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Development of a landslide susceptibility assessment for a rail network

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ABSTRACT

This paper examines the applicability of a landslide susceptibility assessment approach to engineered slopes using data from the Irish Rail network. A logistical regression model was used to determine the susceptibility of landslide occurrence on an asset by asset basis using input factors derived specifically for man-made earthworks. Records of past failures were used to train the model to predict the probability of future failures occurring. The model was used to analyse a substantial section of the Irish Rail network comprising of 1184 slopes. The database of assets was split into training and validation datasets and similar levels of predictive performance were achieved with both datasets indicating the applicability and robustness of the approach. The results of the study show that simple asset databases, partially populated by visual survey data, can be used effectively to carry out a landslide susceptibility analysis. This enables proactive identification of critical assets as opposed to the current reactive industry standard, which represents an important step forward in creating objective risk rating systems for transport network earthworks.

1. Introduction

Landslides are a serious geohazard across the world, resulting in financial losses measured in hundreds of billions euros in damage annually (Aleotti and Chowdhury, 1999), injuries and fatalities (Zêzere et al., 2008; Klose et al., 2015). One of the areas where consequences are high is along major transportation networks, where damage to infrastructure causes significant delays, high replacement/rehabilitation costs and impacts the reputation of the operator. Significant research effort over the last twenty years has been focussed on predicting the triggering mechanisms for landslides, their spatial and temporal distributions and their consequences. As a result, a number of techniques for mapping landslide susceptibility, hazard and risk have been developed and applied to different geographic areas (Guzzetti et al., 1999; Aleotti and Chowdhury, 1999; Dai et al., 2002; Lee and Jones, 2004; Fell et al., 2005; Corominas et al., 2014).

Landslide susceptibility assessments (LSA) considers the likelihood of landslide occurrence in a given study area. It can be considered as an initial step in the landslide hazard and risk assessment process. These extend susceptibility assessment by incorporating temporal characteristics (return periods), landslide magnitude as well as their consequences on elements at risk (Varnes, 1984). Landslide susceptibility assessment methods can broadly be considered as either qualitative or quantitative approaches. Qualitative methods are subjective as they rely solely on expert opinion and engineering judgment. For example, geomorphological mapping uses available maps or terrain surveys to determine landslide susceptibility by identifying sites with similar geological and geomorphological features to those where landslides have previously occurred. These approaches usually include different ranking processes achieved by weighting the various input factors. Although these methods result in numerical values of susceptibility they are still qualitative as the weightings are attained through expert opinion. The most widely used methods include the analytic hierarchy process (Yalcin, 2008; Komac, 2006) and the weighted linear combination (Ayalew et al., 2004; Akgun et al., 2008; Ahmed, 2015).

Quantitative methods are based on finding a numerical correlation between input factors and landslide occurrence. This correlation can be obtained by either a deterministic or a statistical approach. These inputs factors normally include a range of topographical, geological, geotechnical and environmental characteristics of the study area, typically presented in thematic GIS maps. The deterministic approach is based on geotechnical slope stability calculations, and requires either exhaustive knowledge of geotechnical input data or else the simplification of geotechnical and geometrical features (Van Westen et al., 2006; Godt et al., 2008). The statistical approach is based on determining the influence each input factor has on landslide occurrence within the study area by examining past failure data using a variety of statistical techniques.

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Once the influencing factors have been determined, they can then be used to determine the probability of landslide occurrence in other parts of the study area (Carrara et al., 1991).

As statistical methods rely heavily on large datasets for accuracy, having a detailed landslide inventory is an important requirement in order to obtain meaningful results. Multivariate statistical methods simultaneously evaluate the influence that multiple factors have on landslide occurrence, and are widely used in research. Methods including discriminant analysis (Baeza and Corominas, 2001; Süzen and Doyuran, 2004), logistic regression (Dai et al., 2001; Ohlmacher and Davis, 2003; Ayalew and Yamagishi, 2005; Bui et al., 2015) and artificial neural networks have also been developed and widely applied (Ermini et al., 2005; Yesilnacar and Topal, 2005). Comparisons of the performance of these methods can be found in the literature (Nefeslioglu et al., 2008, Yilmaz, 2010, Park et al., 2013, Kavzoglu et al., 2014). As each of the methods has different input requirements, their applicability varies depending on the size of the study area and the scale/availability of input data (Van Westen et al., 2008; Cascini, 2008; Corominas et al., 2014).

Although numerous examples of the development and application of LSA techniques for natural slopes can be found in the literature, there is a dearth of information related to man-made or engineered slopes on transport networks. Given that relatively small landslides are sufficient to cause serious accidents such as train derailments (Fig. 1), the consequences of these slips can be high. Anthropogenic factors related to construction means that in general cut slopes and man-made embankments are at a higher risk of failure than natural slopes with similar geometry (Jaiswal et al., 2010a, 2010b). While landslide susceptibility, hazard and risk assessments for transportation networks are considered in Budetta (2004), Remondo et al. (2008), Bednarik et al. (2010), Jaiswal et al. (2010a, 2010b, 2011), Quinn et al. (2010), Das et al. (2010), Michoud et al. (2012) and Devkota et al. (2013), they usually refer to natural terrain landslides in the buffer zone around relatively short segments of a transport network, and do not deal specifically with the stability of engineered slopes across the entire network. Landslides on cut slopes and fill slopes are briefly discussed in recent risk zoning guidelines by Fell et al. (2008). One possible explanation for the lack of treatment of network wide LSA's is the difficulty in obtaining records of past landslides. Both the earthworks themselves and the landslides triggered on them are of much smaller magnitude than those commonly reported on natural slopes and the debris is usually quickly removed. This makes the preparation of a landslide inventory using conventional methods (i.e. multi-temporal aerial imagery) difficult. The problem is further exacerbated by the long-linear nature of transport networks, which makes the collation of factor maps over such a vast area on a scale detailed enough to adequately describe the assets a significant problem.

a

b

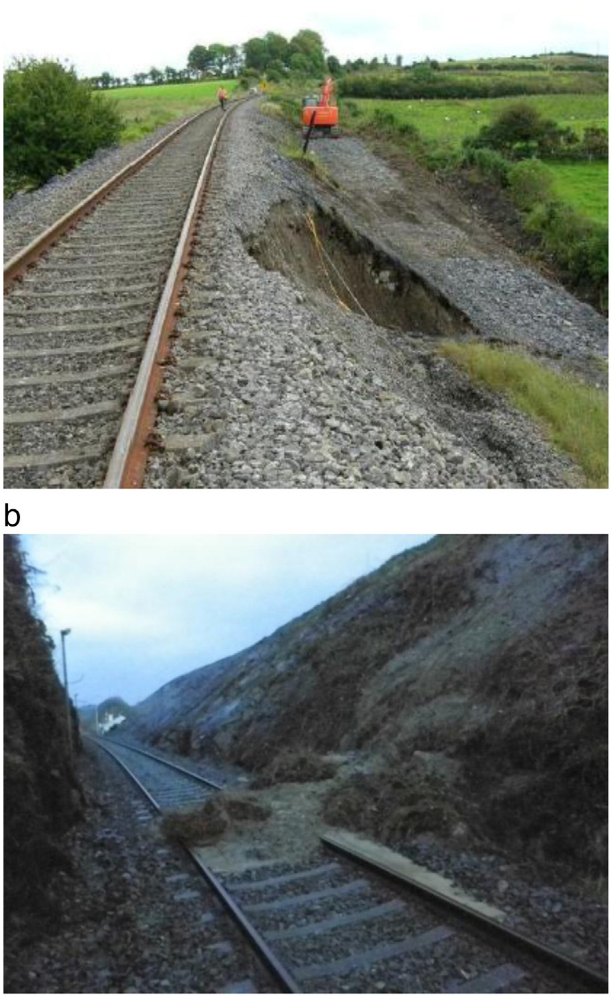

Fig. 1. Typical rainfall induced shallow slides on railway assets in Ireland (a) an embankment on the Dublin – Sligo line, (b) a cutting on the Tralee – Mallow line.

Most asset managers compile databases containing a wide range of data related to the condition of their earthworks. Data is typically gathered through walkover visual surveys and with the help of remote sensing (e.g. LiDAR surveys to measure geometrical characteristics). The data, while comparable to that typically used in landslide susceptibility assessments, has some additional fields for asset specific information (e.g. age, drainage type and condition etc.). Each asset in the database can be used as a mapping unit for a landslide susceptibility assessment.

This study aims to examine the possibility of using a slope database compiled by Irish Rail to develop a landslide susceptibility assessment (LSA) approach. The susceptibility assessment was carried out using a logistical regression technique that is commonly used in LSAs in natural terrain (Budimir et al., 2015). Appropriate input parameters are proposed and their influence on slope stability is examined.

2. Case study on the Irish Rail network

The area chosen for this study is the Athlone division of the Irish Rail network in the western region of the Republic of Ireland (Fig. 2). The division contains approximately one-third of all Irish Rail's earthwork assets. Specifically, there is 550 km of active track containing 709 embankments and 449 cuttings, 74 of which are rock cuttings.

The bedrock underlying the region is primarily composed of limestone and calcareous shales. Surface deposits in the area are largely derived from glacial drift. The most widespread deposit is glacial till, commonly known as boulder clay, an unsorted material characterised by the presence of clasts of differing sizes embedded within a matrix of clay sized particles. It accounts for almost 50% of Ireland's total surface area (Fealy and Green, 2009). Other significant soil types, include glaciofluvial sands and gravels; alluvium found in floodplains; and peat - a soft postglacial deposit with a high proportion of organic materials. The rail track in the study area is generally flat with an elevation ranging from sea-level to a maximum elevation of 115 m above sea-level.

The land surrounding the rail network is primarily used for agricultural purposes (pastures and crops) with deep-rooted vegetation being scarce. The earthworks themselves have more significant tree coverage in places. The climate is temperate oceanic, with average annual precipitation ranging from 1400 mm on the west Atlantic coast to just over 800 mm in the Midlands at the eastern perimeter of the study area (Fitzgerald and Forrestal, 1996).

The soil type encountered in cuttings can be reliably inferred from regional soil maps. The embankments were constructed in the 19th century by end-tipping of locally won material (Nelder et al., 2006) and