Applications of GIS tools to ground hazard assessment for railway infrastructure

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BACKGROUND

The Canadian railways have been exposed to ground hazards since the first transcontinental line was constructed in the late 1800s. Railways have high exposures because of their length and grade limitations. The two national railways in Canada cover on the order of 40,000 sq km, assuming that the track is exposed to a 0.5 km wide hazard zone on either side of the track. In addition, the diversity of soil and rock conditions, the active geomorphological processes associated with the relative youth of the terrain since glaciation, and climate extremes in both precipitation and temperature encountered along rail corridors, increase their risk to ground hazard. As much of the terrain traversed by Canadian railways is sparsely populated, resources available to mitigate these hazards are usually limited. As a result, in Canada there has been a greater need for objective priority setting for mitigative measures by the railway industry. Traditionally, Canadian railways have relied upon experience and subjective assessment for hazard management. Over the last decade there has been increased focus on the risks these hazards pose to railway operations and the management of those risks (Bunce et al 2006). This stems from rising public awareness, greater regulatory scrutiny, increased railway traffic and associated service demands.

Over time, the management of these hazards by the railway industry has evolved from a reactive mode to a more proactive management philosophy. As part of this change in philosophy risk management strategies from other industrial sectors have been evaluated by the railway industry. For example, the "Rockfall Hazard Rating System (RHRS)" was developed by the Federal Highway Administration in the United States for the preliminary evaluation of rock fall hazards and the allocation of priorities for remedial work along highways. The RHRS system was modified by the incorporation of probabilistic algorithms and has been implemented by CN for rock slopes adjacent to its tracks (Abbott et al. 1998, Pritchard et al. 2005).

Incident reporting of ground hazards is now standard practice for all railways operating in Canada. As a result, a catalogue of ground hazard incidents has been collected across the country, which reflects the types of ground hazards encountered by the railways. As with many linear corridors these hazards are often repetitive geographically, i.e., debris flows occur with a certain temporal and spatial frequency. A proactive management of complex repetitive ground hazards requires technology that can be used to assess the lessons from the past as well as manage the unpredictable nature of future events.

A variety of ground hazards, including rock falls, earth slides, rock slides, debris flows and embankment erosions, have been investigated within the Canadian Railway Ground Hazard Research Program (RGHRP, Bunce et al 2006). This research project has focused on the potential impact of ground hazards on railway infrastructure. Geographic Information systems (GIS) are well established as a technology that can store and manage data in essentially any form. GIS technology is also widely used as a land mapping tool and Van Westen (2007) notes its increasing use in mapping landslide hazards. However, the application of GIS is typically in the storing and display of data that has been processed and evaluated by other means. To make GIS technology suitable for assessing complex geotechnical hazards requires the development of a process model for each hazard being assessed. In this paper, the application of GIS to sensitive clay susceptibility mapping and to rock fall process modeling will be discussed.

APPLICATION of GIS TO LANDSLIDE SUSCEPTIBILITY MAPPING

Landslide susceptibility maps have been produced for sensitive clay hazards in the St Lawrence lowlands in Quebec. Simple geostatistical methods have been used to relate the known incidence of landslides to a number of geospatial themes in GIS, including surficial geology, depth to bedrock, elevation above sea level, and characteristics of nearby drainage features. A unitless, non-dimensional susceptibility factor ranging between 0 and 7 has been calculated from an arithmetic combination of these factors. The resulting susceptibility map captures most of the known landslides in areas with susceptibility greater than 2, on the scale devised, and accurately eliminates over 80% of the study area from consideration for landslide susceptibility, providing reasonable results and helping to focus ongoing efforts to assess and manage the hazards posed

ROCK FALL PROCESS MODELLING AND GIS

A hazard to railway operations can be defined as the potential to directly or indirectly result in track failure or make track unsafe for train traffic at the posted speed. Keegan et al (2007) reviewed the historic CN incident database and concluded that railway ground hazards (RGH) could be broadly classified as landslides, subsidence, hydraulic erosion and snow & ice hazard. The characterisation methodology standardizes the identification of railway ground hazard types by grouping the possible hazard events according to the ground conditions and processes involved into hazard scenarios (Figure 1). Besides labelling the hazard, classifying in this manner provides an immediate understanding of the processes of these hazards.

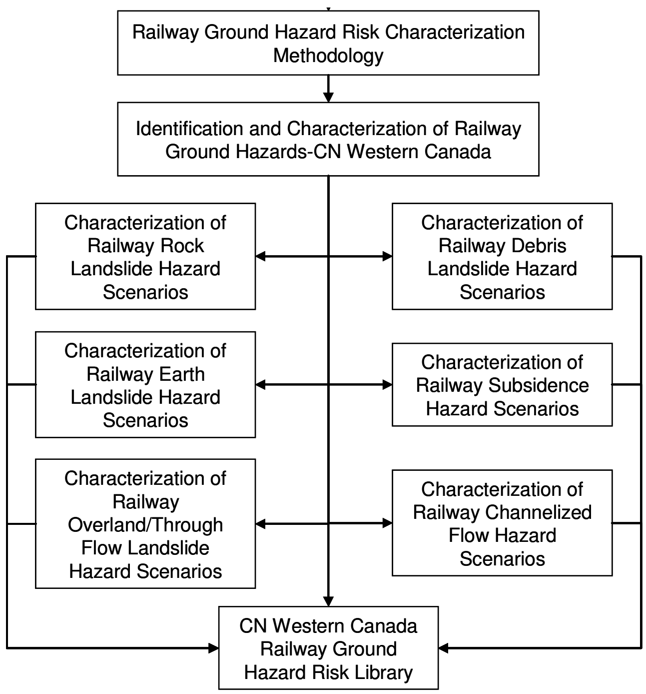

Figure 1: Example of the scenarios used to establish the CN Western Canada Railway Ground Hazard Risk library (modified from Keegan et al, 2007).

As railway ground hazard scenarios typically involve a combination of ground hazard events, Keegan (2007) proposed a simple failure mode and effect analysis (FMEA) logic tree to illustrate the possible events that may be associated with hazard scenarios. While the FMEA logic tree depicts the various events that may occur and impact the railway operations, a process model is required to evaluate the likely occurrence and severity of the event. The term “process modelling” is currently used in many disciplines. Rolland et al (1998) suggested an effective process model in any field should provide a means of communicating complex functions in a form understandable to practitioners in a standardized and repeatable manner, so that personnel can compare and contrast possible outcomes. To develop such a process model requires a complete understanding of the process. A process model of a complex ground hazard must capture the essentials required to meet the objectives of using the model, without including details that are extraneous to these objectives. In geotechnical engineering these objectives can range from ensuring that an engineered structure will perform as intended to managing the risk associated with natural hazards over a larger scale. Establishing the appropriate process is both site and project dependent, and underpins the value associated with the practice of Geotechnical Engineering. Process models in geotechnical engineering for ground hazards have five main components:

1. Generalised description of the ground hazard process
2. Knowledge of the physics that control the process.
3. Evaluation of possible outcome
4. Calibration of the process and outcome with historical data
5. Assessment of the hazard and communication of the risk

In the following sections a process model is examined for two ground hazard scenarios induced by a severe rainfall event: (1) Earth Landslides and (2) Overland/Through Flow Erosion.

A process model was developed within a GIS framework for analyzing rock falls (Figure 2). The methodology used to develop the process model was applied to a case study. The case study illustrates the importance of capturing accurate three-dimensional surface geometry in order to calibrate the simulated rock falls with measured rock falls. The geometry used for the case study was obtained from LiDAR with a vertical resolution of ±150 mm. The rock fall simulations were conducted with Rockfall Analyst: a GIS extension for three-dimensional and spatially distributed rock fall hazard modelling developed for the RGHRP.

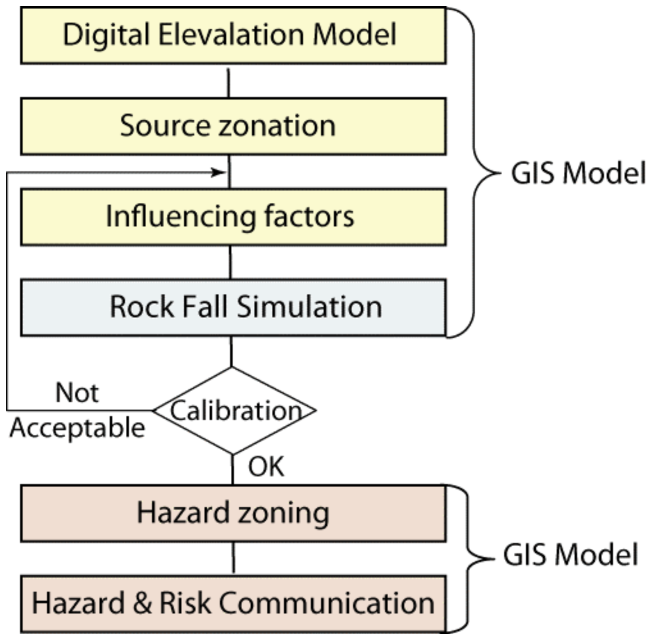

Figure 2: Example of simplified process model for rock fall analyst.

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