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Landslide Hazard Assessment for National Rail Network

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Abstract

There have been a number of high profile reports of landslides on the national rail network of Great Britain (comprising England, Scotland and Wales) over recent years. Events range in size from small wash out failures (St. Bees, Cumbria) to well publicised large failures causing major longer term disruption (Hatfield Colliery, South Yorkshire). In conjunction with negative media attention, derailment and damage to railway infrastructure, failures along the rail network have the potential to cause injury and loss of life.

The national rail network comprises ten strategic routes that cover a variety of terrains and geologies. The British Geological Survey (BGS) have produced, for Network Rail, a high level susceptibility model of landslide hazard from Outside Party Slopes adjacent to the strategic rail network. This assessment was compiled based on Geographic Information System (GIS) techniques and historical landslide records (landslide inventory). The model was designed to give a high level overview of potential landslide hazard to Network Rail senior management and individual Route Asset Managers.

The national study adopted a fixed buffer style analysis of each 5 chain section (~100 m length) of the entire railway network. It included event data from the BGS National Landslide Database superimposed on mapped data from the BGS GeoSure land instability susceptibility model and geologically mapped landslide polygons. The National Landslide Database is the most comprehensive inventory of landslide events in Great Britain. The BGS GeoSure slope instability layer provides a scientifically based 1:50 000 scale assessment of national susceptibility to natural slope failure.

The results of this study have been provided as a spatially attributed dataset with total hazard susceptibility scores A (low)–E (high). Maximum hazard scores are attributed for both up and down-track and 5 chain length for the full network. A high score indicates where conditions imply a significant potential for future landslide hazard. Further refinement of the hazard layers are being developed by BGS to include specific landslide processes such as Rockfall, Earthflow and Debris Flow hazards.

Keywords: *Landslide hazard assessment, Geographic Information System (GIS), Rail infrastructure, Asset Management*

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1 Introduction

When compared with an international context, landslide events within Great Britain (GB) (comprising England, Scotland and Wales) are not a catastrophic phenomenon. GB does not experience the same massive life-claiming natural disasters as reported in countries such as China (Yin, et al., 2009) or the frequency of events as countries such as Italy (Guzzetti, et al., 2006); however, occasional loss of life is sadly reported (Gibson, et al., 2013) but these are isolated incidences. Nonetheless, GB does have abundant relict landslides (remnant features from a post-glacial climate), numerous failure-susceptible lithologies, exposed coastal sections, aging infrastructure slopes and changing weather conditions. This means that landslides still have a significant impact on economy and society; including transport infrastructure.

Figure 1: Network Rail tracks affected by Hatfield Colliery landslide. Photograph taken 23rd February 2013. T. Dijkstra ©NERC

Between 2012- 2014, GB experienced abnormally wet winters. The numbers of reported landslides increased dramatically; in part, a direct result of the affect that they were having on the infrastructure network causing road blockages, commuter disruptions and infrastructure damage (Pennington & Harrison, 2013). A number of high profile events caused specific disruption to rail travel, derailment and major damage to critical railway infrastructure. Examples of such high profile cases were documented in the Rail Accident Investigation Branch Landslips Class Report 2012/13, published in 2014 (Department of Transport, 2014). Events ranged in size from small wash out failures (St. Bees, Cumbria) to well publicised large failures causing major, longer term, disruption (Hatfield Colliery, South Yorkshire; Figure 1). Events such as these gain high levels of media interest and negative attention.

On inspection, a number of these events were declared the result of landslide material failing from upper slopes, and, in some cases, slopes beyond the Network Rail (NR) boundary. Further failures along the rail network have the potential to cause further infrastructure damage, serious injury and even loss of life. It was thus recognised by NR that information on their own property holdings (including engineered embankments and cut slopes) were recorded, however, slopes adjacent to their own land were an unknown potential hazard. Within the NR network there are ten national strategic routes that cover a variety of terrains and geologies. Individual manual assessment of each section of track is not a viable option, and direction is needed in order to ascertain the sections of track having a higher potential for landslide hazard.

Based on Geographic Information System (GIS) techniques and historical landslide records (landslide inventory), the British Geological Survey (BGS) compiled an appraisal of the entire strategic network for NR; it was designed to give a high level assessment for potential landslide hazard due to outside party slopes. Using available BGS hazard datasets, the national study adopted a fixed buffer style analysis of the entire GB railway network. Historical landslide event data were included from the BGS National Landslide Database and geologically mapped landslide polygons; these were superimposed on mapped data from the BGS GeoSure land instability susceptibility model. This paper is reporting on the research carried out to-date.

2 Landslide Event and Susceptibility Mapping

The GB strategic rail network is referred to by distances of Earthwork Inspection units, which are 5 chains (~100 m) in length. Each Earthwork Inspection 5 chain (5ChLen) was defined on the GIS, and an up or a down side attributed to it. A 500 m buffer extending perpendicular to each up and down 5ChLen was created. The 500 m buffer was selected based on previous experience of assessing landslide hazard and potential run out pathways (Dashwood, et al., 2013). This buffer was applied to BGS datasets; a landslide inventory, comprising data from the National Landslide Database (NLD) and mapped landslide deposits (DiGMap50), and a land instability (landslide) susceptibility map (GeoSure).

2.1 Landslide Inventory

Historically, geological mapping has recorded the location of identifiable landslide deposits as ‘landslip’ on field slips. Due to controlling factors such as: natural landform degradation, minimum-scale mapping rules, and identifiable visible extents, the physical recording of deposit detail on a map is not always possible and therefore not captured. Likewise, whilst various landslide types are recognised in field locations, they are rarely classified on geological maps. With the exception of specialised maps for applied geological studies, landslide deposits are commonly mapped as ‘Mass Movement deposits’. Many historical, paper-only geological maps have been digitised retrospectively, thus, in these areas landslide deposits are spatially represented on the published digital 1:50 000 geological maps of Great Britain (DiGMap50) with no further information.

Alongside geological maps, further sources of information may include historic inventories, research papers, and mapping surveys. More recent events can now be recorded from media and social media (Pennington, et al., 2015). However, new events do not appear on geological maps, nor do some other listed data that may identify deposits that were not focused on by historical mapping regimes.

Using these sources, the NLD is the most comprehensive inventory of landslide events in Great Britain and the database currently holds information for over 16 500 records (Pennington, et al., 2015). NLD data are point based, held in an Oracle database, thus can be recorded without a corresponding spatially mapped deposit. Each event entry has an identification number (NLD ID) and is documented with information on location, name, and full bibliographic reference. Where possible, further information is documented: size and dimensions, landslide type, movement date and age, trigger information, and damage caused. The NLD is continually being updated as new events are recorded or reported (Taylor, et al., 2015).

The Oracle database is linked to an ArcGIS which displays the NLD landslides as point data (Figure 2). Using this in parallel to the DiGMap50 mass movement layer ensured all BGS records of historic or recent movement, within the buffered railway network, were included in the model as a landslide inventory.

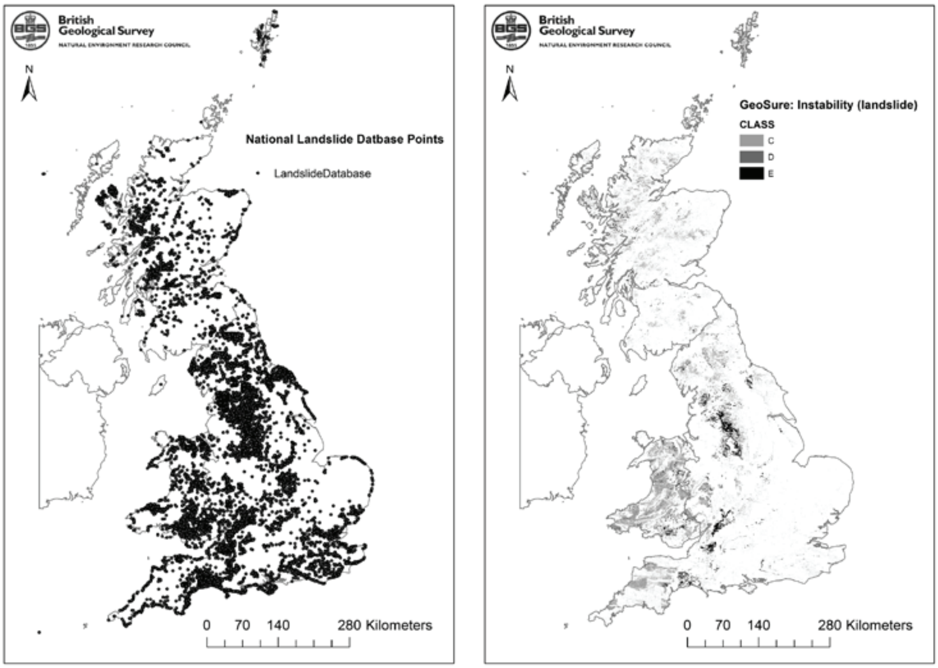


Figure 2: Two of the national data sets used to compile the Network Rail Outside Party Slope hazard model: a) The National Landslide Database and b) GeoSure: Slope instability (landslide) map ©NERC Coastline Ordnance Survey © Crown copyright 2015

2.2 GeoSure: Potential Slope Instability Layer

Unstable slopes occur when particular characteristics of the slope combine to induce instability. The national GeoSure: Landslides (slope instability) layer provides a scientifically based 1:50 000 scale assessment of the potential susceptibility to natural slope failure at a location; using an algorithm combining slope angle, material strength, and the known susceptibility to instability of different lithologies. GeoSure data was initially designed to provide ground stability information, relevant to a wide range of users: in central and local government, insurance and housing industries, engineering and environmental businesses, and the British public (Lee & Diaz Doce, 2014).

The data are combined using a multi-criterion technique and expert knowledge, applying a series of rules against the available data to provide a hazard 'score' at each location (Lee & Diaz Doce, 2014). The GeoSure landslide layer methodology does not categorically map where a site has failed historically; this information is taken into account in the layer's algorithm where there is a spatially mapped deposit and expert interpretation, thus the NLD forms an equally important data feed into a landslide hazard susceptibility assessment. A high susceptibility score of D or E indicates that the ground conditions imply a significant potential for future ground movement via down slope movement of material (Figure 2; Table 1). The hazard rating for each 5ChLen was compiled by calculating and recording the percentage of each GeoSure A-E category contained within the buffer area.

As this study was requested as a first phase, high level, study of hazard location, a different phenomenon to hazard pathway or potential risk, the highest ranked category present within the buffered length was used as the final rating regardless of percentage coverage. Any buffered 5ChLen with either an NLD point or historically mapped landslide present was given an 'E' final rating. This overrode the projected GeoSure score where appropriate, ensuring the inclusion of historically recorded movement into the methodology (Table 1).

Hazard Potential Rating	Interpretation
A	Slope instability problems are not thought to occur, but potential problems of adjacent areas impacting on the site should always be considered.
B	Slope instability problems are not likely to occur, but potential problems of adjacent areas impacting on the site should always be considered.
C	Slope instability problems may be present or anticipated. Site investigation should consider specifically the slope stability of the site.
D	Slope instability problems are probably present or have occurred in the past. Land use should consider specifically the stability of the site.
E	Slope instability problems almost certainly present and may be active. Significant constraint on land use. *Rating E is automatically assigned if landslide database point or DiGMap mass movement polygon recorded within buffered zone.*

Table 1: Descriptions for the GeoSure Hazard ratings used in the assessment of the strategic rail network

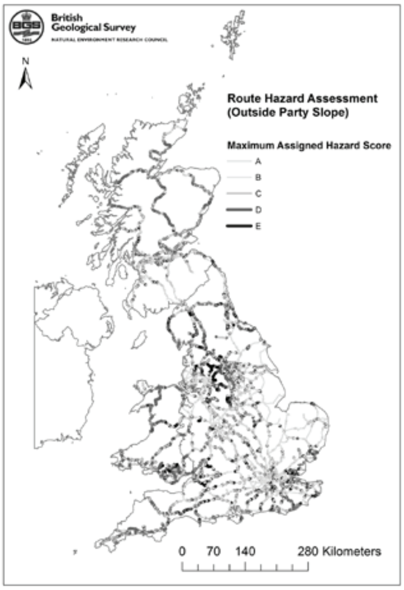
3 Discussion and Future Development

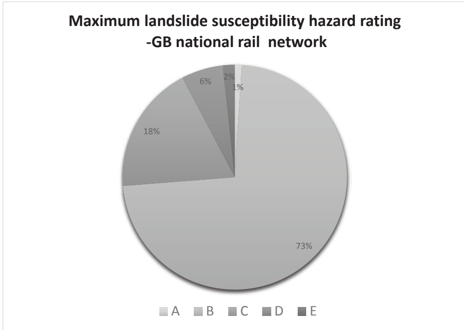
The final results are presented as a spatially attributed dataset displaying the highest total hazard susceptibility score using GeoSure hazard classifications with a modification for category E (Table 1). Scores are attributed for the up-track, down-track and 5ChLen, for both the full network and the ten Regional Routes. This initial study indicates that 26% of the total buffered railway has a combined hazard rating of C or above, 8% is classified as having a hazard rating of D or above and less than 2% is classified as E (Figure 3).

Combining the factors causing slope instability does not mean a damaging event **is** going to occur at that location; it is solely an indication of how many causative factors may be present, thereby increasing susceptibility. The material of a slope may weaken due to weathering, the slope may be steepened by undercutting or a wet winter or severe rainfall event could weaken rocks. For example, it is unlikely that a relict post-glacial landslide in the County of Derbyshire would be as susceptible to failure under current climatic conditions, however some areas may become unstable and reactivated through severe rainfall or human intervention. Thus, if an area is classed as level D, it is possible a relatively small change in conditions might cause a ground movement to take place. Any of the contributing factors could become more significant. A high hazard rating score indicates where datasets show that conditions are conducive to a significant potential for future landslide hazard, or a record of historical movement. As the interpretation is based on the natural slope, it does not take into consideration sections where remedial action may have already occurred.

The value of this dataset lies in the potential to derive efficiencies for prioritisation of field inspection: this in turn contributes to the prioritisation of any third party negotiations or remediation. Whilst national study provides an overview of the susceptibility for the full strategic network, further detail and prioritisation can be achieved through regional route analysis. The resultant data were combined with NR Consequence matrix data. This adds significance to the potential hazard score by indicating the sections of the network which would have the greatest impact if an outside party slope did fail; low impact is given a value of 1 and high impact is given a value of 5. Using this methodology

<1% of the network is currently regarded as 'E5' –high on both hazard rating and consequence matrix (Figure 3). Desk based individual route analysis using this method offers further prioritisation of infrastructure investigation.





	Hazard rating score					
Consequence Matrix	A	B	C	D	E	Total
1	0.03	6.45	2.73	1.17	0.23	10.60
2	0.07	8.35	3.47	1.73	0.38	13.99
3	0.14	21.24	8.74	3.84	1.04	35.00
4	0.11	14.05	5.01	1.50	0.65	21.32
5	0.12	13.38	4.18	0.99	0.41	19.09
Total	0.47	63.46	24.12	9.24	2.72	100

Figure 3: The national coverage of the rail network and sample of the resultant attributed hazard score are shown in the above image. This is taken from the fully attributed model output results. Also shown is an example national summary, combining the Network Rail consequence matrix with landslide hazard score and the resultant percentages. Coastline Ordnance Survey © Crown copyright 2015

The methodology and data allow a desk-based high level assessment of both national and regional assessment of hazard susceptibility. The areas identified will form the basis of the prioritisation of ground truth exercises. Within the final dataset attribute table, separate scores are attributed for each up-track & the down-track 5ChLen, thus providing more transparency as to the origin of the hazard score. This model does not offer interpretation as to pathway or likelihood; it does not factor in the size of hazard, distance from track or of travel, or any impeding factors prior to the network (e.g. rivers, slopes). The results show sections of track where outside party slopes may be affected by natural extreme weather events. It also highlights sections where alterations to the land surface may need to consider the effects on landslide hazard for the railway. For the most part, this will be managed through the application of planning or guidance, enforced by local governments.

In relation to historic landslide information, all recorded deaths due to landslide events in the UK have resulted from rock falls, debris fall or debris flows (Gibson, et al., 2013). As a result of the algorithm and methodologies used, GeoSure will highlight steep slopes and steep rock slope faces, however the product is most successful when considering rotational and translational slides (Lee & Diaz Doce, 2014). Therefore to add further intelligence and integrity to infrastructure modelling such as this, national Debris Flow (Winter, et al. 2005), Earth Flow, and Rock Fall models are being further developed and improved; based on specific factors known to affect these types of failures.

The methodologies for these models have been developed and tested through previous studies, and successfully applied to one regional route in a separate NR project. The models are now being further developed and modified by BGS to be a national scale resource. Once complete these will feed into a more detailed national landslide hazard assessment of Outside Party Slopes to the strategic railway.

Compared with other landslides Debris Flows have a different set of criteria that can lead to their initiation. Published literature indicates that debris flows may be triggered at angles above 30°; however, some evidence is available of flows originating at angles as low as 26° with the exception of peat, which is known to fail at much lower limits (Winter, et al., 2005). The Debris Flow hazard potential layer considers four components in conjunction with slope angle: availability of debris material, hydrogeological conditions, land use, stream channels (Foster, et al., 2012). This analysis has been carried out through an iterative process of attributing or manipulating each of the listed datasets to represent as many of the factors as possible that contribute to debris flow hazards (Harrison, et al., 2008). For example, expertise has been applied to DiGMap to change the standard attribution of polygons (age and type of rock) to numerical codes that estimate bedrock permeability and the degree to which source material for debris flows can be formed.

Production of a national Rockfall model is also underway. Current assessment relies on the identification of the top of crags and cliffs using breaks in slope. The location of these features, combined with engineering property data and a Digital Terrain Model (DTM), will then be used as the input of a model, mapping potential propagation area for a rockfall (Jaboyedoff & Labiouse, 2011).

The presence of variable fine-grained material and multi-layering within glacial till deposits can result in Earth Flow failures from a slope. These can be either slow or rapid but the translational movement can make the slope prone to long term instability (Skempton, et al., 1989). Using a domain map of UK Till deposits of the UK (Entwisle & Wildman, G, 2010), tills are scored according to their relative susceptibility to earth flow (washout) type failures. This scoring system also includes glaciofluvial deposits to represent the influence of interbedded sand and gravel lenses. The data have been combined with a Digital Terrain Model (DTM) and slope angle boundaries to create a refined Earth Flow susceptibility model.

This methodology of combining data to produced hazard models for specific infrastructure could be applied to other forms of hazard assessment (e.g. compressible deposits) or established infrastructure (e.g. highways). Such research can provide a high level assessment of hazard potential along a network, thus forming a method of prioritising research, man power or field investigation for future resilience studies.

4 Conclusion

The study here demonstrates the value of combining multi-layer geological data and information to provide infrastructure companies with an overview hazard assessment presented by outside party slopes. The methodologies described could be applied for additional geohazard or similar international infrastructure assessment, should the susceptibility mapping and historical inventory data be available.

Assessing an area's susceptibility to a geohazard requires knowledge of the distribution of failures combined with an understanding of the causative factors and their spatial distribution. In this example using proven hazard susceptibility modelling data, and integrating it with comprehensive landslide inventories, has given both a regional and national level understanding of potential landslide hazard from Outside Party Slopes, to a strategic rail organization at 100 m scale. The data can now be used to aid site prioritization for ground level investigation or negotiation with third party owners.

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