Landslide site effects analysis in a seismic area: the Utiku landslide (New-Zealand)

S. Garambois & C. Voisin
ISTerre, Université Joseph Fourier & CNRS (UMR 5275), Grenoble, France

C. Massey
Geological and Nuclear Sciences, Upper Hutt, Wellington, New-Zealand

ABSTRACT: A growing number of landslides triggered by earthquakes has raised the need for a thorough assessment of the potential seismic site effects generated by the disturbed material. To better understand its characteristics, a monitoring seismic network was installed for 14 months on the re-activated deep-seated landslide of Utiku (North Island, New-Zealand). As this landslide caused subsidence since 1964 to the main Wellington-Auckland highway and more seriously to the railway, it is thoroughly instrumented and monitored nowadays. A network of 5 broadband (30s – 40 Hz) seismic stations have recorded ambient vibrations as well as a thousand of earthquakes over a period of 14 months from November 2008 to January 2010. Here, we will first present seismic site effects characteristics of the landslide, including its spatial variability controlled by its thickness and its azimuthal sensitivity. In a second step, we will show monitoring results performed using H/V seismic noise and correlation methods, and their sensitivity to water table variations.

1. INTRODUCTION

1.1 Seismic site effects on landslides

The characterization of seismic site effects on landslides is limited to few studies, although site effects have been largely studied for seismic risk assessment and vulnerability. Del Gaudio and Wasowski (2008) investigated the peri-urban slopes of Caramanico Terme – central Italy – to determine how the seismic response is affected by the presence of topographic features and by pre-existing landslides. They have shown that slope response to seismic shaking exhibits an anisotropy factor of 2–3 or larger, the maximal response being parallel to the maximum slope direction, regardless the location of the recorded events determined by the back-azimuth of the epicenters. Topographic and pre-existing landslide conditions may both contribute to site effect patterns. Their respective contributions might be difficult to distinguish because of the limitation of one seismic station per site. The main purpose of this study is to assess site effect characteristics of the Utiku landslide (NZ) and its variability over space and time. We notably compared the site effect assessment derived from ground motions generated by the ambient seismic noise, the railway and the earthquakes. The three techniques provide consistent results for the amplification of the ground movement in terms of amplitude and frequency. In the second part, we tackle the spatial variability of site effect. 74 H/V measurements on seismic noise have been used to derive the geometry of the landslide. We show that differences in the site effect response of the landslide are due to the degree of dismantlement of the material that controls the shear wave contrast. These results indicate that an earthquake solicitation will strongly differ inside a single landslide, even at a scale of hundred meters. We also detected a strong anisotropy of the site amplification for all the stations. The maximal site effect amplification is correlated to the local displacement direction of the landslide rather than to the local maximal slope direction. Finally, time variations are studied using both H/V and correlation methods. The latter appears to show remarkable velocity variations of 2 % which are completely correlated with water table variations recorded in piezometers.

1.2 The Utiku block slide

The Utiku landslide, which is traversed by State Highway 1 (SH1) and the North Island Main Trunk Line (NIMT), is located 1 km south of the central North Island township of Utiku, approximately 7 km south of Taihape in Rangitikei District. Parts of the landslide are moving and causing damage to both SH1 and the NIMT. The Utiku landslide is a complex reactivated, translational block slide-earth flow, which initiated pre-historically, probably triggered by a major seismic and/or rainfall event, following removal of lateral/toe support resulting from the incision of the Hautapu River. It affects sandstones and boreholes show that disturbed material varies from a thickness of 65 m on the Eastern part (UL2 on Fig. 1) to 15 m (UL4), 49 m (UL1) and 28 m (UL5). Current monitored landslide movements are much lower (in magnitude and rate), than those recorded pre-1973 ranging now from between 10 cm/year (UL5) to 3 cm/year (UL2) (Massey, 2010). This decrease is attributed to a lowering of piezometric levels in the upper landslide, possibly as a result of the mitigation works installed between 1965 and 1972. Recently, under static conditions, landslide movement has been recorded when certain piezometric levels have been exceeded and the analyses show that the landslide is sensitive to rainfall-induced changes in piezometric level (Massey, 2010).

2 SEISMIC SITE EFFECT CHARACTERISTICS

2.1 Observations on earthquakes

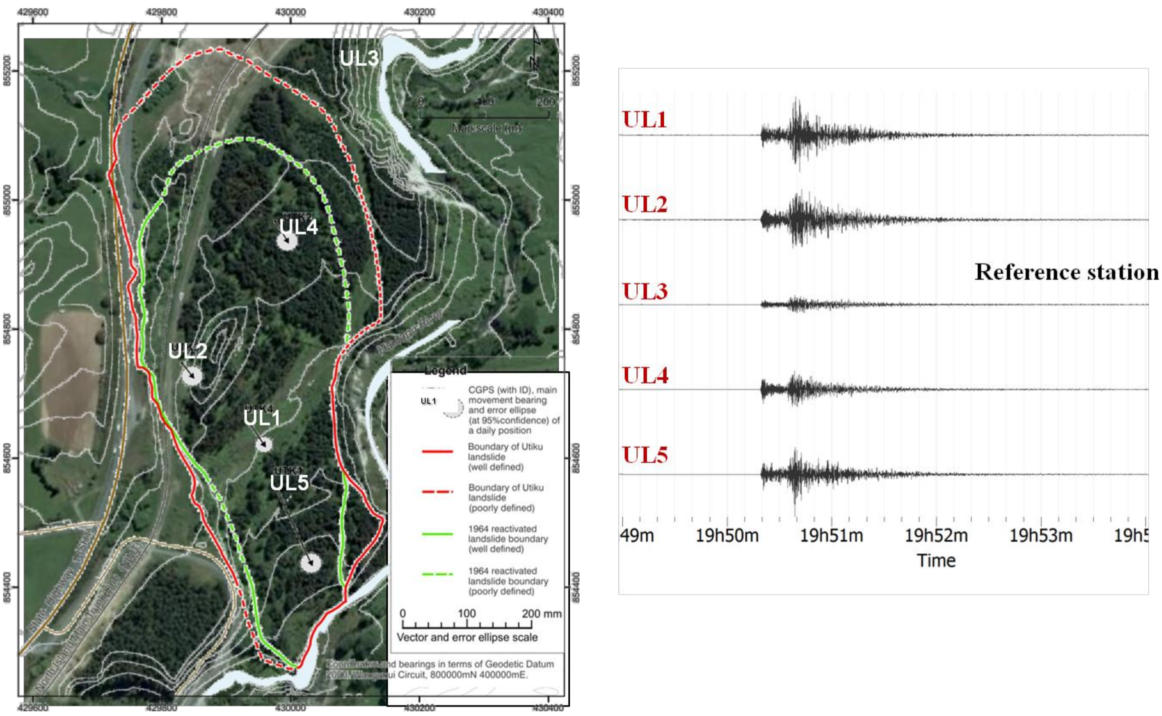

Figure 1. Left: Map showing the limits of the landslide, the location of seismological stations, the relative magnitude of displacements over a one-year period (after Massey, 2010). Right: an example of a seismological recording (Otaki event, Mw=5.1, D=122 km, z=50 km) for all available stations..

.

Four out of five 3-component seismological stations have been installed in different places of the landslides where boreholes and monitoring data (GPS, piezometers) were available (Fig. 1, left). A reference site has been installed north of the landslide. An example of seismic particle velocities recorded after the Otaki event (Mw=5.1) in the E-W direction is shown of Figure 1 (right). It clearly displays the large variations of local response to earthquakes, with a maximum of amplification at UL1 and a minimum at the reference site. In order to better characterize the characteristics and variability of the site effect, we first compared site effect analysis using H/V seismic noise method, H/V performed on train data (very large particle velocity) and spectral ratio computed on earthquakes. All results were consistent. They all show, as displayed on Figure 2 (left), that each site of the landslide display different amplifications both in frequency and amplitude. The local thickness of the landslide strongly controls the frequency, V_s appearing to present smooth variations. The amplitude is the largest at UL1 and UL5, where surface and basal topographies are relatively flat, contrary to UL2 located nearby the edge of the eastern part. Figure 2 (right) also displays the azimutal variability of amplifications. It shows that this variability is large, reaching a factor of 3 for UL1 (amplifications ranging from 2.5 to more than 8). The maximum angle corresponds to the displacement direction recorded at the surface and not to the topography variations.

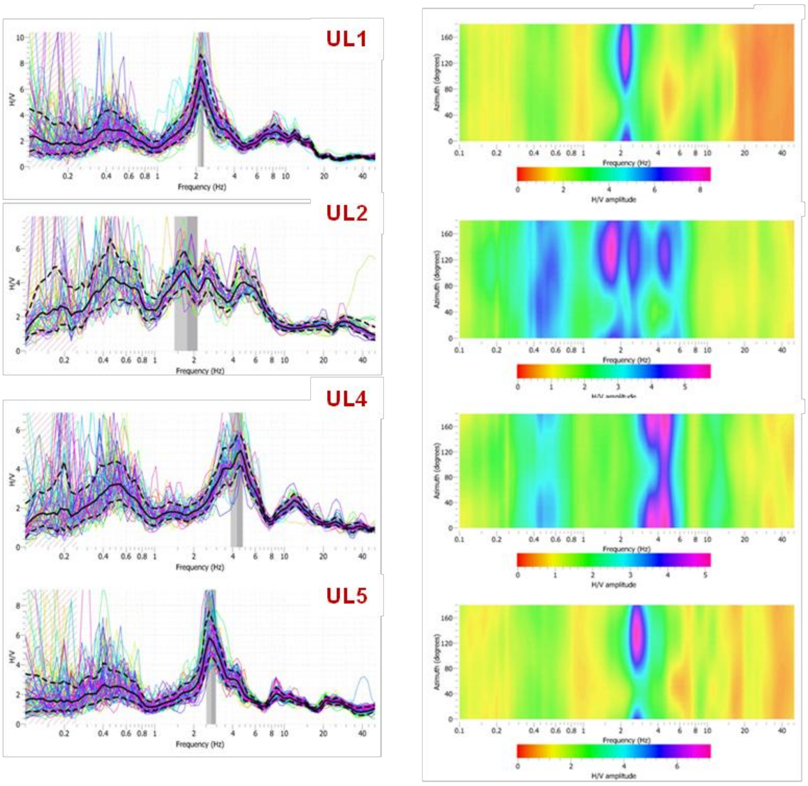

Figure 2. Seismic noise H/V results for all the station (left) and azimuthal variability (right)..

3 SEISMIC NOISE MONITORING RESULTS

Recent studies have highlighted the great potential of noise monitoring methods in the evolution of landslides (Mainsant et al., 2012).

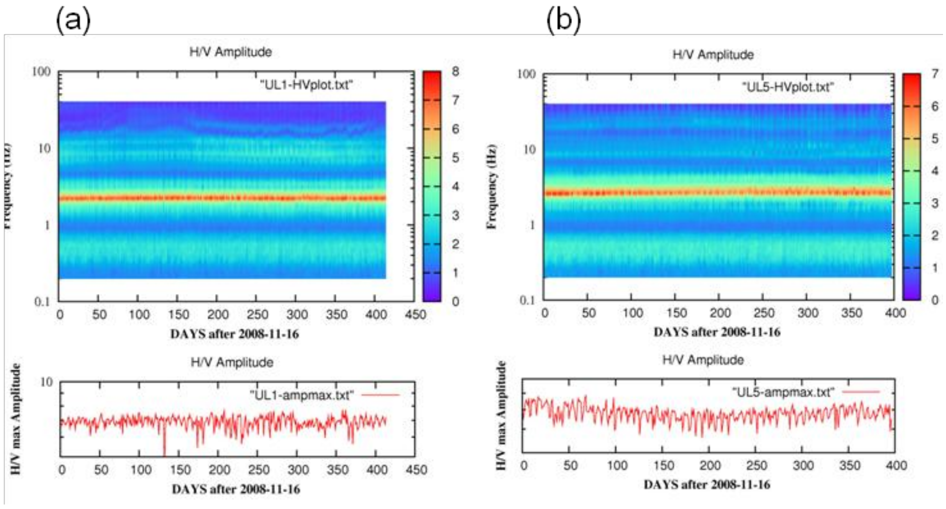

Figure 3. H/V monitoring for UL1 (a) and UL5 (b) stations.

We present here seismic noise data processed for H/V analysis considering one hour of noise / day (chosen during the night) using the Geopsy software (http://www.geopsy.org/). Figure 3 shows evolution of H/V ratio for UL1 and UL5 stations. It is clear that the results are rather constant, the main amplification frequency presenting no variation. However, amplitude of the H/V ratio at this frequency shows week variations (high-frequency noise) but also a seasonal evolution, particularly on the UL5 station. We can also detect larger continuous variations at higher frequencies, particularly for UL1. These variations may be link with water level variations.

The records of the 5 stations located on the Utiku landslide have also been cross correlated on a daily basis. Figure 4 presents the result of this cross correlation over the duration of the experiment for the couple UL1-

UL5 and also the water table variations at UL5. A day by day analysis of the precise arrival time has been used to build the relative velocity change (ΔV/V) using a technique of stretching. One can note important changes up to 1 or 2% in the arrival time, interpreted in terms of velocity change. However, since the stations are placed in a moving environment, a part of this change in arrival time might be due to relative variations in the distance between stations. The differential movements are tracked with the GPS recordings, collocated with each of our seismic stations. A very limited increase of a few centimeters has been measured, representing an increase in the arrival time of 0.04 %, much lower than the increase of 1-2% in the arrival time measured by cross correlation. Interestingly, this velocity change does not appear as permanent, and by the end of the survey it has returned almost to the beginning situation (that serves as a reference). This implies that throughout the seasons, the velocity structure of the landslide evolves accordingly to some environmental cycle rather than to the differential movements. Here, the velocity changes are clearly correlated to the changes of the water table level (at UL5). This is true for annual fluctuations, as well as for second and third order oscillations of the water table, certainly related to local precipitations and discharge properties of the landslide.

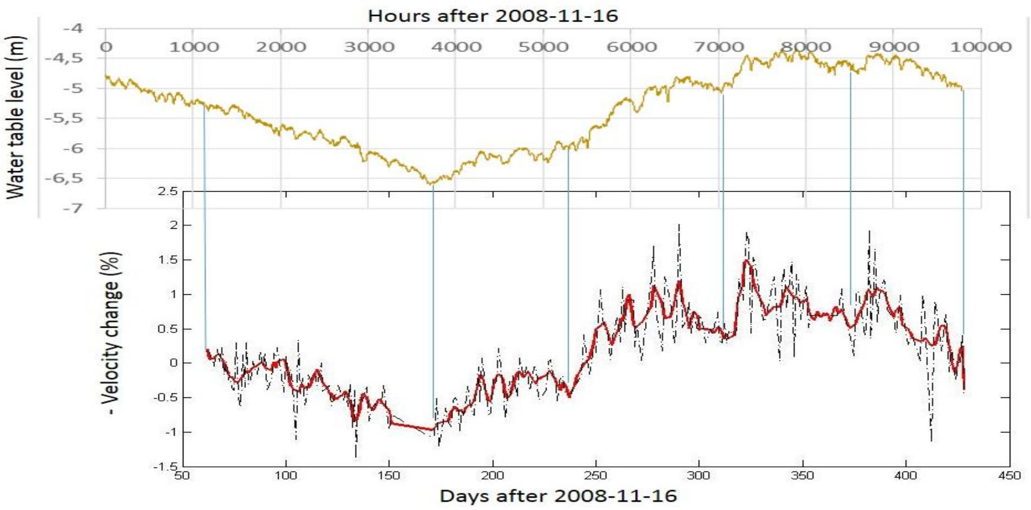

Figure 4. Top: Water table variations during 14 months (at UL5). Bottom: Raw (black) and smooth (red) relative seismic velocity variations between UL1 and UL5. Note the strong correlation of the features of both curves with the water table fluctuations. Vertical lines serve as guides for the eyes.

4 CONCLUDING REMARKS

The seismic monitoring of a landslide has permitted to assess the characteristics of seismic amplification and particularly to show their importance in terms of amplification, their sensitivity to local geometry of the landslide and their anisotropy depending on the azimuth, the maximum being reached at the same angle than the displacements. A monitoring over a 14 months period has permitted to show that H/V measurements are rather constant over time or at not sensitive enough to changes in water table variations, contrary to seismic noise correlation techniques, which permitted to detect 1 to 2 % of seismic velocity variations, remarkably consistent with those of the water table. This new observation needs some sensitivity analysis of surface waves to water table variations to be qualitatively understood.

ACKNOWLEDGMENTS: This work has been supported by an ISTerre internal funding. We would like to thank all the people who helped us during data collections from GNS as well as L. Tatard.

REFERENCES

Del Gaudio V., et al. (2008), Detection of directivity in seismic site response from microtremor spectral analysis, Nat. Hazards Earth Syst. Sci., 8, 751–762, 2008.

Mainsant G. et al. (2012), Ambient seismic noise monitoring of a clay landslide: toward failure prediction, J. of. Geophys. Res., 117, F01030.

Massey, C. (2010), The dynamics of reactivated landslides: Utiku and Taihape, North Island, New Zealand, Durham theses, Durham University. http://etheses.dur.ac.uk/587/.