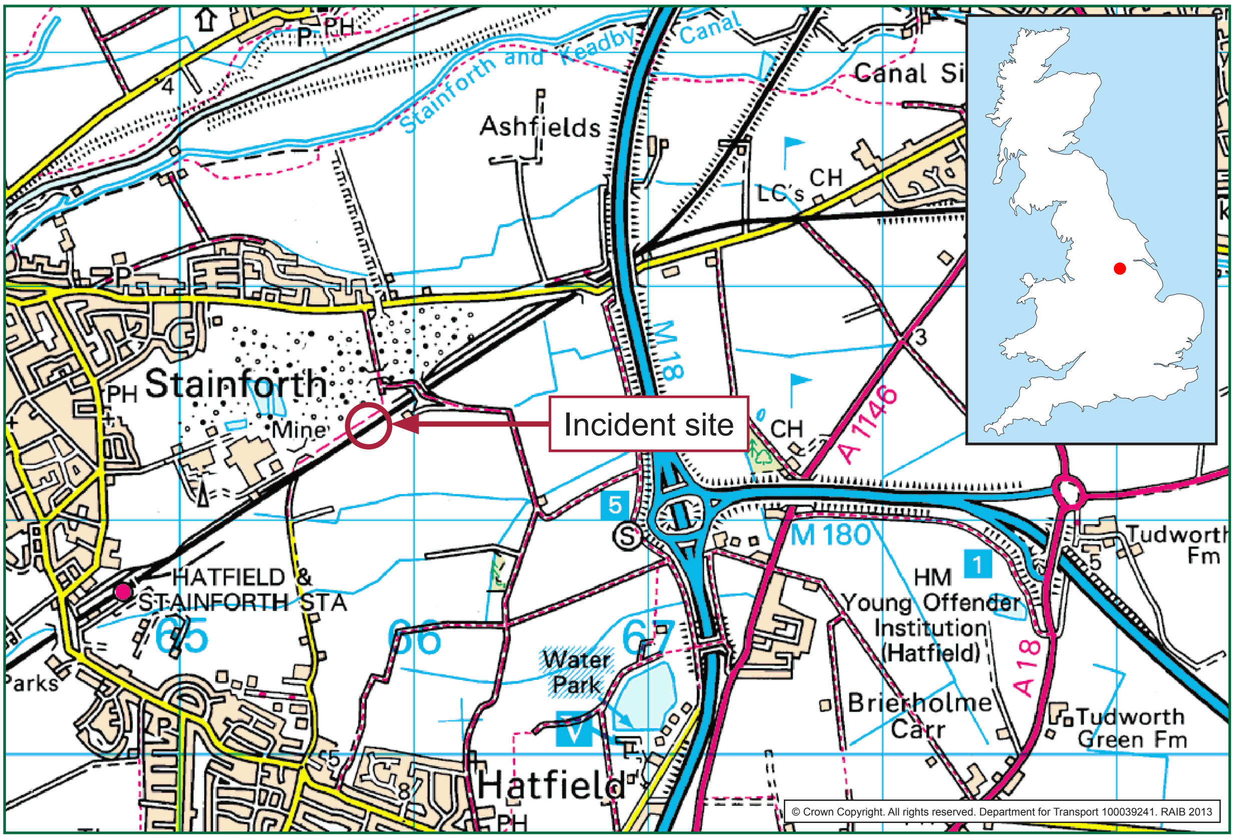

Figure 29: Hatfield Colliery: incident location

12 Recommendations are given at paragraph 168.

13 Mileage measured from Marshgate Junction (Doncaster).

Figure 30: Hatfield Colliery: track deformation (image courtesy of Network Rail)

77 There was no damage to trains and no injuries as a result of the ground movements. However, major works were required to reinstate the railway infrastructure and the railway was not reopened until 8 July 2013.

78 Aerial photographs taken by Network Rail show that the track deformation was a consequence of a large landslip caused by a spoil tip located outside the railway boundary and within Hatfield Colliery (figures 31 and 32). The precise reason(s) why the landslip occurred remain to be determined and, in addition to the ground loading imposed by the spoil tip, may involve factors such as unexpected weakness in the natural ground. RAIB has not investigated these reason(s) because this was not expected to lead to additional RAIB safety recommendations.

79 In the area of the landslip, the railway is running in a cutting up to three metres deep with a side slope of typically 1 in 1.4. When the landslip occurred, photographs seen by RAIB, coupled with desk study information provided by Network Rail, suggest that the nearest toe of the spoil tip was about 9 metres from the top of the cutting and the spoil tip rose about 20 metres above the toe with a side slope of around 1 in 1.5.

80 The last examination of this earthwork took place in November 2009 and resulted in the earthwork being categorised as serviceable, so requiring no further specialist consideration until the next routine examination due after an interval of ten years.

Figure 31: Hatfield Colliery: aerial view (image courtesy of Network Rail)

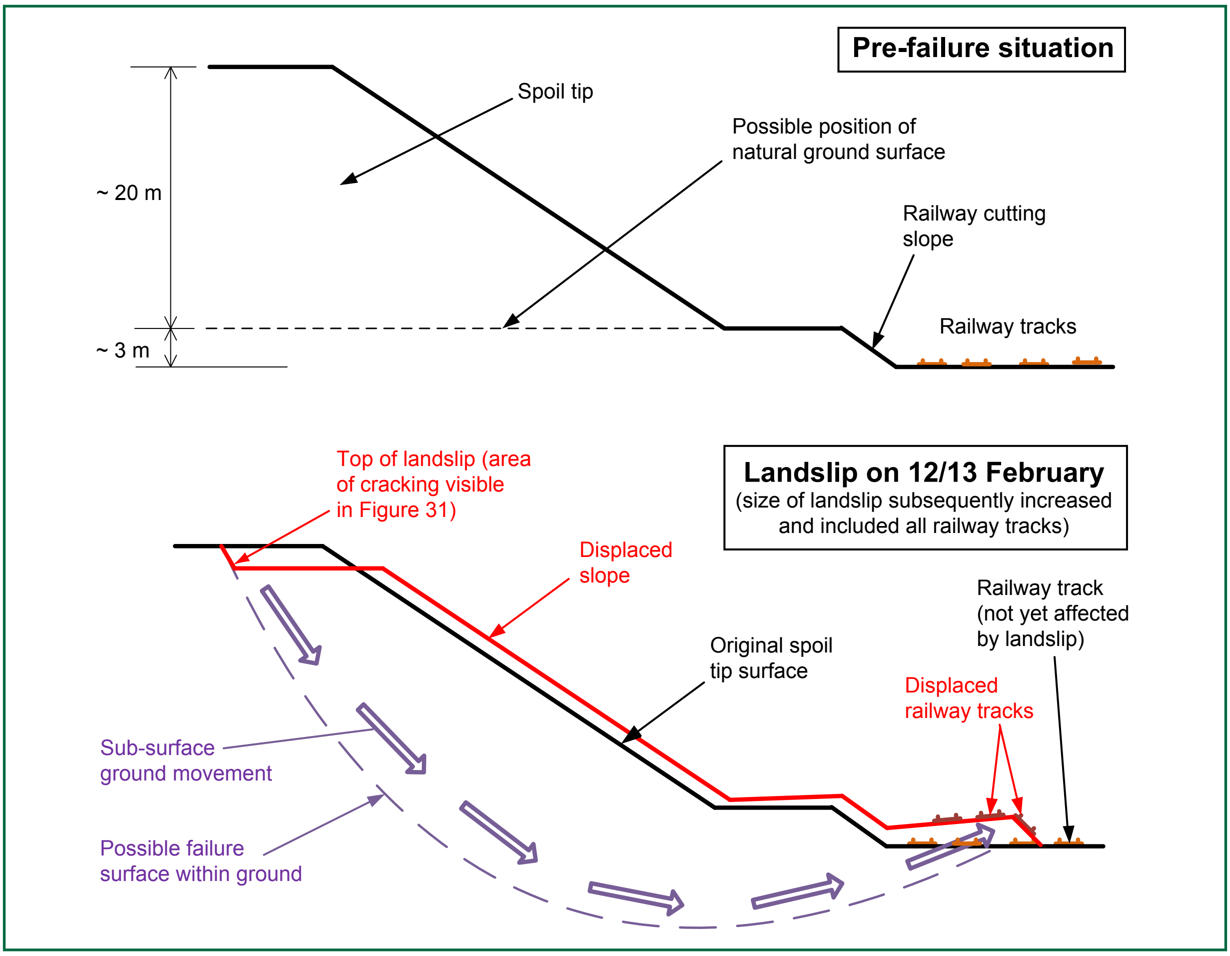

Figure 32: Hatfield Colliery: landslip geometry (cross-section)

81 Network Rail's examination process requires topography outside the railway to be recorded where practical, and considered when deciding the appropriate earthwork management strategy. The examination report notes that the surrounding ground slopes at less than five degrees and makes no reference to a spoil tip. Photographs in the examination report and desk study information provided by Network Rail indicate that, near the railway, the spoil tip was considerably smaller at the time of the November 2009 examination than when the landslip occurred. A senior Network Rail geotechnical engineer has stated that, although examiners usually report risk items outside the railway boundary, a tip of this size would not have been considered a risk to the railway.

82 Network Rail had not considered whether the enlarged tip posed a risk to railway safety before the land slip occurred because, while the tip was being enlarged after 2009, there had been no routine examination or other process to trigger such consideration. On the basis of information provided by Network Rail after the landslip occurred, RAIB believes it unlikely that such consideration would have led to actions which would have prevented the landslip. This is because Network Rail has stated that, even if it was aware that the tip had been enlarged, it would not have taken any action because it would have expected the safety of the tip to have been managed by others.

83 Network Rail has stated that this expectation would have been based on the provisions of the Mines and Quarries (Tips) Act 1969 which, in response to a spoil tip landslip which killed 116 children and 28 adults at Aberfan in 1966, includes a specific requirement for tips to 'be made and kept secure'. The tip is within Hatfield Colliery (an active colliery) and thus the Act imposes specific duties on the mine owner and mine manager intended to achieve this requirement. These duties are subject to overview by the Health and Safety Executive (Her Majesty's Inspectorate of Mines).

Analysis

Railway earthworks

84 Factors which make landslips difficult to predict include:

- natural weathering processes result in a gradual weakening of the ground increasing the likelihood of instability in both natural and man-made slopes;
- water adversely affects slope stability but neither rainfall, nor the rate at which water accumulates within a slope, can be predicted with accuracy;
- vegetation changes with time and this influences the amount of water accumulating within a slope and the strength of the slope (due to the strengthening effect of roots);
- land use in the surrounding area can change and this can alter both the amount of water reaching the railway and the rate at which water reaches the railway;
- many railway cuttings and embankments were constructed with steeper slopes (therefore a greater likelihood of failure) than would be adopted with modern design procedures; and
- existing drainage arrangements are often less good than required by modern design standards and are not always reliable (paragraph 87).

85 Landslips are almost always triggered by relatively high rainfall because:

- water pressure tends to push soil particles apart, thus reducing the frictional forces which tend to resist soil failure;
- water flowing through the ground can wash out soil particles; and
- water can increase the likelihood of a landslip by making parts of a slope heavier than in dry conditions.

86 The importance of rainfall is evidenced by the relationships between earthwork failures and rainfall shown in figures 33 and 34. Earthwork failure data is shown on a monthly basis for England and Wales (figure 33) and on a quarterly basis for Scotland where the length of railway is less and fewer failures occur (figure 34). Rainfall data is presented on a monthly basis on both figures and so does not include the following influences on landslips:

- the distribution of rainfall within a month (particularly periods of heavy rainfall);
- the build up of water in the ground from rainfall over relatively long periods of time (typically several weeks or more); and
- differences between local rainfall and the area averages plotted[14].

[14] Average rainfall for England & Wales and for Scotland from the Met Office's Hadley Centre Observations (www.metoffice.gov.uk/hadobs/hadukp/data/download.html).

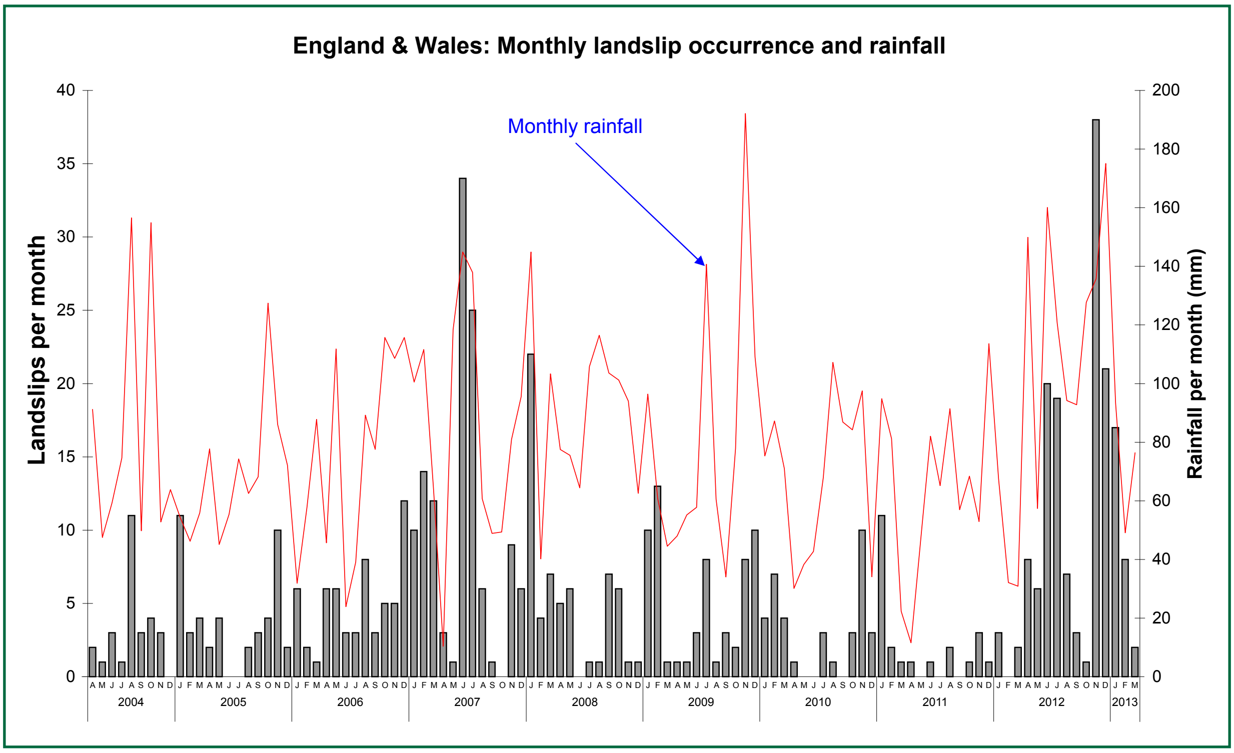

Figure 33: Rainfall and earthwork events on Network Rail infrastructure in England & Wales

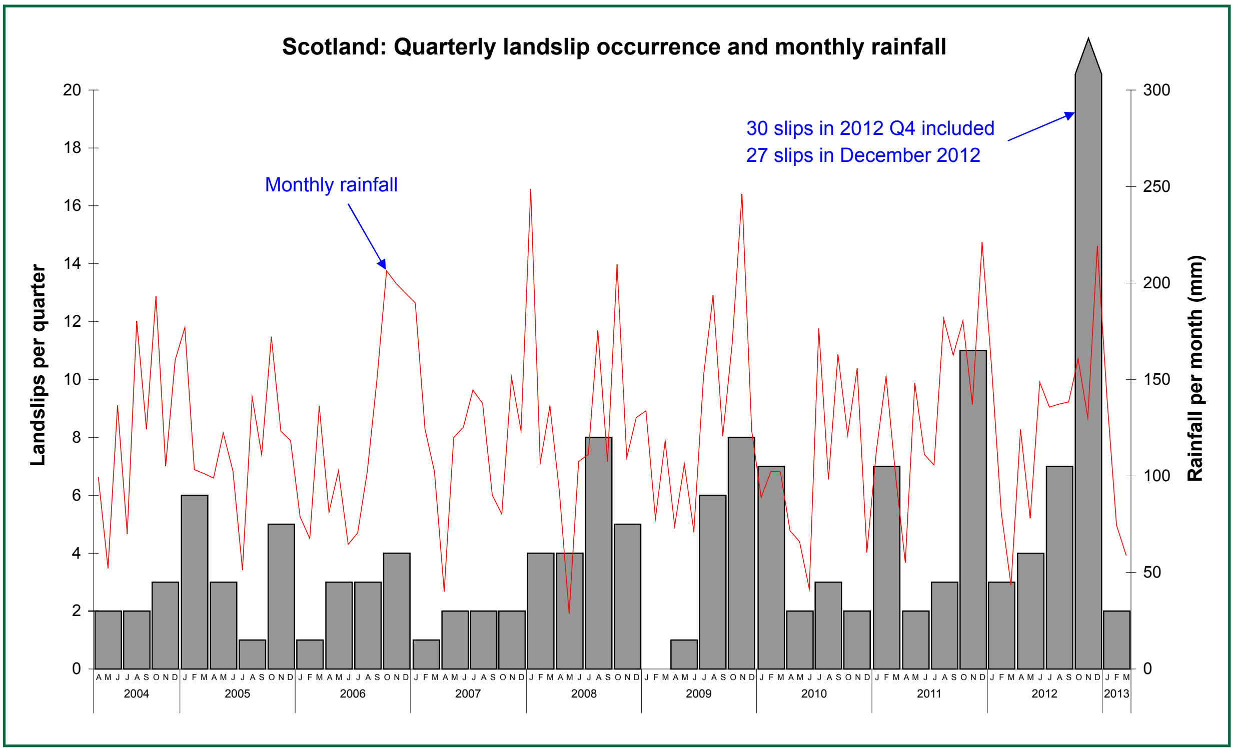

Figure 34: Rainfall and earthwork events on Network Rail infrastructure in Scotland

87 The adverse effects of water can, in some circumstances, be mitigated by drainage systems on railway and/or neighbouring land. However substantial parts of the existing railway-related drainage system were installed before current design techniques were developed and do not meet modern drain design standards. In addition, many parts of the drainage system suffer from a historical legacy of poor maintenance which means that they can be unreliable. Network Rail has an on-going programme to improve this situation but it is unlikely that all parts of the system will achieve modern design standards within the foreseeable future.

88 Although Network Rail is undertaking a programme of improvement works targeted at slopes it judges as presenting the greatest risk to railway safety, many slopes which are steeper than permitted by modern design standards will remain in their current configuration for the foreseeable future.

89 Although there have been no fatalities as a direct result of trains hitting landslips in the UK for more than 50 years, Network Rail needs to manage the risks associated with landslips because their consequences are unpredictable and could lead to a major accident. Nine people were killed[15] when a train hit a landslip near Bolzano in Italy on 12 April 2010 and two people were killed[16] near Beaminster in Dorset when their car was engulfed by a landslip in July 2012.

90 Network Rail's management of landslip risk can be considered in three parts:

- reducing the likelihood of landslips causing an obstruction on the railway due to factors within the railway boundary (a summary of RAIB recommendations already made in this area is given in appendix D);
- reducing the likelihood of landslips causing an obstruction on the railway due to factors on land neighbouring the railway (paragraph 92); and
- predicting when and where landslips may occur and then implementing steps to reduce the likelihood of a landslip causing serious harm to trains and their occupants (paragraph 125).

91 The problems associated with railway earthworks are not unique to Network Rail infrastructure. Examples of other railways with similar problems and with earthwork management systems based on similar principles include Norway, New Zealand and Northern Ireland.

Risk from neighbouring land

92 **Debris from a landslip on neighbouring land caused the derailment at Loch Treig. Water flowing from neighbouring land triggered the landslips at Falls of Cruachan, Rosyth, St Bees and Bargoed. Loads applied to the ground by a spoil tip on neighbouring land caused the track movements at Hatfield Colliery.**

[15] http://news.bbc.co.uk/1/hi/world/europe/8617148.stm.

[16] http://www.guardian.co.uk/uk/2012/jul/18/beaminster-tunnel-deaths-police-ipcc.

Interaction with neighbours

93 The actions, or inactions, of neighbours can affect both drainage systems and other factors with the potential to trigger landslips affecting railway safety. The legal situation concerning the duties of neighbours and Network Rail in relation to railway risk arising from neighbouring land is not precisely defined. Responsibilities under civil law depend on whether they are governed by English or Scottish law but those imposed by the Health and Safety at Work Act (the legislation which is usually most relevant) are the same in both jurisdictions. Responsibilities depend on circumstances at particular locations and the legal overview given in paragraphs 94 to 99 is not intended to cover all aspects relevant to a particular site.

94 The Health and Safety at Work Act 1974 places duties on employers to protect the safety of those affected by their undertaking. If this principle is applied in the railway context, employers in control of land neighbouring the railway have a duty to avoid, as far as reasonably practicable, work activities which adversely affect railway safety. However, this duty does not apply if the adverse effect is not related to the work activity, for example, slope instability in an area which is adjacent to a factory but is not affected by the factory or an associated work activity. The Health and Safety at Work Act does not apply to organisations which are not undertaking work activities.

95 A neighbour is likely to be responsible in civil law for the reasonably foreseeable consequences of any deliberate action they take on their own land. This provides Network Rail with the opportunity to intervene if a neighbour acts in a way which adversely affects railway operations.

96 When a hazard occurs naturally on a neighbour's land, civil law may impose a duty on a neighbour to take reasonable steps to avoid reasonably foreseeable adverse effects on the railway. The extent of any duty depends in part on the particular circumstances (including financial circumstances) of the neighbour and Network Rail. At least in English law, the duty related to naturally occurring hazards is much more restricted than duties arising from the neighbour's own actions.

97 In respect of drainage, English civil law has the effect of placing a greater obligation on neighbours than Scottish law. In English law a neighbour is likely to be liable for damage caused to Network Rail infrastructure by water escaping from a drain which the neighbour knows about. A neighbour would only be liable in Scottish law if there was robust evidence that the neighbour acted negligently.

98 A neighbour can sometimes be responsible for warning Network Rail about a risk even if the neighbour has limited, or no, responsibility for mitigating the risk.

99 Network Rail has a duty to take reasonably practicable steps to identify and take appropriate action to manage risks arising from neighbouring land, irrespective of any duty owed to Network Rail by the neighbour. This does not imply a requirement to recognise all such risks. Constraints on Network Rail's ability to deal with these risks include:

- the extent to which neighbouring land can be viewed and accessed by railway staff; and
- the extent to which neighbours are willing to co-operate with railway staff.

100 Several RAIB investigations (including the present investigation and an investigation into a derailment near Gillingham tunnel on 28 November 2009, RAIB report 19/2010) have shown that Network Rail takes a flexible approach to managing risk from neighbouring land. This can include:

- implementation of mitigation measures on railway property (drains to intercept water flows, warning systems activated if rocks fall onto the railway, etc);
- implementation of mitigation measures on neighbouring land (eg clearing neighbours' drains); and
- advising neighbours that they need to take action in order to mitigate a risk.

Examinations

101 Network Rail standard NR/L2/CIV/086, 'Management of Earthworks' (June 2011), defines the requirements for managing earthworks so that 'when meeting these requirements there would be no unacceptable risk to the safe operation or performance of the rail infrastructure'. The standard states that:

- its scope includes '*outside party* earthworks (irrespective of height) whose failure could pose an unacceptable risk to the safe operation or performance of rail infrastructure';
- soil slopes and rock slopes are included in the term 'earthwork'; and
- man-made cuttings, man-made embankments and natural slopes are all considered as 'earthworks'.

102 Section 6 of this standard sets out a process for examining earthworks, evaluating their condition and, where necessary, taking appropriate actions. The standard states that these actions can include strengthening/repairing earthworks, installing drainage systems, maintenance and operational restrictions such as temporary speed restrictions or temporary closure of the line.

103 The practical detail of the earthwork examination process is contained in Network Rail standard NR/L3/CIV/065, 'Examination of earthworks'. The December 2008 version of this standard was superseded by an updated version issued in June 2012 with a compliance date of September 2012. Unless noted otherwise, the technical requirements described in this report are the same in both versions of the standard.

104 Standard NR/L3/CIV/065 provides a methodology for recording key parameters relating to each part of an earthwork. These parameters were detailed in the December 2008 standard but are now held on a list maintained by Network Rail HQ. The required information is collected by people holding the Network Rail '*earthwork examiner*' competency and the report is reviewed by people holding the '*earthwork engineer'* competency. In most instances the examiner and examining engineer are employed by a contractor who is responsible for undertaking the examination and submitting the examination report to Network Rail.

105 Earthwork examiners are trained by Network Rail to collect information about earthwork slopes within and outside the railway boundary by standing on the side of the track and, providing it is safe to do so, by walking up and down slopes within the railway boundary. They are not expected to go outside the railway boundary, and safety considerations (eg very steep slopes) sometimes prevent examiners reaching the boundary. These constraints mean that collection of information about slopes outside the boundary may be restricted (Recommendation 1).

106 In order to manage the large amounts of earthwork data collected by examiners and to promote consistency in the earthwork management system, Network Rail has implemented a process which allocates scores to many of the earthwork characteristics recorded during examinations. The process then uses an *algorithm* to combine these scores and give a composite score intended to reflect the overall condition of the earthwork. This composite score, designated the *soil slope hazard index* (SSHI) for soil slopes and the *rock slope hazard index* (RSHI) for rock slopes, is used to categorise the earthwork as serviceable, marginal or poor.

107 Slopes categorised as poor are subject to an evaluation by specialist Network Rail geotechnical staff using a process described in Section 6.4 of Network Rail standard NR/L2/CIV/086, 'Management of earthworks'. This includes a review of the examination report and determines the management strategy for the earthwork. The strategy will include, as a minimum, annual examinations and may include more frequent examinations, monitoring or construction of improvement works.

108 If the algorithm classifies a slope as marginal or serviceable, Network Rail processes generally require no further action until the next examination (after five years for marginal slopes and after ten years for serviceable slopes). Reports for marginal and serviceable slopes are only reviewed by Network Rail staff if the slope is among the 1% selected for checks on examination quality or in special circumstances such as a proposed change of land use which could affect the slope.

109 Reliance on the algorithm to determine whether Network Rail review examination reports means that Network Rail can be unaware of important slope characteristics if these have no effect on the algorithm. Examples of slope characteristics which do not affect the algorithm include:

- examiners reporting the presence of loose boulders with the potential to roll onto the railway; and
- examiners reporting a disagreement with the categorisation given by the algorithm, a particular problem if the slope is automatically assigned a marginal or serviceable categorisation but the examiner's professional judgement indicates it should be managed as a poor earthwork.

110 Network Rail geotechnical specialists responsible for acting on information about slope characteristics have described instances when they have searched systematically in non-poor reports for particular slope characteristics. The selected characteristic(s) varied between witnesses and all agreed that there is no robust process requiring them to identify and review reports containing this type of information unless the slope has been categorised as poor (Recommendation 2).

111 RAIB became aware of the anomaly described in paragraph 109 when reviewing the examination process for the slope above the Loch Treig accident site. Although there were loose boulders on this slope and Network Rail had installed special precautions to deal with these elsewhere above Loch Treig (paragraph 19), the incident slope was categorised as marginal. This would not have altered if the examination data was reprocessed taking account of minor changes made to the reporting system since the last examination[17]. The marginal classification meant that, if the staff managing the earthwork had lacked the local knowledge held by the incumbent personnel, they could have been unaware of the need to consider precautions to deal with loose boulder risk.

Risks developing between examinations

112 Examinations generally take place annually for poor earthworks, five-yearly for marginal earthworks and ten-yearly for serviceable earthworks. Changes in the use of neighbouring land can result in risk to the railway developing between examinations. Network Rail is required to take reasonably practicable measures to recognise and manage these risks (paragraph 99).

113 Network Rail geotechnical staff were unaware that a risk of this type had been developing at the Hatfield Colliery site for several years. As a result, they did not consider whether they needed to take any action. RAIB considers that Network Rail geotechnical staff should have been aware that the tip was being enlarged and that they should have considered whether they needed to initiate a response. It is possible that consideration would have led to the conclusion that no response was needed (paragraph 82).

114 RAIB considers that a process is required to recognise, and report to geotechnical staff, significant changes which occur between examinations and which could adversely affect earthwork stability. Changes of this type can occur outside and within the railway boundary. They include man-made and natural processes which result in additional loadings at the top of slopes, excavation at the bottom of slopes and changes in the way water flows onto and through railway property. They are changes which would be apparent to a non-specialist observer given appropriate training.

115 A requirement of this type was included in the now superseded August 2005 standard for 'Inspection and maintenance of permanent way' (Network Rail standard NR/SP/TRK/001). This required patrollers (staff who visually inspect the line at intervals not exceeding eight weeks), to identify and report the following where 'it is reasonable to do so':

- in respect of lineside and lineside security:
  - activities of neighbours that may affect track and/or train safety, eg construction work, excavation, tree felling and drainage work; and
- in respect of cutting and embankment slopes:
  - signs of loose, displaced or fallen material (particularly after severe frost, heavy rainfall or thaw); and
  - signs of cracking (particularly in clay slopes during very dry weather).

[17] A box to be ticked if loose boulders were present had been added to the standard examination report after the March 2011 examination.

116 These requirements for non-specialist observation of earthworks and neighbouring land are not in the current version of the standard, NR/L2/TRK/001 (issue 6, December 2012). The current version only requires patrollers to identify and report locations at which landslip debris is blocking the line and locations where landslips have caused track movement (although the wording has changed, these requirements were also in the August 2005 standard). RAIB has not identified any other current standard which allocates responsibility for non-specialist observation of earthworks.

117 A member of staff representing Network Rail HQ has stated that the current version of NR/l2/TRK/001 reflects the company's expectation from patrollers. However, geotechnical specialists from at least one route (Scotland) have briefed patrollers on slope stability issues so that the patrollers can recognise and report issues requiring consideration by geotechnical specialists.

118 Although patrollers may not be the most appropriate people to carry out non-specialist observation of earthworks and activities on neighbouring land, RAIB considers that such information should be collected by an appropriate means (Recommendation 1).

Reviewing neighbouring land management strategy

119 Section 8.7 of Network Rail standard NR/L2/CIV/086 requires that, 'so far as is reasonably practicable' the following should apply to neighbouring earthworks where 'there is evidence or concern that the failure of the earthwork presents an unacceptable risk to the safe operation or performance of the railway':

- the management policy for outside party earthworks shall be obtained and reviewed;
- the earthwork shall be subject to examination [by Network Rail] if the owner is unable to demonstrate that it is being managed in a satisfactory manner;
- the owner of the earthwork shall be advised of defects identified or known to Network Rail; and
- where necessary, 'action shall be taken so that there is no unacceptable risk to the safe operation or performance of railway infrastructure'.

120 There was no review of the landowner's land management strategy for the slopes above the accident sites at Loch Treig, Falls of Cruachan or Bargoed. All these slopes had the potential to adversely affect railway safety and thus met the criteria which should trigger a review. However, for reasons given in paragraphs 20, 35 and 71, RAIB does not believe that a review was likely to have prevented any of the accidents.

121 Witness evidence shows that neighbours' land management strategy is not routinely reviewed as part of Network Rail's earthwork management process. A senior Network Rail geotechnical engineer has stated that it would be impractical to implement this process for all slopes with the potential to adversely affect railway safety. RAIB considers that a review of neighbour's land management strategy is not necessary if the likely level of risk can be established either from a visual inspection of the slope by a railway industry geotechnical specialist or by an alternative means (Recommendation 1).

Gathering intelligence concerning neighbouring land

122 Network Rail has used aerial photography in the past to recognise risks outside the railway boundary in Scotland. Computers were used to process large amounts of topographic data as part of Network Rail's '*washout and earthflow risk mapping*' (WERM) process which identified areas where ground topography concentrates surface water flows at particular locations along the railway. Network Rail has stated that it is involved with a research project investigating the use of satellite images to provide information about earthworks.

123 These activities show that aerial sensing and computer analysis provide opportunities for Network Rail to obtain a better understanding of landslip-related risk originating outside the railway boundary. RAIB notes that both aerial sensing and computer capabilities are improving as new technology becomes available. It is possible that developments of this type could assist Network Rail to identify those slopes where management of neighbouring land is of particular concern and further action, possibly including reviewing the owner's land management strategy, is necessary (Recommendation 1).

124 Although developments in aerial sensing and computer aided analysis have the potential to improve railway safety, RAIB does not expect that they will provide a means to prevent all landslip-related risk from neighbouring land. For example, it is impractical for Network Rail to continuously monitor drainage arrangements on neighbouring land so as to avoid inadequate drainage triggering landslips as occurred at Falls of Cruachan (paragraph 27).

Operational risk management

125 **It is possible that improved operational risk management could have prevented trains hitting the landslips, or reduced the speed of collision with debris, at Loch Treig, St Bees and Bargoed.**

126 The use of operational measures to manage landslip risk is considered in three components:

- identifying 'at risk' earthworks;
- recognising when special precautions are required; and
- implementing appropriate measures.

127 Network Rail began modifying its approach to managing landslip risk using operational measures in December 2012. These modifications were triggered by Improvement Notices issued by the Office of Rail Regulation. All accidents described in this report took place at locations where the old arrangements were in use when the accident occurred. Network Rail has reported that roll out of the new arrangements across their entire network was completed on 28 February 2014. The new arrangements are not yet reflected in formal Network Rail documentation.

Identifying 'at risk' earthworks

128 The old arrangements are given in Network Rail standard NR/L3/TRK/1010 'Management of responses to extreme weather conditions at structures, earthworks and other key locations' (issued 28 August 2008). This requires geotechnical staff to prepare a register of earthworks 'at risk' due to heavy rainfall (the 'at risk' register). The criteria used to determine whether an earthwork is 'at risk' are given in Network Rail standard NR/L2/CIV/086 and include consideration of earthworks outside the railway boundary and risk arising outside the railway boundary.

129 Under these old arrangements, the 'at risk' registers contained sites with a known history of instability together with some sites added based on individual's professional judgement. There was no guidance about the risk level justifying inclusion in the register, no formalised process for considering the consequence of a landslip and no formalised process for considering any effects from land outside the railway boundary.

130 The need to consider consequence is illustrated by the accidents at Loch Treig, Falls of Cruachan, St Bees and Bargoed. In all these locations a derailment could lead to a train falling a significant distance down a steep slope (although, among the accidents described in this report, Loch Treig was the only accident where this actually occurred). However, a derailment near Falls of Cruachan in 2010 resulted in a carriage beginning to fall down a slope towards a road and a loch before it was restrained by trees (RAIB report 11/2011).

131 The new arrangements (paragraph 127) include a structured approach to the identification of earthworks to be included on the 'at risk' register. This considers both the likelihood of an earthwork failure and the potential consequence. It compares sites and identifies the highest risk sites using a methodology developed using a combination of professional judgement and a review of historic events.

132 The methodology assesses likelihood of failure taking account of historic instability and indicators suggesting possible future instability. These indicators include earthwork category and the status of any slope drainage recorded during the examination process (paragraph 106). The methodology for assessing likelihood also takes account of any water concentration features identified by the WERM process (paragraph 122). Consequence is assessed by taking account of adverse physical features (a steep drop from the track, proximity to tunnel entrance, etc.) and the amount of rail traffic.

133 Details of the criteria for inclusion on the new 'at risk' register are not yet included in formalised Network Rail documents, so RAIB cannot establish whether these will include the prompt updating of the 'at risk' register in response to significant warning indicators, such as the landslip at Bargoed six months before the accident (paragraph 69).

134 The methodology used to assess the likelihood of a landslip is compatible with good practice among other infrastructure owners as described in the Construction Industry Research Association reports ‘Infrastructure embankments - condition appraisal and remedial treatment’ (report C592) and ‘Infrastructure cuttings - condition appraisal and remedial treatment’ (report C591D). However, the methodology used to assess a particular earthwork is heavily reliant on evidence gained from historic performance of this earthwork and comparison of this earthwork with similar earthworks on the network. As a consequence the ‘at risk’ register will not necessarily identify sites (possibly including sites similar to Rosyth[18]) where an earthwork:

- encounters particularly extreme weather conditions which occur only very rarely; and/or
- shows few, or no, risk factors but is susceptible to relatively small changes in external circumstances (eg small changes in surface or sub-surface drainage conditions).

Timing of mitigation

135 The strong likelihood that any landslips will be triggered by rainfall means that operational mitigation of landslip risks is implemented during, and shortly after, periods of heavy rainfall.

136 The old arrangements are set out in National Control Instructions and the Network Rail standard ‘Weather – managing the operational risk’ (NR/L3/OCS/043/7.1 and NR/L2/OCS/021). These required a meeting (usually a teleconference) of relevant managers and implementation of operational mitigation at earthworks on the ‘at risk’ register if more than 25 mm of rainfall was forecast during a 24 hour period in lowland areas or more than 40 mm was forecast for upland areas.

137 The old arrangements relied on forecasts prepared daily for Network Rail by a specialist meteorological organisation at around 03:00 hrs and applicable for a 24 hour period commencing at 06:00 hrs. If forecast conditions changed significantly, an updated forecast was issued. The trigger values took no account of rainfall intensity within the 24 hour period and no account of ground saturation caused by earlier rainfall. The process did not incorporate real-time information from rain gauges and there was no pro-active process for seeking real-time information from other sources.

138 New mitigation measures (described in paragraph 143) were originally implemented in response to amber and red national severe weather warnings issued by a specialist meteorological organisation. This organisation states that an amber warning indicates a need to be prepared and a red warning indicates a need to take action. The warning status is updated every six hours, or more frequently if the forecast changes significantly. In respect of rainfall, the status takes account of total rainfall expected during the next 24 hour period, the anticipated rainfall intensity and the extent to which ground is already saturated. The trigger values for amber and red warnings reflect conditions which are likely to affect a range of infrastructure and vary across Great Britain to take account of normal climate variation. Network Rail is currently developing trigger criteria which reflect the particular characteristics of railway infrastructure.

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[18] Network Rail has stated that the Rosyth accident earthwork would not have been categorised as ‘at risk’ if the new arrangements had been in place before the accident occurred.

139 In addition to weather forecasts, the new arrangements will use rainfall data from automatic gauges being installed by Network Rail. At present, Network Rail is commissioning 99 of these gauges in Scotland and intends to expand the network into England and Wales at a later date. Network Rail has stated that it is still developing the process for incorporating rainfall data into its mitigation strategy. It already intends to use data from the gauges when heavy rain is forecast. RAIB notes that rain gauges could also provide a warning of heavy rain when this has not been forecast (Recommendation 1).

140 As weather forecasting is not always accurate and some rainfall events are localised, some extreme rainfall events may be neither correctly forecast nor occur at locations where rain gauges are providing real-time data to Network Rail. However, events of this nature are likely to cause substantial flooding and disruption to non-railway infrastructure and this was evidenced by the local disruption found by RAIB when attending the St Bees accident. Rapid acquisition of information about such events would allow the railway industry to take appropriate precautionary action (Recommendation 3).

Mitigation

141 The old arrangements for mitigating landslip risk at earthworks are given in Section 7.3 of Network Rail standard NR/L3/TRK/1010. This required a competent person to observe each earthwork on the ‘at risk’ register and to take appropriate measures (eg stopping trains) if there was evidence of ground movement or other indicators of a potential landslip. This approach meant that the number of earthworks which could be observed was sometimes limited by the availability of staff. It also meant that the observers were asked to work alone in potentially hazardous and physically demanding conditions.

142 The risk to an individual train increases if there has been a relatively long period since the previous train passed the site, a situation which often applies to the first train of the day. The risk is increased in these circumstances because there is a longer ‘time window’ for an event to occur and because there is less likelihood of someone seeing any warnings of impending danger (eg water flowing across the track or soil beginning to move down a slope). The risk is further increased if the first train operates before dawn or on other occasions when visibility is reduced. The accidents at Bargoed and St Bees both involved the first train of the day. The old arrangements made no explicit provision for the first train of the day or for other circumstances when there is a long period between trains.

143 The new arrangements (paragraph 127), as first developed for the Scotland route, require a person to observe ‘at risk’ earthworks at intervals not exceeding 2 hours during red weather warnings and not more than 4 hours during amber weather warnings. In daylight, the observations are normally carried out from the cab of a train travelling at no more than 60 mph (96 km/h). During darkness and other periods of poor visibility, the inspection of ‘at risk’ earthworks should be carried out by a person who visits at appropriate intervals (thus some risk to staff safety remains). If observations are not continued through the night and there is no inspection before the first morning train, the new process requires that this train must travel at caution (a speed allowing the train to be stopped safely if the driver sees an obstruction on the track). If observation of earthworks is impractical due to lack of resources, the new process permits risk mitigation by limiting train speeds or suspending train services in selected areas.

144 The underlying principles for the new arrangements apply throughout Network Rail infrastructure although the detailed arrangements differ to reflect both the varying technical challenges and the availability of differing resources.

145 In addition to special measures implemented at selected locations during and immediately after periods of heavy rainfall, mitigation against landslip risk is also provided by continuous ground movement monitoring at other locations which are considered to have a high landslip risk. This can be permanent monitoring (eg monitoring cliff stability at Folkestone, Kent) or temporary installations where permanent slope stabilisation is required but has not yet been implemented. The technology available for monitoring ground movements (sometimes by verifying that the railway is unobstructed) is continually advancing. Network Rail reports that it reviews the opportunities offered by improved technology and, where considered appropriate, implements trial and permanent installations. This type of technology offers the opportunity to mitigate risks due to ground instability triggered by events on land neighbouring the railway (Recommendation 1).

146 The new arrangements will not eliminate all risk to trains except when all services are suspended. For example, observation from a train cab (paragraph 143) is unlikely to identify a sudden event, such as a falling boulder, in time to prevent an accident. Some mitigations, such as temporarily limiting all train services to 40 mph (64 km/h), would not necessarily prevent a train hitting a landslip but could reduce the severity of the resulting accident and would be equally effective for events which occur with and without warning.

147 Although a temporary speed limit of 40 mph (64 km/h) could provide significant benefit for ‘at risk’ earthworks on relatively high speed lines, it would have had no effect on events described in this report except at St Bees where the train was travelling at 49 mph (78 km/h) when it hit the first landslip. The train at Rosyth was travelling at 55 mph (88 km/h) but the 40 mph (64 km/h) speed limit would not have been applied because the earthwork would not have been classified as ‘at risk’ (paragraph 134).

148 The new arrangement does not indicate that additional measures could be required if very large amounts of rainfall or very intense rainfall cause conditions which are significantly worse than those normally associated with a red warning. It is possible that the St Bees accident lies in this category. Witness evidence shows that, at least in respect of the unusual winds experienced on 28 October and 5 December 2013, Network Rail does implement precautions beyond those explicitly stated in its formal documentation. Similarly, the response of Network Rail to the very large amounts of rainfall in late 2013 and early 2014 indicates an appreciation that standard precautions are not necessarily adequate in all conditions (Recommendation 5).

Summary of key issues and conclusions

149 Network Rail acknowledges that risk to the railway can arise from earthworks and drainage on neighbouring land, and its processes require that it gives consideration to these risks. These arrangements are currently being updated (paragraph 127). This investigation has identified six issues which will remain after the implementation of the new arrangements:

- earthwork examiners cannot always see all relevant features beyond the fence line (paragraph 105, **Recommendation 1**);
- Network Rail formal processes can result in Network Rail's geotechnical staff being unaware that earthwork examinations have identified loose boulders or some other issues of concern if the earthwork has been categorised as marginal or serviceable by the algorithm used for earthwork categorisation (paragraph 109, **Recommendation 2**);
- Network Rail processes do not provide a robust means of identifying activities on neighbouring land which could increase railway risk between routine examinations (paragraph 118, **Recommendation 1**);
- Network Rail staff do not routinely review the land management strategy applicable to neighbouring land as required by current Network Rail standards (paragraph 121, **Recommendation 1**);
- some very severe rainfall events are neither forecast nor detected by real-time rainfall monitoring (paragraph 140, **Recommendation 3**); and
- there is no explicit provision for earthworks which could become unstable due to rainfall events significantly worse than those normally associated with a red warning (paragraph 148, **Recommendation 5**).

150 It is uncertain whether the new arrangements described in paragraph 127 will include prompt application of mitigation when the failure of an earthwork or other unexpected circumstances reveals a significant, previously unrecognised risk (paragraph 73, **Recommendation 4**).

151 Aerial sensing and computer aided analysis offer possible means for Network Rail to acquire an improved understanding of earthwork related risks arising from neighbouring land (paragraph 123, **Recommendation 1**).

152 Real time monitoring of rainfall provides a means to warn Network Rail that heavy rainfall is occurring in areas where it has not been forecast (paragraph 139, **Recommendation 1**).

153 Improving technology offers the potential for mitigating risks due to ground instability triggered by events on neighbouring land (paragraph 145, **Recommendation 1**).

154 Network Rail's process for identifying adverse weather conditions relevant to earthworks is being modified to take account of rainfall intensity and ground saturation in addition to considering the total rainfall expected in a 24 hour period (paragraph 138).

Previous RAIB recommendations

155 Previous RAIB reports, detailed in appendix D, have included earthwork-related recommendations targeted primarily at earthworks within the railway boundary, and thus mainly covering areas outside the scope of this report. These recommendations have covered the following issues:

- effective examination process
- effective management of earthworks
- effective drainage; and
- responses to adverse weather.

156 RAIB has made some previous recommendations related to the identification of earthwork and drainage risk on neighbouring land. These include some of the recommendations arising from investigations into derailments at Oubeck North (RAIB Report 19/2006) and Gillingham (19/2010) and covering:

- identification of earthworks prone to failure due to drainage flows from neighbouring property (Oubeck North recommendation 2 and Gillingham recommendation 1);
- Network Rail maintenance actions needed to ensure continued functionality of drainage (Oubeck North recommendation 2 and Gillingham recommendation 1); and
- proper allowance to be made in risk assessments for any lack of accessibility to earthworks and drainage, or inadequate information (Oubeck North recommendation 3).

157 The previous RAIB class investigation into management of earthworks (25/2008) also includes recommendations relating to earthwork and drainage risk on neighbouring land, and covering the following issues:

- routine inspection and reporting of '*off-track*' issues, including drainage issues on neighbouring land (recommendations 1 and 6); and
- guidance to staff on the management of risk associated with neighbouring land (recommendation 3).

158 The Office of Rail Regulation has reported that a number of actions have been taken by Network Rail to address the areas of risk identified in the above recommendations. These recommendations were then subject to further review in connection with the Office of Rail Regulation's inspection project, 'Management of Earthworks 2011/12'. The actions reported to date include:

- Network Rail has issued a new company standard for drainage. This defines Network Rail's requirements for design, installation, inspection and maintenance of drainage systems as well as guidance on identifying and managing the associated risks (including the risk of factors beyond the boundary).
- A major drainage survey has been carried out to build a comprehensive drainage asset list.

- Clarification has been provided on the identification and reporting by track maintenance staff of track defects such as debris falls and areas liable to subsidence.
- Updated standards have been issued that require the review of neighbouring land management policies for all slopes where there is evidence or concern about the safe operation of the railway, and visual examination of slopes on neighbouring land by earthworks examiners (from inside the railway boundary).
- Development of a model for predicting water flows in proximity to the railway (as a tool for identifying areas of risk).

159 RAIB observes that although Network Rail has made progress in introducing processes to manage risk on neighbouring land, it has still to implement a way of reliably identifying, where reasonably practicable, emerging risks (eg spoil tip construction) that occur on neighbouring land between formal earthworks examinations. It has also expressed the view that, while track maintenance staff are required to report obvious 'off-track' issues, it does not wish to distract such staff from their core activity of spotting track defects by requiring them to actively look for earthwork risks on neighbouring land.

160 Given the need to detect, where reasonably practicable, precursors of earthwork failure and emerging problems on neighbouring land, and the potential to exploit new technology, RAIB is recommending that Network Rail looks again at its methods of identifying and managing risk on neighbouring land (Recommendation 1).

161 Specific issues relating to previous recommendations are discussed in paragraphs 162 to 167. RAIB does not intend that implementation of Recommendation 1 should be limited to dealing with these specific issues.

162 The RAIB investigated a previous accident which occurred at Falls of Cruachan on 6 June 2010, about 1.5 km from the accident site described in this report. The previous investigation identified that, in some instances, earthwork management was based on the marginal or serviceable categorisations provided by the SSHI/RSHI algorithms (paragraph 106) without consideration of an examiner's professional judgement that the slope should be managed as a poor earthwork. Recommendation 3 of the previous report stated:

Network Rail should amend its earthworks management system so that...:

- *where examiners and examining engineers disagree with the SSHI and/or RSHI condition ratings, their judgement of the slope condition rating should be recorded on the examination report and taken into account when deciding how to manage the earthwork.*

163 The Office of Rail Regulation has reported that the recommendation has been implemented. Network Rail's June 2011 update of NR/L2/CIV/086 added a requirement for examiners to report apparently incorrect condition ratings by including appropriate words in the comments section of the examination report. However, this investigation has found that the Network Rail geotechnical staff who are expected to respond to these comments are not always aware of them as, for reasons explained in paragraph 110, the Network Rail staff do not review all relevant reports (Recommendation 2).

164 RAIB investigated an accident near Moy, Inverness-shire, in which a train was derailed by a landslip on 26 November 2005. The landslip was probably triggered by water flowing from adjacent land outside the railway boundary (RAIB Report 22/2006). Recommendation 3 of this investigation stated:

Network Rail should review its procedures to address the issues identified below and implement the resulting changes to its operations:

a) water infiltration risks on land adjacent and above cutting slopes. Ensure that these risks, which will include issues such as areas of permeable and semi-permeable land on which surface run-off could collect, are identified and managed (paragraph 278)...

f) the lack of guidance in classifying earthworks for inclusion in the 'at risk' list for adverse or extreme weather warnings. The guidance should, on a regular basis, import the latest knowledge from the earthworks management process into the 'at risk' classification process. The guidance should also enforce regular review and update of the 'at risk' list. Appropriate consideration should be given to earthworks, which are prone to failure due to water infiltration during intense rainstorms (paragraph 250).

165 The Office of Rail Regulation reported to RAIB in September 2008 that this recommendation had been implemented.

166 Network Rail standard NR/L2/CIV/086 deals with issues relating to neighbouring land and was updated after publication of the Moy recommendation. The previous version (RT/CE/S/086, issue 1, June 2005) required investigation of slope failures on neighbouring land and, where these posed a significant risk to the railway, a requirement for Network Rail to manage the risk subject to legal constraints and to seek co-operation from the landowner. The updated version (NR/L2/CIV/086, issue 2, September 2009) required Network Rail to seek and review neighbouring land management policy for all slopes where there was evidence or concern about safe operation of the railway. A similar requirement, quoted in paragraph 119, appears in the current version of NR/L2/CIV/086 (issue 3, September 2011). Although the update reflected part *a)* of the recommendation, witness evidence shows that the requirement to obtain and review neighbours' land management policy is not being consistently applied to individual earthworks (paragraph 121, Recommendation 1).

167 Network Rail standard NR/L2/CIV/086 (September 2011) requires the management strategy for an earthwork to be reviewed in circumstances which include 'following a special examination', 'following a geotechnical assessment' and 'when works are proposed' (section 8.1.2). The July 2012 earthwork failure at Bargoed met these criteria. Although RAIB considers that the review should have led to the rapid inclusion of the site on the 'at risk' register, the site was not added to the register before the January 2013 accident. Section 8.4.3 of NR/L2/CIV/086 requires (in the context of a situation such as that at Bargoed) the 'at risk' register to be updated at least annually and following severe floods. RAIB considers that neither the time interval specified, nor the event type specified, was sufficient to deal with situations requiring rapid action. In this respect, the Network Rail process did not meet the intent of part f) of the Moy recommendation (Recommendation 5).

Recommendations

168 The following recommendations are made[19]:

1 *The intent of this recommendation is that Network Rail revises its processes for managing earthwork and drainage risk associated with neighbouring land so that the processes are accurately documented, proportionate, reflect practical limitations and take account of benefits offered by new technology such as aerial sensing and the use of computers to process large amounts of data.*

Network Rail should review and improve its processes for managing earthworks related risk arising from neighbouring land, including associated drainage issues. This should provide a documented process which takes account of the extent to which it is practical and proportionate for Network Rail to review and/or rely on land management activities undertaken by neighbours.

The new process should, where reasonably practicable:

- obtain relevant information from other sources where it cannot be collected by earthwork examiners (eg where examiners are unable to view areas due to access constraints, fences, etc);
- take advantage of opportunities offered by current technology to assess areas at risk from ground movement and areas where ground movements are occurring;
- provide a robust process for identifying, and responding appropriately, to activities on neighbouring land which have the potential to significantly increase risk to the railway between routine earthwork examinations; and
- take advantage of opportunities offered by real-time rainfall monitoring to issue alerts identifying heavy rainfall when this has not been forecast.

continued

[19] 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.

2 *The intent of this recommendation is to ensure that Network Rail takes account of all safety related information contained in reports for slopes that have been categorised as marginal or serviceable by the SSHI and RSHI algorithms (ie reports which, at present, are not necessarily reviewed by Network Rail's geotechnical staff).*

Network Rail should review and improve its processes so that due consideration is given to all safety related information provided by earthwork examiners and earthwork engineers, including safety related information associated with slopes categorised as marginal or serviceable by the SSHI and RSHI algorithms.

3 *The intent of this recommendation is to increase the likelihood that appropriate Network Rail staff are aware of landslip risk due to adverse rainfall conditions which have not been forecast or detected by Network Rail's formal rainfall monitoring processes.*

Network Rail should implement a process for real-time collection (and appropriate use of) intelligence about very unusual rainfall or flooding conditions. Development of this process should take into account the differing risk levels on different parts of the infrastructure and should consider using the following information sources:

- emergency service control centres;
- other organisations involved in the provision and management of rail and non-rail transport;
- reports (encouraged by appropriate railway industry publicity) from on-duty and off-duty railway industry staff including those employed by train operating and maintenance companies; and
- rain gauge and other types of weather sensor capable of providing data in real time.

4 *The intent of this recommendation is for Network Rail to formalise the processes already being developed and introduced with the intent of improving management of earthworks during adverse weather, and for these processes to include timely updating of the 'at risk' register.*

Network Rail should complete initial development of its modified adverse weather earthwork management system. It should then alter its standards and, if necessary, other formal documentation to reflect the modified system. The updated documentation should include a process for the rapid updating of the 'at risk' register when significant risks become apparent.

continued

5 *The intent of this recommendation is for Network Rail to formalise the process for dealing with the rare circumstances when the mitigation normally provided in response to a red warning would be inadequate. This requires consideration of additional mitigation for locations on the 'at risk' register and consideration of mitigation for locations which are not normally considered to be at risk during extreme weather conditions.*

Network Rail should formalise the process for implementing additional mitigation if very extreme rainfall conditions mean that the mitigation normally provided in response to a red warning is inadequate for earthworks on the 'at risk' register and/or there is a significant likelihood of landslips at locations not included on this register.

Appendices

Appendix A - Glossary of abbreviations and acronyms

RAIB	Rail Accident Investigation Branch
RSHI	Rock slope hazard index
SSHI	Soil slope hazard index
WERM	Washout and earthflow risk mapping

Appendix B - Glossary of terms

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

Algorithm (SSHI & RSHI)	A process for obtaining a SSHI or RSHI by combining scores relating to individual slope characteristics.
'At risk' (for earthworks)	An earthwork considered to be at risk of failure during adverse weather conditions.
'At risk' register (for earthworks)	Listing of earthworks considered to be 'at risk'.
Bogie	An assembly of wheels (usually four wheels) on a frame pivoted beneath the coach.
Chain	22 yards (approximately 20 metres).
Culvert	A structure, sometimes comprising a pipe, that allows water to flow under a railway, road or similar obstruction.
Cutting	An excavation that allows railways lines to pass at an acceptable level and gradient through the surrounding ground.
Earthwork	Man-made cuttings, man-made embankments and natural slopes.
Earthwork examiner	Person competent to collect information relating to the condition of an earthwork.
Earthwork engineer	Person competent to review information relating to the condition of an earthwork.
Emergency brake (application)	The (abnormal) full application of all available braking effort, sometimes using a more direct and separate part of the control system than used for a service brake application.*
Evaluation (of earthwork)	An appraisal of information regarding the stability, condition, use and location of an earthwork to determine the actions required to maintain acceptable levels of safety and performance.
Examination (of earthwork)	A visual inspection of an earthwork undertaken to identify and record signs of slope instability.
Marginal (slope condition rating)	Part of Network Rail system which categorises slopes as poor, marginal or serviceable.
Natural slope	Sloping ground that has been formed by natural processes.
Old military roads	A network of roads constructed in Scotland by the British government during the eighteenth century.
Off-track	Areas which are neither part of, nor close to, the track.
Outside party	A term used by Network Rail to describe a neighbour or other party whose activities do, or may, affect railway operation.

Poor (slope condition rating)	Part of Network Rail system which categorises slopes as poor, marginal or serviceable.
Rainfall intensity	The amount of rain falling within a given time period.
Rain gauge	A device for measuring the amount of rain falling at a given location, usually operated to determine the amount of rain falling in given time periods.
Rock slope hazard index	A score reflecting the potential for a rock slope to fail and cause harm.
Serviceable (slope condition category)	Part of Network Rail system which categorises slopes as poor, marginal or serviceable.
Site of special scientific interest	Area of land classified by the relevant government body as of special interest by reason of its wildlife (habitats and species) or geology.
Service brake (application)	The normal application of the brakes on a train producing a comfortable deceleration.*
Soil slope hazard index	A score reflecting the potential for a soil slope to fail and cause harm.
Washout and earthflow risk mapping	A computerised process for identifying parts of the railway at particular risk due to concentrated flows of water from neighbouring land.
Weather radar	A device which sends out electromagnetic pulses to measure the location and intensity of precipitation (rain, hail and snow) in real time.

Appendix C - Network Rail standards referenced in this report

NR/L2/CIV/086	Management of earthworks
NR/L2/OCS/021	Weather – managing the operational risk
NR/L3/CIV/065	Examination of earthworks
NR/L3/OCS/043/7.1	National control instructions
NR/SP/TRK/001	Inspection and maintenance of permanent way
NR/L3/TRK/1010	Management of responses to extreme weather conditions at structures, earthworks and other key locations
RT/CE/P/044	Managing structures works

Appendix D - Previous recommendations

RAIB reports dealing with the specific events listed below, and the previous RAIB class investigation into management of earthworks, include recommendations targeted primarily at the management of earthworks within the railway boundary. The recommendations have covered the following issues:

Effective examination process

- Moy, RAIB Report 22/2006, recommendations 6 and 7;
- Hooley cutting, RAIB Report 5/2008, recommendation 7;
- Management of existing earthworks, RAIB Report 25/2008, recommendation 6;
- Gillingham, RAIB Report 22/2010, recommendations 2, 3 and 5;
- Falls of Cruachan (June 2010 accident), RAIB Report 11/2011, recommendations 1,2 and 3;
- Dryclough Junction, RAIB Report 17/2011, recommendation 5.

Effective management of earthworks

- Moy, recommendation 7;
- Oubeck North, RAIB Report 19/2006, recommendations 2 and 3;
- Hooley cutting, recommendations 3, 4 and 6;
- Management of existing earthworks, recommendations 1 and 5;
- Gillingham, recommendation 4;
- Falls of Cruachan (2010), recommendations 4 and 5.

Effective drainage

- Moy, recommendation 1;
- Oubeck North, recommendation 1;
- Gillingham, recommendation 1.

Adverse weather response

- Management of existing earthworks, recommendation 4.

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