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Contributed Paper

An MASW Survey for Landslide Risk Assessment: A Case Study in Valjevo, Serbia

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ABSTRACT

The MASW method is applied to the slope of landslide-risk area near Valjevo, Serbia. This is a part of SEG's Geoscientists without Borders project, following the rain-caused disasters in the Balkan area in 2014. Association of Geoscientists and Environmentalists of Serbia organized the project involving specialists from around the world, local students, government individuals, and local communities. The data were primarily collected for reflection seismic analyses. The MASW processing used a subset of the data by extracting appropriate traces. The S-wave velocity sections analyzed through MASW are compared with the reflection seismic section and consistent features are identified to lead to a geologically plausible interpretation. This result will be integrated with electric resistivity survey and drilling data to contribute to designing disaster mitigation plan.

Keywords: MASW survey, seismic survey, landslide, Serbia

1. INTRODUCTION

In May 2014, a heavy rainfall caused an extensive disaster in the Balkan region (Figure 1). The damage was particularly severe in the catchment area of the River Sava. According to the European Bank for Reconstruction and Development (EBRD) the damage was estimated at around 1.5 to 2 billion euro in Serbia, and about 1.3 billion euro in Bosnia and Herzegovina (BiH), [1]. More than 150,000 people were evacuated and the total number of affected people reached 1.6 million. Houses were destroyed or partially damaged by floods due to overflowing rivers; and failed river banks

affected houses in the plain areas, and by landslides in the hillsides. There were over 2000 landslides. This highlighted the danger of living in landslide-prone areas, and assessment of the landslide potential is desired.

Among the wide range of aid from all over the world, the Society of Exploration Geophysicists (SEG) sponsored a Geoscientists *without* Borders (GwB) project initiated by Association of Geoscientists and Environmentalists of Serbia (AGES) titled "Assessment of flood-damaged infrastructures in Bosnia & Herzegovina

and Serbia". This project connects geophysics specialists from five countries, students and graduates of four universities in three countries, local geophysical contractors, engineers and politicians of local governments, and residents of the local areas in geophysical surveys (Figure 2).

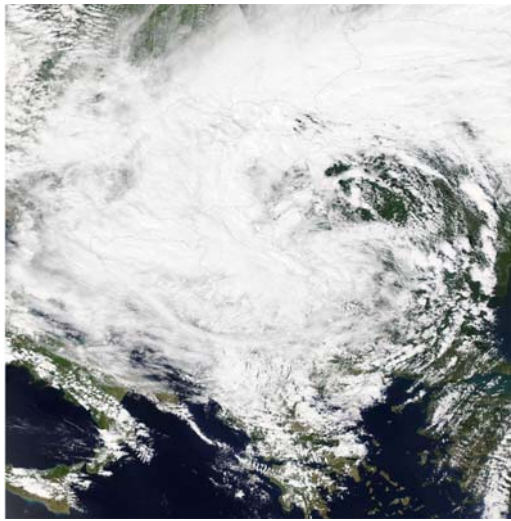


Figure 1. Satellite image of the rain cloud covering Europe on 13 May 2014.

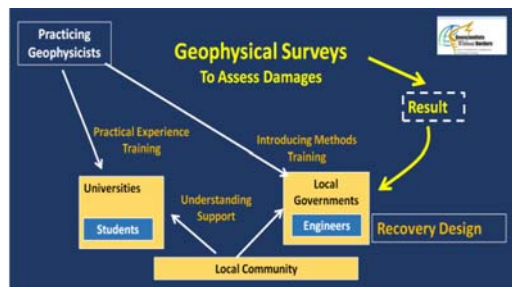


Figure 2. Schematic diagram of relationship of stakeholders of the GwB project.

In June 2015, seismic reflection, refraction, MASW and electric resistivity surveys were carried out in three locations in Serbia and BiH. Additionally, three locations were surveyed in September. This presentation focuses to the result of MASW survey in one of the survey areas: Valjevo, Serbia.

The MASW method [2] is gaining popularity in recent years. It analyzes seismic data in the frequency-velocity domain to estimate the subsurface S-wave velocity structure. Its previous applications include investigation of fill sites [3, 4], bridge foundation [5], flood damaged road [6], construction site [7] and planned tunnel alignment [8]. This method is considered effective in mapping the subsurface in potential landslide areas to aid in estimating the strength of the subsurface material and depth of slip surface.

2. PROJECT OUTLINE

2.1 Geoscientists without Borders

The Geoscientists *without* Borders is an initiative of SEG through its Foundation to support humanitarian applications of geoscience around the world [9]. Projects are often selected in the areas in need of assistance for which geophysics can be a tool. The topics include archaeology, water management, pollution mitigation and disaster management due to earthquakes, landslides, tsunami and volcanoes.

Applications of geophysics to landslide areas have previously been GwB projects in Brazil and Sweden in 2010-2011 [9]. The current project was selected only a few months after the disastrous rain in response to the application by AGES. It started with discussion with local community and site scouting in March 2015 followed by field data collection in June and September 2015. Twelve geophysical experts, twenty-two students and graduates from Serbia, BiH, Australia, Sweden, Italy and Japan participated in the fieldwork. It was supported by six local governments and many residents of the local community. The outcome will be delivered to the local engineers for designing their recovery plan.

2.2 Study Area

Six locations in Serbia and BiH were surveyed so far in the project in 2015. They are evenly spread between Serbia and BiH, and even in BiH, evenly spread in regions within BiH, in consideration of sensitivity both in political and religious background. The project areas are in the greater Sava basin, the catchment of Sava, Drina and

Klubara Rivers.

Among the six areas, this report presents the result of the survey in the Valjevo area in the western Serbia, upstream of Klubara River. The site is about 20 kilometers north of Valjevo city center and amongst orchards of cherry, peach, apricot and pear (Figure 4). Some evidence of landslide and erosion were apparent on the slope.

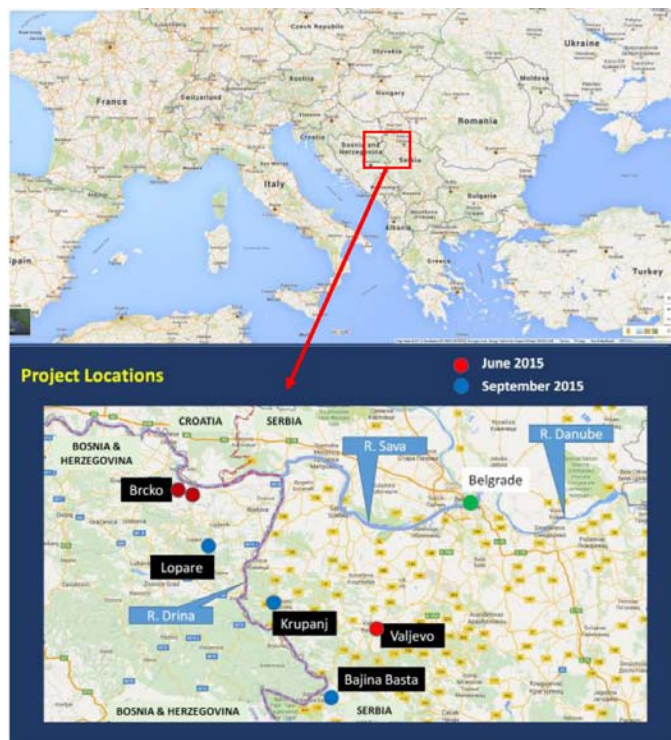


Figure 3. Project areas.



Figure 4. Valjevo survey site and seismic lines.

2.3 Methods Used

The project deployed seismic and electric methods. The seismic survey is primarily for reflection method, but the parameters are designed to suit refraction and MASW analysis as well. In this report, the MASW aspect is focused with a comparison with result of seismic reflection processing. It is anticipated that more comprehensive results will be reported once all the data of the other surveys are processed.

3. DATA ACQUISITION

3.1 Site Description

The survey site is approximately 20 km north of the City of Valjevo (Figure 4). This is lightly populated agriculture area mainly with orchards of various fruit trees on the slope. The main road shown in Figure 4 runs along the ridge of the topography. The seismic lines were run on the eastern flank of the hill. The lines run through orchards, vegetable gardens, bush land, gardens of residence and grass land. The gradient of the slope is generally around 10 degrees on average over the lines: i.e. about 17m drop over 100m horizontal distance.

3.2 Survey Procedure

The line locations were roughly decided by the engineers of the local government. These locations are considered to be an area of landslide risk. The lines were not cleared and the cables were laid through the grass (Figure 5).

Geophone locations were manually measured with tape measures. Every sixth geophone station was marked with a peg 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, and the equipment was retrieved by the vehicle on the road at the bottom of the hill.



Figure 5. A typical seismic line.

3.3 Parameter Selection

Geophones with different natural frequencies (4.5Hz and 10Hz) were compared for the use of the MASW survey. The reason for this comparison is to examine whether the 10Hz geophones can produce data comparable with the 4.5Hz geophones. While over 150 10Hz geophones for the reflection survey were prepared, only 24 4.5Hz geophones were available. If the data by 10Hz geophones are good enough, a separate survey with 4.5Hz geophone is not necessary. The experiment took place for the first 125 meters, at the top of the hill of the first line (Line A). The 4.5Hz geophones are laid out at a 1 meter geophone interval in five 24-channel spreads. The data using 10Hz geophone were “cut out” from the 132-channel data acquired for reflection analysis for the same geophone locations as the 24Hz spreads.

Figure 6 shows the dispersion images of the start of Line A with geophones of 4.5Hz and 10Hz. The main difference between the two images is in the low frequency band under 5Hz. It is noted the higher-mode surface wave component is stronger at around

15Hz in the 4.5Hz geophone data, while it is stronger over 30Hz band in the data with 10Hz geophones. These differences do not influence the analysis of the

dispersion curve of the fundamental mode Rayleigh waves. Although there are minor differences, these images are regarded comparable.

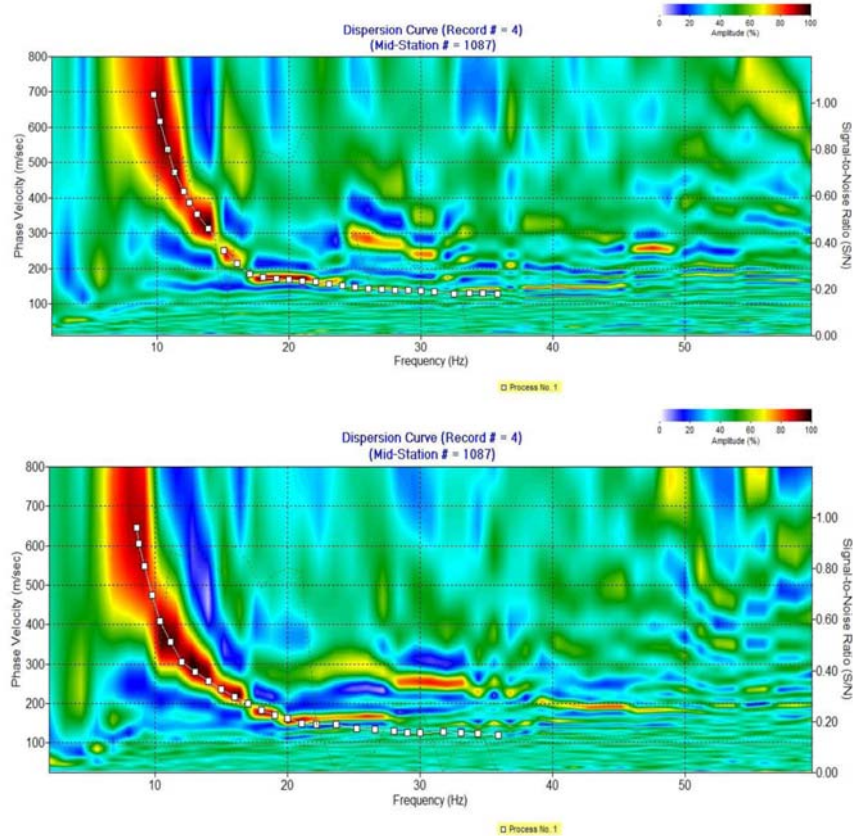


Figure 6. Comparison of dispersion images using different geophones. (Top) 4.5Hz (Bottom) 10Hz.

The S-wave velocity sections generated by the analysis of first five records are shown in Figure 7. These sections are regarded sufficiently similar with some variation perhaps caused by variability in picking dispersion curves.

From this experiment, it is decided to collect the data only for reflection analysis and to use a subset for MASW, although the data acquisition parameters for the reflection survey are primarily designed to resolve the top 30 to 50 meters. For this high-resolution mode of the reflection survey, a very short geophone interval

1 meter and high-fold are needed. The maximum number of channels is limited by the availability of the equipment, which is 132. All the geophones are planted and connected to live, and seismic data are recorded sourced by a 6 kg sledgehammer. The source points are between every two geophones. This procedure produces a dataset with the number of folds variable from 1 to 132. Where the survey line is longer than 132m, the geophones are rolled along as appropriate as the source location progresses. The final data acquisition parameters are summarized in Table 1.

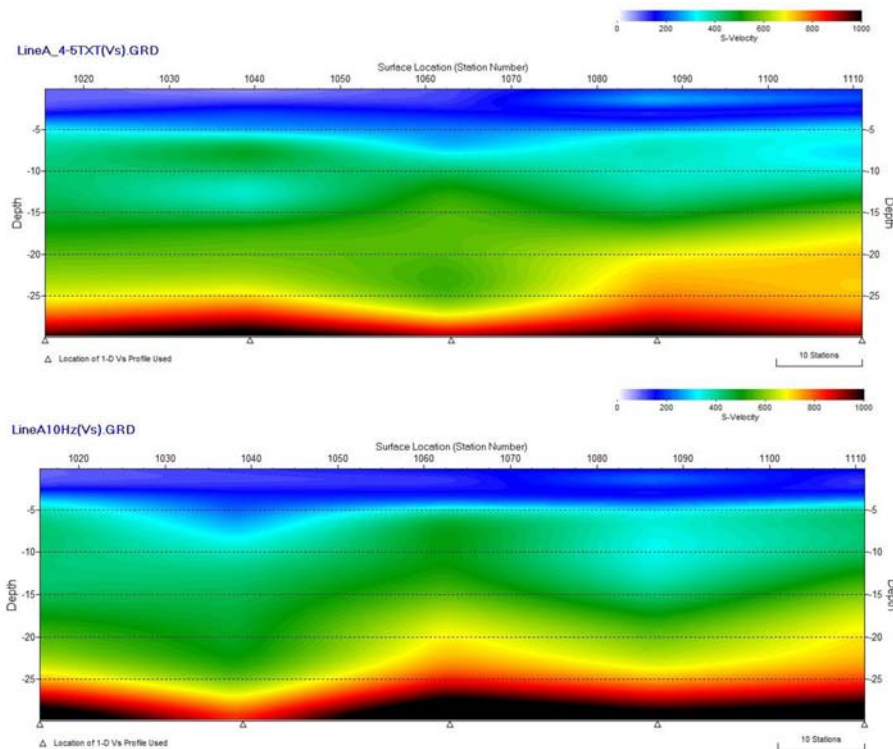


Figure 7. Comparison of inverted S-wave velocity sections using different geophones. (Top) 4.5Hz (Bottom) 10Hz.

Table 1. Data acquisition parameters.

No. of channels	132
Natural frequency of geophones	10Hz
Receiver interval	1m
Source	Sledgehammer 6 kg
Source interval	1m
Sampling interval	0.5 ms
Record length	2s

4. DATA ANALYSIS

The volume of data collected for reflection analysis is far larger than needed for MASW. Every sixth record was used for analysis. Thirty-one traces were extracted from each of these records making the offset range from 6 to 35 meters (Figure 8). The part drawn in red was extracted and used for the MASW analysis.

The data quality is reasonable as seen in Figures 8 in the time-distance domain and in Figure 5 in the frequency-velocity domain. The data were analyzed using the SurfSeis 4.2 software by Kansas Geological Survey. On the four lines totaling 726 meters, 112 records were analyzed for dispersion curves at an interval approximately 6 meters. The Inversion process in SurfSeis is an iterative inversion to match the dispersion curve. The half-space depth d_{max} of the initial model is determined by the lowest frequency f_{min} and corresponding phase velocity in the dispersion curve as: $d_{max} = 0.35 f_{min} V_{ph}$. As the number of expected geological layers is unknown, the maximum number of the software (20) is used for the model. The iterative inversion to match the dispersion curve does not accept much control during the process

beyond the half-space depth and number of layers. If the result is far from geological reality, an examination of the dispersion curve and number of layers are only items

to check. However, such re-examination was not necessary in this case: the inversion produced models geologically plausible.

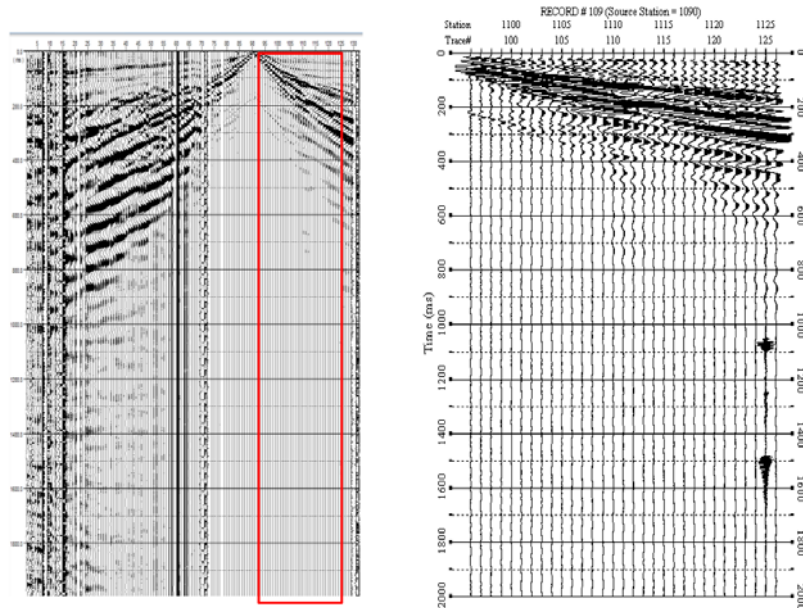


Figure 8. Original 132 channel record collected for reflection analysis (left) and 31-channel subset for MASW (right).

5. DISCUSSION

The seismic data were primarily collected for reflection processing and analysis. The reflection data were processed and some results have been reported by Urosevic et al. [10].

Figure 9 and 10 compare S-wave velocity sections from the MASW analysis and P-wave reflection sections of two selected lines: Line B and Line D. In each figure, the S-wave section is on the top and reflection section is in the middle. The bottom figure is the same S-wave velocity data adjusted to the surface topography. The reflection section is final stack with DMO applied.

The two lines display similar feature. A tentative interpretation is added to each section. The slow S-wave velocity of

the surface layer (blue) about 5 meters thick is equivalent to the velocity of top soil and soft clay. It is underlain by a thin relatively high velocity layer. The top of this layer (marked as white horizon) may be a potential slip surface. The layer between white and black horizons is a mixture of fast and slow material, which may indicate variable debris of several episodes of previous landslides. In the reflection section, this region is characterized by the noisy inconsistent texture. This could be another layer to collapse under worse conditions. Under the black horizon is a reasonably consistent layer with S-wave velocity about 500m/s (green). This is about the velocity of weathered but competent rocks. A relatively uniform layer of the S-wave velocity around 600m (yellow to red-black) is reached at the

depth 15 to 25 meters (blue horizon). This is interpreted as the depth of stable fresh rock.

The reflection sections show poor continuity of reflectors at this depth range presented in the Figure 9 and 10. However the stack quality improves in the deeper part of the section and further interpretation of deeper structure may lead to a more refined interpretation in relation to the deeper geological structure. If borehole data is available, the interpretation will

be refined to match soil or rock types.

With the section adjusted to the topography, the profiles of velocity structure are better visualized. It shows the variation of the soft material near the surface in terms of topography. The areas with steeply dipping slide surface with thin loose material are considered of higher risk of landslide. At this stage, however, these interpretations are only speculative until geological ties by drilling are provided.

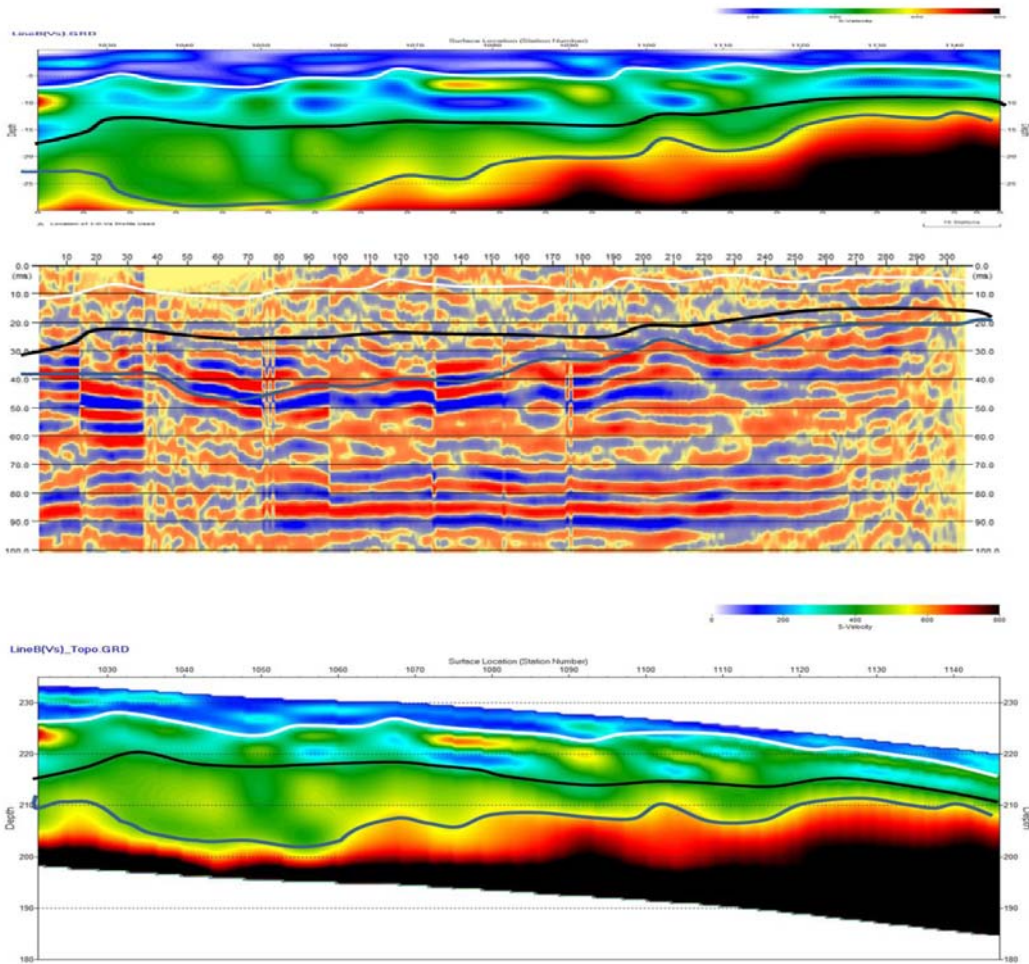


Figure 9. Seismic sections – Line B. (Top) S-wave velocity section from MASW - surface referenced; (Middle) Reflection section - DMO stack; (Bottom) Topography-adjusted S-wave velocity section.

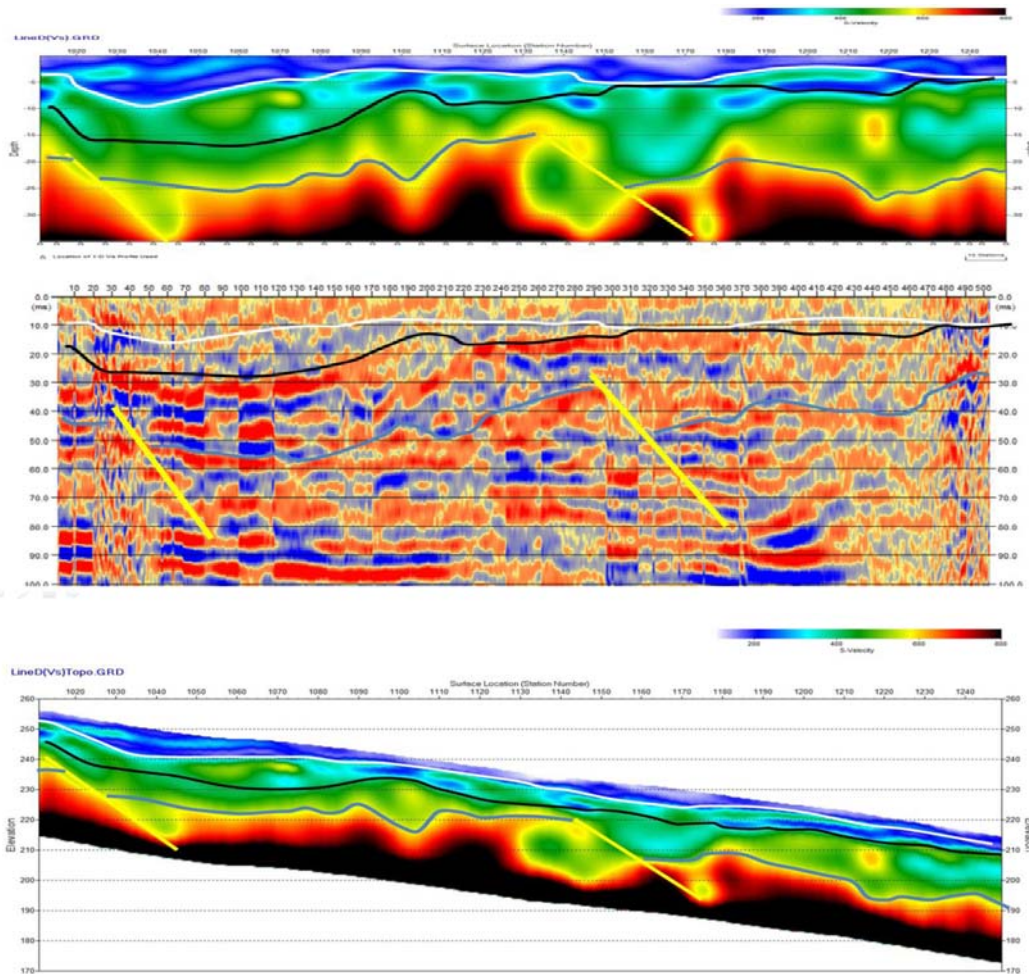


Figure 10. Seismic sections - Line D. (Top) S-wave velocity section from MASW - surface referenced; (Middle) Reflection section - DMO stack; (Bottom) Topography-adjusted S-wave velocity section.

6. CONCLUSION AND FUTURE WORK

As a part of the 2015-2016 GwB project of “Assessment of flood-damaged infrastructures in Bosnia & Herzegovina and Serbia”, seismic surveys were carried out. The data collected for reflection analysis were analyzed by the MASW method. The S-wave velocity sections from the MASW survey were compared with the P-wave reflection section and found the features were comparable. The preliminary interpretation of the seismic sections led to a sensible geological model of subsurface structure

and a potential slip surface.

As a next phase of the project, these data will be compared with electric resistivity data collected on the same lines. A few drilling sites have already been proposed. These data will be integrated into a comprehensive interpretation to contribute to landslide risk analysis.

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