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GEOPHYSICAL SURVEYS TO STUDY A LANDSLIDE BODY (NORTH-EASTERN SICILY)

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Introduction

Two field surveys, performing recordings of environmental noise combined with a MASW survey were carried out in 2010/11 and 2015. in an area affected by landslide, near the village of Tripi (Messina) (Fig. 1a). The Tripi area is greatly affected by instability phenomena triggered by intense rainfalls on the particular geological and morphological characteristics of the territory, characterized by very steep slopes (Fig. 1b).The Tripi country with its hamlet “Casale” are among the centers, in Sicily, at higher hydrogeological risk, since the landslides and rockfalls that often mobilize, put at risk the population and the structures (P.A.I.- Hydrographic basin of the Mazzarrà creek).

The landslide studied in this work activated on December 14th, 2009, just north of the Tripi village, threatening the main road between this center and its hamlet Casale, the landslide then re-activated again on February 21st, 2012.

On December 22nd, 2010 and January 18th, 2011, 36 measures of noise were carried out. They were located along 3 different profiles within the landslide body arranged orthogonal to the movement direction, and a MASW survey located near the profile performed at lower altitude.

During the second field survey performed on April 28th, 2015, 34 environmental noise recordings on 3 profiles were acquired; two section partially mark those performed 5 years earlier and, even in this case, an investigation MASW. The main purpose is to obtain information for the geometric reconstruction of the landslide slip surface and to observe the possible variations over time.

Geological and tectonic setting

The study area is located on the border between the northeastern sector of the Nebrodi mountains and the northwestern sector of Peloritani mountains, that is the southernmost tip of the Calabrian-Peloritan arc, that connects the Apennines with Sicilian Maghrebids. The geology is characterized by metamorphic units of medium and high grade (Lentini et al., 2000) (Fig. 1c).

From a tectonic point of view, is an area of broad Late Quaternary, regional uplift, approximately trending NE-SW and dipping towards NE, bounded at its edges by the Ionian and Tyrrhenian zones down from systems of normal faults oriented NE-SW (Messina-Giardini system) and ENE-WSW (peritirrenic system), referring to the phase essentially relaxing that took place in the Upper Pliocene-Pleistocene (Caliri et al., 1993; Lentini et al.,2000).

This stratigraphic and structural edifice show a tangential compressive deformative stress to main south convergence that has created a system of folds, layers of cover and structural axes movements generally orientated E-W, including transverse structures with functions of cinematic " junction" represented by fault transpressive system with a discrete component vertical orientated NW-SE (Caliri et al., 1993; Lentini et al., 2000). The morphology of the area around Tripi is characterized by very steep slop and deeply incised valleys. Watersheds are short and with high slope, and were affected by intense recent geomorphological dynamic. In fact, analysis of maps of Hydrogeological Plan of the Sicilian Region, referring to the hydrographic river basin of the creek "Mazzarra" and attached maps show that the area is affected by instability phenomena of collapse.

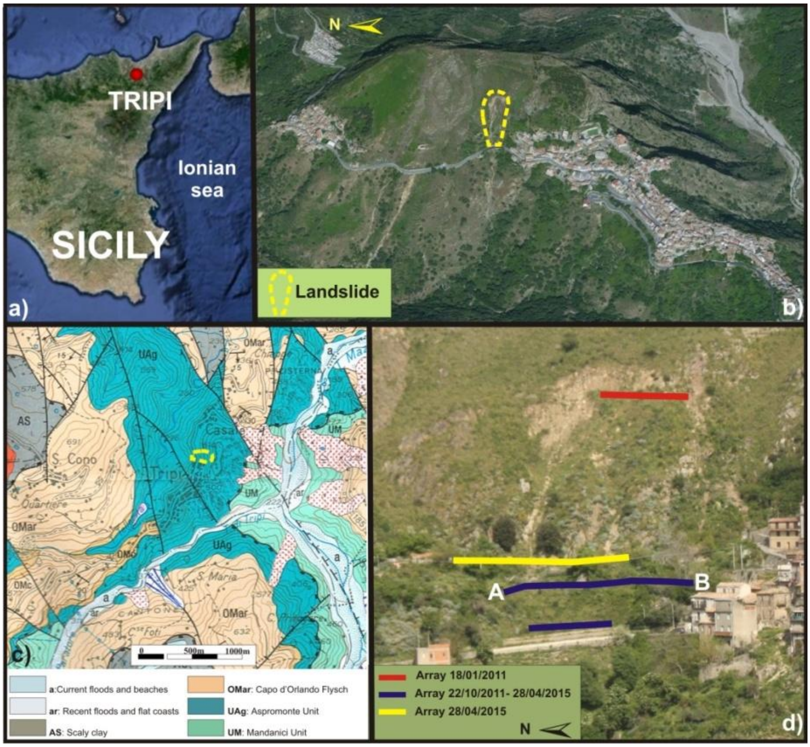

Figure 1. a) Location of Tripi (Messina) Sicily; b) the picture show at right the Tripi village and at left the hamlet Casale, yellow dashed line point out the landslide; c) geological and tectonic map of Tripi area (Lentini et al., 2000); d) location profiles on the study area.

Geophysical Surveys

To achieve the objective, we used the acquisition of noise processed with the technique of Nakamura (1989), integrating the results with a MASW; the joint fit of the dispersion curve, obtained from the analysis MASW with spectrum HVSR, result of microtremor measures, has allowed to get a Vs profile with depth. Environmental noise recordings were acquired, with preset spacing along alignments in order to obtain seismo-stratigrafic sections that could allow the reconstruction of sliding plane through the detection of impedance contrast caused by the passage between the bedrock and the landslide body.

The “passive seismic single-station” methodology, providing information on the local seismic response, is based on the acquisition of environmental seismic noise, characterized by low energy and amplitude (Okada, 2003). It consists in calculating the spectral ratio between the average of the horizontal and vertical components of the signal. This method was applied for the first time by Nogoshi and Igarashi (1970) and, subsequently, it became popular thanks to Nakamura (1989). In recent years, several authors have highlighted how this methodology allows to obtain information on the stratigraphy of an investigated site (e.g. Field and Jacob, 1993; Lachet and Bard, 1994; Ibs-Von Shet and Wohlenberg, 1999; Delgado et al., 2000a; Parolai et al., 2002; Imposa et al., 2013).

In a simple two-layer system of soft sediments, with a shear-wave velocity Vs and a thickness H, covering a hardrock basement, the equation (1) links the resonance frequency "f" to the thickness "H" of the resonating layer, depending on the shear waves velocity:

$$f = n\, Vs/4H \qquad (1)$$

where n (= 1, 3, 5 ...) indicates the order of the mode of vibration (fundamental, first superior etc.), Vs and H represent the shear waves velocity and the thickness of the resonating layer respectively.

Equation 1 allows to understand how the H / V technique can also provide information on stratigraphic features. Indeed, starting from a noise measurement providing f, knowning the Vs of the coverage, the depth of the main seismic reflectors or vice versa can be estimated (Ibs-Von Seht and Wohlenberg, 1999; Delgado et al., 2000b; Gosar and Lenart, 2010). Each peak in the H / V graph corresponds to a possible reflector (seismic-stratigraphic level) that presents an impedance contrast compared to the neighbour levels. In this case, the impedance contrast is associated to the landslide slip surface.

In this surveys a total number of 70 environmental noise samplings, distributed along six profiles, with regular spacing of 5 m, except for the profile done at higher altitude, where it was used a spacing of 4 m, were sampled in order to obtain a two-dimensional “impedance contrast” section. The profile has been located in perpendicular direction to that of landslide movement (Fig. 1d).

The recordings of environmental noise were carried using 6 portable digital seismographs series TROMINO® (Micromed S.p.A.), equipped with three electrodynamic orthogonal sensors (velocimeters) responding in the band 0.1 ÷ 1024 Hz. Seismic noise has been acquired following a standard procedure (Castellaro et al., 2005), with a sampling frequency of 128 Hz, amplified and digitalized to 24-bit equivalent, and recorded for 20 minutes. This allowed obtaining “stable” H/V ratios and ensured that the recorded signal was the result of "dominant" sources. Recordings were processed through the software package Grilla® (Micromed).

During the two acquisition campaigns we also proceeded to the execution of two MASW, to estimate the various seismic waves velocities in the subsurface and reach, in particular, to the definition of an average velocity of the uppermost layers necessary for the development of impedance contrast sections (Fig. 2a-c).

The methodology MASW was introduced by the Kansas Geological Survey (Park et al., 1999); the energization is effected at various distances and with various repetitions (stacking technique), the signals obtained are algebraically added in order get a signal clearly stronger than environmental noise. The MASW technique is based on the registration of Rayleigh surface waves in the time domain and the subsequent analysis in the frequency domain to reconstruct the trend of shear waves velocity in the subsoil; the measuring of S waves velocity through the use of surface waves is possible because the two velocity Vs and Vr in the same medium differ by few percentage units (Richart et al., 1970; Achenbach, 2000).

The seismic signal was acquired through a digital multi-channel array, SoilSpy Rosina, Micromed S.p.A., able to record continuously; the array formed by 12 vertical geophones to natural frequency of 4.5 Hz, with spacing of 5 meters, for a total length of 55 m. The time series acquired by the multichannel system SoilSpy, was drawn in frequency - phase velocity domain (slant-stack, and Fourier transform) in order to discriminate the energy associated with Rayleigh waves .

The maximum energy associated with Rayleigh waves defines the dispersion curve trend, that associates to each frequency the propagation wave velocity. The 1D seismic stratigraphic models (Fig. 2b-d), showing the variation of shear wave velocity at depth, were obtained through mutual "constraints" of depth resulting from conjunct fit between the dispersion curve, obtained from MASW technique and HVSR spectrum, obtained from noise recordings**.**

Results

Based on processing of the acquired data you may notice a slight deepening of the impedance contrast between sections obtained from recordings made in December 2010-January 2011 and those made five years later. A good agreement between the depth where it is found the most significant velocity change and the depth of the impedance contrast can also be observed, this can therefore associated with the passage between the detrital material in landslide and the underlying substrate, thereby permitting the identification of the trend of probable sliding surface.

The section shown as example in figure 2, along the profile AB (Fig. 1) identifies an important seismic refractor associable with the slip surface. The depth of the surface, was approximately 3 m on December 2010 and about 4 m 5 years later, in April 2015. Above this surface, the deposits have very low shear wave velocity (Fig. 2b-d), around 200 m/s, associable to deposits involved in the landslide. Under these deposits the shear wave velocity increases rapidly, around 500-600 m / s, this is associated with the bedrock.

Data processing allowed to obtain information about the sliding surface depth through an interpretation of geometric reconstruction of the track along the alignments of profiles that take into account the strong impedance contrasts associated with the transition between the body landslide and substrate; it was also obtained Vs variations with depth profiles, which allows to evaluate the shear waves velocity of landslide material and bedrock.

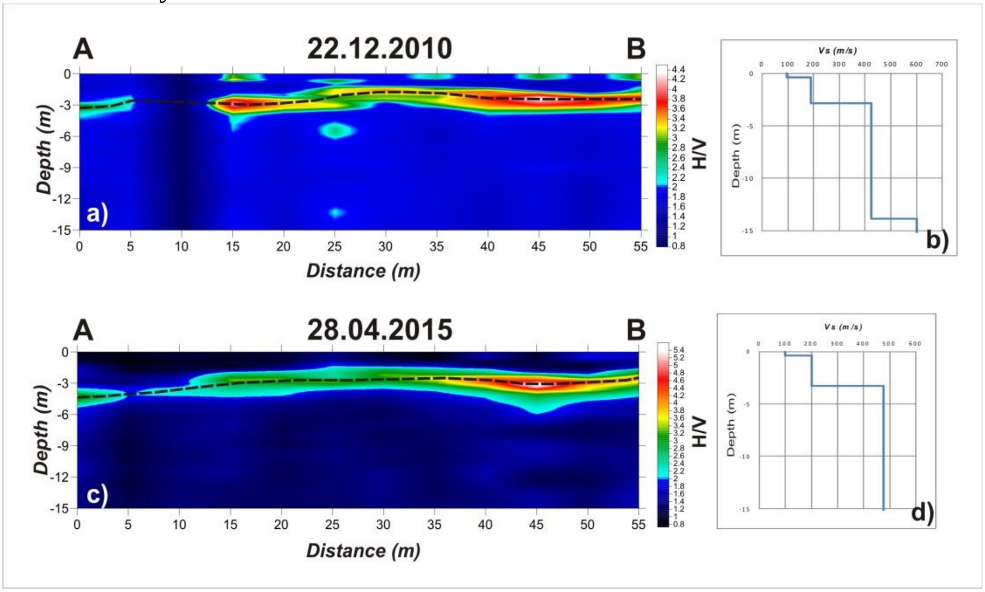

Figure 2. a)-c) Example of impedance contrast sections,at two different acquisition times; the dashed black lines show the trend of the sliding surface; b)-d) velocity values vs depth.

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