Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0863

XVII European Conference on Soil Mechanics and Geotechnical Engineering
ECSMGE 2019 Reykjavik

Development and implementation of a landslide susceptibility zoning system for the UK rail network

Développement et mise en œuvre d'un système de zonage de susceptibilité aux glissements de terrain pour le réseau ferroviaire UK

I.M. Nettleton, G.M. Butler & M. Duffy-Turner
Coffey Geotechnics Ltd, a Tetra Tech company, Manchester, UK

A.J. Butler & R.M. Denney
Network Rail, Manchester, UK

H.J. Reeves & C. Dashwood
British Geological Survey, Keyworth, Nottingham, UK

ABSTRACT: During 2012 and 2013 six landslides occurred on Network Rail (NR) infrastructure in the UK, which affected the safety of the railway, and in some cases caused derailment of trains. A number of the landslides initiated on slopes outside NR's boundary. As a result, NR's London North West (LNW) route decided to investigate the options for identification and assessment of these natural hazards. The LNW Route runs from Carlisle in the north to London in the south and accounts for 24% of Britain's railways. An initial review indicated that developments in Geographic Information Systems (GIS) and the availability of digital terrain models (DTM) coupled with NR's and the British Geological Survey's (BGS) landslide inventories and the project teams experience of investigating landslides provided the opportunity to develop a Landslide Susceptibility Zoning system. An initial trial and ground truthing on two pilot routes was undertaken, which highlighted particular requirements for DTMs and geological mapping. The system was refined and rolled out across the LNW route in 2016 and has been applied to the whole UK rail network. This paper presents the authors' experiences and the critical issues for the development and implementation of such a system on country wide basis.

RÉSUMÉ: En 2012 et 2013, six glissements de terrain survenus sur l'infrastructure Network Rail (NR) ont affecté la sécurité de la voie ferrée et, dans certains cas, ont provoqué le déraillement des trains. Un certain nombre de glissements de terrain ont commencé sur des pentes hors des limites de NR. En conséquence, la liaison Londres Nord-Ouest (LNW) de NR a décidé d'examiner les options d'identification et d'évaluation de ces options. La route LNW relie Carlisle au nord à Londres au sud et représente 24% des chemins de fer britanniques. L'examen initial a révélé que l'évolution des systèmes d'information géographique (SIG) et la disponibilité de modèles numériques de terrain (MNT) associés aux inventaires de glissements de terrain de NR et du British Geological Survey (BGS); les ressources d'évaluation du glissement de terrain du BGS; et l'expérience des équipes de projet en matière d'enquêtes sur les glissements de terrain a été l'occasion de développer un système de zonage sensible aux glissements de terrain. Un premier essai et une vérification au sol sur deux itinéraires pilotes ont été entrepris, qui ont mis en évidence les besoins particuliers en matière de DTM et de cartographie géologique. Le système a été perfectionné et déployé sur la ligne LNW en 2016 et a été appliqué à l'ensemble du réseau ferroviaire britannique. Ce document présente les expériences des auteurs et les questions critiques pour le développement et la mise en œuvre d'un tel système à l'échelle du pays.

Keywords: Landslides; Slopes; Railways; Susceptibility; GIS

1 INTRODUCTION

There have been a number of historic and recent events where landslide material from slopes outside the Network Rail (NR) boundary, have resulted in derailments or caused damage to railway infrastructure. The source slopes of many of these failures have not been routinely assessed by NR and its predecessors. For example, in Scotland in 2000 / 2001 there were a number of slope failures, including a significant incident at Stromeferry where the failure of a slope from outside the railway boundary had a serious impact on railway safety. In June 2010 a passenger train was derailed on the Crianlarich to Oban railway line, just west of the station at the Falls of Cruachan, when the train struck a boulder that had fallen on to the track from a slope above a railway rock cutting slope. In August 2012 a train was derailed near Nethertown, on the Cumbrian Coast line, by a landslide from a natural coastal slope into which the railway had been cut (Photo 1).

Figure 1. Earth flow failure which derailed a train at Nethertown on the Cumbrian coast.

In the investigation following the Falls of Cruachan derailment the Rail Accident Investigation Branch (RAIB) highlighted that the risks posed by the slopes lying above cuttings (upper slopes) were not examined under the existing NR procedures (RAIB, 2011).

Following on from the above events, NR London North Western Route (LNW) decided to review their procedures against the NR Management of Earthworks (NR/L2/CIV/086) and Examination of Earthworks (NR/L3/CIV/065) standards (NR, 2011 & 2012). As a result, LNW decided to investigate the options for identification and assessment of natural and manmade earthworks (cuttings, embankments and slopes) which are located on land outside NR ownership (Outside Party Earthworks - OPE).

2 LANDSLIDE ZONING APPROACHES

There are three principal forms of landslide zoning (AGS 2007) as described below. There is much confusion over the difference between Susceptibility Zoning which does not include quantitative judgements of likelihood (frequency), and Hazard Zoning which does.

2.1 Landslide Susceptibility Zoning

This involves determining the location, classification, volume / area and spatial distribution of existing and potential landslides in the study area.

Landslide susceptibility zoning usually involves developing an inventory of landslides which have occurred in the past together with an assessment of the areas with a potential to experience landsliding in the future, but with no assessment of the frequency of landslides (annual probability).

In many cases susceptibility zoning needs to extend outside the study area to cover areas from which landslides may travel onto or regress into the area being zoned.

2.2 Landslide Hazard Zoning

This involves assigning an estimated magnitude and frequency of potential landslides to landslide susceptibility zoning.

The hazard can be expressed as the frequency of a particular type of landslide of a certain volume or landslides of a particular type, volume and velocity (magnitude) or, in some cases, as the frequency of landslides with a particular intensity where intensity could be measured in kinetic energy terms.

2.3 Landslide Risk Zoning

This takes the outcome of landslide hazard zoning and assesses it in terms of the potential damage to persons and to property, accounting for temporal and spatial probability and vulnerability.

3 UK LANDSLIDE ASSESSMENT

3.1 BGS - National Landslide Database

The first UK national assessment of landsliding was undertaken for the Department of the Environment in the mid-1980s (Foster, 2008). More recently, the resulting database has been updated and incorporated into the National Landslide Database (NLDB) which contains over 17,500 entries and is managed by the BGS (Foster *et al.*, 2008). Sources for the data entries include, the National Digital Geological Map at 1:10,000 scale (DiGMap10) and 1:50,000 scale (DiGMap50), media reports, journals and field mapping.

3.2 BGS - GeoSure

Building on the NLDB, GeoSure was developed by the BGS using a deterministic and heuristic approach to incorporate assessment of likely causative factors, hazard classification and the presence of the causative factors (Foster *et al.*, 2008). This is based on a 25m grid DTM with an output which groups together the various forms of landslides. Resulting scores identify the conditions with the potential for future landsliding, irrespective of previous instability events.

3.3 Transport Scotland

Following a series of debris flows affecting the Scottish trunk road network in 2004, Transport Scotland commissioned a GIS based hazard assessment of debris flow potential for the trunk road network in Scotland, led by the Transport Research Laboratory (TRL). The assessment included five components of debris flows: availability of debris; slope angle; hydrogeology; land use; and proximity of stream channels. The study output included a GIS layer highlighting slope susceptible to debris flows based on a 50m grid DTM (Harrison, *et al.*, 2008).

3.4 Forestry Commission

Forestry Commission (FC) in Wales and Scotland commissioned a GIS based study to identify and quantify landslide hazards which had the potential to affect 3rd party assets such as infrastructure, property and communities. BGS undertook this study using existing datasets as a desk based study (Foster *et al.*, 2012). Ground truthing and validation of around 100 locations in Scotland with high landsliding potential was subsequently carried out by Coffey and BGS.

3.5 Network Rail Inventories

NR hold a database (CIV28) of all earthworks failures that have caused an operational restriction to be placed on a line. In addition, NR collate a register of problem sites (Butler, 2013).

4 NETWORK RAIL APPROACH

For NR to identify OPEs which present '…*an unacceptable risk to the safe operation or performance of the railway*…' (NR, 2011) in a defensible, logical and prioritised manner it was decided that an initial screening approach should be developed using a landslide zoning methodology. This was to be based on Geographic Information System (GIS) techniques and historical landslide records (landslide inventory) to provide a landslide susceptibility zoning as described by Fell *et al.* 2005, AGS, 2007 and JRC, 2007.

To enable a hazard and ultimately a risk assessment to be undertaken an analysis of the frequency of landsliding (likelihood assessment) and the run-out of potential landslides (i.e. was there a potential to reach the railway?) was required.

UK railway convention is that track is split into lengths called *chains* (unit of length equivalent to 22 yards (~20.1m) and examinations and management is based on '*5 chain lengths*' (equivalent to 110 yards (~100.5m). Hence, all screening had to be undertaken for the railway based on 5 chain lengths; which may contain earthworks on one, both or neither sides of the railway.

Following the initial project meeting (NR, 2013) and the review of UK and international practice, the following approach was deemed appropriate.

5 PHASE 1 - DEVELOPMENT, RESEARCH AND PILOT STUDY

For the development of the methodologies, two pilot study two areas of the railway; between Carnforth and Penrith and Silecroft to Workington, were identified to use as pilot areas. These two sections of railway contain a significant number of existing landslides across the various landslide classifications. These areas encompassed a wide variety of terrains and contain significant drainage issues. NR, Coffey and the BGS used their detailed 'on the ground' experience in these areas to assist with the validation of the approach.

5.1 Landslide Susceptibility Zoning Development

A catchment layer identifying catchments directly adjacent to the railway in the two pilot areas was developed to provide initial potential source areas for water and landslides. This identified 56 separate catchments along the railway in the pilot areas.

A buffer zone layer was developed based on the catchments and a distance from the railway, and was intended to denote areas from which landslides may affect the railway. A wavy line buffer was created by using either the edge of the catchment or in the instance of a large catchment a distance of 500 m either side of the railway.

Based on discussions with NR (Butler, 2013 & NR, 2013) the BGS NLDB and GeoSure susceptablity layers were amended and additional layers developed including debris flow, rock fall and earth flow susceptibility as described further below.

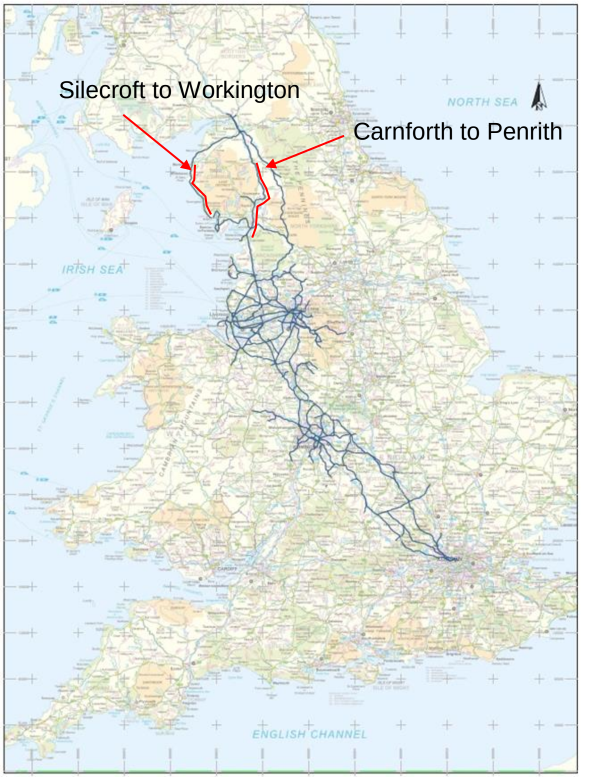

Figure 2. London North West Route (blue) and the Carnforth to Penrith and Silecroft to Workington pilot areas (red). Contains OS data © Crown copyright and database rights (2018).

5.1.1 Landslide Inventory & Geosure

The NR CIV28 database of failures that have caused an operational restriction to be placed on a line, and the register of reported problem sites (Butler, 2013) were reviewed and incorporated into a rail specific version of the BGS National Landslides Database. This yielded 46 landslide data points in the pilot study areas.

For the NR pilot study areas the BGS GeoSure layer was reprocessed using a 5m gridded DTM to provide enhanced resolution.

5.1.2 Debris Flow

For the debris flow layer the methodology developed for the Tansport Scotland debris flow hazard assessemt (Section 3.3) was followed.

5.1.3 Rock Fall Susceptibility

A methodology was developed which utilised the heuristic BGS GeoSure approach and applied different causal factors and scoring algorithms based on rock outcrop; rock strength; discontinuity spacing; rock mass variability; and slope angle from the 5m grid DTM.

5.1.4 Earth Flow – Washout

Given the significant variation in glacial till deposits it was important to try and differentiate the different types of till enabling better clarity of the landslide susceptibility of these materials. The Nethertown landslide in August 2012 (Figure 1) provided a good example of the significance of these materials in major landslide events. The BGS GeoSure methodology was developed to incorporate the latest BGS Till Domain Map or Till Thematic Layer, taking account of the till type; variability; multilayer lithology; and slope angle. The assessment was made with a 5m grid DTM to provide enhanced resolution.

5.2 Scoring

For each catchment the landslide susceptibility score for each hazard layer was derived by assigning one of five categories from low to high susceptibility. The total landslide susceptibility for each catchment was derived by adding the contributions from each layer and assigning a total landslide susceptibility class (Total Class) between 1 (Low) and 4 (Very High).

5.3 Ground Truthing & Results

Following the initial development of the landslide susceptibility layers and application of the system on the two trial pilot areas of the network a ground truthing of seven sites was undertaken to validate the results utilising site inspections and assessment of aerial photography. This was then used to further refine and calibrate the causal factors scores, scoring algorithms and susceptibility classes and their boundaries.

This study adopted the catchment scale analysis and identified 29 catchments of the total 56 within the pilot area where landslide susceptibility was considered to be high to very high. This result matched the project team’s knowledge of the areas derived from the investigation and remediation of landslides in the areas.

6 PHASE 2

The aim for Phase 2 was to generate a GIS based landslide susceptibility zoning model for the whole LNW route.

The LNW route runs from Carlisle in the north to London in the south and it consists of approximately 4,500km of track (Figure 2).

The methodology developed in Phase 1 was applied to the whole LNW route. Following a review of aerial photograph imagery (Google Earth) combined with the initial outputs from the GIS landslide susceptibility layers, 22 locations (approximately 2% of LNW route) were selected for a field calibration across the LNW route. Each location was chosen to represent one or more of the GIS susceptibility layers: NLDB; GeoSure; Rock Fall; Debris Flow; and Earth Flow. Field calibration visits were undertaken by Coffey and BGS. Based on the findings of the field calibration visits the individual GIS layers were reviewed and, where considered necessary, the parameters updated.

6.1 Landslide Hazard Layer Updates

The NLDB and GeoSure layers were found to be functioning as expected and no updates were made.

The Debris Flow layer was generally functioning as expected but was found to not pick up the smaller debris flow source areas using the 50m DTM. Unfortunately, at the time it was not possible to process the whole of LNW route with a

5m DTM. However, to understand how a more detailed DTM would affect the debris flow layer a known debris flow area (Aisgill) was processed using the enhanced resolution. Figures 3 and 4 show the extract for Aisgill which shows the debris flow source areas using the 50m and 5m DTMs respectivelu (red and green represent Very High and Low susceptibility respectively).

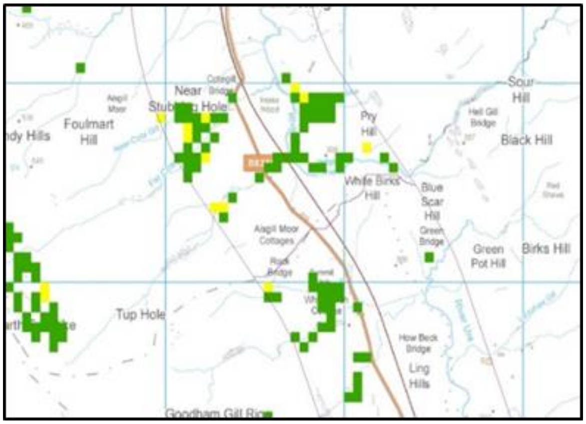

Figure 3. Aisgill processed with 50m resolution DTM

For the Debris Flow layer it was also found that DTMs tend to average out slope angles meaning the lower slope angle thresholds were too high; therefore, these were reduced to 5° for peat and 26° for other soils.

For the Rock Fall layer it was found that the rock outcrop ornament on the Ordnance Survey (OS) 25,000 scale mapping was not as representative as that on the OS Mastermap mapping. The overall methodology was simplified to look for medium strong (or stronger) rock combined with slope angles greater than 35° (angle reduced to account for DTM averaging of slopes) and / or a cliff ornament on the OS Mastermap.

For the Earth Flow layer it was found that the variability and multilayer criteria (Section 5.1.4) tended to double count and over influence the results. Hence, criteria was reassessed and based purely on a lithological characterisation.

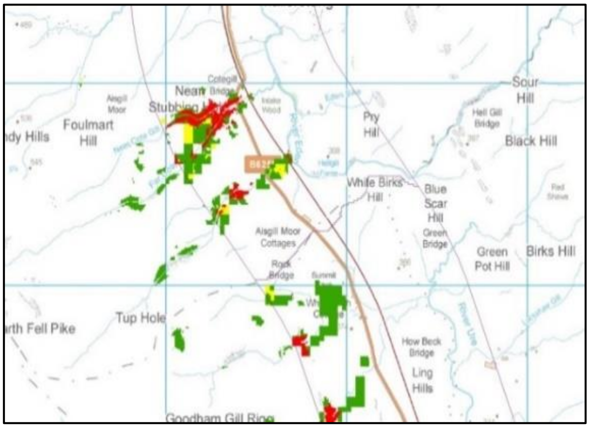

Figure 4. Aisgill processed with 5m resolution DTM

6.2 Scoring

For each of the 1114 catchments within the Phase 2 study the maximum score for each landslide susceptibility layer was determined by the highest score value of that layer in the catchment, irrespective of distance from the track.

The maximum score from any of the 5 landslide susceptibility layers (between 1 and 5) for each 5 chain length was taken and assigned a Max Class value in accordance with Figure 5. The Max Class is represented by the values A to E in accordance with NR requirements, with A being the lowest susceptibility to landsliding and E being the highest.

6.3 Validation

In total 1114 catchments were identified along the LNW route and 110 of the catchments (approximately 10% of the total no.), were subject to a validation process to evaluate whether the GIS results were representing site conditions. A random number generator was used to select catchments which would be part of the validation process.

Max Score	Max Class	Susceptibility
1	A	Very Low
2	B	Low
3	C	Moderate
4	D	High
5	E	Very High

Figure 5. The final scoring system.

A basic review of each catchment was undertaken looking at which GIS susceptibility layers were present and determining access for field validation. 56 catchments with good access routes were selected for field validation and 54 catchments were selected for Aerial Photograph Interpretation (API).

The aim of the validation was to identify any possible landslide, debris flow, earth flow or rock fall potential areas within a catchment and to try and manually attribute a value to it as per the scoring system.

The validation led to 16 of the catchment being down graded in score and two being upgraded. Two points stand out:

- Man-made earthworks tended to score too high as the slopes were steeper than the natural geology would suggest is stable.
- The use of the 50m DTM for the Debris Flow layer led to one area of known debris flow problems having to be manually upgraded. This was due to the lack of resolution of the debris flow source area. Figures 3 and 4 show the difference between a 50m and a 5m DTM.

7 RESULTS

The purpose of the study was to highlight areas of the LNW route potentially susceptible to landslides from Outside Party land (natural slopes). The study highlighted the presence of any pixel(s) of low to very high susceptibility rating from any of the five landslide susceptibility layers (GeoSure, Debris Flow, Earth Flow, Rock Fall and NLDB), within the 5 chain length sections. This methodology skews the results to a worst case scenario; however, the presence of any D or E ratings within the 5 chain length is important and needs to be reported. Results for the whole route are presented in Figure 6.

Max Class	No. 5 chain lengths	% Across Whole Route
A	262	2.76
B	30589	90.29
C	15013	5.29
D	12341	0.98
E	7838	0.67

Figure 6. Number of 5 chain lengths and % of area in each Class.

An indication of landslide susceptibility does not necessarily mean that a location will definitely be affected by ground movement. Such an assessment can only be made by full inspection and investigation of the area in person.

The Area (pixels) of A, B, C, D and E values within each 5 chain length was compared to the Area of the buffered 5 chain lengths for the whole route. This allowed assessment of the extent of landslide susceptibility across the route.

The results showed that although 12% of the 5 chain lengths (7,838 out of 66,043) were assigned an E category, only 0.67% of the whole route was actually flagged with E ratings (on an Area basis).

8 CONCLUSIONS

The project successfully developed and validated a GIS based strategy and system for assessing the landslide susceptibility from land outwith NR's ownership. Over 66,000 approximately 100m lengths of cutting, slope and embankment were assessed.

DTM sampling grid tends to ‘smooth’ landform features out, sometimes leading to reduced or averaged out slope angles. This is particularly significant for steep, relatively low height, rock outcrops which as a result may not be flagged and for setting slope angle thresholds for landslide susceptibility categories.

DTM sampling grids need to be used which will appropriately resolve small source areas. In many cases 5m DTM grids will be required.

Historical geological mapping was used for a variety of purposes, and for detailed landslide assessments detailed upto date mapping of superficial dposits is required

9 ACKNOWLEDGEMENTS

The authors would like to thank Network Rail for the opportunity to develop the approach and their colleagues for the many technical discussions. This paper is published with the permission of the Executive Director BGS (UKRI).

10 REFERENCES

AGS. 2007. Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management. Australian Geomechanics Society, Australian Geomechanics, Vol 42, No1.

Butler, A.J. 2013. Personal Communication, Senior Asset Engineer (Geotechnical), London North West Zone, Network Rail.

Fell, R., Ho, K.K.S., Lacasse, S., Leroi, E., 2005. A framework for landslide risk assessment and management. In: Hungr, O., Fell, R., Couture, R., Eberhardt, E. (Eds.), Landslide Risk Management. Taylor & Francis, London, pp. 3–26.

Foster, C., Gibson, A.D. & Wildman, G. 2008. The new national landslide database and landslide hazards assessment of Great Britain. In: Sassa, K, Fukuoka, H & Nagai, H + 35 others (eds), Proceedings of the First World Landslide Forum, United Nations University, Tokyo. The Int. Promotion Committee of the International Programme on Landslides (IPL), Tokyo, Parallel Session Volume, 203-206.

Foster, C., Reeves, H.J., Pennington, C., Hobbs, P.R.N., Culshaw, M.G., Plim, J., Smith, J.T., MacCulloch, F., Queen, G., Winter, M.G. 2012. Landslide hazard assessment and characterisation for forestry asset management in Great Britain. In: Eberhart, E., (ed.) Landslides and Engineered Slopes: Protecting Society through Improved Understanding. Proceedings of the 11th Int. & 2nd North American Landslides Symposium, Banff, Alberta, Canada, 2-8 June. CRC Press, 6pp.

Harrison, M., Gibson, A., Forster, A., Entwisle, D and Wildman, G.(2008).GIS-based assessment. In: Scottish Road Network Landslides Study: Implementation (Eds: Winter, M G, Macgregor, F & Shackman, L), 47-64. Transport Scotland, Edinburgh.

Network Rail. 2011. Management of Earthworks, Standard NR/L2/CIV/086. Network Rail, London, UK. 23pp.

Network Rail. 2012. Examination of Earthworks, Standard NR/L3/CIV/065. Network Rail, London, UK. 22pp.

Network Rail. 2013. Evaluation of Geotechnical and Drainage Risks from Third Party land - Meeting Minutes, 13th April 2013. Network Rail, Manchester.

RAIB. 2011. Accident at Falls of Cruachan, Argyll, 6 June 2010. Report 11/2011, Rail Accident Investigation Branch, Department for Transport, Derby: UK. 44pp.