Geophysical Study of the Peace River Landslide

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Summary

We have demonstrated the use of different geophysical methods to study the extents and processes of a landslide at Peace River. Due to the sensitivities of the different geophysical techniques to various physical properties, diverse and important information about the landslide can be obtained. This information would be very useful to the geotechnical personnel and engineers in designing a feasible and effective landslide mitigation procedure.

Introduction

Landslides are significant geohazards that pose active threats to lives and infrastructure, if left unmitigated. Surficial examination of landslide areas may be inadequate in determining key features of the mass movement, including its geometry and associated rupture (or shear) surfaces. However, geophysical techniques have the potentials of providing the much needed knowledge about the subsurface structure as well as the physical properties of the constituting materials that can be used to access the slope stability.

Mass movements have been occurring since the Holocene geologic epoch in the Peace River Lowlands of Alberta and British Columbia (Davies et al., 2005). This contribution seeks to provide a geophysical understanding of one such landslide situated on a major slope at the Town of Peace River with the aim of reducing the geohazard risk to lives and infrastructures. Seismic and electrical resistivity methods were utilized, in combination with existing geophysical well logs, to provide interpretable static geophysical images of the subsurface at the location of the landslide on the basis of contrasts in physical properties (Ogunsuyi, 2010).

Method

A high-resolution 2D reflection seismic line that overlaps the surface over disturbed and undisturbed ground was acquired at the site of the landslide. In addition, a VSP survey was conducted in a wellbore that is located close to the 2D line. Further, a high-resolution and low-resolution electrical resistivity tomography (ERT) datasets were collected along the 2D profile line. The locations and acquisition parameters of these geophysical ventures are outlined in Ogunsuyi (2010). The seismic reflection profile was processed in the standard CMP method (Yilmaz, 2001) together with spiking deconvolution and radial domain processing (Henley, 1999) to enhance reflections and reduce linear noise (see Ogunsuyi, 2010 for details). First arrival traveltimes from the seismic dataset were inverted using a nonlinear optimization technique called generalized simulated annealing (Pullammanappallil and Louie, 1994) to obtain a representative P-wave seismic velocity distribution of the subsurface. Moreover, the apparent resistivities from the ERT surveys were inverted with a nonlinear smoothness-constrained least-squares inversion method (Loke and Barker, 1996) to produce a possible true resistivity of the subsurface.

The various geophysical techniques used here are sensitive to contrasts in different physical properties and so they make available diverse information about the material properties of the rocks. The reflection profile provides a structural image of the subsurface, and hence, the possible geometry of the landslide, while the VSP survey supplies a time-to-depth relationship for the various geologic formations in the vicinity of the wellbore. The ERT method offers information about the associated processes of the landsliding on the basis of the contrasts in the electrical resistivities of the rocks.

Results

The Peace River landslide has been previously determined to be a relict, retrogressive, translational earth slide (J. Morgan, personal communication, 2010). The bedrock geology of the landslide area is explained by Hamilton et al. (1999) while the Quaternary stratigraphy is described by Morgan et al. (2008). The Peace River Formation, which is considered to be the lowest stratigraphy unit related to the landslide, underlies the bedrock shales of the Shaftesbury Formation (Cretaceous) that are prone to sliding (Cruden et al., 1990). Apart from the slide-susceptible Shaftesbury Formation, slope failures are common also in the overconsolidated glaciolacustrine sediments of the Late Wisconsin (Quaternary) advance-phase period (Davies et al., 2005).

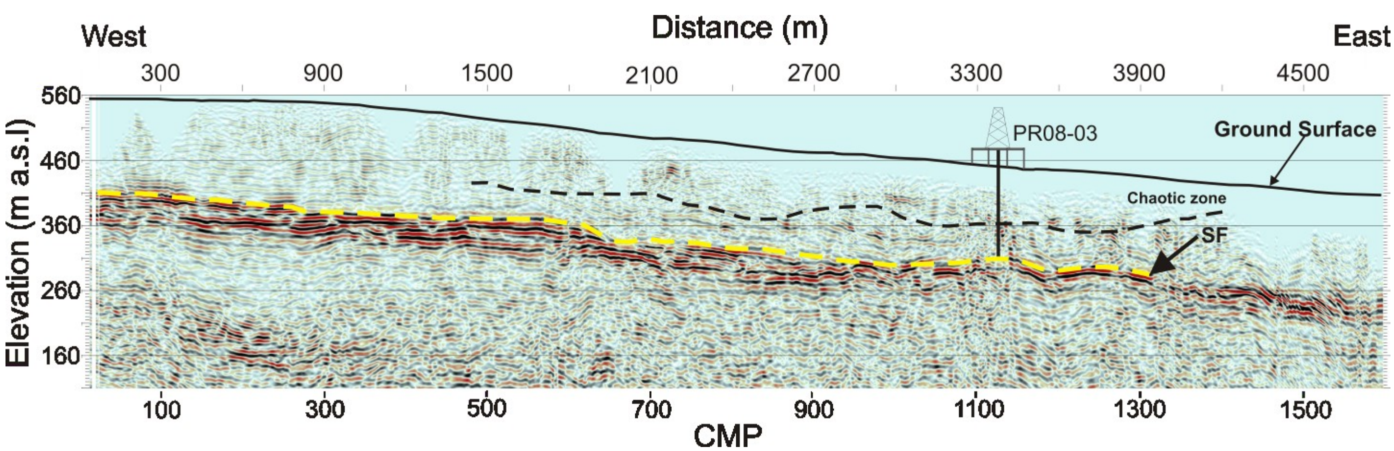

Figure 1: Depth converted profile of the 2D time reflection seismic line. The top of the Shaftesbury Formation **SF** bedrock (yellow broken line) and the rupture surface (black broken line) that separates the chaotic zone from the coherent zone are shown. Location of the wellbore in which the VSP survey was performed is also shown.

A simple time-to-depth conversion of the processed time reflection profile was performed by using final average velocities from a typical CMP velocity analyses (Figure 1). The strong reflector **SF** (yellow broken line) dipping from west to east (towards the Peace River) on the reflection profile is the top of the Shaftesbury Formation bedrock as determined from the VSP survey and well logs. The uneven topography associated with the top of the formation suggests a buried erosional surface that was possibly shaped by the pre-glacial Peace River. On top of the bedrock lies the Quaternary sediments that are characterized by chaotic reflections above a certain surface (black broken lines) in a section of the profile (see Figure 1). The discontinuous reflections observed in this zone are interpreted to be associated with areas that are more disturbed by the landsliding as against the areas characterized by continuous events that could be indicative of areas unaffected or minimally affected by the landslide processes. The surface between the chaotic and coherent zones, marked by the black broken lines, is interpreted to be the possible rupture surface of the landslide.

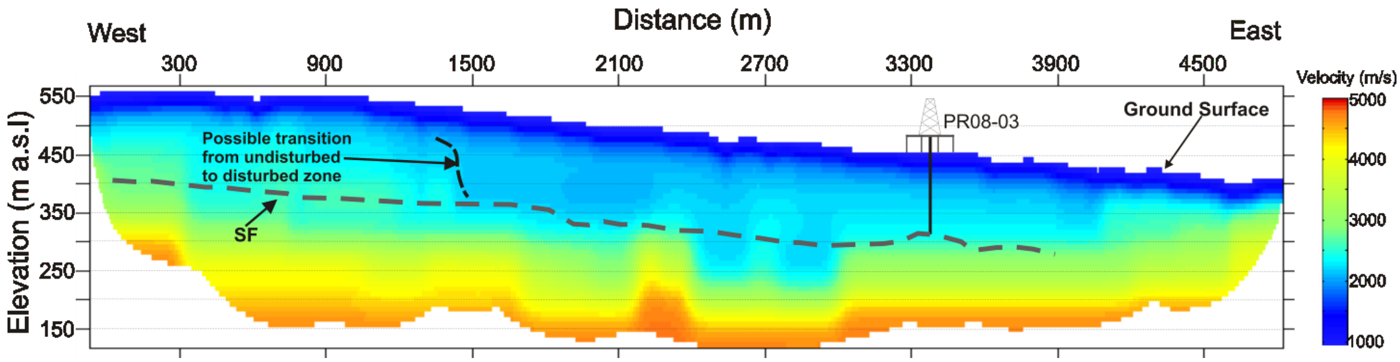

Figure 2: The velocity distribution of the subsurface as obtained from the first arrival traveltimes inversion. The transition area, interpreted on the basis of the velocities, from the undisturbed to the disturbed zone is shown in black broken lines.

The velocity field obtained from the first arrival traveltimes tomography shows a transition from higher velocities (~ 2500 m/s) to lower velocities (~ 2100 m/s) from west to east at distance ~ 1500 m (Figure 2). Since P-wave velocities are typically lower within landslide masses than in undisturbed zone (Jongmans and Garambois, 2007) possibly due to the weathered and fractured nature of the landslide mass, such velocity evolution from west to east suggests transition from relatively undisturbed zones to more disturbed areas. Thus, this boundary (marked by broken lines in Figure 2) could indicate a possible scarp of the landslide.

The materials above the interpreted rupture surface (black broken lines) shows high heterogeneity in the resistivity values, with most areas characterized by lower resistivities (< 10 ohm.m) than others (Figure 3). These low resistivities areas are interpreted to be clayey silt tills as indicated on the borehole logs (Morgan et al., 2009), and they are possibly related to the slide-prone overconsolidated glaciolacustrine sediments of the Late Wisconsin advance-phase period. The high resistivity areas are possibly related to sandy/gravel deposits. From the ERT results, it can be inferred that lithology is one of the most important factors in the slope stability at Peace River, with clayey sediments more prone to sliding than sandy formations.

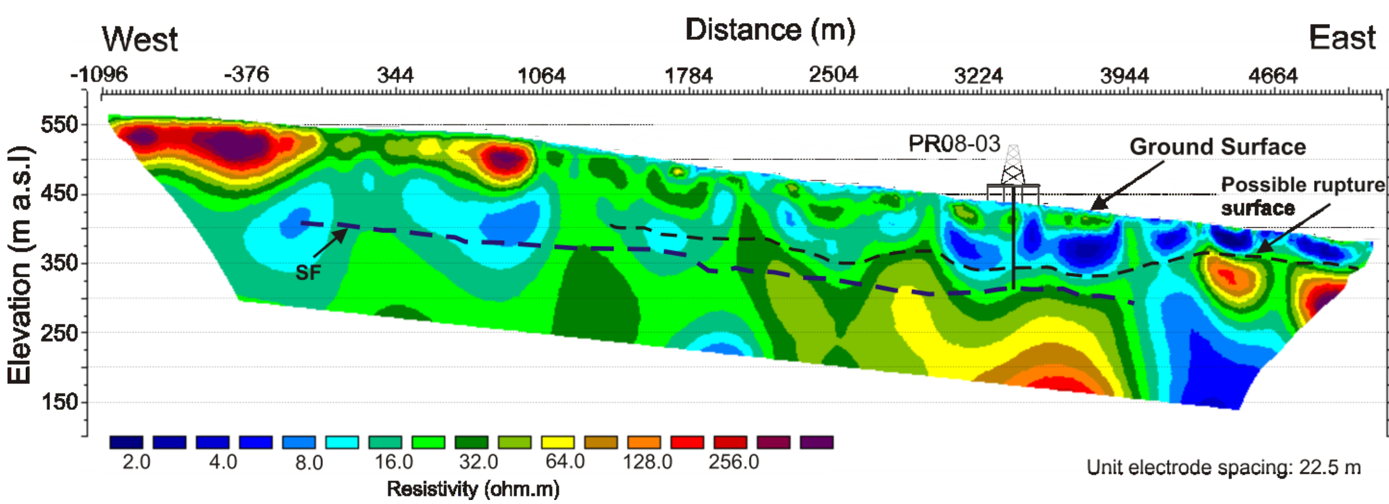

Figure 3: Results of the ERT data inversion for 22.5 m electrode spacing. The top of the Shaftesbury Formation **SF** bedrock (deep-blue broken line) and the rupture surface (black broken line) are shown.

Conclusions

We have shown the results of a geophysical study, consisting seismic and geoelectic methods, to investigate the extents and processes of the Peace River landslide. The seismic reflection data was processed and depth-converted, the seismic first arrival traveltimes were inverted for the velocity structure of the subsurface, and the ERT data were also inverted for the true resistivity subsurface structure of the area. Interpretations made from these geophysical techniques resulted in the determination of the possible rupture surface as well as the significant role of lithology in the slope stability at the area. Considering the extent of interpretations made from the different geophysical methods, it is concluded that carefully and accurately processed data sets are able to provide valuable insights in the study of landslides. However, it is emphasized that employing various complementary geophysical techniques as against the use of a single method is expected to provide a better understanding of the landslide and its processes because of the sensitivities of different geophysical methods to varied physical properties.

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