Multi-technique approach to characterize ancient deep-seated landslides in seismic regions

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1 Why?

Motivation of the study - Mountain ranges in seismically active regions often present vast numbers of deep-seated and voluminous landslides. In general, the comprehension of factors contributing to such slope failures can help to better understand the dynamic history of a region.

2 Where?

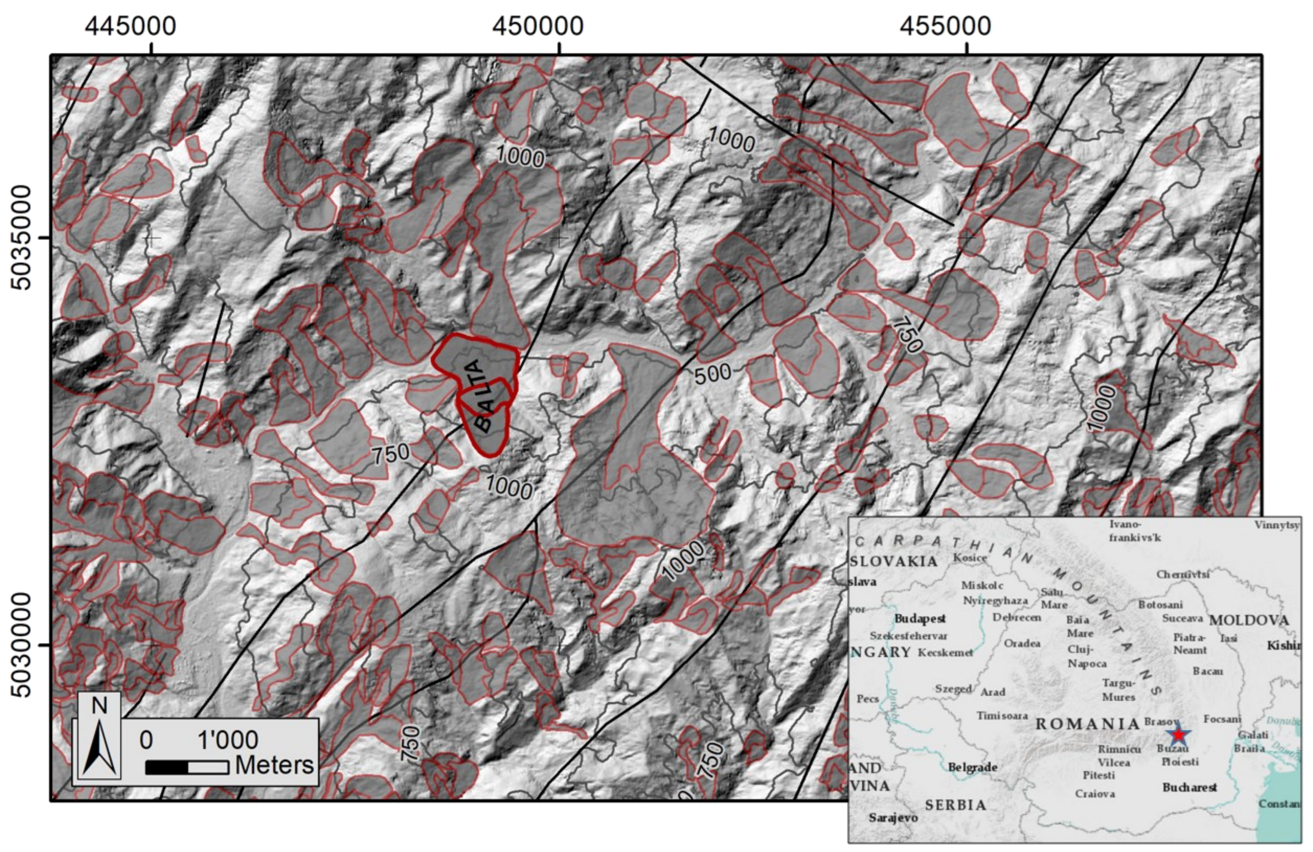
Study area - The Buzau-Vrancea seismic region in the Romanian Carpathian Mountains presents numerous massive slope failures.

Furthermore, the area is characterized by an important seismic history (USGS, 2017):

1804	"the Great Quake"	M_W 7.8 - 7.9	HD 150 km
1838	Vrancea EQ	M_W 7.5	HD 150 km
1940	Vrancea EQ	M_W 7.8	HD 90 km
1977	Vrancea EQ	M_W 7.5	HD 94 km
1986	Vrancea EQ	M_W 7.2	HD 132 km
1990	Vrancea EQ	M_W 7.0	HD 89 km

(EQ earthquake; Mw moment magnitude; HD hypocentral depth)

Could there be a link between the landslides and the dynamic history of the region?



3 What?

General approach - "Softened" hummocky morphologies that result from weathering and aging can make it difficult to understand the circumstances of slope failure development and to trace the limits between in-situ and displaced material. We use several geophysical techniques to map lateral and basal boundaries of landslide masses in order to complement geomorphological analyses. The use of multiple methods also allows to overcome limitations in terms of investigation depth and lateral resolution of single methods.

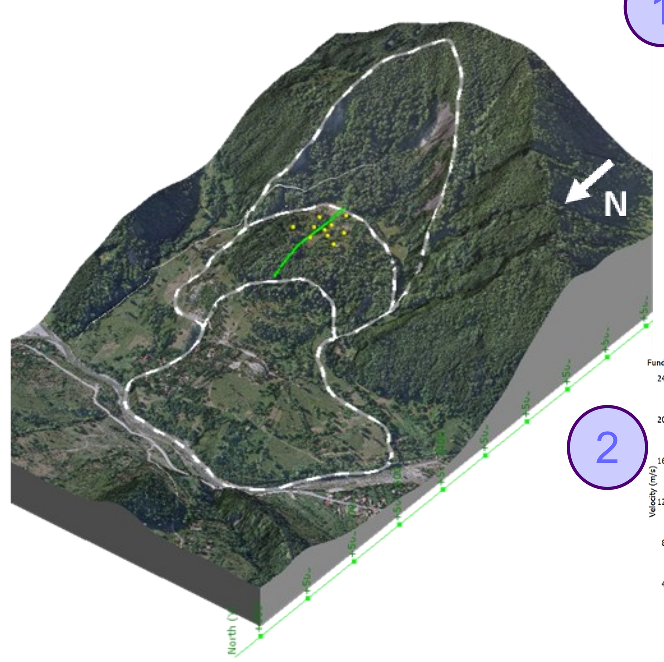
4 How?

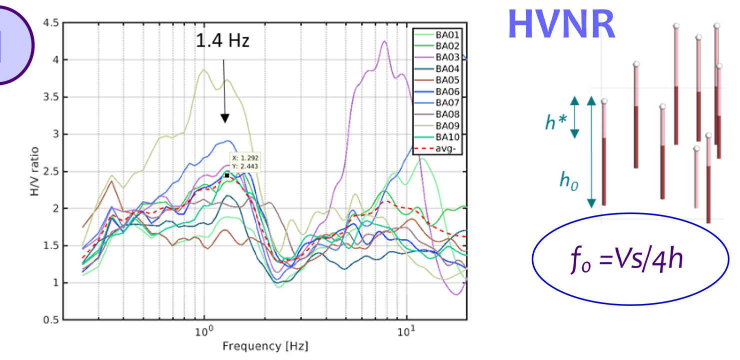
Used techniques - With the combination of several geophysical techniques we attempt to distinguish the basal shearing horizon of the studied landslide, its volume and general geometry, as well as geomechanical parameters:

I	ERT	Electrical resistivity tomography	- lithological information - water content of landslide deposits
II	SRT	Seismic refraction tomography	- actively triggered seismic energy - 2D P-wave contrast profiles
III	MASW	Multichannel analysis of surface waves	- actively triggered seismic energy - 1D S-wave contrast profiles
IV	HVNR	Horizontal-to-Vertical Noise Ratio	- 1D single station ambient noise measurements - impedance contrast of materials
V	Array	Small-aperture seismic array	- multiple station ambient noise measurements - surface (Rayleigh) waves characterization

In contrast to P-wave velocity and electrical resistivity prospections, surface and shear wave velocity measurements are able to reveal contrasts that are independent of the soils water content. The latter is used to define the mechanical properties of the involved rocks and soil materials of complex slope deformations based on velocity responses. Depending on the possible technical set-up and local environment, ambient noise array methods generally allow very deep sounding.

5 Geophysical Results





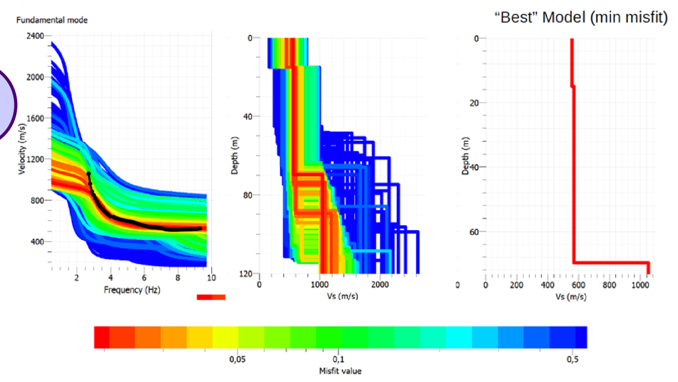
HVNR

Peak frequency f_0

f_0 = 1.4 Hz

upper part of the slope

$f_0 = Vs/4h$



Seismic array

Surface wave velocity *Vs*

Vs = 520 ms^{-1}

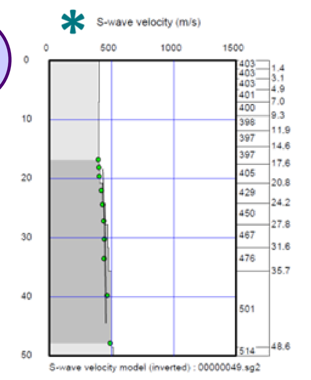
Impedance contrast depth *h*

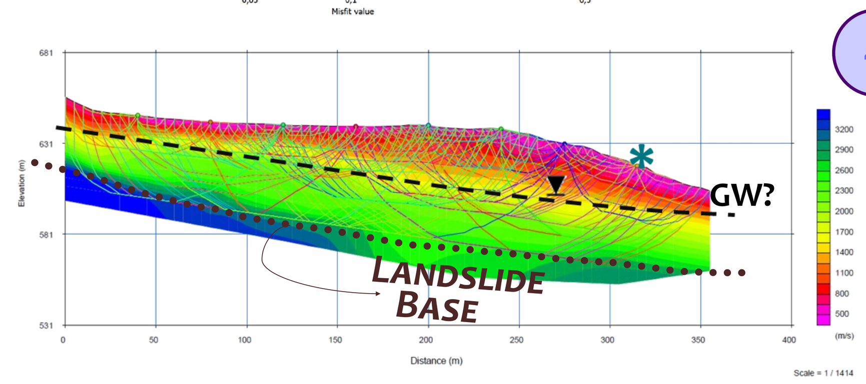
h = 70 - 90 *m*

MASW 3

S-wave velocity at 30 m depth

Vs_{30} = 460 ms^{-1}



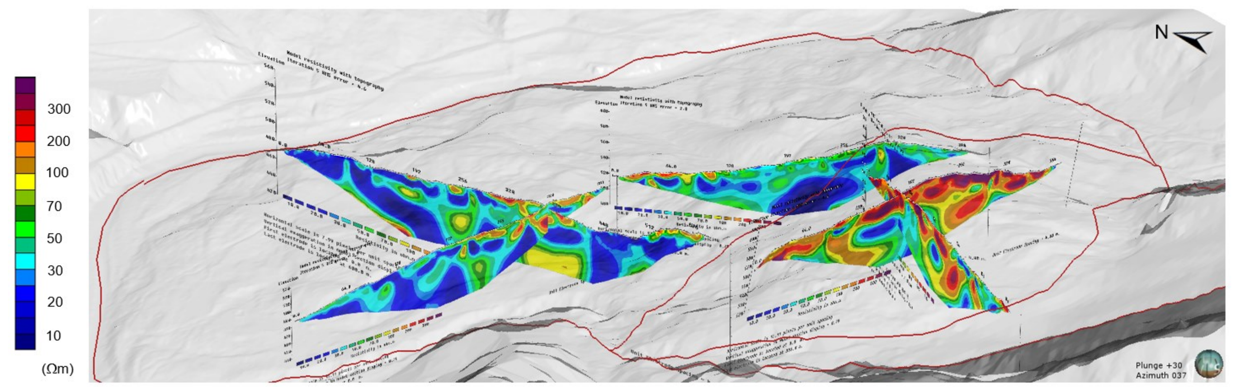


SRT 4

P-wave velocity *Vp*

Vp = 1800 ms^{-1}

Groundwater ? ▼

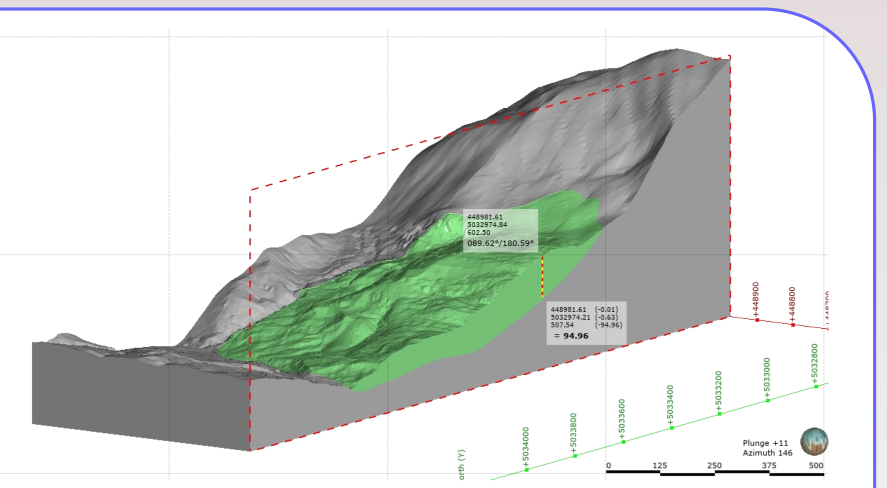


ERT 5

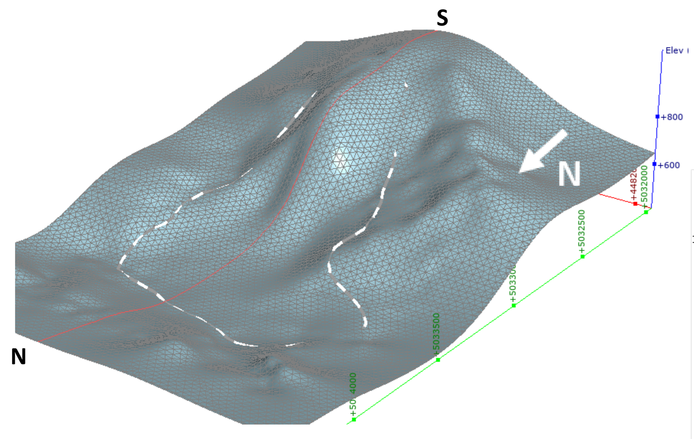
Electrical resistivity values:

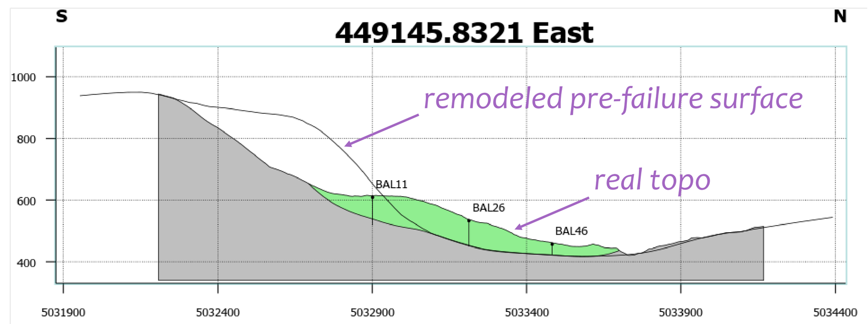
- Upper part > 150 Ωm (dry landslide deposits?)
- Lower part < 100 Ωm (water saturated?)

6 Discussion



Geophysical and geomorphological prospections suggest the Balta landslide to be an anti-dip, deep-seated rotational failure. The volume of the failed mass is estimated to be ~ 30 Mm³. In this case, most significant results were revealed by the use of active and passive seismic techniques. The use of the ERT results is rather limited due to the elevated water content and the chaotic structure of the landslide deposits. The lateral and basal borders of the failed rock mass were defined and visualized in a detailed 3D geomodel of the slope (Seequent, 2019).

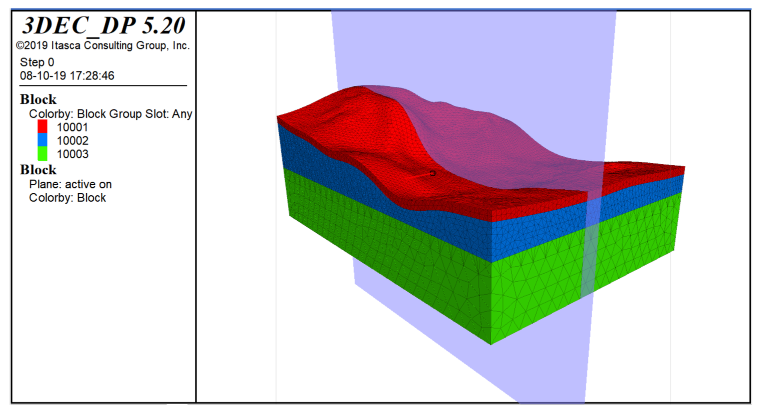


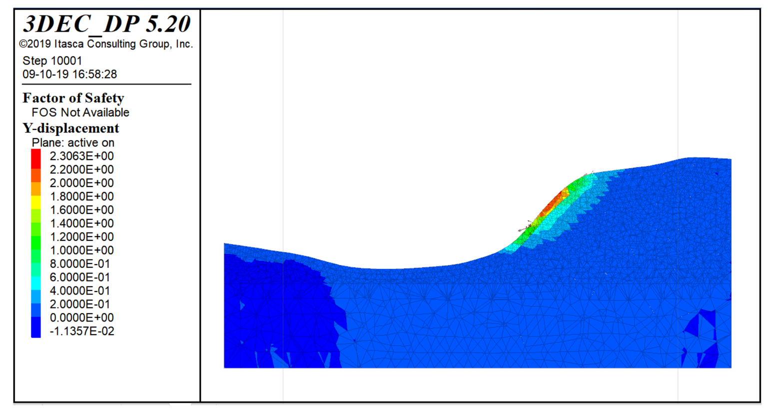


In a next step, the calculated failed volume (+ 13.1 % due to estimated volume loss) was placed back in place to remodel a possible pre-failure state of the slope. The latter is used as basis for a numerical back-analysis considering contributing factors such as material rock properties, structural control and seismic energy.

7 Outlook

Numerical calculations aiming at a back-analysis of the landslide development (in a static and dynamic domain) are currently in progress. The software used is the 3D discrete element code 3DEC 5.2 from Itasca (2016).





The key element of these simulations is the definition of the structural setting (bedding orientation, joints) as well as the mechanical properties of rock. First results indicate the necessity of dynamic energy to reproduce the studied failure.

Acknowledgements

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Seequent, 2019. Leapfrog Geo 3D, last accessed August 20, 2019 at http://www.leapfrog3d.com.

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