Application of the GRASS GIS model r.rotstab.layers for the deterministic analysis of deep-seated slope stability in a complex geological setting

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We implemented the computer model r.rotstab.layers to explore the possibilities of GIS for catchment-scale deep-seated slope stability modelling in complex geology. For the 10 km² Ripoli area in Umbria, central Italy, we show that (1) considering the geological layers is essential for deep-seated slope stability modelling, and that (2) the seepage direction of the groundwater is a major source of uncertainty.

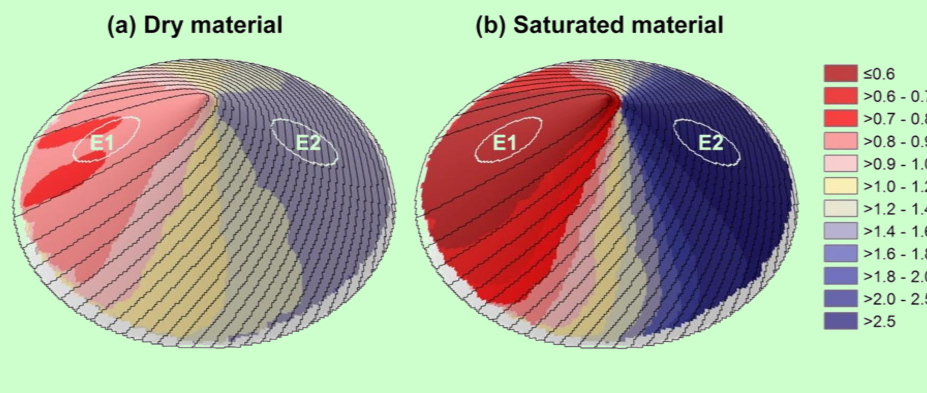
Model r.rotstab

r.rotstab represents a GIS-based, 3D slope stability model implemented as a GRASS GIS raster module. It makes use of a modification of Hovland's sliding surface model, revised and extended by Xie and co-workers. Given a DEM and a set of thematic layers, the model evaluates the slope stability for a large number of randomly selected ellipsoidal and/or truncated potential slip surfaces, For each cell, the lowest value of the safety factor and the depth of the associated slip surface are stored. This information can be used to obtain a spatial overview of potentially unstable regions over an area up to several square kilometres.

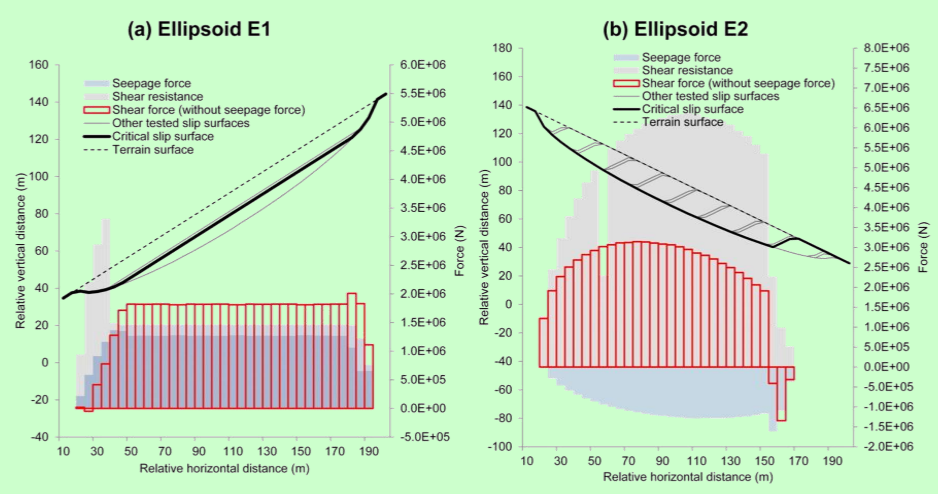
Scope and objectives

We extended r.rotstab by including the strike and dip of the geological layers into the slope stability calculations (r.rotstab.layers). The objective of the work is to identify the capability of such an approach as well as its limitations and the most urgent needs for further research.

Test with regular cone



Safety factors computed with r.rotstab.layers for a regular cone assuming (a) dry material, (b) saturated material with layer-parallel seepage. The black lines represent the traces of the weak layers.



Forces acting along the main axes of the ellipsoids E1 and E2.

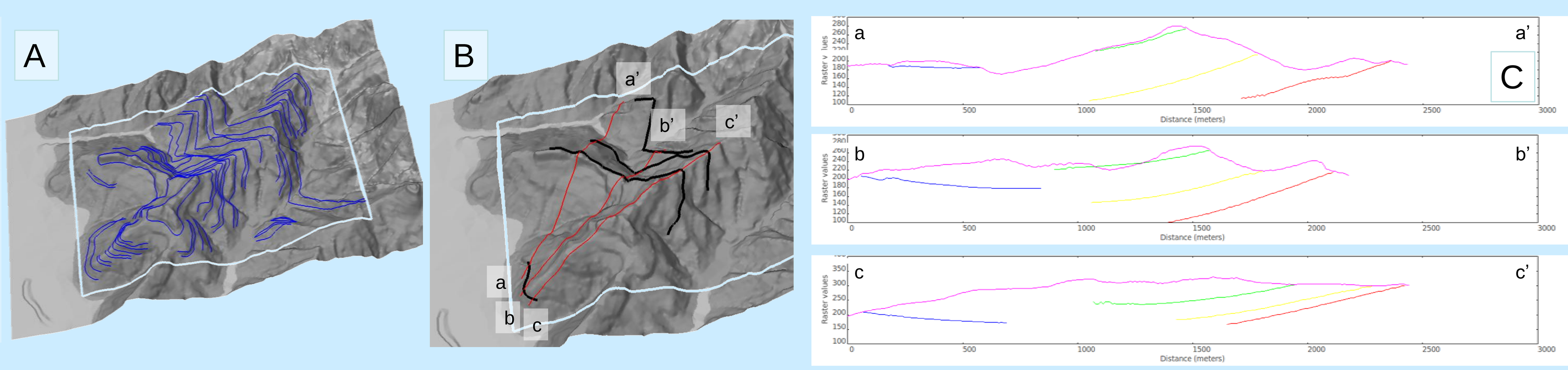
A regular cone with parallel bedding planes of alternating strong and weak layers is used to demonstrate the model performance. The side with cataclinal layering clearly shows lower safety factors than the side with anaclinal layering. This effect is enhanced for saturated material (layer-parallel seepage forces).

For the ellipsoid E1, the most critical slip surface corresponds to the bottom of the only weak layer intersected whilst the ellipsoid E2 intersects several weak layers of anaclinal orientation. The much higher safety factor than the one associated with E1, and the higher safety factor computed for saturated conditions are a consequence of (i) the high shear resistance over most of the tested slip surfaces of E2, (ii) the negative shear force of the anaclinal truncated surface and (iii) the negative seepage force.

Ripoli area

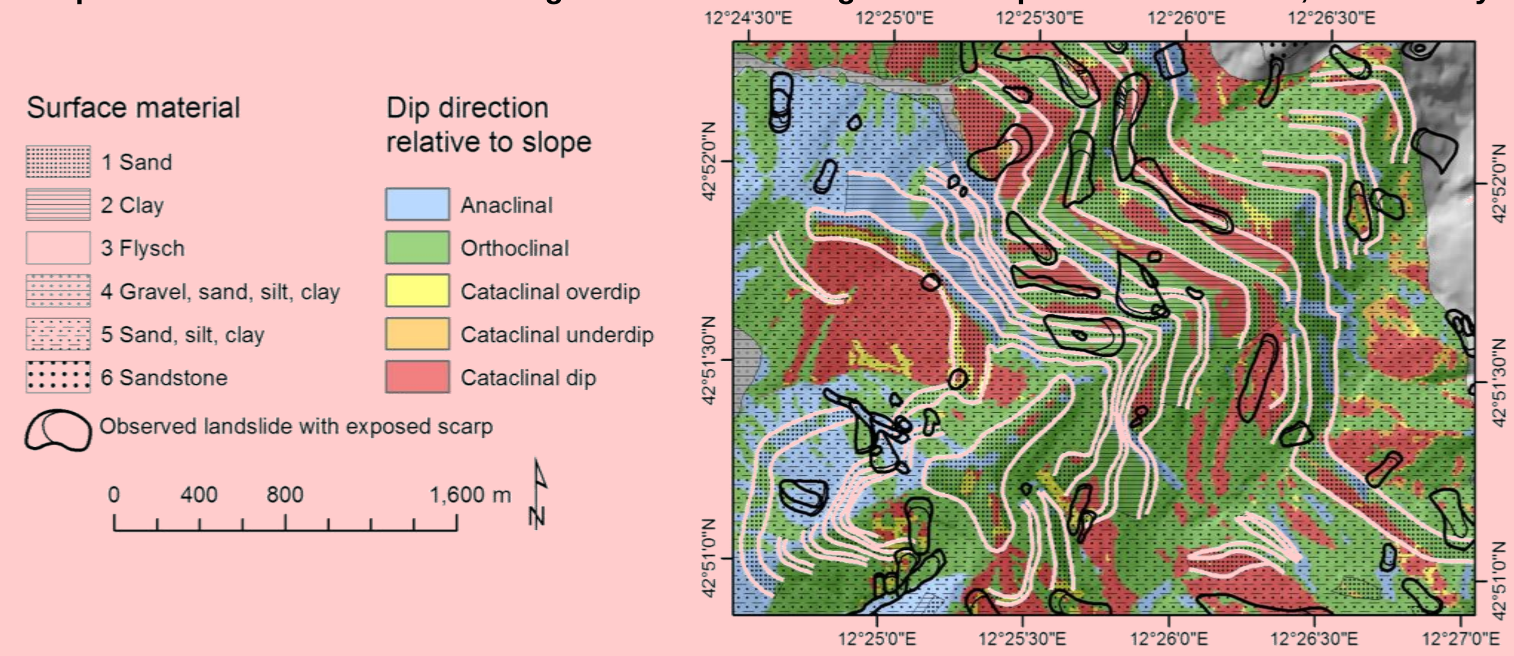
We test r.rotstab.layers for the 10 km² Ripoli area in Umbria, central Italy. According to field observations in the Ripoli area, morpho-structural settings play a crucial role for deep-seated landslide distribution. We have prepared a model of the geological layers based on surface information on the strike and dip directions of each layer, and we use this model as input for r.rotstab.layers.

(A) Available geological strata. (B) Subset of strata selected to show an example of the (C) sub-surface geologic model.



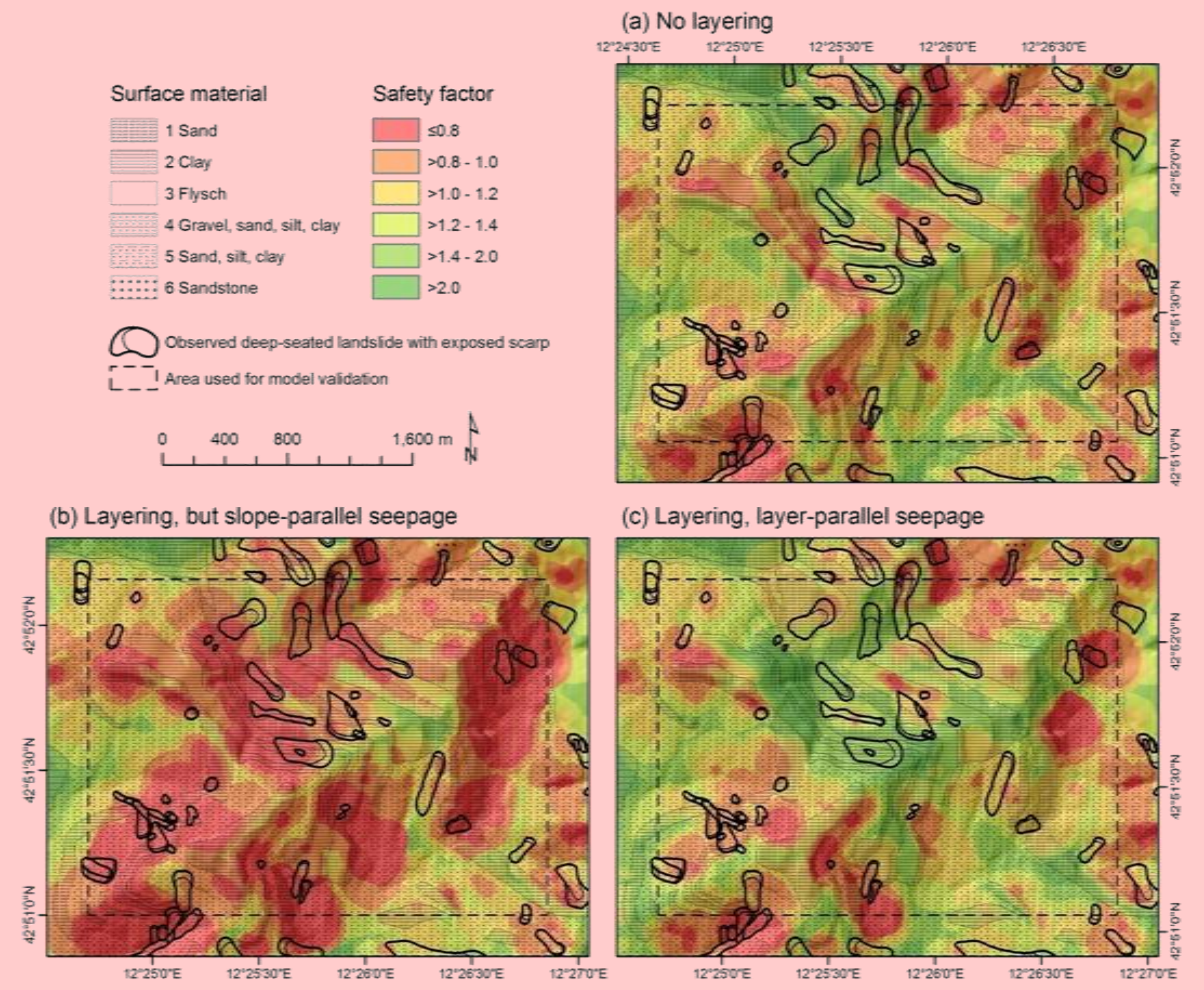
Application to Ripoli area

Deep-seated landslides and lithologic/structural settings of the Ripoli area in Umbria, central Italy.



The model was applied with the assumption of a vertically homogeneous substrate - no layering - and with two different assumption of seepage orientation: in the slope parallel direction and in the dip direction of the layers (*a*, *b* and *c* in the next figure).

Safety factors computed with three different assumptions of layering and seepage direction.



The results are then compared and validated with the distribution of observed deep-seated landslides in the Ripoli area.

Validation of the model results for the Ripoli area. (a) No layering, (b) layering, but slope-parallel seepage, (c) layering with seepage in dip direction of layers.

Indicator	(a)	(b)	(c)
True negative predictions TN	64.2%	27.7%	70.3%
False positive predictions FP	27.0%	63.4%	20.8%
False negative predictions FN	5.3%	1.5%	6.2%
True positive predictions TP	3.5%	7.4%	2.7%
Total rate of true predictions rTN + rTP	67.7%	35.1%	73.0%

Conclusions

We conclude that morpho-structural settings exerts a significant impact on the results of deep-seated slope stability computations. Further, we have demonstrated that the seepage direction strongly influences the slope stability modelling of saturated materials.