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# EVALUATION OF A RISK ASSESSMENT SYSTEM FOR HERITAGE RAILWAY EARTHWORKS

Eamonn Doherty, Paul Kelly and Martin Crapper
School of Engineering, The University of Edinburgh, The King's Buildings, EH9 3JL, UK
Martin.Crapper@ed.ac.uk

## ABSTRACT

There are currently over 100 heritage railways in the UK carrying 6.8 million passengers on 15 million passenger journeys and contributing an estimated £579 million to the UK economy. Many of these lines include significant earthworks, which present a considerable risk to their safe operation. In the last decade there have been major slips at several heritage railways causing major disruption to operations and a serious threat to business continuity.

This research describes the application of a risk assessment system based on that used by Network Rail but specifically adapted for heritage railway conditions. Adaptations include significant alterations to the consequence categories used in prioritization of earthwork issues and a simple low-cost method of implementation based on paper forms and Excel spreadsheets.

Use of the system on two heritage railways, the Bo'ness and Kinneil Railway and the Strathspey Railway is evaluated by means of discussion with railway engineering staff and civil engineering volunteers.

It is concluded that whilst the system represents a realistic and useful approach to management of earthwork assets, the system could not be used by heritage railway volunteer staff without targeted training. Such training, however, would be straightforward to provide, perhaps under the auspices of the Heritage Railway Association.

## INTRODUCTION AND BACKGROUND

There are currently over 100 heritage railways (HRs) in the UK carrying 6.8 million passengers on 15 million passenger journeys and contributing an estimated £579 million to the UK economy (Lord Faulkner 2011). Many of these lines include significant earthworks created during the expansion of the rail network in the nineteenth century, for which no construction records exist and which are obviously steeper than would be permitted using modern design techniques. These earthworks therefore present a considerable risk to the safe operation of HRs. In addition to major landslips on the Severn Valley Railway in 2007 and on the Gloucester and Warwickshire Railway in 2010 and 2011, there have been three traffic-affecting landslips this year (2013) alone, on the Spa Valley Railway, the Llangollen Railway and the Wensleydale Railway (2013). Whilst no lives have been lost, there has been considerable disruption to the business of these railways and major costs incurred. There is therefore a clear requirement for HRs to be able to manage their earthwork assets effectively. However, HRs are primarily volunteer-run organizations and often do not always have regular access to trained engineering staff.

One example of a HR with which the authors have on-going links is the Bo'ness and Kinneil Railway (B&KR), a five-mile heritage railway running from Bo'ness (Borrowstounness) on the Forth Estuary to a junction with the Edinburgh and Glasgow main line between Linlithgow and Polmont. This line, originally constructed in the 1840s, has a large number of significant earthworks, some of them 15-20m high, steep and typically wet. Disruption of any of these would have the potential to remove the railway's access to all its income streams, including both passenger ticket sales and revenue associated with rail tour movements to and from the main line.

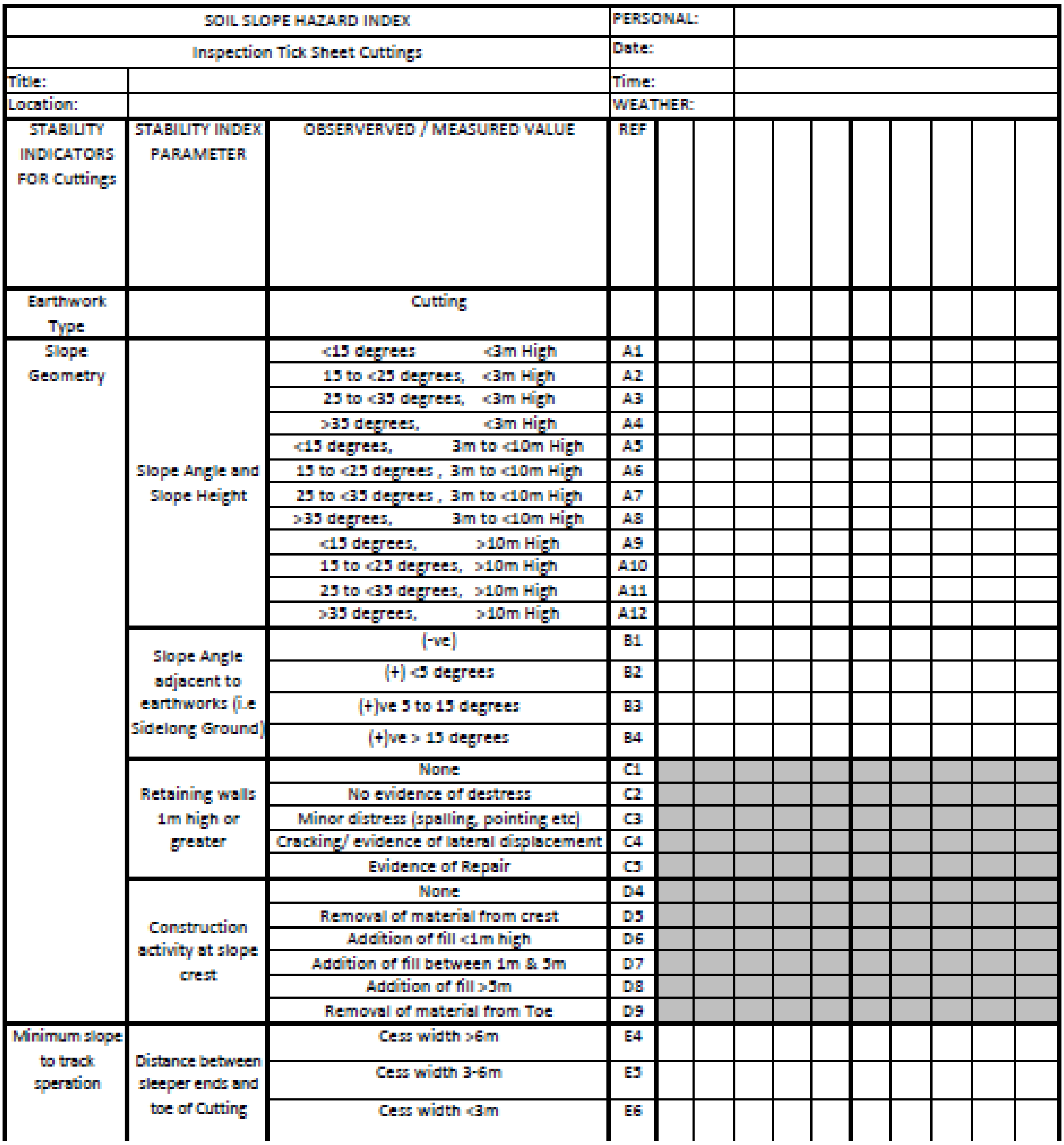
In order to better manage the B&KR assets, the Network Rail (NR) system of earthworks was adapted to the HR context (Crapper, Fell et al. in press). This worked satisfactorily to give a good indication of priorities for monitoring and possible engineering intervention. However, the system developed was somewhat ad-hoc and quite difficult to implement.

Since then, the adapted system has been developed to provide a user-friendly method of earthworks inspection and monitoring for general application on any heritage railway, with a view to its being implemented by volunteer staff. This paper describes in outline the system discussed in (Crapper, Fell et al. in press), and details its development and testing by volunteers on the B&KR and on another HR, the Strathspey Railway. Conclusions are then drawn as to the usefulness and possible future development of the HR earthwork inspection system.

## THE HR EARTHWORK INSPECTION SCHEME

The NR earthwork inspection scheme is a two-stage process based on the work of (Manley and Harding 2003) and (Mott MacDonald and Network Rail 2006). In the first stage, for short sections of railway, consideration of a wide range of factors such as underlying geology, slope geometry and drainage contribute to the development of a *Soil Slope Hazard Index* (SSHI) describing the geotechnical risk of a particular section of earthwork against *rotational, translational, washout, earthflow* and *burrowing* types of failure. The worst-case SSHI is then included, along with many other parameters, including *line speed*, *alternative route availability* and *likely delay costs* into a risk calculation to determine the priority of failure against various consequence categories including *safety* and *disruption*. This calculation is done for each section of railway, and the overall is an order of priority of locations for monitoring and possible engineering intervention.

The first change in applying the scheme to HRs was to convert it to a paper-based system, using forms instead of the bespoke hand-held computers utilized by NR. Thus the on-site inspection could proceed using forms and a clip board. An extract of the paper form used on site is shown in Figure 1. Following the on-site inspection, data from the paper forms was entered into Excel spreadsheets for calculation of the SSHI and subsequent prioritization.



| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOIL SLOPE HAZARD INDEX | | | PERSONAL: | | | | | | | | | | |
| Inspection Tick Sheet Cuttings | | | Date: | | | | | | | | | | |
| Title: | | | Time: | | | | | | | | | | |
| Location: | | | WEATHER: | | | | | | | | | | |
| STABILITY INDICATORS FOR Cuttings | STABILITY INDEX PARAMETER | OBSERVERVED / MEASURED VALUE | REF | | | | | | | | | | |
| Earthwork Type | | Cutting | | | | | | | | | | | |
| Slope Geometry | Slope Angle and Slope Height | <15 degrees <3m High | A1 | | | | | | | | | | |
| | | 15 to <25 degrees, <3m High | A2 | | | | | | | | | | |
| | | 25 to <35 degrees, <3m High | A3 | | | | | | | | | | |
| | | >35 degrees, <3m High | A4 | | | | | | | | | | |
| | | <15 degrees, 3m to <10m High | A5 | | | | | | | | | | |
| | | 15 to <25 degrees , 3m to <10m High | A6 | | | | | | | | | | |
| | | 25 to <35 degrees , 3m to <10m High | A7 | | | | | | | | | | |
| | | >35 degrees, 3m to <10m High | A8 | | | | | | | | | | |
| | | <15 degrees, >10m High | A9 | | | | | | | | | | |
| | | 15 to <25 degrees, >10m High | A10 | | | | | | | | | | |
| | | 25 to <35 degrees, >10m High | A11 | | | | | | | | | | |
| | | >35 degrees, >10m High | A12 | | | | | | | | | | |
| | Slope Angle adjacent to earthworks (i.e Sidelong Ground) | (-ve) | B1 | | | | | | | | | | |
| | | (+) <5 degrees | B2 | | | | | | | | | | |
| | | (+)ve 5 to 15 degrees | B3 | | | | | | | | | | |
| | | (+)ve > 15 degrees | B4 | | | | | | | | | | |
| | Retaining walls 1m high or greater | None | C1 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | No evidence of destress | C2 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | Minor distress (spalling, pointing etc) | C3 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | Cracking/ evidence of lateral displacement | C4 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | Evidence of Repair | C5 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | Construction activity at slope crest | None | D4 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | Removal of material from crest | D5 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | Addition of fill <1m high | D6 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | Addition of fill between 1m & 5m | D7 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | Addition of fill >5m | D8 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| | | Removal of material from Toe | D9 | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |
| Minimum slope to track speration | Distance between sleeper ends and toe of Cutting | Cess width >6m | E4 | | | | | | | | | | |
| | | Cess width 3-6m | E5 | | | | | | | | | | |
| | | Cess width <3m | E6 | | | | | | | | | | |

Figure 1: Extract of paper form used for on-site earthwork inspection on HRs

The other issue in adapting NR's earthwork inspection procedures to HR use was that many of the prioritization parameters – for example alternative route availability discussed above – have no relevance at all to the HR context, whilst others are affected by the low line speeds and annual traffic tonnages that are universal on UK heritage railways (where passenger trains are generally limited to a maximum of 25mph/40 kph). The prioritization scheme and the consequence categories on which it was based were therefore completely revised as fully explained in (Crapper, Fell et al. in press), the actual SSHI determination remaining identical to that set out in (Manley and Harding 2003). Details of the changes are reproduced here for clarity and are shown in Table 1. NR's four consequence categories of *safety, value for money, disruption and environment* were simplified to three HR ones of *safety, financial* (ie direct costs of damage and repairs) and *disruption* (including indirect costs, lost income and reputational issues).

The factors affecting each consequence category can be identified by the Xs in the table. Each parameter value has a prioritization score associated with it (not shown in the table – see (Crapper, Fell et al. in press)). For parameters which remained as in the original NR scheme (Mott MacDonald and Network Rail 2006), these were unaltered. For new factors scores were developed using the authors' engineering judgement.

Table 1: Comparison between original NR and new HR consequence factors

| | Original NR Prioritization Factors | | | | | New HR Prioritization Factors | | | |
|---|---|---|---|---|---|---|---|---|---|
| Category | Parameter | Safety | Value for Money | Disruption | Environmental | Parameter | Safety | Financial | Disruption |
| Geotechnical Information | Earthwork Type | X | X | X | X | | | | |
| | Failure Mode | X | X | X | X | Failure Mode | X | X | X |
| | Predicted Earthwork Condition Trend | X | X | X | X | | | | |
| | | | | | | Site Access | X | X | X |
| | | | | | | Detectability | X | X | X |
| Track Condition | Track Recording Vehicle (TRV) Data – Current Track Condition | X | | X | | | | | |
| | TRV Data – Trends | X | | X | | | | | |
| | Risk of Temporary Speed Restrictions | X | X | X | | | | | |
| Track Layout | Track Layout | X | | X | | Track Layout | X | | X |
| Geographic Weather Risk | Geographic Weather Risk (including flooding potential) | X | | X | | Geographic Weather Risk (including flooding potential) | X | | X |
| Past Failures | Past Failures | X | | X | | Past Failures | X | | X |
| Consequence Potential | Route Sensitivity | | X | X | | | | | |
| | Impact on other assets | X | X | X | X | Impact on other assets | X | X | X |
| | Route Speed | X | | X | | | | | |
| | Infrastructure Flexibility | | X | X | | | | | |
| | Potential Delay Costs | | X | X | | | | | |
| Legal Requirements | 3rd Party Liabilities/Legal Obligations | | X | X | X | 3rd Party Liabilities/Legal Obligations | | X | X |
| | Environmental Obligations | | X | X | X | Environmental Obligations | | X | X |
| | | | | | | Shared Responsibility | | X | X |
| Available Mitigations | e.g. drainage, vegetation, TSR, watchmen, track maintenance etc. | X | X | X | X | e.g. drainage, vegetation, TSR, watchmen, track maintenance etc. | X | X | X |
| Other Projects | Opportunities provided by other projects | X | X | X | X | | | | |
| | Drivers from other projects | X | X | X | X | | | | |
| | | | | | | Opportunities and drivers provided by other projects | X | X | X |

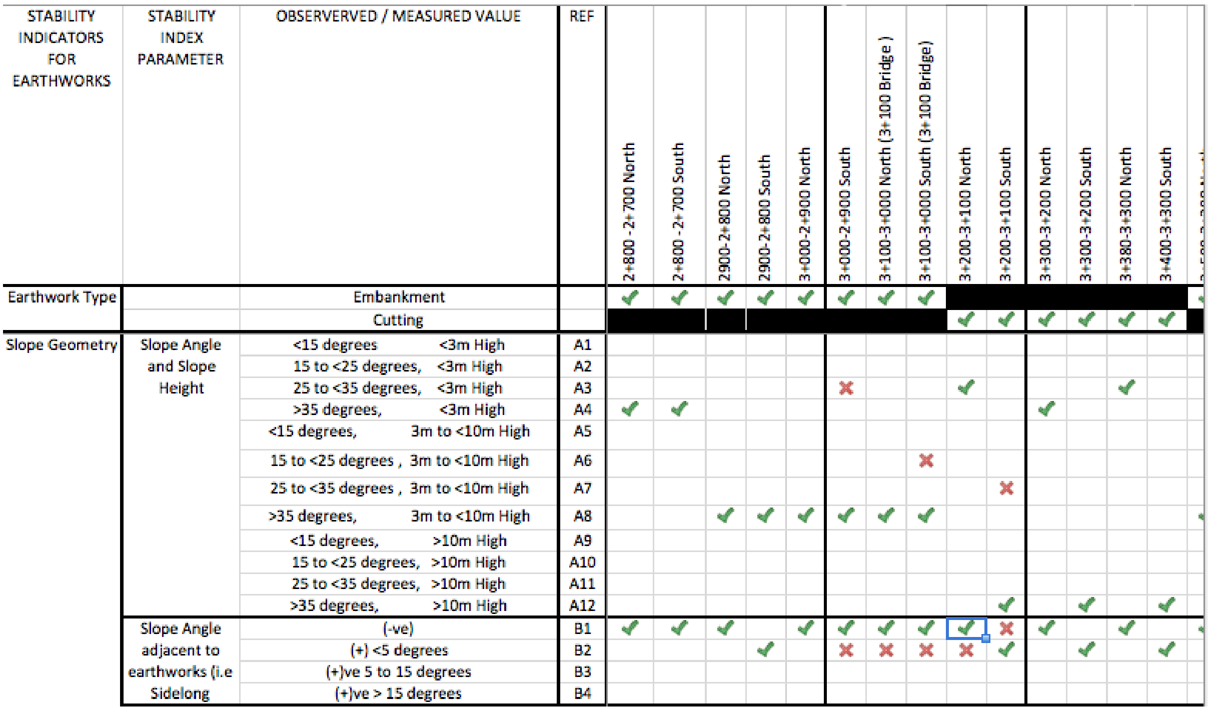
## MAKING THE SYSTEM USER-FRIENDLY AND GENERALLY APPLICABLE

Having successfully applied the HR earthworks inspection scheme to the B&KR, generating sensible results, it has been developed with the intention of making it possible for volunteer, non-engineering staff to use it and to make it 'portable' to other UK HRs who have a need to manage their earthwork assets.

Initially, this process focused on the data processing which occurs after the on-site inspection. It was decided to retain Microsoft Excel for this purpose due to its wide availability (it is likely to be on most computers available to HR volunteers), its ease of use and the wide readability of its data files. The original spreadsheet system was however re-written from scratch, with a view to ease of use and, crucially, ease of checking and maintenance.

The original system had been developed for the B&KR and was limited to the 114 sections used to cover that railway. The new system has a variable number of sections allowing it to be adapted to any railway. The length of the sections is taken as 100m but this is not a fixed property of the system, any length can be used.

Considerable error checking was then built into the Excel system. All data entry was limited to a single page, with much use being made of conditional formatting and locked cells to prevent mistaken input. For example, different values are used for embankments and cuttings; when one or other of these is chosen the cells corresponding to data applicable only to the other one are blacked and locked out (Figure 1).

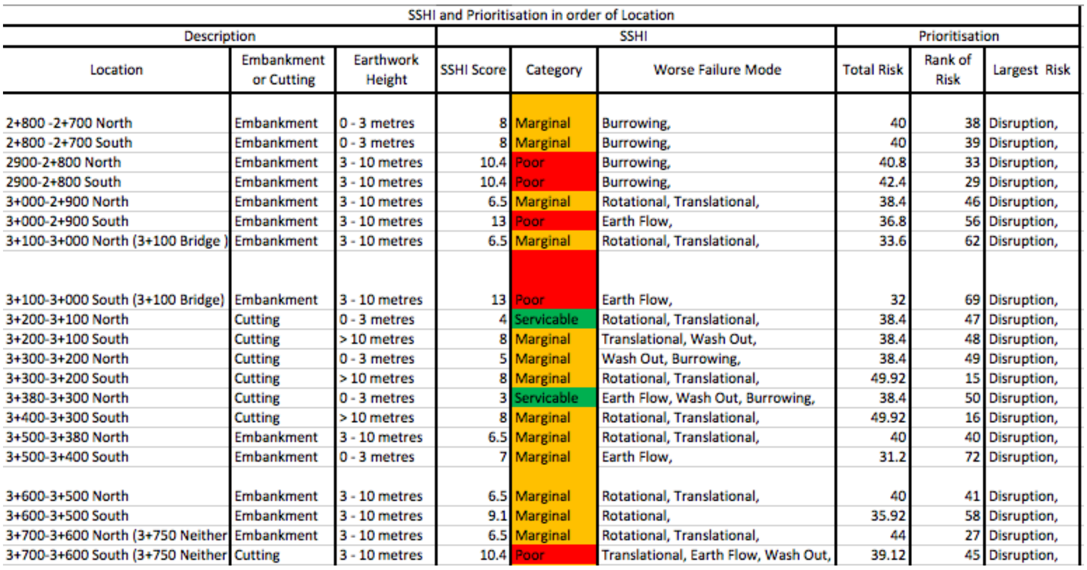


| STABILITY INDICATORS FOR EARTHWORKS | STABILITY INDEX PARAMETER | OBSERVERVED / MEASURED VALUE | REF | 2+800 -2+700 North | 2+800 -2+700 South | 2900-2+800 North | 2900-2+800 South | 3+000-2+900 North | 3+000-2+900 South | 3+100-3+000 North (3+100 Bridge ) | 3+100-3+000 South (3+100 Bridge) | 3+200-3+100 North | 3+200-3+100 South | 3+300-3+200 North | 3+300-3+200 South | 3+380-3+300 North | 3+400-3+300 South |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Earthwork Type | | Embankment | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | |
| | | Cutting | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Slope Geometry | Slope Angle and Slope Height | <15 degrees <3m High | A1 | | | | | | | | | | | | | | |
| | | 15 to <25 degrees, <3m High | A2 | | | | | | | | | | | | | | |
| | | 25 to <35 degrees, <3m High | A3 | | | | | | ✗ | | | ✓ | | | | ✓ | |
| | | >35 degrees, <3m High | A4 | ✓ | ✓ | | | | | | | | | ✓ | | | |
| | | <15 degrees, 3m to <10m High | A5 | | | | | | | | | | | | | | |
| | | 15 to <25 degrees , 3m to <10m High | A6 | | | | | | | | ✗ | | | | | | |
| | | 25 to <35 degrees , 3m to <10m High | A7 | | | | | | | | | | ✗ | | | | |
| | | >35 degrees, 3m to <10m High | A8 | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | |
| | | <15 degrees, >10m High | A9 | | | | | | | | | | | | | | |
| | | 15 to <25 degrees, >10m High | A10 | | | | | | | | | | | | | | |
| | | 25 to <35 degrees, >10m High | A11 | | | | | | | | | | | | | | |
| | | >35 degrees, >10m High | A12 | | | | | | | | | | ✓ | | ✓ | | ✓ |
| | Slope Angle adjacent to earthworks (i.e Sidelong | (-ve) | B1 | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | | ✓ | |
| | | (+) <5 degrees | B2 | | | | ✓ | | ✗ | ✗ | ✗ | ✗ | ✓ | | ✓ | | ✓ |
| | | (+)ve 5 to 15 degrees | B3 | | | | | | | | | | | | | | |
| | | (+)ve > 15 degrees | B4 | | | | | | | | | | | | | | |

Figure 2: Spreadsheet initial entry form with cells shaded out and error checking on entry

Error checking also means that if incorrect input is detected then no SSHI or prioritization result will be calculated and a null return will be shown on intermediate and final output sheets.

Finally visual guidance including shading of cells where multiple inputs are required and colour coding of output for ease of reference was incorporated (Figure 3).

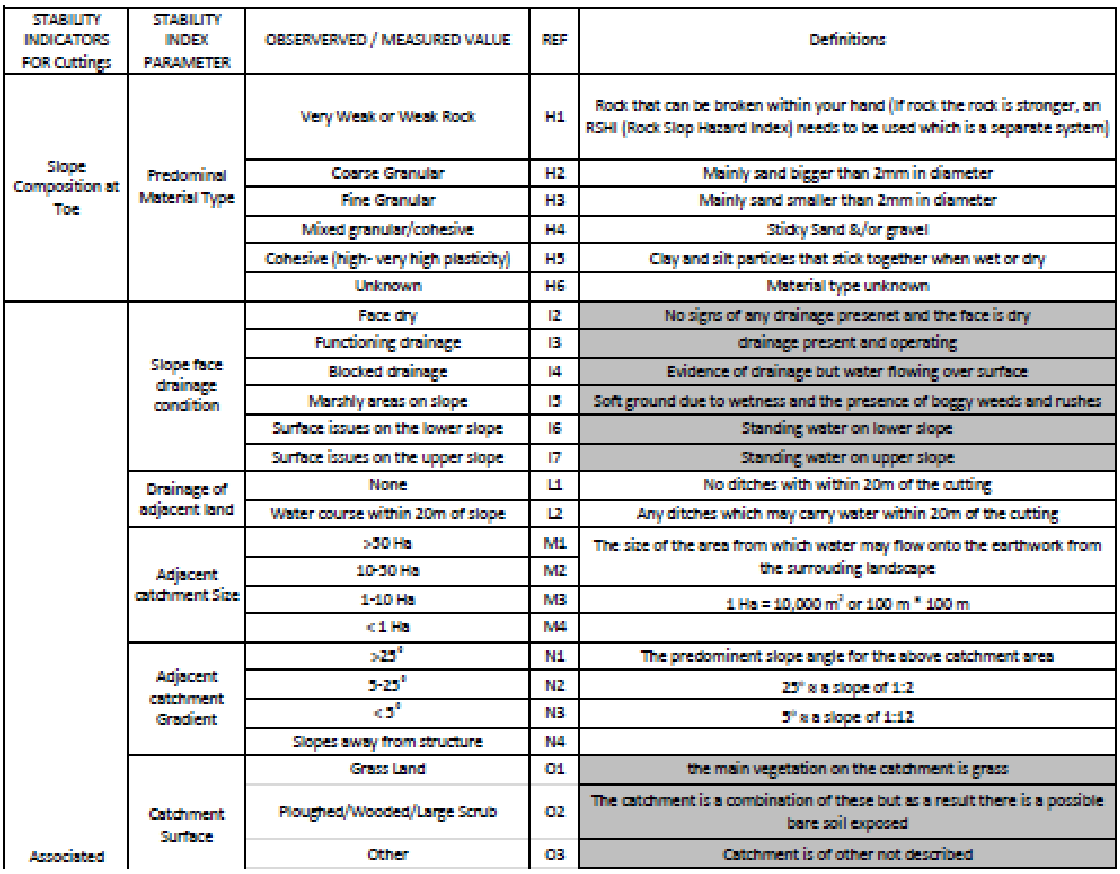


SSHI and Prioritisation in order of Location

| Description | | | SSHI | | | Prioritisation | | |
|---|---|---|---|---|---|---|---|---|
| Location | Embankment or Cutting | Earthwork Height | SSHI Score | Category | Worse Failure Mode | Total Risk | Rank of Risk | Largest Risk |
| 2+800 -2+700 North | Embankment | 0 - 3 metres | 8 | Marginal | Burrowing, | 40 | 38 | Disruption, |
| 2+800 -2+700 South | Embankment | 0 - 3 metres | 8 | Marginal | Burrowing, | 40 | 39 | Disruption, |
| 2900-2+800 North | Embankment | 3 - 10 metres | 10.4 | Poor | Burrowing, | 40.8 | 33 | Disruption, |
| 2900-2+800 South | Embankment | 3 - 10 metres | 10.4 | Poor | Burrowing, | 42.4 | 29 | Disruption, |
| 3+000-2+900 North | Embankment | 3 - 10 metres | 6.5 | Marginal | Rotational, Translational, | 38.4 | 46 | Disruption, |
| 3+000-2+900 South | Embankment | 3 - 10 metres | 13 | Poor | Earth Flow, | 36.8 | 56 | Disruption, |
| 3+100-3+000 North (3+100 Bridge ) | Embankment | 3 - 10 metres | 6.5 | Marginal | Rotational, Translational, | 33.6 | 62 | Disruption, |
| 3+100-3+000 South (3+100 Bridge) | Embankment | 3 - 10 metres | 13 | Poor | Earth Flow, | 32 | 69 | Disruption, |
| 3+200-3+100 North | Cutting | 0 - 3 metres | 4 | Servicable | Rotational, Translational, | 38.4 | 47 | Disruption, |
| 3+200-3+100 South | Cutting | > 10 metres | 8 | Marginal | Translational, Wash Out, | 38.4 | 48 | Disruption, |
| 3+300-3+200 North | Cutting | 0 - 3 metres | 5 | Marginal | Wash Out, Burrowing, | 38.4 | 49 | Disruption, |
| 3+300-3+200 South | Cutting | > 10 metres | 8 | Marginal | Rotational, Translational, | 49.92 | 15 | Disruption, |
| 3+380-3+300 North | Cutting | 0 - 3 metres | 3 | Servicable | Earth Flow, Wash Out, Burrowing, | 38.4 | 50 | Disruption, |
| 3+400-3+300 South | Cutting | > 10 metres | 8 | Marginal | Rotational, Translational, | 49.92 | 16 | Disruption, |
| 3+500-3+380 North | Embankment | 3 - 10 metres | 6.5 | Marginal | Rotational, Translational, | 40 | 40 | Disruption, |
| 3+500-3+400 South | Embankment | 0 - 3 metres | 7 | Marginal | Earth Flow, | 31.2 | 72 | Disruption, |
| 3+600-3+500 North | Embankment | 3 - 10 metres | 6.5 | Marginal | Rotational, Translational, | 40 | 41 | Disruption, |
| 3+600-3+500 South | Embankment | 3 - 10 metres | 9.1 | Marginal | Rotational, | 35.92 | 58 | Disruption, |
| 3+700-3+600 North (3+750 Neither | Embankment | 3 - 10 metres | 6.5 | Marginal | Rotational, Translational, | 44 | 27 | Disruption, |
| 3+700-3+600 South (3+750 Neither | Cutting | 3 - 10 metres | 10.4 | Poor | Translational, Earth Flow, Wash Out, | 39.12 | 45 | Disruption, |

Figure 3: SSHI and prioritization output from spreadsheet with colour coding for ease of reference

Having developed the spreadsheets, the paper forms were refined, and in particular a *definitions* sheet was created explaining the meaning of all the parameters required as shown in Figure 4.



| STABILITY INDICATORS FOR Cuttings | STABILITY INDEX PARAMETER | OBSERVERVED / MEASURED VALUE | REF | Definitions |
|---|---|---|---|---|
| Slope Composition at Toe | Predominal Material Type | Very Weak or Weak Rock | H1 | Rock that can be broken within your hand (If rock the rock is stronger, an RSHI (Rock Slop Hazard Index) needs to be used which is a separate system) |
| | | Coarse Granular | H2 | Mainly sand bigger than 2mm in diameter |
| | | Fine Granular | H3 | Mainly sand smaller than 2mm in diameter |
| | | Mixed granular/cohesive | H4 | Sticky Sand &/or gravel |
| | | Cohesive (high- very high plasticity) | H5 | Clay and silt particles that stick together when wet or dry |
| | | Unknown | H6 | Material type unknown |
| Associated | Slope face drainage condition | Face dry | I2 | No signs of any drainage presenet and the face is dry |
| | | Functioning drainage | I3 | drainage present and operating |
| | | Blocked drainage | I4 | Evidence of drainage but water flowing over surface |
| | | Marshly areas on slope | I5 | Soft ground due to wetness and the presence of boggy weeds and rushes |
| | | Surface issues on the lower slope | I6 | Standing water on lower slope |
| | | Surface issues on the upper slope | I7 | Standing water on upper slope |
| | Drainage of adjacent land | None | L1 | No ditches with within 20m of the cutting |
| | | Water course within 20m of slope | L2 | Any ditches which may carry water within 20m of the cutting |
| | Adjacent catchment Size | >50 Ha | M1 | The size of the area from which water may flow onto the earthwork from the surrouding landscape |
| | | 10-50 Ha | M2 | |
| | | 1-10 Ha | M3 | 1 Ha = 10,000 m$^2$ or 100 m * 100 m |
| | | < 1 Ha | M4 | |
| | Adjacent catchment Gradient | >25° | N1 | The predominent slope angle for the above catchment area |
| | | 5-25° | N2 | 25° is a slope of 1:2 |
| | | < 5° | N3 | 5° is a slope of 1:12 |
| | | Slopes away from structure | N4 | |
| | Catchment Surface | Grass Land | O1 | the main vegetation on the catchment is grass |
| | | Ploughed/Wooded/Large Scrub | O2 | The catchment is a combination of these but as a result there is a possible bare soil exposed |
| | | Other | O3 | Catchment is of other not described |

Figure 4: Extract of definitions sheet corresponding to paper forms for on-site inspection

EVALUATION

Following development, the earthworks inspection system was tested on the B&KR and on the Strathspey Railway, with application directly by the authors, and by HR volunteers. The test programme is set out in Table 2 below.

Table 2: Test programme for HR earthworks assessment system

In this table, CEng means "Chartered Civil Engineer"

| Date | Railway Inspected | Details of Area Inspected | Weather | Staff Carrying out Inspection | Qualifications of Staff |
|---|---|---|---|---|---|
| 26-Nov-12 | B&KR | Wooded with steep cuttings | Damp due to rail in preceding days | Authors | 2 no final year MEng students<br>1 no CEng |
| 04-Mar-13 | B&KR | Wooded with steep cuttings | Dry and sunny | Authors | 2 no final year MEng students<br>1 no CEng |
| 15-Mar-13 | B&KR | Mainly open fields with some wooded areas | Rain and hail showers | Authors and B&KR volunteers | 2 no final year MEng students<br>1 no CEng<br>Volunteer with computer background but no civil engineering knowledge |
| 18-Mar-13 | B&KR | Wooded with steep cuttings | Damp | Authors Kelly and Crapper and B&KR volunteers | 1 no final year MEng students<br>1 no CEng<br>Volunteer with senior management background but no civil engineering knowledge |
| 23-Mar-13 | Strathspey Railway | Mostly open fields | Light snow | Authors Doherty and Kelly and Strathspey Railway volunteers | 2 no final year MEng students<br>Volunteer who was CEng. |

DISCUSSION

## Robustness of the system

The primary aim of the earthworks inspection scheme is to allow HRs to effectively manage the risks associated with their earth slope assets. For this to be achieved, it requires the system to effectively highlight potential failures before they occur.

On the Strathspey Railway, a section of track near mile post (MP) 87 has a known issue of long term settlement and constant intervention is required to maintain alignment. This section was inspected and, noting that regular maintenance had been required on the inspection data, an SSHI result of *poor* was returned, with a score 13 and potential failure modes of *rotational*, *translational* and *earthflow*. When the *regular maintenance* parameter was set to *no*, the SSHI result remained *poor* with a score of 13 for *earthflow* only. Settlement, as such, is not one of the failure modes considered in the SSHI and was not readily apparent to the authors when inspecting the site, of which they had no previous knowledge. Thus, the SSHI result and subsequent prioritization does not give an indication of the known settlement problems, so without local engineering knowledge the earthwork inspection scheme would not provide a complete method of managing the asset in this area.

On the other hand, the inspection and prioritization of the B&KR indicated the top priority for monitoring and possible intervention to be one of the high cuttings to the south of the railway, near MP28½, and this very slope subsequently experienced a minor slip, with, fortunately, no impact on the railway line itself.

On balance, the information gained from the earthworks inspection regime appears to return good value for the time invested in the inspections, and is a fairly comprehensive approach to determine the stability of earthwork assets, but it can only be relied upon in conjunction with appropriate long-term local knowledge and sound engineering management.

## Volunteer staff perspectives

The B&KR volunteers testing the system did not have any civil engineering background, and took time and explanation to come to terms with the definitions of the various parameters. However, after examination of first few sections of railway their speed of input increased to almost the same level as the authors.

Volunteers felt that not all parameters (for example *slope composition* and *size of adjacent catchment*) could be readily assessed from track level , whilst other parameters needed much clearer definition for a layman; for example explaining that defining slope face as *dry* did not necessarily mean literally 'bone' dry, so much as there being no observable drainage issues. Another issue raised was the difficulty for the layman in identifying the animals causing burrowing; the suggestion was made that this might be changed to simply recording the size of the burrows. Also noted was that in some cases the whole of a 100m section could not be observed from one place, and that it might be better to select different lengths of sections so that each one could be assessed without needing to move along the line. This would of course be a safety improvement if inspections are to be carried out when the line is under traffic.

Volunteers noted the range of questions on matters such as geology that could be answered only by desk study, and others such as whether or not *regular maintenance required* applied to a section, which could only be determined from local knowledge or records.

One volunteer took the view that the system was too prone to error, as "if the wrong option can be chosen, it will be." Also suggested was the addition of a *remarks* field on the forms to allow the on-site inspector to note any features that they cannot readily fit into the questions.

A further feature of discussions with volunteers was simply that the number of ticks required on the form, and the number of sections to complete the inspection, was excessive, and staff would not be motivated to do it. It was commented that "there was already enough paperwork in operating the track," and that only regulatory requirement would motivate them to use the earthwork risk assessment system. The use of separate questionnaires for cuttings and embankments was also thought to be a potential source of confusion and error. However, another volunteer did comment that he saw the point of having so many parameters to guarantee a comprehensive inspection, and that completing the forms made him think about the earthworks when previously he had not.

After the on-site inspection, volunteers were shown the data entry into Excel. This was generally found to be good with good use of functions to visually enhance ease of inputting data and sufficient redundancies and error checks to prevent the entering of incorrect information.

### Use on other railways

The most significant difference encountered in inspecting the Strathspey Railway was the length of the line. At 10 miles, it is twice the length of the B&KR and consequently involves many more inspection sections and corresponding paperwork. On the other hand, the earthworks are generally less extensive, and thus appear superficially to be less of a hazard, making motivating volunteers to carry out a detailed risk assessment more difficult. The earthworks are also more uniform over longer mileages than on the B&KR.

### Suggested developments

The evaluation of the earthwork inspection system by volunteer railway staff and its testing on the Strathspey Railway have given rise to a number of suggestions for further development in the future.

The main focus of these was to reduce the complexity of the system. One suggestion was to apply the system once, using it to highlight priority areas which could then be mapped and inspected regularly during routine track patrols. Use of fewer, longer sections, particularly where earthworks are uniform over a long distance as on parts of the Strathspey Railway, was also suggested.

More significantly, it was noted that a significant number of inspection parameters, most notably geology, past failures, weather risk and legal issues, are determined by desk study and not on site. It seems logical to remove these entirely from the on-site questionnaire to make it less daunting. The desk study can then be collected separately for each section and entered directly into the Excel spreadsheets.

A further possibility is to have ‘condensed’ on-site sheets for the second and subsequent inspections, given that many parameters such as slope height and angle, adjacent catchment area, etc, will not generally change. This would make regular repeat inspections more efficient.

A key issue if non-engineer, volunteer staff are to carry out inspections is to extend and clarify the definitions sheet. Realistically, for inspections carried out by volunteers to be reliable and repeatable, some training in the correct use of the system will be necessary. This will be relatively straightforward to provide, and will perhaps best be achieved in conjunction with an organization such as the Heritage Railway Association as part of its provision of guidance to the HR sector.

Whilst paper forms are a reasonable method of recording inspections, the NR system on which our work is based use hand-held computers, and one suggestion is to develop the HR system for use on a mobile device such as an iPad, which is something that many HR volunteers will possess, and which can potentially back up data via the 3G network as an inspection progresses. A test was carried out using an implementation of Excel directly on a tablet (which may not be the best way) and it was found that more time was required on site, with a corresponding saving in time spent entering data afterwards. It was noted that time spent on site is perhaps better minimized due to weather issues and the safety aspects of being on the line; data entry in an office (or home) environment has no safety implication and is not affected by weather.

Some volunteers suggested reducing the number of parameters entered in total; as discussed just above it may be possible to simplify inspections by eliminating desk studies and fixed parameters on re-inspections, but any global reduction in parameters assessed will only undermine the robustness of the system.

## CONCLUSIONS

An earthworks inspection system developed for use on UK Heritage Railways (HRs) has been evaluated for use by volunteer, non-engineering staff and by testing on two HRs. It is concluded that the system represents a comprehensive approach to manage the risk of earthwork assets, but it must be used in conjunction with appropriate local and engineering knowledge. Whilst the system could be used by volunteer, non-engineering staff, in order for this to be done in a robust manner training will be necessary. This would be straightforward to provide, perhaps under the auspices of the Heritage Railway Association.

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