An integrated geophysical survey at a landslide-prone area

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SUMMARY

A heavy rainfall of May 2014, caused an extensive disaster to the catchment of River Sava in Serbia and Bosnia and Herzegovina (BiH). The number of landslides exceeded 2000 in Serbia and BiH. This prompted an urgent investigation of the areas which have potential of further landslide.

Association of Geoscientists and Environmentalists of Serbia (AGES) initiated a project of geophysical investigation of these areas supported by Geoscientists *without* Borders (G*w*B) of Society of Exploration Geophysicists (SEG). Over twenty students participated from three countries and more than ten technical professionals from six countries joined in the project.

Reflection seismic, MASW and resistivity surveys were carried out in the Vrazici area in BiH in June 2015. Two survey lines were surveyed totaling about 120 meters along a slope of grassland and orchard.

A clear increase of S-wave velocity from 250 to 350m/s at about 3 to 5m below the ground surface is observed by the MASW analysis, which is consistent with the reflection profile at the same area. This depth roughly corresponds to the resistivity boundary at 80 ohm-m. It is interpreted the interface between soft soils and relatively competent rock. The depth profiles of these boundaries show that the soft soils are thicker toward the lower part of the slope. This landslide can be classified as Varnes's classification "earth slide or earth flow".

Key words: near-surface geophysics, landslide, MASW, seismic reflection, resistivity

INTRODUCTION

In May 2014, a heavy rainfall caused severe damage in the Balkan region. The damage was particularly intense in the catchment of River Sava, including failure of river banks, flooding and landslide. The European Bank for Reconstruction and Development (EBRD) estimated the damage was around 3 billion Euros in Serbia, and Bosnia and Herzegovina (BiH) (SBS, 2015). Total number of affected people reached 1.6 million including more than 150,000 people evacuated and. Floods due to overflowing rivers destroyed houses or partially damaged; house in the plain areas were affected by failed river banks; and those in the hillsides by landslides. The number of landslides counted over 2000. This highlighted the danger of living in landslide-prone areas, and assessment of the landslide potential is desired.

A wide range of aids came from all over the world. The Society of Exploration Geophysicists (SEG) sponsored a Geoscientists *without* Borders (G*w*B) project, which was initiated by the Association of Geoscientists and Environmentalists of Serbia (AGES), titled "Assessment of flood-damaged infrastructures in Bosnia & Herzegovina and Serbia". The G*w*B is an initiative of SEG through its Foundation to support humanitarian applications of geoscience around the world (SEG website). This project combined geophysical specialists from five countries, students and graduates of four universities in three countries, local geophysical contractors, engineers and politicians of local governments and the local residents (Figure 1). The specialists provided training and knowledge transfer to students and local engineers, and the governments and the community gave logistical and moral support.

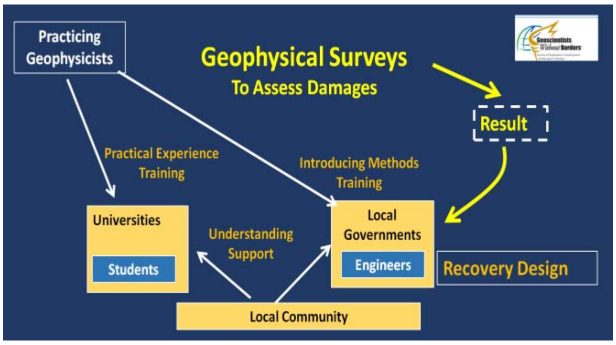

Figure 1: Schematic diagram of relationship of stakeholders of the G*w*B project.

Seismic reflection, refraction, MASW and electric resistivity surveys were carried out in three locations in Serbia and BiH in June 2015. Further three places were surveyed in September (Figure 2).

The MASW method (Park, *et al.,* 1999) is gaining popularity in recent years. Among its broad applications, it was used for assessment of flood damaged road (Suto and Kristinoff, 2014), and this method is considered effective in mapping the subsurface in potential landslide areas to aide estimating the strength of the subsurface material and depth of slip surface. The velocity boundaries are recognised by the reflection seismic section. The resistivity tomography method delineates electric resistivity of the ground allowing estimation of interaction of grain size, porosity and moisture contents form ground water. It was successfully applied to landslide surveys in other areas (Shan *et al.*, 2013).

STUDY AREA

Among the six areas, this report presents the result of MASW, reflection and resistivity surveys in the Vrazici area in the Brcko District of BiH. The site is approximately 20 km south of the City of Brcko. This is an agricultural area mainly with pasture land and orchards of various fruit trees on the slope and is lightly populated. The survey lines are laid on the eastern flank of the hill (Figure 3). The lines run through orchards, vegetable gardens, bush land, gardens of residence and grass land. A grid for mini-3D reflection survey was laid in the lower part of the slope. The gradient of the slope is generally around 10 degrees on average over the lines: i.e. about 20m drop over 100m horizontal distance.

Figure 2: Project locations.

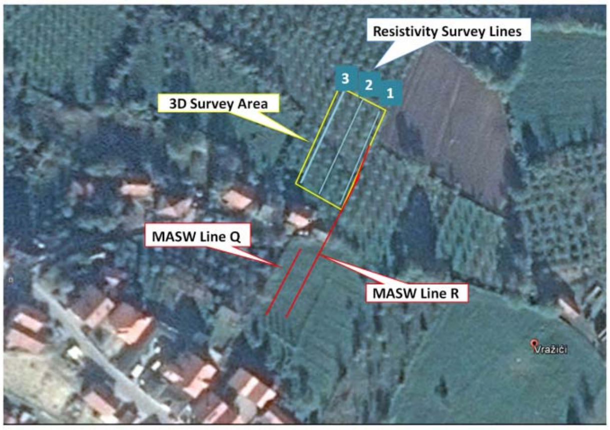

Figure 3: Vrazici survey site and survey lines.

DATA ACQUISITION

Survey procedure

The line locations are roughly decided by the engineers of the local government. The location is considered to be a landslide risk area as it shows signs of landslide phenomenon (Figure 4). The lines are not cleared and the cables are laid through the grass.

Figure 4: A typical survey line.

No. of channels	24
Natural frequency of geophones	4.5Hz
Receiver interval	1m
Source	Sledgehammer 12 lbs
Source interval	6.5m
Sampling interval	0.5ms
Record length	2s

Table 1: Data acquisition parameters for MASW.

No. of channels	144
Natural frequency of geophones	10Hz
Receiver geometry	12 x 12 at 2m interval
Source	Sledgehammer 12 lbs
Source interval	2m
Sampling interval	0.5ms
Record length	2s

Table 2: Data Acquisition parameters for "mimi-3D"

No. of electrodes	41
Electrode array	Wenner
Electrode spacing	2m
Max. number of data levels	8

Table 3: Data acquisition parameters for resistivity tomography.

Geophones for both mini-3D, MASW and electrodes for the resistivity survey were manually located with tape measures. Stations were marked with pegs for geodetic (location and elevation) survey, which followed later. Because of the difficulty of vehicular access due to the slope and vegetation, all the equipment had to be hand-carried. The data acquisition started on the top of the hill working downward. Data acquisition parameters are listed in Tables 1, 2 and 3.

DATA ANALYSIS

Data processing

The software used for processing the mini-3D data is Seisspace (Halliburton). The data were processed using a conventional 3D land processing work flow. The depth sections were generated using 95% of the average stacking velocity field.

The MASW data were analysed using SurfSeis 4.2 software by Kansas Geological Survey with an interval approximately 6 meters.

The resistivity tomography inversion was carried out with RES2DINV software by Geotomo Software, Malaysia. Inversion results were optimized in the GRID domain to visualize the resistivity contrast around the landslide plane.

Data analysis and results

Seismic depth section of the edge of the 3D reflection survey is shown in Figure 5. The section is referenced to the floating datum, which approximately follows the topography. The red box indicates approximate range of the section displayed in Figure 6.

Figure 6 shows the output of the MASW S-wave velocity of Line R and resistivity sections of Line 1 with corresponding part of the seismic section from the mini-3D survey. The primary output of the MASW analysis is referenced to the ground surface, this section is adjusted to the slope topography by sliding the columns according to the elevation. The seismic section is tilted to the approximate gradient of the ground surface for the ease of comparison.

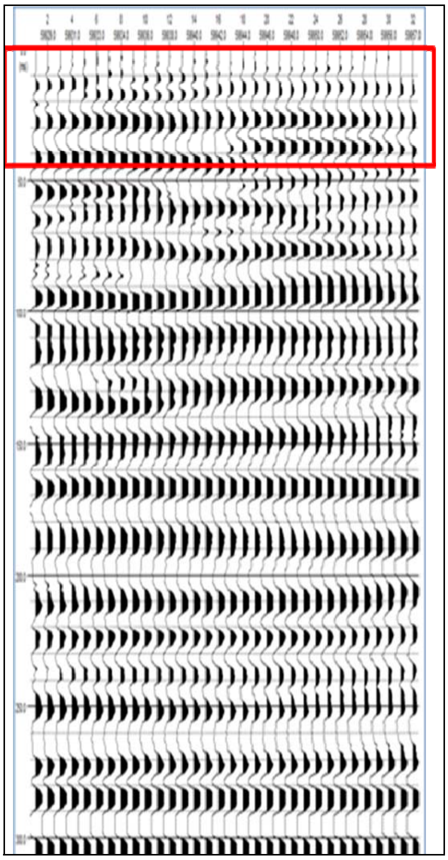

Figure 5: Seismic depth section (0-300m) of the edge of the 3D survey.

PRELIMINARY INTERPRETATION AND CONTRIBUTION TO PREVENTION DESIGN

Results of the MASW survey showed a clear increase of S-wave velocity from 250 to 350m/s at about 3 to 5m below the ground surface, which is indicated by the blue-green transition in the S-wave velocity section of Figure 6. These depths roughly correspond to the resistivity boundary at 80 ohm-m (light blue horizon). The seismic section shows this feature by the first event. This is considered as a potential slip surface under a certain condition. These findings generally agree with the results of the preliminary site walkover inspections and topographic study.

A small velocity reversal is observed in the S-wave velocity section (the blue layer observed for much of the section that is under the green-yellow layer). This velocity contrast is prominent in the seismic section appearing as a high amplitude event below. This could be a looser material than the layer above, indicative of earlier landslide event. However no corresponding feature is seen in the resistivity tomography section.

Based on these findings, the authors consider that this area is a shallow landslide site consisting of thin layers of top soil and residual soils overlying weathered rocks. According to Varnes' classification (1978), this landslide can be classified into "earth slide or earth flow" which is the most common landslide type in BiH. Prevention measures will be designed accordingly.

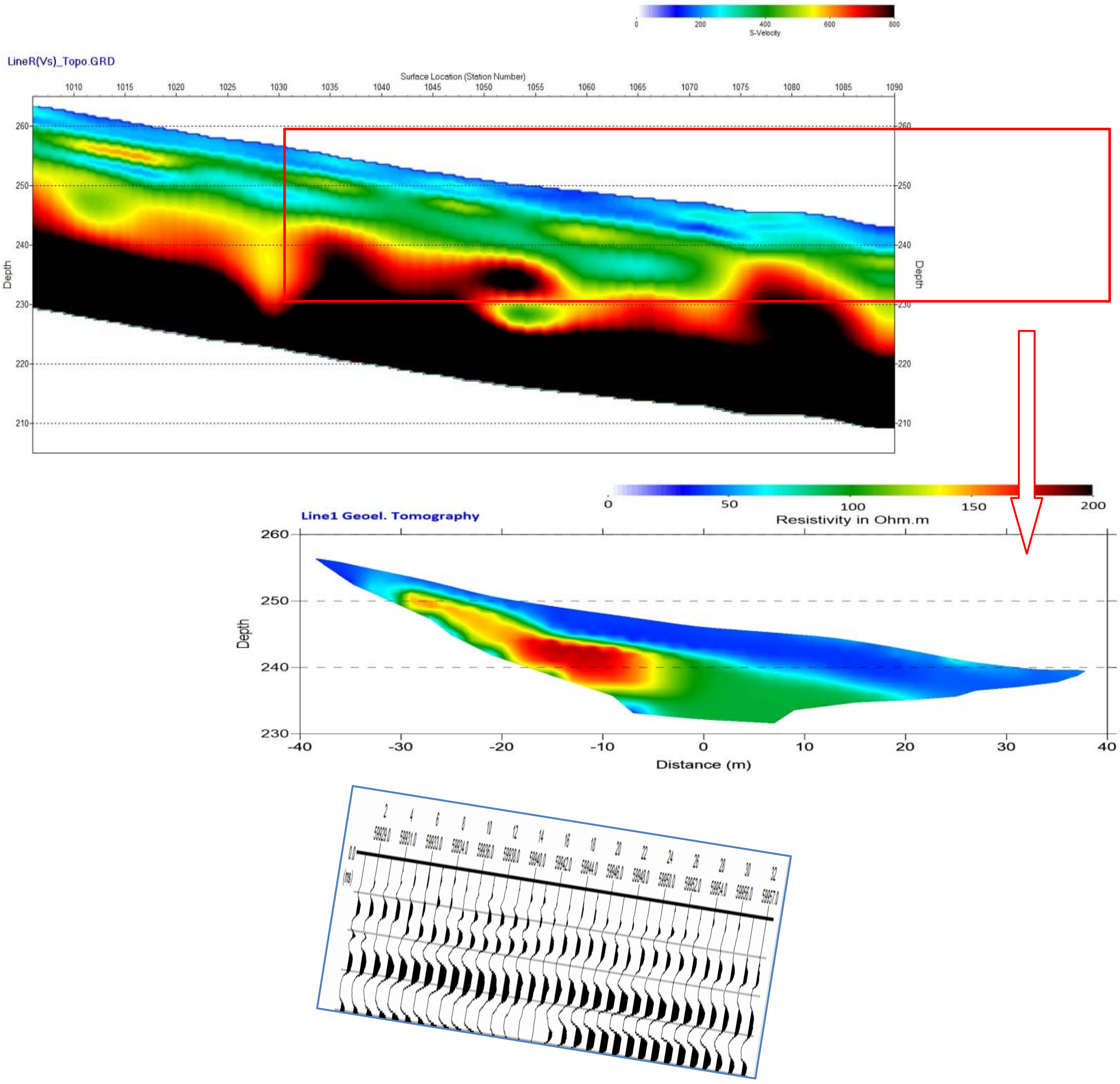

Figure 6: S-wave velocity of Line R, resistivity section of Line 1 and corresponding seismic reflection section (red box in Figure 5).

CONCLUSION AND FUTURE WORK

A part of the 2015-2016 G*w*B project of "Assessment of flood-damaged infrastructures in Bosnia & Herzegovina and Serbia", seismic and resistivity tomography surveys were carried out in the Vrazici area in BiH. The output of these surveys shows a consistent feature of potential slip surface at about 3-5m below surface. It will be used as a basis of prevention design.

In the next stage of the project the 3D reflection and refraction analyses of the same data will be completed. These data will be integrated into a comprehensive interpretation for use in landslide remediation. Similar analysis of other five locations of the project will be carried out as well.

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