SLOPE INVENTORY FOR ROCKFALL HAZARD ASSESSMENT ALONG RAILWAYS AT INTERMEDIATE SCALE

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The initial stage of the geological surveillance plan for railways corresponds to an inventory of potentially hazardous slopes, for its implementation to a case study some new tools were tested. This case study was also used to check the usefulness of the cartographic product for risk prevention that ICGC is performing since 2007.

Keywords: hazard assessment, GIS-based analysis, slope catalogue, railway surveillance.

SLOPE CATAOGUE FOR INFRASTRUCTURE SURVEILLANCE

During last two decades, a close collaboration between the Geological Institute of Catalonia (nowadays ICGC) and FGC railways company (Ferrocarrils de la Generalitat de Catalunya), both depending from the Catalan Government, was established. From the first study stages in Núria [1] and Montserrat rack-railways, technical know-how has grown up and a geological – geotechnical controlling work has been set up for the whole FGC railway network. The knowledge basis for this task is an inventory of natural slopes or catalogue, characterizing its hazard and potential risk from the railway perspective, so further periodic inspections can be done in a systematic way for monitoring the hazard and reviewing the risk management.

In 2013 the FGC railway that connects Martorell and Manresa towns along Llobregat valley has been included into ICGC surveillance. This railway track is about 33 km long, where several sections are exposed to rockfall, and some protections already exist. To perform the initial inventory, a hazard assessment was carried out applying the tools proposed by [2]. The aim of the slope catalogue is to localize problems, organize information, priorize actions, and become the basis for the geological security management. For every slope, an index card is performed including all issues related to rockfall.

REGIONAL TO LOCAL SCALE FOR HAZARD ASSESSMENT ON RAILWAYS

Considering that our goal is to obtain a first stage overview of the railway line, a regional scale study can be set similarly to the 1:25,000 – 1:50,000 geological susceptibility/hazard maps for land use planning (like the Geological Risk Prevention Map of Catalonia by ICGC, MPRG-25k [3] at 1:25,000). Although for the railway management purposes detailed assessment is needed, a full study (typically larger scales than 1:5,000) could not be recommendable for getting only an overall approach. By the other hand, it must be considered that transportation corridors are linear infrastructures, where each section determines the overall service, differing from other land uses, so for equivalent studies and purposes it must be set a slightly higher scale to extract consistent results along the track line.

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Consequently, the scale for this slope inventory is set at 1:10,000 nominal value for visualization (spite some terrain analysis are at deeper detail), so we call this catalogue as intermediate regional – local scale (SC-10k). A main issue for this communication is to compare the results of this catalogue to the MPRG-25k. This is a multihazard map at 1:25,000 scale conceived to be used for land use planning. It includes the representation of evidence, phenomena, susceptibility and natural hazards of geological processes, including rockfall.

The performed analysis is quite similar to those done by [2] for roads, with combination of two practical tools for this scale range of study, both developed by University of Lausanne: HistoFit and Flow-R software. At the present state of study, no risk analysis was performed, remaining only on the hazard consideration.

DETACHMENT SUSCEPTIBILITY

The Martorell – Manresa railway line crosses a humble mountain range called Pre-Litoral. Common process of hazard analysis applied for the SC-10k leads to 30 slope domains considering homogeneous properties in the sense of rock mass, geomorphology, drainage basins, relative position to railway, etc. Along this track we can identify 5 geological contexts, with different rock mass nature and resulting geomorphology. For each one, a geomorphometric analysis has been performed like proposed by [4] in the basis of the 5x5 terrain elevation model (TEM) available for the whole Catalan territory by ICGC. The aim of this GIS analysis is to identify systematically the source areas for rockfall. The steepest terrain corresponds to the rock faces and outcrops where source polygons can be drawn. The next terrain class corresponds to steep slope where several small outcrops are included, but due to its small height, they are not identified like the first class. Then, source lines are drawn according to the stratigraphic disposition of hard rock levels (see Tab. 1 and Fig. 1).

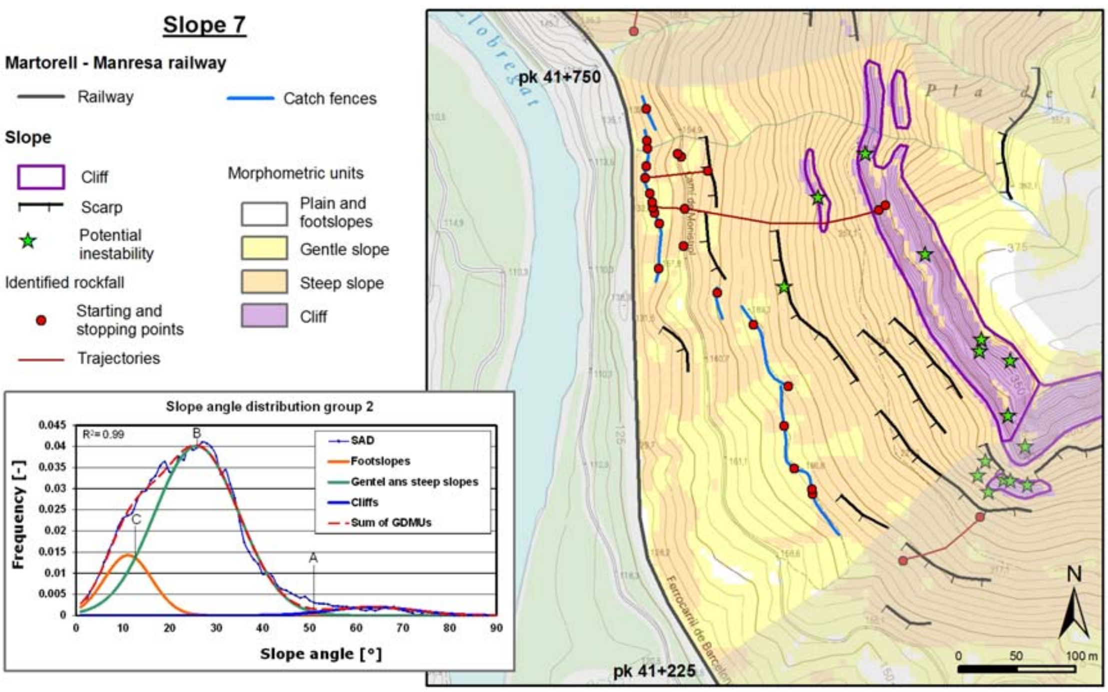


Fig. 1 Example in slope nº7 for the terrain analysis map and geomorphometric analysis.

For every catalogued slope, the detachment susceptibility is assessed on the basis of common parameters for approach to magnitude and frequency, locally and exponentially scaled as done in [5]. It was not used qualitative rating as usually applied for dug talus adjacent to roads [6].

Tab. 1 Threshold values for geomorphometric analysis for every geological unit and considered reach angle.

Slope Group	Slope-based morphological units				Reach angle
	Plain and slope foot	Gentle slope	Steep slope	Cliff	
1	<19º	19º - 31.4º	31.4º - 48º	>48º	34º
2	<13º	13º - 25.8º	25.8º - 51º	>51º	29º
3	<25º	25º - 26º	26º - 46º	>46º	32º
4	<19º	19º - 28.7º	28.7º - 43.5º	>43.5º	32º
5	<25º	25º - 33.7º	33.7º - 51º	>51º	34º

SPREADING SUSCEPTIBILITY

The runout susceptibility is calculated using the Flow-R software [7], which allows computing probabilistic trajectories according to the reach angle. Comparing to ConeFall software [8], which projects the reach angle in radial sense independently of the terrain topography under the cone, Flow-R improves greatly the results, and new capabilities overcome the limitations found by [9]. Some preliminary tests were done to better understand the available algorithms, comparing observed rockfalls and simulations, like for calibration tests. In this case we have found good agreement using Holmgren algorithm for the flow direction, with an exponent x = 10 controlling the divergence, and an over-elevation of dh = 1 m. The persistence function was set as the cosine, and the runout capability limited by the reach angle, which values depend on every defined slope groups (see Tab. 1). Although Flow-R is originally focused on debrisflow, its use for rockfall is also satisfactory and we have found several advantages comparing to ConeFall (see Fig. 2).

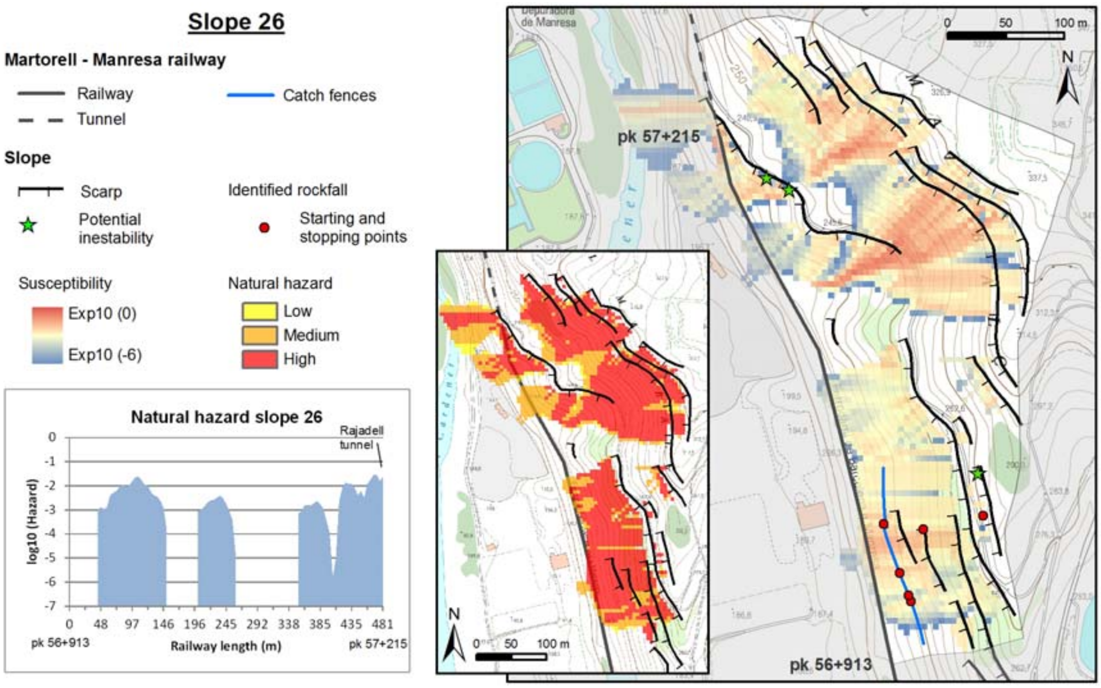


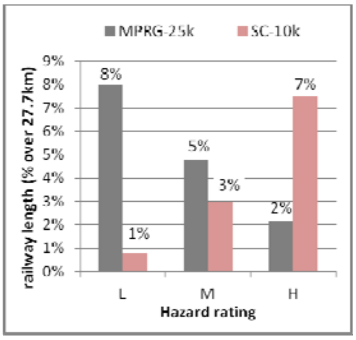
Fig. 2 Example in slope nº26 for the result of propagation susceptibility and resulting hazard on the railway.

HAZARD ON THE RAILWAY

Combining the results of rockfall propagation with the value of detachment susceptibility, assigned to every slope domain, we obtain a summary hazard map, from which is extracted a longitudinal profile of hazard logarithmic index along the railway (see Fig. 2). Similar to hazard zoning task for land use planning, for transportation corridors management it is useful this kind of hazard sectoring along the linear infrastructure. From these results, and homogenizing to 3 degree hazard (high – medium – low) comparable to MPRG-25k expression, a histogram is extracted along the track to compare MPRG-25k and SC-10k (see Tab. 2). Both products are coincident in rating for 85% of the railway length, especially for the no-significant hazard (null) determination. Where both products identify hazard, only at 32% of the length the ratings are coincident, because qualitative assessment criteria are rather different, and for 61% of the length the rating of SC-10k is higher than MPRG-25k (as seen in the graph of Tab. 2). In comparison to this one, SC-10k allows to identify some spots under unnoticed hazard, but mainly to discard some stretches, thanks to its higher detail.

Tab. 2 Hazard rating comparison between both products in relative terms to the length of railway (without tunnels).

Rockfall hazard		MPRG 25k			
		H	M	L	Null
Slope catalogue SC 10k	H	1.49%	2.73%	1.57%	1.69%
	M	0.43%	0.79%	0.67%	1.09%
	L	0.08%	0.12%	0.30%	0.24%
	Null	0.18%	1.14%	5.43%	82.06%



CONCLUSIONS

In conclusion, MPRG-25k is an appropriate product not only for land use planning but also for preliminary planning of surveillance along transportation corridors. Further studies like the presented SC-10k can refine the results on the railway track for specific purposes in infrastructure safety management. Through this practical case, we found that Flow-R is appropriate for rockfall analysis at regional – intermediate scale. It improves significantly the results from ConeFall allowing an appropriate application of the reach angle. To prove how complete is the physical sense of the probability distribution, it should be performed a test comparing the results with a 3D cinematic calculation in the next future. This methodology allows a comprehensive analysis of all factors influencing hazard. Further improvement should go in the way of quantitative rating in absolute scale for the cliffs, getting the full sense of detachment probability, allowing the comparison between places under different conditions.

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