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Creation of danger and hazard maps for rock falls in a regional scale. A comparison between an empirical and a numerical model

K. Mayer (1), A. von Poschinger (2)

(1,2) Bayerisches Geologisches Landesamt (Hess-Str. 128, 80797 München, Deutschland; Tel.: +49-89-9214-2600; Fax: +49-89-9214-2647; email: georisiken@gla.bayern.de)

1. Introduction:

One essential precondition for the development of Danger Maps concerning mass movements is the knowledge of the susceptible zones and for rock falls especially the location of the starting zones. Only with this information, statements can be made about the size of the areas affected by a potential event. Within the Interreg III-B Project “CatchRisk”, co-financed by the EU, a regional scale method has been carried out to attain the maximum run-out zones of rock falls. The method was developed and executed with the Program ArcGis 8.2 and the extension Spatial Analyst and compared with an other method. The modelling of rock falls knows two different methods. The numeric mathematical methods with trajectories and the empiric models with global angles. For the Bavarian Alps exist the "GEORISK documentation and information system" (GIS) collecting all information about former mass movements and transforming it in digital form. Out of this information system all potential starting zones of rock falls can be extracted. To find the potential maximum run-out zone of these rock falls one of the mentioned 3D-models has to be applied. Considering the fact, that in a long term the area covered by the simulation is very great and the financial resources for this work are limited, the most economic methods had to be compared and/or developed. Already existing mathematical models require a high resolution digital elevation model (DEM) and damping values in the transition and accumulation zone of the potential rock falls. As Crosta (2004) mentioned, not only the longitudinal but also the lateral spreading of the run-out zones depends on the DEM resolution. The numeric models are simulating the falling, rolling and jumping of single blocks along the shortest line downhill. The result of the modelling is a map with trajectories and maps indicating the energy and the rebound height of the blocks. Programs to simulate the rock falls with trajectories in 3-D are not available on the market but are properties of private engineering companies. They also require a high standard of experience. Examples are the programs of GEOTEST as well as the program STONE. Therefore such simulations with the numeric models can not be made without contracting external experts who own the programs. The empiric models are more resistant to the resolution of the DEM. The method is very easy to carry out and programs are free available in the internet (e.g. Conefall). Also the empiric models based on the global angle method can be carried out with standard tools of ArcGis (ESRI). Below, the theoretical background and the way how to compose a global angle model for rock falls with ArcGis and the extension Spatial Analyst is presented.

2. Theoretical background:

To identify the maximum run-out zone of a potential rock fall, empiric global angle methods can be used. Global angle methods have been defined for example by Lied (1977), Onofrie & Candian (1979), Evans & Hungr (1993), Wiezcorek et al. (1998), Meißl (1998) etc. Common to all these methods is, that the maximum run-out zone is defined by minimal global angles between the horizontal line and the line connecting the farthest block and different points of the detachment area or the top of the so called talus. For the modelling in the CatchRisk project we used two different global angles. The first and more important angle is the shadow angle as defined by Evans & Hungr (1993). Evans & Hungr described that the maximum run-out zone is characterised by the angle between the horizontal line and the top of the talus. Usually this angle is not smaller than 27°. The other angle, which marks the maximum run-out zone is the so called geometrical slope angle introduced by Heim (1932) and described by Meißl (1998). It is the angle between the horizontal line and the top of the detachment zone. It is not smaller than 30°. To avoid an over- or an underestimation of the maximum run-out zone, one of the two angles has to be used subjected to the morphology respectively the shape of the slope. If the quotient between the tangent of the shadow angle (27°) and the tangent of the geometrical slope angle (30°) is smaller than 0,88, the shadow angle has to be used. If it is greater than 0,88 the geometrical slope angle describes the maximum run-out zone better. So, for high rock cliffs an application of the shadow angle is recommended.

3. 3-D modelling with ArcGIS (Spatial and 3D Analyst):

A spatial approach to create danger maps for rock falls in a regional scale requires 3 dimensional modelling. The 3-D modelling has to be carried out in three steps: The first step is to find the potential detachment zones or starting points for rock falls in the 3 dimensional space. For this a digital elevation model (DEM) is required. For the global angle models the requests on the DEM is not as high as in numeric modelling methods. Even though a raster resolution as high as possible is the best, the method also can be carried out with a raster resolution of 10 m. If detailed data e.g. from laser scan flights are not available, it is possible to interpolate a 10 m raster from the digitised elevation lines (equidistance 10 m or 20 m). The DEM should be interpolated linear. The second step is to prepare the data for the modelling. The modelling tool (Viewshed Function) requires special attributes for the potential start points of rock falls. Step by step these attributes can be created by means of the Spatial Analyst of ArcGis. According to the theoretical background all areas have to be checked to evaluate whether the geometrical slope angle or the shadow angle have to be used. In areas where the shadow angle is required, only those starting points may be used which are at the bottom of the cliff respectively at the top of the talus. All other points have to be deleted. In a third step the modelling can be carried out. A key tool in acquiring the run-out zone of rock falls is the Viewshed Function (Spatial Analyst). The Viewshed Function identifies the locations (cells) on a surface (DEM input raster) that can be seen from one or more observation points. The starting points of the potential rock falls are declared to be the observation points of the Viewshed Function. Using the items VERT1 and VERT2 in the attribute table, the vertical angle of the view can be limited according to the analysis of Evans & Hungr (1993) and Meißl. The horizontal view angle (lateral spread from the fall line) can be limited with the items AZIMUTH1 and AZIMUTH2. To process the slope exposition based on the DEM the Aspect Function can be used. The evaluation of the control attributes can be carried out semi-automatically using further tools like the Reclassify Function and the Raster Calculator. In Bavaria all information about Landslides and rock falls are collected in the GEORISK- information system. Based on these data the potential starting zones for rock falls are widely known. Especially in housing areas the data are well detailed so that the digital starting point data can be extracted from the "maps of activity" and from the digital scar areas. For areas without specific GEORISK information as a substitute information of lower quality can be used. For those cases, based on the DEM also areas, in which the slope angle is steeper than 45° can be extracted. Slopes steeper than 45° can be defined as potential starting zone for rock or stone falls. All data first have to be converted to raster data. After the definition of the areas, that have to be treated with either the method of the geometrical slope angle or that of the shadow angle and after deleting those points which are not needed for the modelling, the second step can be carried out. In this step the "aspect data" have to be created and the required attribute tables for the modelling have to be completed. The third step is the modelling. It has to be carried out with the Viewshed Function (Spatial Analyst). After the modelling, the result has to be checked concerning the plausibility. Artefacts like “holes” in the processed area eventually have to be filled, as well as the start areas of the rock falls have to be added to the danger area. The process of definition of the application of one of the two methods, that of deleting starting points, not used for modelling, removal of obvious systematic mistakes and the validation are “manual” work. All other operations can be carried out automatically and standardised.

4. Comparison of the results:

The validation of the so created map has been carried out with field work (analysis of “silent witnesses”) and by modelling with a numeric model (trajectories). The main difference in the results can be found in the transition zone of the rock falls. In case of application of the shadow angle, the empiric model is not able to detect the complete transmission zone. On the other hand the numeric model sometimes underestimates the maximum run-out zone because only single blocks can be simulated. The empiric model is based on observations which include collapses of greater rock masses, that cannot easily be simulated by numeric models until now.

5. Conclusions:

Modelling of rock falls in a regional scale (1:25.000) generally can be carried out with empiric as well as with numeric methods. In the project the possibilities of the empiric method have been worked out, verified and compared to the numeric method: One advantage of the empiric methods is that no special software is required. The method itself is very easy to execute, but the selection of the correct starting points for the modelling can not be standardised. There is no objective procedure and the choice between the two possible approaches does not favour an easy handling. Therefore, a lot of experience is required and the results have to be verified. The trajectory models instead demand a higher quality of the DEM, a special simulation program that is not available on the free market and experts who have the experience to handle them. The results of the numeric models are generally reproducible. Furthermore, they give additional important information, because maps of rebound height, velocity or energy can be derived. Taking into account the fast development on the IT market and also for the remote sensing technology, it is only a matter of time that high resolution DEMs will be at general disposal. In case of already existing data that are requested for the numeric modelling like potential starting points and dumping values (as in the case of GEORISK) this can reduce the costs for the numeric modelling remarkably. So in the near future the numeric models will be not only more objective but probably also cheaper than the empiric models.

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