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Earthworks risk assessment on a heritage railway

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The UK is home to a substantial number of heritage and tourist railways, which make a significant contribution to their local economies. They are mostly constructed on the routes of closed lines, and include large numbers of earthworks of uncertain construction and unknown strength. Recently, there have been earthwork collapses, most notably on the Gloucester and Warwickshire Railway during 2010 and 2011. The Office of Rail Regulation has also noted a number of safety incidents on heritage railways, all attributable to management failures. This paper describes an analysis of the Victorian earthworks on the Bo'ness and Kinneil Railway, a 8 km-long heritage railway in central Scotland. The analysis and risk prioritisation method used by Network Rail was found to be unsuitable for direct application to heritage railways, owing to the different operating context. A new system was therefore developed, removing some risk factors from the Network Rail approach, adding others, and modifying further ones. The new system was successfully applied, and the Bo'ness and Kinneil Railway earthworks were found to be generally stable and safe.

1. Introduction: safety risks on UK heritage railways

In times when there is much talk of high-speed rail, it is worth considering that the UK is home to a significant industry based on low-speed rail – the heritage and tourist sector. There are currently over 100 heritage railways (HRs), employing 2000 paid staff and 18 000 volunteers, carrying 6·8 million passengers on 15 million passenger journeys, turning over £84 million, and contributing an estimated £579 million to the UK economy (Lord Faulkner, 2011).

Being passenger-carrying railways, HRs are subject to exactly the same requirements for safety as any other passenger railway, although they are generally restricted to speeds of 25 miles/h (40 km/h) or less. Although they have much lower annual tonnages of traffic than the mainline system, they use historic steam and diesel locomotives, and consequently their axle loads can be relatively high, typically of the order of 25 t. In most cases, HRs occupy trackbeds formerly part of the national rail network, often branch lines closed in the 'Beeching Cuts' – the substantial reduction of the UK rail network carried out while Dr Richard Beeching was chairman of British Rail in the 1960s (British Railways Board, 1963a, 1963b). In common with the rest of the UK network, their infrastructure often dates from a time when there was relatively little theoretical understanding, design or quality control, and typically no records exist either of construction or of maintenance. Further, although HRs sometimes rely on a core of paid employees, they are generally staffed by volunteer enthusiasts who come from a wide range of backgrounds, and in many cases do not have either long experience or formal technical qualifications.

The UK HR sector has a good record of safety. From 1951 to 2010 there was a year-on-year reduction in safety incidents. However, over the two years after that there was a significant reversal, with reportable incidents on over 20 railways, some staff fatalities and eight Office of Rail Regulation (ORR) enforcement notices, all of which are traceable to failings in the management structure of HRs (Keay, 2012). The ORR regards this as so serious that special seminars were arranged by way of the Heritage Railway Association in an attempt to prevent further accidents.

There have also been notable failures of earthworks. The Severn Valley Railway (SVR) was subject to a series of major earthwork failures following abnormally high rainfall events in June and July 2007, costing £3·7 million to repair (Sowden, 2012), and the Gloucester and Warwickshire Railway (G&WR), which occupies a 16 km former British Railways (BR) route between Toddington and Cheltenham Racecourse in central England, experienced two severe slips, at Gotherington in April 2010 and at Chicken Curve near Winchcombe in early 2011. Both slips occurred in embankments where drainage was an issue, and which had given trouble and required ongoing maintenance in BR days and before (see http://www.gwst.com). Fortunately, neither the SVR nor the G&WR incident led to loss of life.

2. The Bo'ness and Kinneil Railway

The Bo'ness and Kinneil Railway (B&KR) (see http://www.bkrailway.co.uk) is a 8 km HR running from Bo'ness to a junction with the Network Rail (NR) Edinburgh and Glasgow mainline. The HR was opened in stages from the early 1980s, but occupies the line of the Slammanan and Borrowstounness (Bo'ness) Railway opened in 1851. A map showing the location of the railway is included as Figure 1.

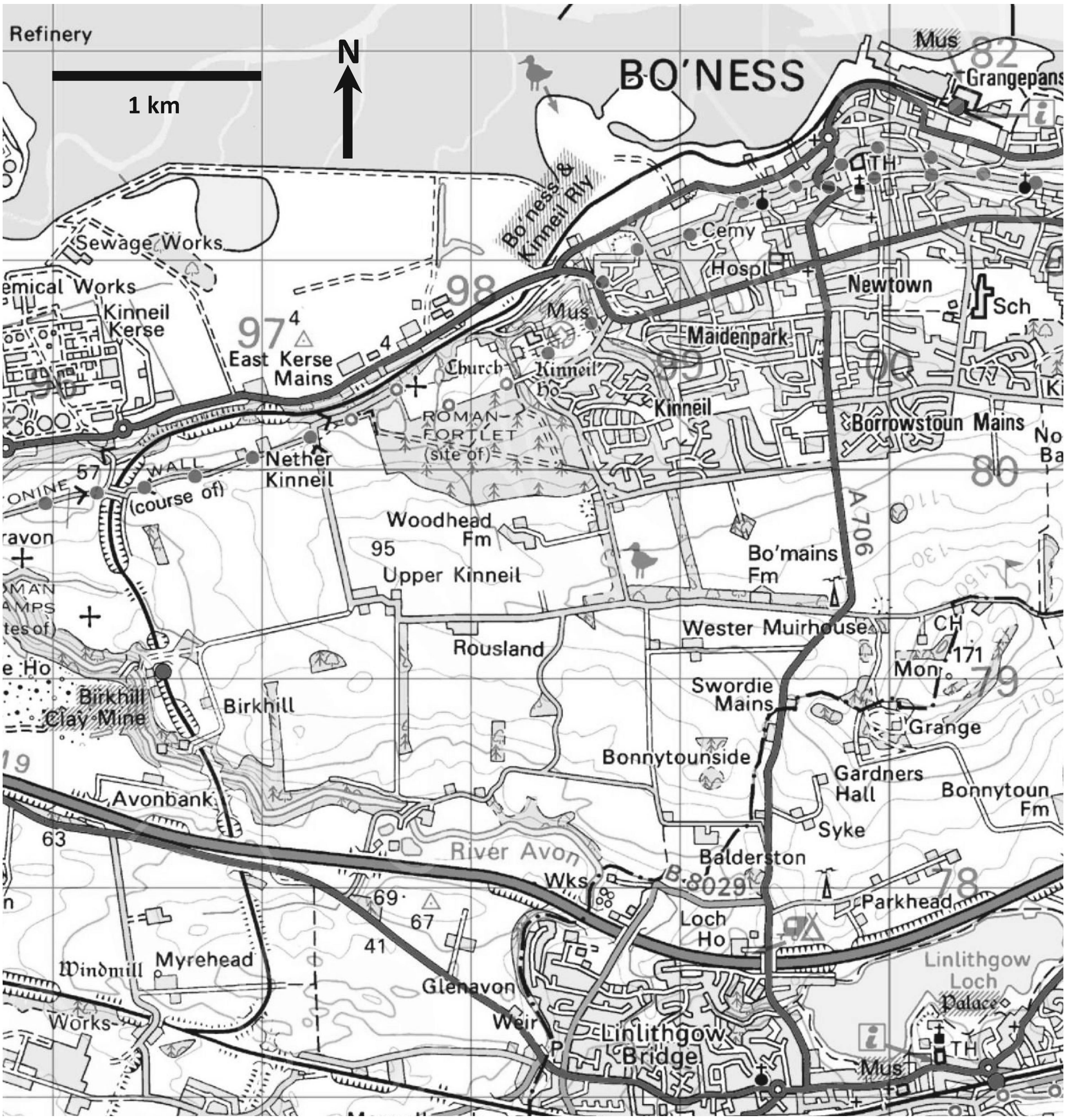

Figure 1. Map of the Bo'ness and Kinneil Railway. © Crown Copyright/database right 2013. An Ordnance Survey/EDINA supplied service

For 2·4 km of its length, the line occupies the side of a steep escarpment close to the Forth Estuary between Bo'ness and Grangemouth, with the track supported on the north side by steep earth embankments, typically 15 m high, and cut on the south side by soil and in some places rock slopes up to 10 m high (Figure 2). Thereafter the line turns south, passing through some moderately deep cuttings and over two further sections of embankment before reaching the mainline junction at Manuel.

All the earth and rock structures have been subject to somewhat irregular, but reasonably frequent, inspections by independent competent persons (i.e. qualified permanent way/engineering staff not having a direct interest in the railway), including in March 2010 and May 2011, and are considered safe. However, they are almost all heavily vegetated, occasionally subject to animal burrowing and are generally wet. No details of their construction or historic maintenance survive, although there is evidence of past failure due to washout in places, and at one point the installation of a pipeline has led to a reconstruction. It cannot therefore be claimed that they represent a zero risk.

Any failure of the B&KR earthworks, in addition to putting passengers and railway staff at risk, would have a very serious impact on business: apart from the heritage passenger trains, access is required to the mainline junction for movements of rail tour coaching stock, which brings in considerable revenue to the line's owners.

In view of this, and bearing in mind the events described at the SVR and G&WR, together with the ORR's concerns with management structures for safety, it has been determined that a proper risk-based assessment procedure is appropriate for the B&KR earthworks. The assessment procedure has to be commensurate with the HR operation, be based on HR safety and business priorities and bear in mind the volunteer staff who will operate it, and the low speed, low traffic and low resource availability context of the B&KR and HR sector in general.

Figure 2. The Bo'ness and Kinneil Railway, showing typical cutting and embankment structure

The aim of this study was therefore to develop a risk assessment procedure for earthworks that is applicable to the HR sector, bearing its nature in mind, and to apply this to the B&KR and use it to determine any monitoring or remedial actions necessary.

3. Previous work on earthworks risk assessment

3.1 The Bo'ness and Kinneil Railway

Recent inspection reports by independent competent persons have noted that the B&KR earthworks 'appear generally stable', while noting the presence of mature slips and other minor issues (Watson, 2010, 2011). There is, however, currently no prioritisation of inspection or maintenance activity on the B&KR, and previous interventions have been largely reactive to incidents or perceived problems.

3.2 Network Rail

NR employs a risk-based approach to the prioritisation of earthworks. This is a two-stage process, commencing with an analysis and scoring of the geotechnical hazard of various types of failure. These geotechnical hazard scores are then converted to a 'likelihood of failure' score, and used in a prioritisation algorithm that combines it with various potential consequences of failure. The process is explained in more detail in the following paragraphs.

3.3 Geotechnical hazard

For earth slopes, NR uses the Soil Slope Hazard Index (SSHI) (Manley and Harding, 2003). The entire network is divided into 5 chain (approximately 100 m) lengths, and each side of the railway is considered separately. A site inspection is carried out by a trained operative, who examines over 30 separate parameters covering earthwork type, size and shape, vegetation and drainage, as well as indicators of ongoing or potential failure, such as tension cracks, angled trees, the presence of animal burrows, and other risk factors such as a history of track misalignment, past interventions or mining in the area. The values noted against the various factors are recorded using a Trimble™ hand-held computer with an inbuilt camera for photographing observations.

The observed parameters are then fed into an algorithm derived by Manley and Harding (2003) to determine the SSHI. This accounts for five principal mechanisms in which earthworks can fail – rotational, translational, earthflow, washout and burrowing – and scores each section inspected for each of these mechanisms. The highest geotechnical hazard score (i.e. the highest risk score) obtained is used to classify an individual 100 m length as either serviceable, marginal or poor for the failure mechanism to which the score corresponds.

For rock slopes, a related process is used to assess the stability of the rock, based on the Rail Rock Slope Risk Appraisal (RRSRA) (McMillan and Manley, 2003).

Poor slopes are then reinspected at least every 2 years, marginal slopes every 5 years and serviceable slopes every 10 years.

3.4 Prioritisation calculation

Having determined the numerical geotechnical hazard score, this is then fed into a more general prioritisation algorithm derived by (Mott MacDonald and Network Rail, 2006). This algorithm considers the likelihood and consequences of different potential failure mechanisms against four categories weighted for their relative significance, as shown in Table 1: safety, value for money, disruption and environment.

In addition to the geotechnical hazard, a variety of other factors contribute to these consequences, including track condition and the significance of temporary speed restrictions (TSRs), track layout (straight, curved or switches and crossings), geographical weather risk, past failures, route speed, potential delay costs and the availability of alternative routes. Some of these are assessed on site and some by means of a desk study, but all must be determined for each 5 chain length (approximately 100 m) of one side of the railway.

Each factor contributes to some or all of the various consequences based on a relative scoring scheme, developed through a wide-ranging consultation and testing exercise by Mott MacDonald and Network Rail (2006) (see Table 2). For example, in terms of the geotechnical failure mode, potential rockfall and washout failures count for 24 (high risk) against all four consequence categories, whereas burrowing and earthflow count for 13 and 11 respectively (lower risk). Cuttings are scored at 18, a greater risk than embankments at 14. On the other hand, route speed contributes

Consequence category	Definition	Weighting
Safety	The level of safety of the travelling public, NR staff or third parties	0·4
Value for money	The optimum combination of whole-life cost and quality	0·25
Disruption	The effect of disruption to the NR network, by delay minutes, adverse publicity, or other factors	0·25
Environment	A positive or detrimental effect on the environment	0·1

Table 1. Network Rail consequence categories (Mott MacDonald and Network Rail, 2006)

Category	Parameter	Safety	Value for money	Disruption	Environmental	Hazard options	Scoring
Geotechnical information	Earthwork type	×	×	×	×	Embankment	14
						Cutting	18
						Bund (i.e. not supporting track)	6
	Failure mode	×	×	×	×	Rockfall	24
						Rotation	19
						Translation	19
						Earthflow	11
						Washout	24
						Burrowing	13
						Subsidence/Settlement	16
	Predicted earthwork condition trend	×	×	×	×	No significant deterioration	0
						Gradual deterioration	4
						Rapid deterioration	6

Table 2. Network Rail prioritisation scoring (Mott MacDonald and Network Rail, 2006) (continued on next page)

Category	Parameter	Safety	Value for money	Disruption	Environmental	Hazard options	Scoring
Track condition	Track recording vehicle (TRV) data: current track condition	×		×		Green – good Yellow – satisfactory Blue – poor Red – very poor Cyan – super red	0 1 2 4 6
	TRV data: trends	×		×		No significant deterioration Gradual deterioration Rapid deterioration	0 2 4
	Risk of temporary speed restrictions	×	×	×		N/A Low risk Medium risk High risk	0 3 6 9
Track layout	Track layout	×		×		Straight track/flat curve Curve: high cant/cant deficiency S&C/tilting curve	2 4 5
Geographic weather risk	Geographic weather risk (including flooding potential)	×		×		Very high High Medium Low	7 6 4 2
Past failures	Past failures	×		×		No previous local failures or normalised delay minutes 0–60% Some known local failures or normalised delay minutes 60–90% Extensive local failures or normalised delay minutes 90–100%	3 5 7
Consequence potential	Route sensitivity		×	×		Very high: primary route High (London commuter routes and main secondary routes) Medium (secondary routes) Low (rural) Very low (freight)	8 7 5 3 1
	Impact on other assets	×	×	×	×	Track OHLE Power/telecom cables/signalling Signalling equipment NR structures Third-party structures	4 3 3 4 1 1

Table 2. (continued on next page)

Category	Parameter	Safety	Value for money	Disruption	Environmental	Hazard options	Scoring
	Route speed	×		×		0–79 miles/h[a] 80–99 miles/h 100–110 miles/h 111–125 miles/h	2 5 8 9
	Infrastructure flexibility		×	×		U/D (i.e. single bidirectional) UD UUDD UDUD	8 7 5 3
	Potential delay costs		×	×		High Medium Low	7 4 1
Legal requirements	Third-party liabilities/legal obligations		×	×	×	Very significant Significant Not significant	7 5 0
	Environmental obligations		×	×	×	Very significant Significant Not significant	4 3 0
Available mitigations	Drainage, vegetation, TSR, watchmen, track maintenance etc.	×	×	×	×	Feasible long-term: low cost Feasible long-term: high cost Feasible short-term: low cost Feasible short-term: high cost	0 4 6 8
						Not feasible	9
Other projects	Opportunities provided by other projects	×	×	×	×	High Medium Low None	4 2 1 0
	Drivers from other projects	×	×	×	×	Significant constraints Moderate constraints Minor constraints N/A	7 5 3 0

[a] 1 mile/h = 1·6 km/h

Table 2. (continued)

only to safety and disruption, and not to value for money or environment, with (obviously) higher speeds scoring a higher number of risk points than lower ones (2 for 0–79 miles/h, 5 for 80–99 miles/h, 8 for 100–110 miles/h and 9 for 111–125 miles/h) (1 miles/h = 1·6 km/h).

The risk points scored by each parameter against each consequence category are summed, and the total is multiplied by the weighting of the consequence category (Table 1). The four products are then summed to determine a total prioritisation score. The highest score is taken as the highest risk priority for monitoring and engineering intervention. Full details of the original NR consequence scoring are included in Table 2.

This risk-based analysis has passed its accreditation process, it is credible to senior earthwork engineers and it has been used by NR for a decade. In 2008, following three separate incidents involving earthworks failures, an investigation by the Rail Accident Investigation Branch (RAIB) concluded that the SSHI algorithm as adopted by NR was technically sound, but noted a number of issues regarding its implementation, principally related to variations in practices in different localities, and the lack of a significant number of data points (i.e. earthwork-related incidents) to form a scientific judgement (RAIB, 2008).

4. Assessing the Bo'ness and Kinneil Railway

The NR approach was the obvious starting point for a logical and complete assessment of the B&KR earthworks. However, the NR methodology had to be adapted, since access to the Trimble™ – or indeed any hand-held computer – was not possible. The parameters were therefore set out on a paper questionnaire, exactly as in the original NR scheme. The first 2·4 km of railway from Bo'ness station to where it passes under the main Bo'ness–Grangemouth road is on flat land (the foreshore area) with no earthworks present, so this section was excluded from the study. The remainder of the railway was divided into 114 sections of length approximately 100 m, each section being one side of the railway only.

A questionnaire was filled in for each section. Questions to do with underlying geology and adjacent catchment area were answered by means of a preliminary desk study, the remainder being addressed on site during two visits to the line on 21 November and 5 December 2011, when engineering possessions and associated protection arrangements ensured that there was no safety risk from train movements. Subsequently, the responses were transferred to a spreadsheet, which was in turn programmed to implement the SSHI algorithm and the prioritisation process.

5. Initial results and discussion

The completion of the analysis, particularly filling in the questionnaire at the line side, is a process that clearly requires training. In this instance the authors carrying out the work were final-year undergraduate MEng civil engineering students. They took some time to get used to the process, but thereafter found completion of the questionnaires to be relatively straightforward, based on geotechnical engineering knowledge acquired during the preceding years of their degree programme.

5.1 SSHI results

The SSHI (i.e. the geotechnical hazard) results are summarised in Table 3. Of the poor slopes, most were cutting slopes (i.e. above rail level) on the south side of the railway, with some being cutting slopes located south of Birkhill Station, on both sides of the railway. Only a few were embankment slopes (below rail level) located near where the railway turns south away from the Forth Estuary. A variety of potential failure modes were exhibited, with some of the high, steep embankment slopes giving indications of rotational and translational failure, and some of the cutting slopes additionally appearing vulnerable to washout and earth flow type failures.

It is stressed that a result of 'poor' does not mean that the earthwork presents an immediate safety hazard; it is rather an indication that monitoring is needed on at least a biennial basis to avoid a risk developing.

5.2 Initial prioritisation

In order to prioritise possible interventions on the B&KR earthworks, the prioritisation toolkit was applied using all the original NR scheme unaltered. The main results of this analysis are shown in Figure 3, in which the prioritisation of earthworks is indicated by the large boxed numbers, with 1 indicating the earthwork section with the highest priority for monitoring and possible intervention. Some areas have equal priority, and thus the same number appears twice; the priorities shown are not all consecutively numbered, as some of the priorities between 1 and 17 were on sections of the railway not covered by the figure.

In this result, the top priority is at a location where there has been previous disturbance due to excavation for an oil pipeline crossing in the 1980s, and the consequence includes possible impact on the pipeline. This therefore appears to make sense. However, many of the next priorities are cutting sides on the south side of the railway. Applying engineering judgement, the prioritisation of these areas makes much less sense, since examination on site, together with the experience of some small past failures, suggested that the cutting sides could collapse with no significant consequence to third parties, there being only woodland or agricultural land on the top side of the cutting.

SSHI geotechnical hazard	Number of 100 m lengths of one side of railway	Percentage of all slopes on railway
Poor	25	22
Marginal	49	43
Serviceable	40	35

Table 3. SSHI results for Bo'ness and Kinneil Railway

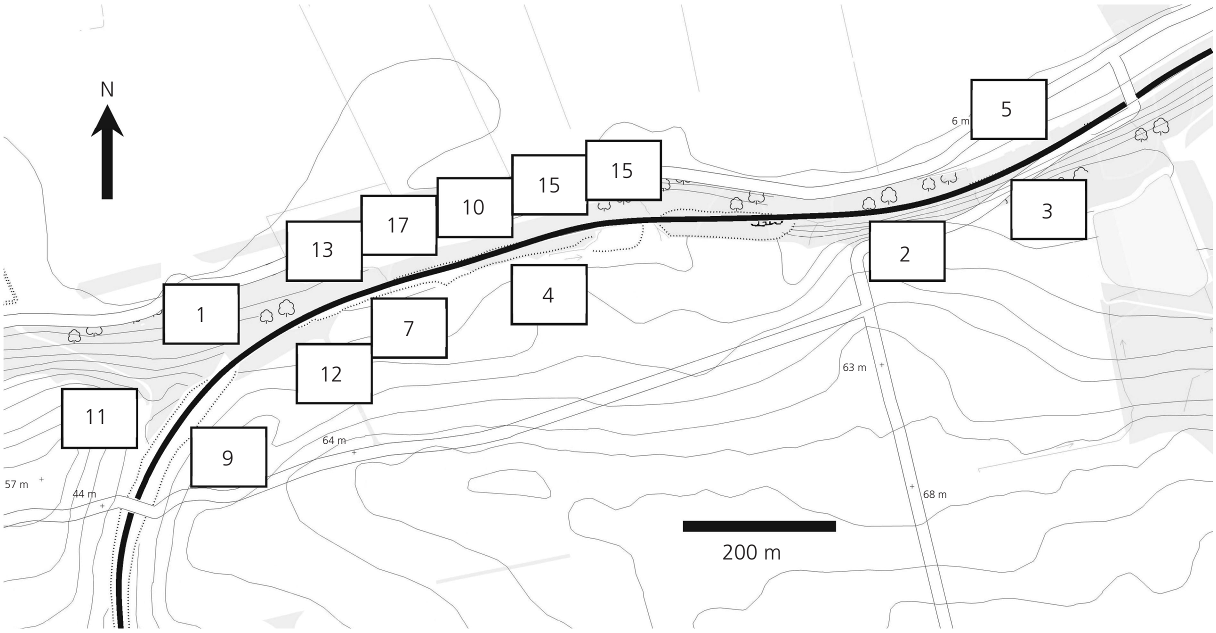

Figure 3. Earthworks prioritisation based on Network Rail weightings. Base map © Crown Copyright/database right 2013. An Ordnance Survey/EDINA supplied service

There is also a wide area by the line side to accommodate any debris, and if any debris did fall on the rails, the visibility for train crews was generally sufficient to achieve a controlled stop in the distance available, given the 20 miles/h (32 km/h) maximum line speed in the area.

On the other hand, the embankment slopes given the 10th, 13th, 15th and 17th priorities had poor SSHIs, and engineering judgement suggested that any failure here could have a major impact on the railway. This would include undermining the track formation, severing the line and causing all income-generating operations to cease, as well as presenting a safety risk to trains and in some cases to owners of domestic property positioned below the railway.

In view of this, it was decided to reassess the prioritisation approach in the light of needs specific to HR operation. This was done with the assistance of a focus group consisting of ex-NR civil engineers, currently practising independent competent persons with both NR and HR experience, and civil engineers with earthwork experience outside the rail environment.

5.3 Adapting NR risk weightings to HRs

A number of issues were found when applying the NR prioritisation in an HR context. In terms of the four generic consequence categories (Table 1), the presence of 'environmental' appeared to be over-emphasised for HRs. This is not to say that HRs do not take environmental impact seriously, but in general this impact is probably low, and is strongly linked with factors such as tourism and traffic to access their stations. Thus use of 'environmental' as a consequence category is unlikely to make significant distinction between priorities for earthwork monitoring or intervention. In the NR system, as well as 'environmental' being a consequence category (Table 1), 'environmental obligations' is a parameter considered under 'legal obligations' (Table 2), and it was felt that its presence here was sufficient for HRs without including it as a separate consequence category as well.

Further, the 'value for money' consequence was thought to be too complex, and was therefore simplified to 'financial', covering the actual cost of repair of a damaged earthwork. 'Disruption' was also modified, since detail such as delay minutes is less relevant to HR operations as no fines are payable to train operating companies. Instead, disruption was used to consider indirect costs such as loss of income, the inability to run trains (including engineering trains) and impacts on the reputation of the individual railway or the HR movement in general.

Accordingly, the consequence categories were redefined for use on HRs, as shown in Table 4.

The prioritisation scoring factors used by NR (Table 2) then needed to be adapted to the new consequence categories shown in Table 4. Further issues were also identified with the prioritisation scoring factors, as described in the following sections.

5.3.1 Geotechnical information

NR prioritises cuttings over embankments for statistical reasons, as more accidents have occurred as a result of cutting failure (RAIB, 2008). For similar reasons, rockfalls and washouts are

Consequence category	Definition	Weighting
Safety	The level of safety of the travelling public, HR staff or third parties	0·4
Financial	The direct costs resulting from an earthwork failure: e.g. the cost of repair of an earthwork and any damages incurred by the failure including third parties	0·25
Disruption	Indirect costs of failure such as loss of earnings due to inability to run passenger services; the inability to run trains, including works trains; and the effect on the reputation of the HR or the HR movement generally	0·35

Table 4. New heritage railway consequence categories

given a higher priority over other types of failure. However, these statistics, derived from NR operations, will not necessarily have any bearing on HR operations, where conditions – and line speeds in particular – are very different, so (unless further information becomes available in the future) it was thought more appropriate to consider all these factors equally. NR also uses a geotechnical engineer's assessment of earthwork (and rock slope) condition and trend as part of the geotechnical scoring, and this is unlikely to be generally available to many HRs, which do not have geotechnical specialists available to make routine assessments.

5.3.2 Track condition
NR considers track condition, including geometry, trends and risks of TSRs with impact on train operating companies (TOCs) in its risk assessment; however, these factors are less relevant to HRs. Track condition is likely to be generally poorer than mainline standards, but matters less at low line speeds, and the financial penalties of a TSR are also not relevant when line speed limits are always less than 25 miles/h (40 km/h).

5.3.3 Consequence potential
In this general category, the NR system considers route sensitivity, which covers the availability of a diversion for through traffic. This is clearly irrelevant to HRs. Route speed, flexibility of wrong-line running on multiple tracks and potential delay payments to TOCs are also not relevant.

5.3.4 Other projects
Although not irrelevant, the treatment of opportunities and drivers associated with other projects were thought to be overly complex for HR implementation, and suitable for simplification. Conversely, it was considered that there were a number of factors relevant to HRs that were not included in the NR system. These are as follows.

5.3.5 Site access
On the B&KR, and many other heritage railways, access for plant and personnel to repair a damaged earthwork, particularly if the railway itself was no longer passable, would be a serious issue. This was, in fact, a notable issue in the repairs to the SVR after the 2007 flooding (Sowden, 2012). It is therefore more important to maintain difficult-to-access earthworks in a serviceable state than is the case for the more accessible ones.

5.3.6 Detectability of failure
A key issue for HRs is the likelihood of incipient failure being detected; this will have a clear impact on the safety consequence, and is likely to be more variable on HRs relying on volunteer staff with diverse responsibilities, as opposed to NR, where there is a clearly set-out inspection programme, with dedicated staff to administer it. Some earthworks and rock slopes will be more frequently observed, for example those near staffed stations, whereas features in more remote locations, where there is heavy vegetation or features above cutting horizons, are less likely to be noticed. It was thought that this variability should be included in a risk assessment for HRs.

5.3.7 Shared responsibility
This factor was added to account for situations such as the pipeline crossing on the B&KR, where the earthwork, and consequently any repairs, would be a shared responsibility with the pipeline operators. In general, this will apply in many HR contexts, such as where the earthwork supports a highway bridge structure or adjacent road.

5.4 New prioritisation for the B&KR
In view of the foregoing discussion, a revised prioritisation scoring against the new consequence categories (Table 4) was prepared, which it is thought more accurately reflects the situation on the B&KR and on other HRs. This is detailed in Table 5. For factors that are unaltered from the original system, the scoring remains the same. For new categories, scores have been determined based on engineering judgement of their relative significance.

For added clarity, a comparison of the original NR scheme and the new prioritisation scheme is shown, without scoring, in Table 6.

6. Revised results
The new HR prioritisation scheme was applied to the B&KR. No change was made to the SSHI calculation, for which the results remain as shown in Table 3. These were used with the conse-

Category	Parameter	Safety	Financial	Disruption	Hazard options	Scoring
Geotechnical information	Failure mode	×	×	×	Rockfall	24
					Rotation	19
					Translation	19
					Earthflow	11
					Washout	24
					Burrowing	13
					Subsidence/settlement	16
	Site access	×	×	×	Easy	0
					Moderate	5
					Obstructed	9
	Detectability	×	×	×	High	0
					Medium	2
					Low	4
Track layout	Track layout	×		×	Straight track/flat curve	2
					Curve: high cant/cant deficiency	4
					S&C	5
Geographic weather risk	Geographic weather risk (including flooding potential)	×		×	Very high	7
					High	6
					Medium	4
					Low	2
Past failures	Past failures	×		×	No previous local failures or normalised delay minutes 0–60%	3
					Some known local failures or normalised delay minutes 60–90%	5
					Extensive local failures or normalised delay minutes 90–100%	7
	Impact on other assets	×	×	×	Track	4
					Power/telecom cables/signalling	3
					Signalling equipment	4
					NR structures	1
					Third-party structures	1
Legal requirements	Third-party liabilities/ legal obligations		×	×	Very significant	7
					Significant	5
					Not significant	0
	Environmental obligations		×	×	Very significant	4
					Significant	3
					Not significant	0
	Shared responsibility		×	×	Yes	0
					No	3
Available mitigations	Drainage, vegetation, TSR, watchmen, track maintenance etc.	×	×	×	Feasible long-term: low cost	0
					Feasible long-term: high cost	4
					Feasible short-term: low cost	6
					Feasible short-term: high cost	8
					Not feasible	9
Other projects	Opportunities and drivers provided by other projects	×	×	×	High	7
					Medium	5
					Low	3
					None	0

Table 5. New heritage railway prioritisation scoring

Category	Original NR prioritisation factors					New HR prioritisation factors			
	Parameter	Safety	Value for money	Disruption	Environmental	Parameter	Safety	Financial	Disruption
Geotechnical information	Earthwork type	×	×	×	×				
	Failure mode	×	×	×	×	Failure mode	×	×	×
	Predicted earthwork condition trend	×	×	×	×				
						Site access	×	×	×
						Detectability	×	×	×
Track condition	Track recording vehicle (TRV) data: current track condition	×		×					
	TRV data: trends	×		×					
	Risk of temporary speed restrictions	×	×	×					
Track layout	Track layout	×		×		Track layout	×		×
Geographic weather risk	Geographic weather risk (including flooding potential)	×		×		Geographic weather risk (including flooding potential)	×		×
Past failures	Past failures	×		×		Past failures	×		×
Consequence potential	Route sensitivity		×	×					
	Impact on other assets	×	×	×	×	Impact on other assets	×	×	×
	Route speed	×		×					
	Infrastructure flexibility		×	×					
	Potential delay costs		×	×					
Legal requirements	Third-party liabilities/legal obligations		×	×	×	Third-party liabilities/legal obligations		×	×
	Environmental obligations		×	×	×	Environmental obligations		×	×
						Shared responsibility		×	×
Available mitigations	Drainage, vegetation, TSR, watchmen, track maintenance etc.	×	×	×	×	Drainage, vegetation, TSR, watchmen, track maintenance etc.	×	×	×
Other projects	Opportunities provided by other projects	×	×	×	×				
	Drivers from other projects	×	×	×	×				
						Opportunities and drivers provided by other projects	×	×	×

Table 6. Comparison between original NR and new HR consequence factors

Figure 4. Earthworks prioritisation based on Heritage Railway weightings. Base map © Crown Copyright/database right 2013. An Ordnance Survey/EDINA supplied service

quence factors in Table 5 to calculate revised priorities for monitoring and engineering intervention.

The revised priorities are indicated in Figure 4. They now tie in much more effectively with engineering judgement, the high, steep and sometimes wet embankment slopes north of the railway being given the highest priorities. If damaged, these embankments would potentially undermine the line, perhaps in a way not immediately noticeable from the driving cab of an approaching train, and they might result in collapse onto line-side property. The resulting disruption would entirely remove the railway's access to an income stream either from sale of passenger tickets or from revenue associated with rail tour movements, for which mainline access from Bo'ness station is required.

6.1 Monitoring and remediation

The application of the SSHI calculation and revised prioritisation merely calculates a relative risk for given sections of earthwork or rock slope. It does not indicate the presence or absence of an absolute problem; this determination will always rely on on-site inspection by suitably qualified engineers. In the case of the B&KR this has been done, being formally reported in Watson (2011) and informally on more recent occasions. There have been minor issues connected with the need to repair drainage ditching, and minor slips associated with large trees being uprooted by winter gales, but the underlying stability of all the earth and rock slopes is not currently in question. However, in the light of the collapses on the SVR and G&WR previously mentioned, and bearing in mind the railway's responsibility for the safety of its staff, passengers and neighbours, it is appropriate to take steps to manage any potential risk. It is therefore proposed to repeat the risk assessment inspections on a regular basis.

It was notable in both the SVR and G&WR cases that failures were related to drainage issues, where in some cases the existence and operation of culverts was previously unknown (Sowden, 2012). A careful investigation of all drainage structures on the B&KR has thus been carried out to ensure that this situation is less likely to arise.

Further, it is commonly noted that earthwork failure is rarely sudden or without warning (e.g. Bonnett, 2005, section 6.5, p. 85), and simple monitoring techniques are available to give early warning, the most obvious one being 'telltales', which consist of a number of pegs set out in a straight line. Any significant movement of the earthwork would result in pegs moving out of line, which would be readily observable even by an unqualified staff member. The matter could then be further investigated, and potential consequences reduced. Four sets of telltales have therefore been placed in priority areas 1 to 4, as shown in Figure 4, and will be inspected regularly, with the distance from the running edge of the rail and track cant being monitored at each peg (Figure 5).

7. Conclusion and further work

A risk assessment has been carried out on the Bo'ness and Kinneil Railway with the aim of managing potential hazards associated with earthworks and rock slopes supporting a HR.

Figure 5. Setting out telltales in a priority area

Techniques used by NR to calculate a SSHI and prioritise risk were found to be unsuitable for HR application, owing to the irrelevance of a number of factors used in determining the severity of potential consequences, and the absence of other factors important to HR operations. A revised approach was created, taking into account the specific context in which HRs work, and the revised prioritisation gave risk results that related well to engineering judgement regarding the structures in question.

It is concluded that at the time of writing the earth and rock slopes on the B&KR are not a cause for concern; however, the revised risk management process works well, and should be applied regularly, with the highest-risk slopes being subject to more frequent formal inspection and recording, with the assistance of simple monitoring techniques to give early warning of any slope movement. This will provide continued reassurance that the B&KR formation remains safe for traffic.

Work on this project is continuing, to provide a more user-friendly method of implementation commensurate with volunteer inspectors in a HR environment, and to trial the method on other HRs, which may lead to further developments in the prioritisation scoring, particularly for the new factors introduced as part of this work.

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